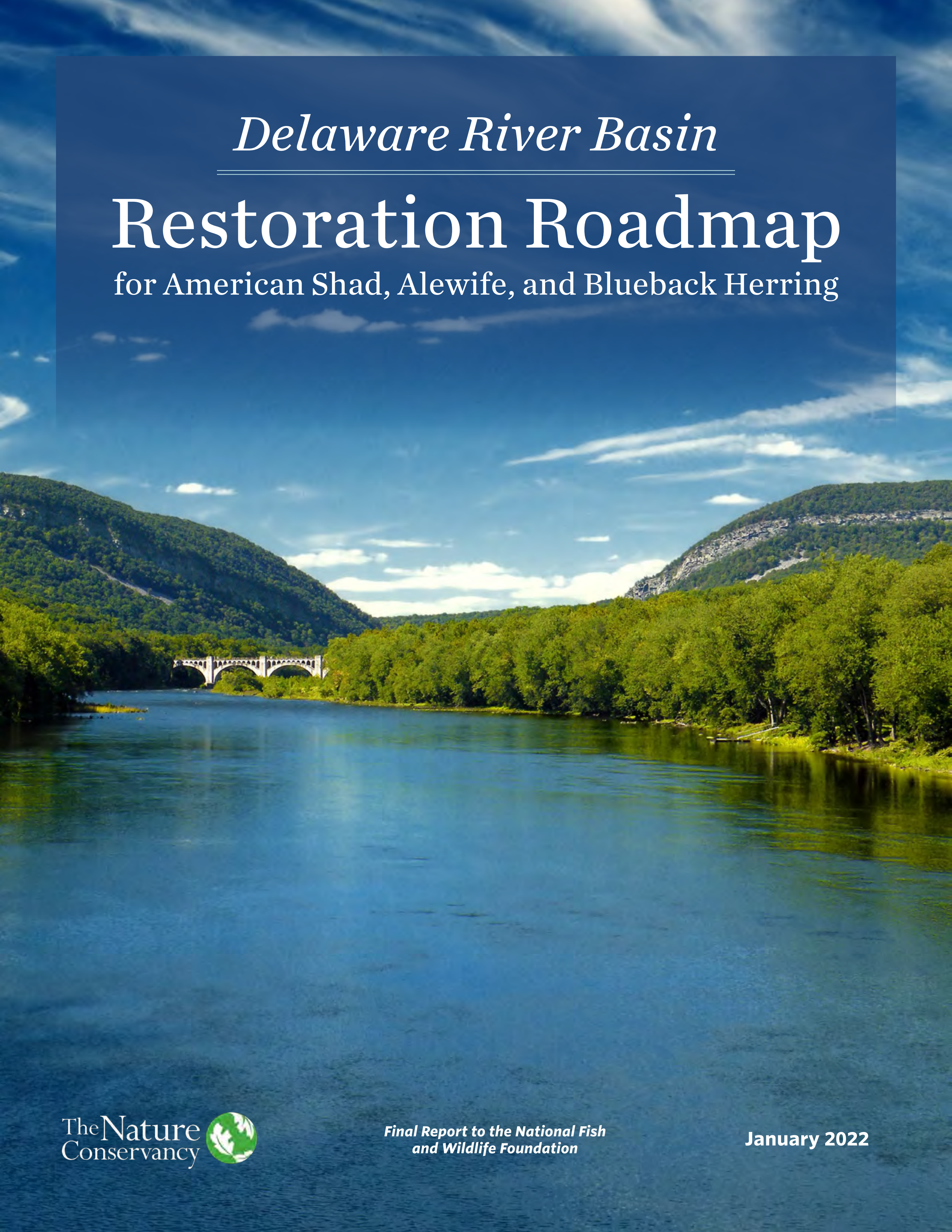


Delaware River Basin

Restoration Roadmap

for American Shad, Alewife, and Blueback Herring

The Nature Conservancy

Final Report to the National Fish and Wildlife Foundation

January 2022

Acknowledgements

Land Acknowledgement

This report is focused on the Delaware River Basin, which is part of the traditional territory of the Lenni-Lenape—called "Lenapehoking"— and much of the work to develop this document was completed on these lands. The Lenape lived in harmony with one another upon this territory for thousands of years and would congregate along the Delaware River and its tributaries during the spawning runs each spring to catch a bounty of American Shad, Alewife, Blueback Herring, and other migratory fish that would ascend the rivers. European settlement led to the significant decline of these abundant migratory fish populations resulting from the construction of dams and canals, degraded water quality, and overfishing—all still challenges to restoring these populations. During the colonial era and early federal period, many Indigenous peoples were removed west and north, but some also remain among the continuing historical tribal communities of the region: The Nanticoke Lenni-Lenape Tribal Nation; the Ramapough Lenape Nation; and the Powhatan Renape Nation, The Nanticoke of Millsboro Delaware, and the Lenape of Cheswold Delaware. We acknowledge the Lenni-Lenape as the original people of this land and their continuing relationship with their territory—with the Lenape language still evident in the names of many places and streams throughout the basin. In our acknowledgment of the continued presence of Lenape people in their homeland, we affirm the aspiration of the great Lenape Chief Tamanend, that there be harmony between the indigenous people of this land and the descendants of the immigrants to this land, "as long as the rivers and creeks flow, and the sun, moon, and stars shine."

This acknowledgement was adapted from the Nanticoke Lenni-Lenape Tribal Nation ***website***.

Cover Image: Delaware Water Gap. ©Nicholas Tonelli.

Project Funding

Funding for this project was provided in part by a Delaware Watershed Conservation Fund (DWCF) grant from the National Fish and Wildlife Foundation with funding from the U.S. Fish and Wildlife Service.

Project Partners

The Nature Conservancy would like to give a special thanks to Kristie Fach and Abigail Pattishall of Wildlands Conservancy for their insights on the Lehigh River. Special thanks to Mike Stangl, Jason Fischel, Daryl Pierce, Ben Lorson, Joe Perillo, and Mike Kaufmann for their considerable support of this project as well as the partners listed below.

- Brandywine Shad 2020
- Delaware Department of Natural Resources and Environmental Control
- Delaware River Basin Fish and Wildlife Management Cooperative
- National Oceanic and Atmospheric Administration
- National Park Service
- NJDEP, New Jersey Division of Fish and Wildlife
- New Jersey Statewide Dam Removal Partnership
- NYDEC, Division of Marine Resources
- Pennsylvania Aquatic Connectivity Working Group
- Pennsylvania Department of Conservation and Natural Resources
- PADEP, Bureau of Abandoned Mine Reclamation
- PADEP, Division of Dam Safety
- Pennsylvania Fish and Boat Commission
- Philadelphia Water Department
- University of Delaware, Water Resources Center
- United States Fish and Wildlife Service

Inclusion on this list does not indicated endorsement of the final report.

Authors

Lyndon L. DeSalvo, The Nature Conservancy, *lyndon.desalvo@tnc.org*

Mari-Beth DeLucia, The Nature Conservancy, *mdelucia@tnc.org*

Erik H. Martin, The Nature Conservancy

David H. Keller, Academy of Natural Sciences of Drexel University

Please cite this document as: DeSalvo, L. L., M. DeLucia, E. H. Martin, and D. H. Keller. 2022. Delaware River Basin Restoration Roadmap for American Shad, Alewife, and Blueback Herring. The Nature Conservancy's final report to National Fish and Wildlife Foundation (Grant No.: 65162). The Nature Conservancy, Harrisburg, Pennsylvania.

Table of Contents

Acronyms

AMD	Abandoned Mine Drainage
ANS	Academy of Natural Sciences of Drexel University
AOP	Aquatic Organism Passage
ASMFC	Atlantic States Marine Fisheries Commission
ACCSP	Atlantic Coastal Cooperative Statistics Program
BAMR	Bureau of Abandoned Mine Reclamation (Pennsylvania DEP)
CPUE	Catch Per Unit Effort
CWIS	Cooling Water Intake Structures
DNREC	Delaware Department of Natural Resources and Environmental Control
DNREC-WATAR	Watershed Approach to Toxics Assessment and Restoration (WATAR)
DRBC	Delaware River Basin Commission
DRB FWMC	Delaware Basin Fish and Wildlife Management Cooperative (Co-op)
DRWI	Delaware River Watershed Initiative
eDNA	Environmental DNA
FERC	Federal Energy Regulatory Commission
HUC	Hydrologic Unit Code
JAI	Juvenile Abundance Index
MARCO	Mid-Atlantic Regional Council on the Ocean
MWA	Musconetcong Watershed Association
PADEP	Pennsylvania Department of Environmental Protection
NFWF	National Fish and Wildlife Foundation
NJDEP	New Jersey Department of Environmental Protection
NJFW	New Jersey Division of Fish & Wildlife
NJSDRP	New Jersey Statewide Dam Removal Partnership
NOAA	National Oceanic and Atmospheric Administration
NEFSC	Northeast Fisheries Science Center
NMBA	Northampton Borough Municipal Authority
NRHP	National Register of Historic Places
PADCNR	Pennsylvania Department of Conservation and Natural Resources
PFBC	Pennsylvania Fish and Boat Commission
PWD	Philadelphia Water Department
TEWG	Technical Expert Working Group (river herring)
T&E	Threatened and Endangered
TNC	The Nature Conservancy
UDWRC	University of Delaware, Water Resource Center
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant
YOY	Young-of-year

List of Figures

List of Tables

Executive Summary

Once a historic stronghold for American Shad, river herring, and other migratory fish, the Delaware River and its tributaries currently support a tiny fraction of the former spawning runs yet present an incredible opportunity to restore these populations by strategically reconnecting, preserving, and restoring high-quality habitat on priority tributaries throughout the basin.

The Nature Conservancy received a National Fish and Wildlife Foundation Delaware Watershed Conservation Fund grant to prioritize restoration opportunities for reconnecting habitat for alosines (American Shad, Alewife, and Blueback Herring, specifically) within the Delaware River Basin.

In the Delaware Basin, American Shad and river herring (Alewife and Blueback Herring, collectively) are at historically low abundance and despite fishery closures, bycatch caps, and some habitat improvements there has been a lack of corresponding recovery of these important migratory fish. The Atlantic States Marine Fisheries Commission's 2020 American Shad stock assessment found that restricted access to spawning habitat, with 40% of historic habitat in the U.S. and Canada currently blocked by dams and other barriers, severely limit shad recovery (ASMFC 2020). River herring are at historic lows coastwide and were considered for listing under the U.S. Endangered Species Act in 2012.

The Delaware River was once home to some of the greatest migratory fish runs on the Atlantic coast of the United States, but today these populations are at historically low levels.

For thousands of years, the Indigenous Lenape and Nanticoke peoples would congregate along the Delaware River and its tributaries each spring to catch a bounty of American Shad, Atlantic Sturgeon, river herring and other migratory fish, with the runs numbering in the millions. When the Europeans arrived, they continued this tradition of fishing for shad and other migratory fish in addition to constructing dams to power mills—and later canals to transport goods—that ultimately changed the natural flow of the rivers and blocked the annual migrations of these species. The combination of dams and other impediments blocking spawning rivers, water pollution, and overfishing severely depleted shad and river herring populations by the turn of the 20th century.

"Rivers and migrations are the connective tissue of our planet – and migratory fish are bellwethers for not just rivers, but for the countless other systems they connect, from the deep sea to coastal forests. Losing these fish means losing so much more."

- Jeffrey Parrish, Global Managing Director for Protect Oceans, Land and Water at The Nature Conservancy.

Figure ES-1. *The Columbia Lake Dam on the Paulins Kill, before and after removal. Following the removal of the dam in 2018, American Shad and other migratory fish species now have access to an additional 10 miles of habitat upstream of the former dam site. Credit: Jeffrey Burian/TNC.*

The goal of the Restoration Roadmap is to increase the spawning runs of American Shad, Alewife, and Blueback Herring within the Delaware basin by enhancing aquatic connectivity and habitat quality in priority tributaries. With no dams along its mainstem, the Delaware is the longest undammed river east of the Mississippi and holds tremendous potential for the recovery of migratory fish species.

Advancing an aquatic connectivity strategy in the Delaware River basin is essential to the recovery and resilience of these species and identifying a roadmap that can galvanize partners and align funding resources behind a set of shared goals has been shown to be an extremely effective strategy for restoring migratory fish populations elsewhere in the northeast. For example, the Penobscot River restoration involved a large-scale partnership, including state and federal agencies, nonprofits, hydropower companies, and the Penobscot Indian Nation, that ultimately enabled endangered Shortnose Sturgeon to reach habitat that had been blocked by dams for more than a century in addition to recording over half-a-million river herring (45 times more than in 2013) at a former dam site. Recent dam removals and restoration projects on various tributaries in the Delaware basin have demonstrated that American Shad and other migratory fish species are quick to utilize newly available habitat (Figure ES-1).

The Restoration Roadmap outlines a basinwide strategy for reconnecting historic and high-quality habitat and seeks to leverage both the ecological benefits of multiple restoration projects within a watershed as well as the potential for shared funding and capacity needs by targeting a reduced number of systems.

The Roadmap identifies 45 priority barriers on 13 tributaries across the basin to focus shad and river herring restoration efforts and highlights key actions to significantly improve fish passage and restore habitat (Figure ES-2). Building off previous plans and prioritizations, the list of priority tributaries for American Shad and river herring restoration within the basin were determined using a variety of criteria, including:

- Documented historic and current spawning runs,
- Expert opinion from fisheries biologists and key stakeholders,
- Presence and conditions of dams and fishways,
- Opportunity and project feasibility, and
- Habitat suitability

The priority tributaries (and the dams along them) are further separated into three tiers, with Tier 1 being the highest priority for restoration (Table ES-1, p. 10). For these Tier 1 barriers, the report includes an in-depth assessment of existing conditions, including images and fact sheets, as well as key actions, potential partners, and funding sources to improve fish passage via dam removal and habitat restoration.

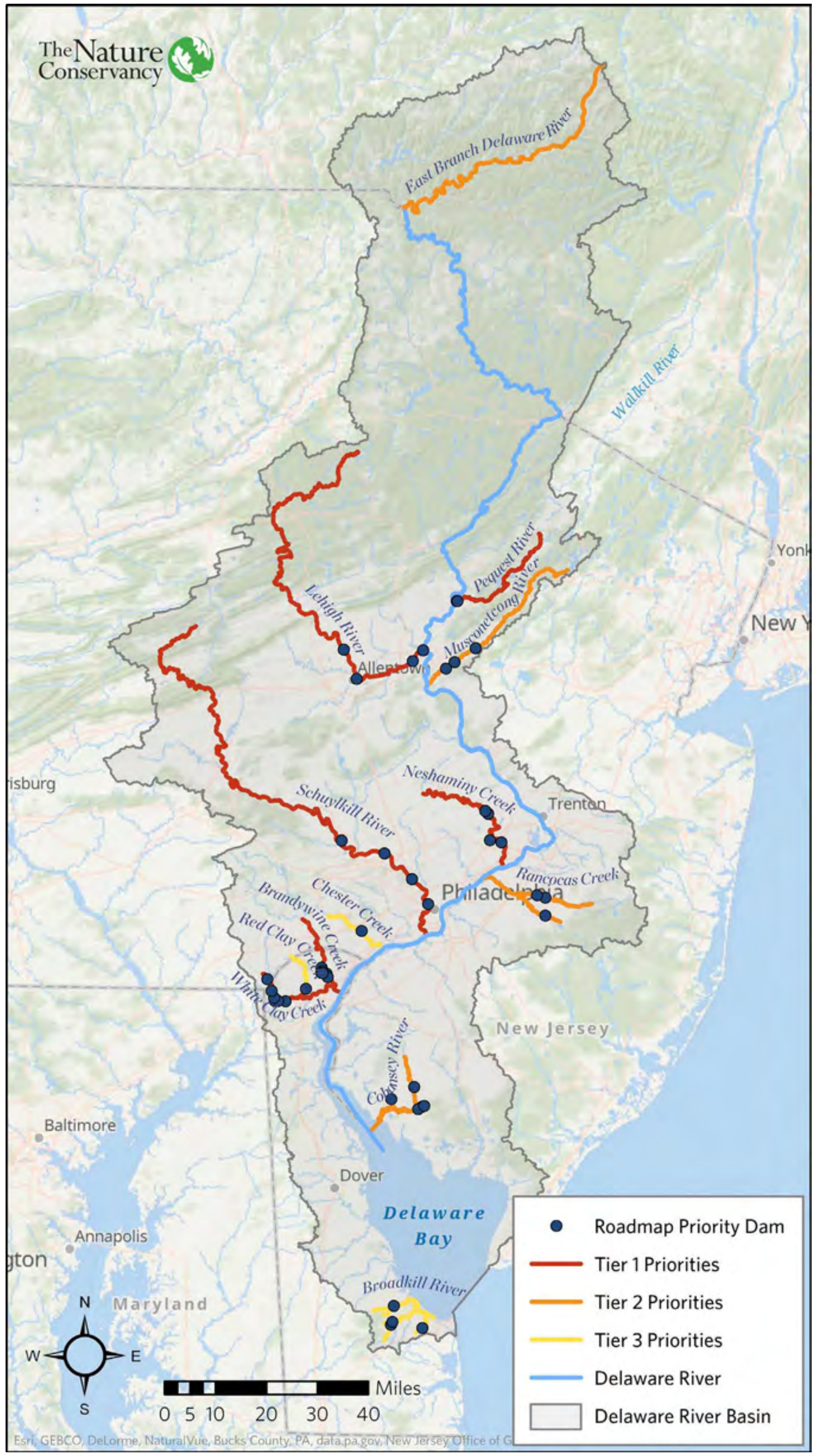


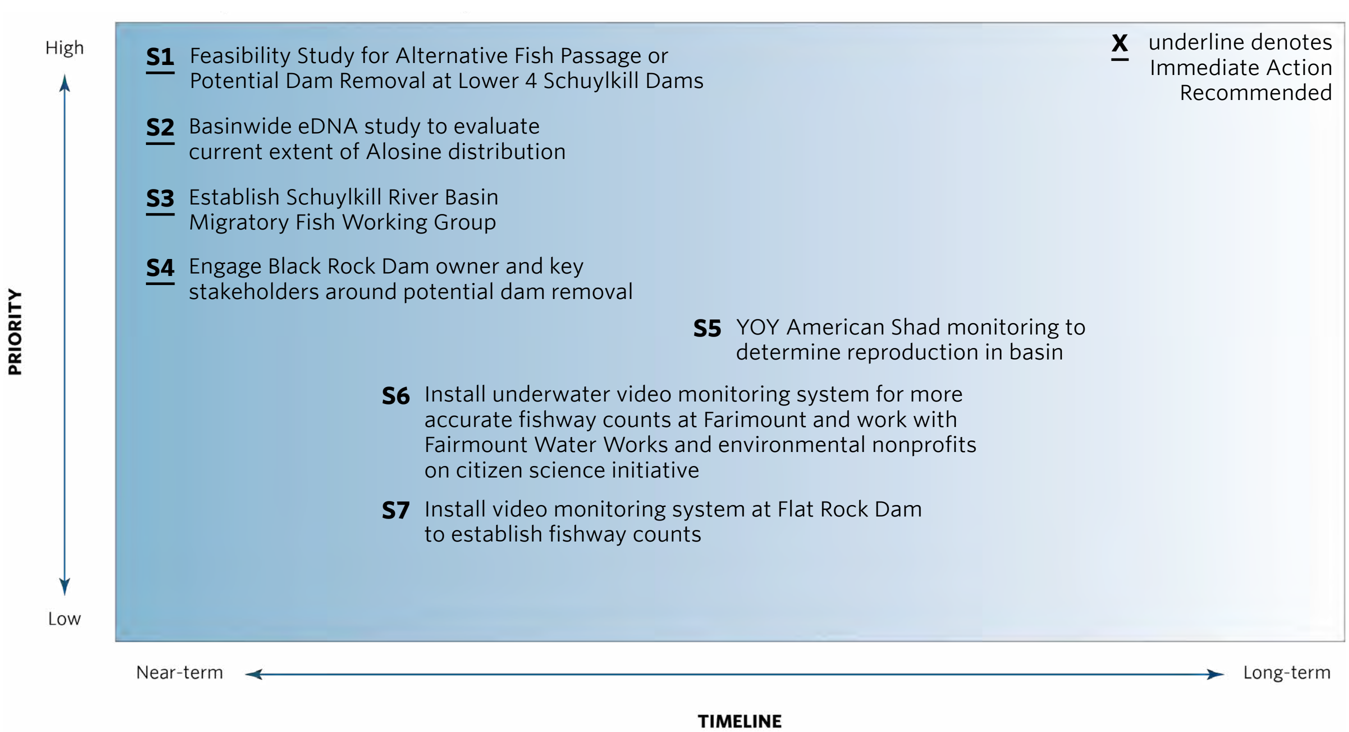
Figure ES-2. *Restoration Roadmap priority tributaries and dams. The priorities are separated into three tiers: Tier 1 – highest priority; Tier 2 – priority; and Tier 3 – exploratory.*

Tier 1 - Highest Priority	Tier 2 - Priority	Tier 3 - Exploratory
• Schuylkill River • Brandywine Creek • White Clay Creek • Lehigh River • Pequest River • Neshaminy Creek	• Musconetcong River • Rancocas Creek • Cohansey River • East Branch Delaware River*	• Red Clay Creek • Broadkill River • Chester Creek

Table ES-1. *Priority Tributaries for American Shad and river herring restoration in the Delaware River basin. (*The East Branch Delaware River is included as a priority tributary with the aim of modifying releases from the Pepacton Reservoir to improve conditions for alosines.)*

Each of the priority tributaries have an easy-to-read chart of key actions necessary to begin to address connectivity issues in that system. The action charts for all Tier 1 priorities are included here:

Schuylkill Priority Actions



Brandywine Priority Actions

PRIORITY: High → Low

B1 Design and construction of alternative fish passage at Dam #2, including monitoring and O&M plan

B3 Continue seine sampling for juvenile alosines to develop JAI and measure restoration impacts

B2 Design and construction of alternative fish passage or potential dam removal of Dam #5, including monitoring and O&M plan

B4 Estimate the production potential of alosines in the Brandywine Creek

B5 Engage Wilmington community around migratory fish restoration efforts (i.e. ShadFest, Shad in Schools, etc.)

B6 Feasibility study in coordination with Hagley Museum to determine potential for dam removal or fish passage at Dams #7-10

X underline denotes Immediate Action Recommended

Near-term ← TIMELINE → Long-term

White Clay Priority Actions

PRIORITY: High → Low

W1 Assess passability of alosines at notched Dam #1 site and upstream rock vane and implement any necessary steps to improve passage

W2 Design and construction for removal of Dam #3

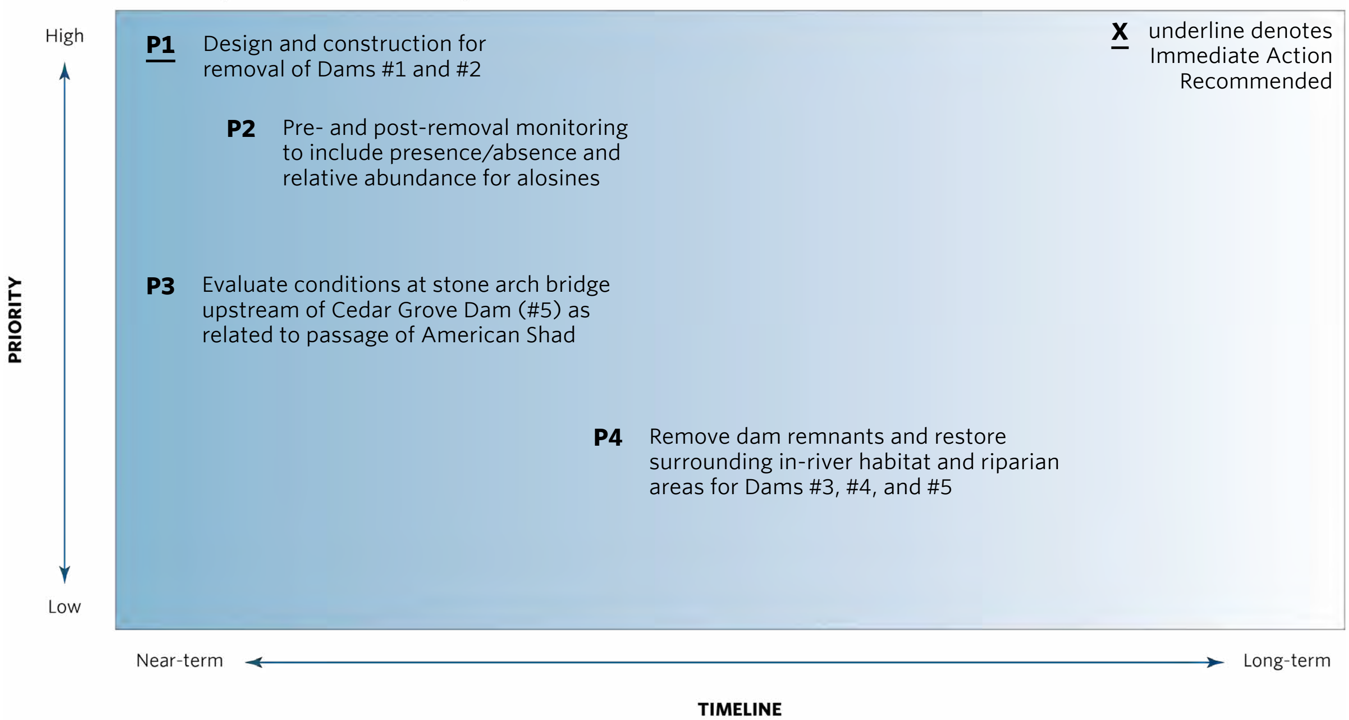
W3 Design and construction for removal or alternative fish passage at Dam #5

W4 Monitor for alosines habitat use upstream of Dam #2 following removal

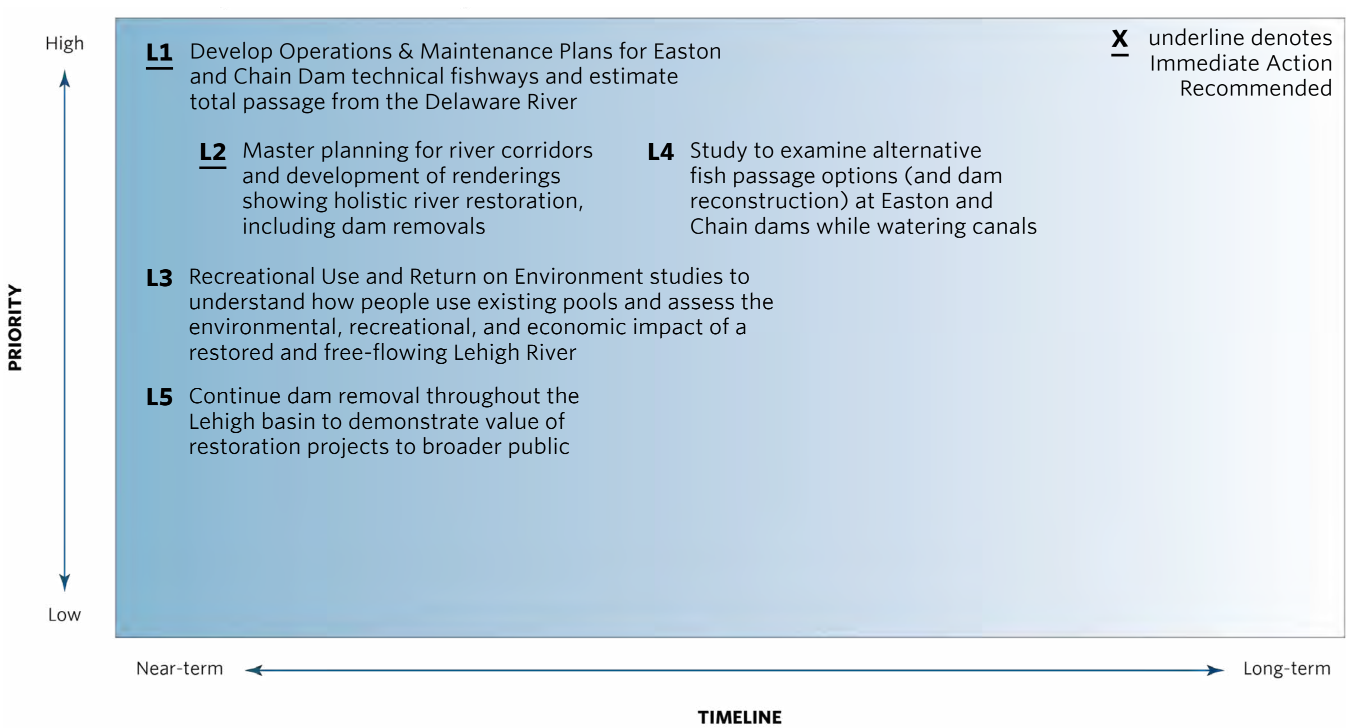
X underline denotes Immediate Action Recommended

Near-term ← TIMELINE → Long-term

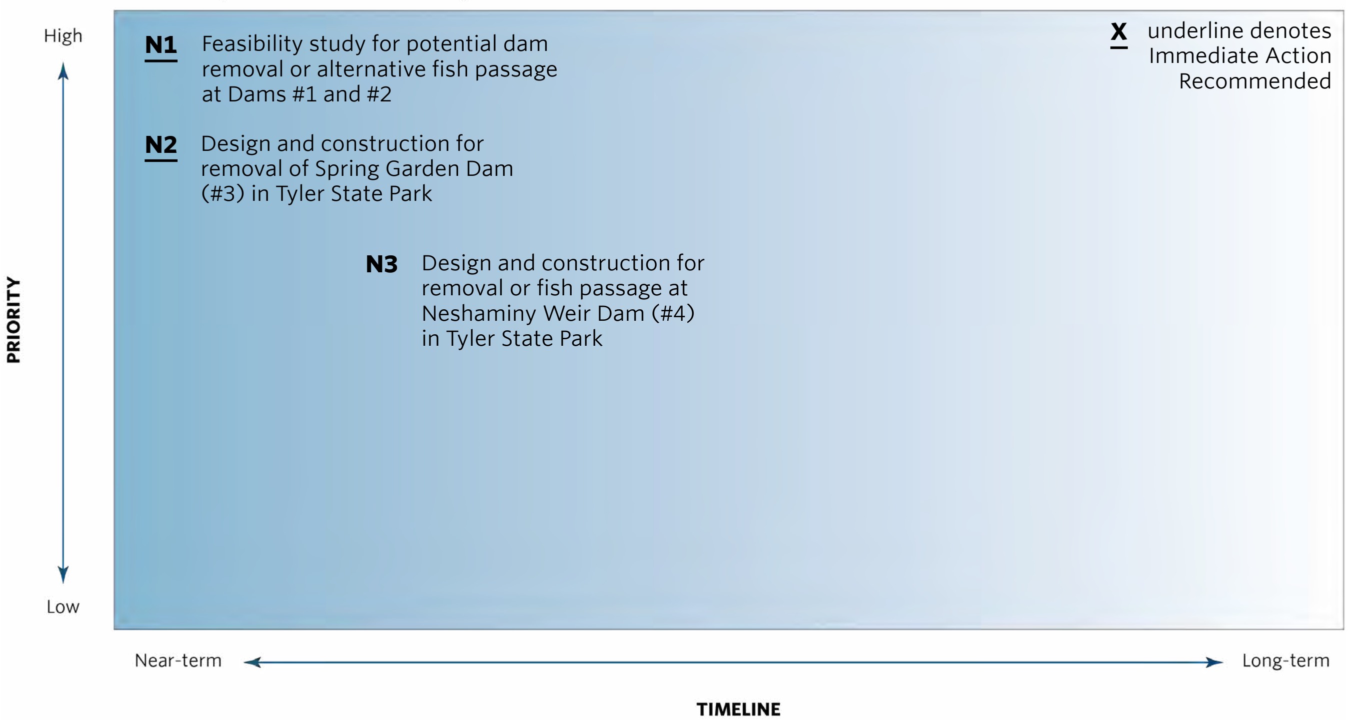
Pequest Priority Actions



Lehigh Priority Actions



Neshaminy Priority Actions



Although the actions outlined in this report are ambitious, the loss of these species and the role they play in the broader ecosystem is not an acceptable outcome.

Shad and river herring are important forage fish for many of our commercial and recreationally significant species, such as Striped Bass. They also serve as hosts that allow freshwater mussels to distribute their larvae throughout the watershed. Until recent times, shad and river herring supported important commercial and recreational fisheries.

Sustained federal funding through the Delaware Watershed Conservation Fund and new aquatic connectivity funding opportunities through the 2021 Infrastructure and Investment Act should provide the broader restoration community with much of the funding needed to restore spawning and rearing habitats for shad and river herring as well as remove obsolete infrastructure that was not designed to withstand the increased flooding associated with climate change.

Section 1

Introduction

In 2019, The Nature Conservancy received funding from the National Fish and Wildlife Foundation (NFWF) through its Delaware Watershed Conservation Fund with funding provided by the U.S. Fish and Wildlife Service to prioritize restoration opportunities for reconnecting habitat for alosines (American Shad, Alewife, and Blueback Herring, specifically) within the Delaware River Basin. The 2016 Delaware River Basin Conservation Act established the Delaware River Basin Restoration Program to support efforts to implement conservation, stewardship, and enhancement projects throughout the Basin, with funding for the conservation and restoration of fish and wildlife habitat.

1.1 The Need for a Restoration Roadmap

The Atlantic States Marine Fisheries Commission's 2020 American Shad stock assessment found that restricted access to spawning habitat severely limit shad recovery, with 40% of historic habitat in the U.S. and Canada currently blocked by dams and other barriers (ASMFC 2020). River herring (Alewife and Blueback Herring, collectively) are at historic lows coastwide and were considered for listing under the U.S. Endangered Species Act in 2012.

In the Delaware Basin, American Shad and river herring are also at historically low abundance and—despite fishery closures, bycatch caps, and some habitat improvements—there has been a lack of corresponding recovery of these important migratory fish. The Delaware River is the longest undammed river east of the Mississippi and migratory fish have access far up into its headwaters where in other similar East Coast aquatic systems they have long been extirpated. For this reason, the Delaware holds enormous potential for the recovery of migratory fish, but fragmentation caused by more than 1,400 dams and other barriers on its tributaries significantly reduces available spawning habitat (Martin and Apse 2011). Some of the dams that restrict access to spawning habitat are obsolete and no longer serve their intended purpose; some are dangerous to human life (Figure 1-1), and others, not designed to withstand the increased flooding associated with climate change, pose risks to local communities. Over the past decade, dam removal has become more socially acceptable as local communities understand the benefits that barrier removal provides to both people and nature.

Figure 1-1. *New Kernsville Dam. The Schuylkill River dam is being removed as it is a public safety risk. Credit: Flickr user Jack.*

A successful model for the Delaware Basin is the Penobscot River restoration, which involved a large-scale partnership that included state and federal agencies, nonprofits, hydropower companies, and the Penobscot Indian Nation. In 2015, endangered Shortnose Sturgeon reached habitat in the Penobscot River that had been blocked by dams for more than a century, and more than half-a-million river herring—45 times more than in 2013—were counted at a former dam site.

The work on the Penobscot started with a prioritization of barriers, recognition of restoration needs, and the beginnings of a large-scale partnership of the size and depth needed to address a problem at the scale of half the state of Maine. This is the type and scale of work needed to effectively catalyze an aquatic connectivity strategy in the Delaware River Basin. A holistic approach to migratory fish restoration is essential, and a host of tools and strategies at the site level can be identified and employed such as dam removal, fish passage retrofits, land protection to improve water quality, streamflow, and changes to permitting for restoration (Bowden 2013). With future constraints on availability of funds and staffing, it is even more critical to be strategic about investments in connectivity restoration projects.

Figure 1-2. Delaware River Basin Map. Wikimedia Commons

1.2 Migratory Fish of the Delaware River Basin

The 330-mile-long (531 km) Delaware River is the longest undammed river east of the Mississippi. It drains an area of 13,539 mi^2 (35,065 km^2) in four U.S. states: Delaware, New Jersey, New York, and Pennsylvania. The Schuylkill and Lehigh rivers in Pennsylvania are its largest tributaries (Figure 1-2).

Advancing an aquatic connectivity strategy in the Delaware River Basin—a historic stronghold for American Shad, Alewife, and Blueback Herring—is essential to the recovery and resilience of these species. Identifying a roadmap that can galvanize partners and align funding resources behind a set of shared goals has been shown to be an extremely effective strategy for restoring migratory fish populations elsewhere in the northeast.

Figure 1-3. *Shad Fishing - Fishers & Catch, 1915. Credit: Library of Congress.*

Ten species of diadromous fish were historically found in the basin, including Atlantic Sturgeon, Shortnose Sturgeon, American Eel, Striped Bass, Sea Lamprey, Rainbow Smelt, and four alosine species: American Shad, Alewife, Blueback Herring, and Hickory Shad. Rainbow Smelt are generally considered extirpated from the Delaware River (Enterline et al. 2012).

The Delaware River was once home to some of the greatest migratory fish runs on the East Coast of the United States. For thousands of years, the Indigenous Lenape and Nanticoke peoples relied heavily on these spawning runs and would congregate along the Delaware River and its tributaries each spring to catch a bounty of shad and other migratory fish. Driving posts into the bottom of the river in a fence-like fashion to create a *fishweir*, they would then use weighted nets to gather the fish in a confined location. When the Europeans arrived, they continued the Lenape tradition of fishing for shad and other migratory fish, often using drift and seine nets. The largest population of Atlantic Sturgeon was found in the Delaware and, in the late 1800s, Philadelphia was considered the “caviar capital of North America”.

However, European settlement throughout the basin also led to the dramatic decline of migratory fish populations. While some mill dams date back to the 1600s, the dam and canal building era commenced in earnest in the early 1820s and significantly

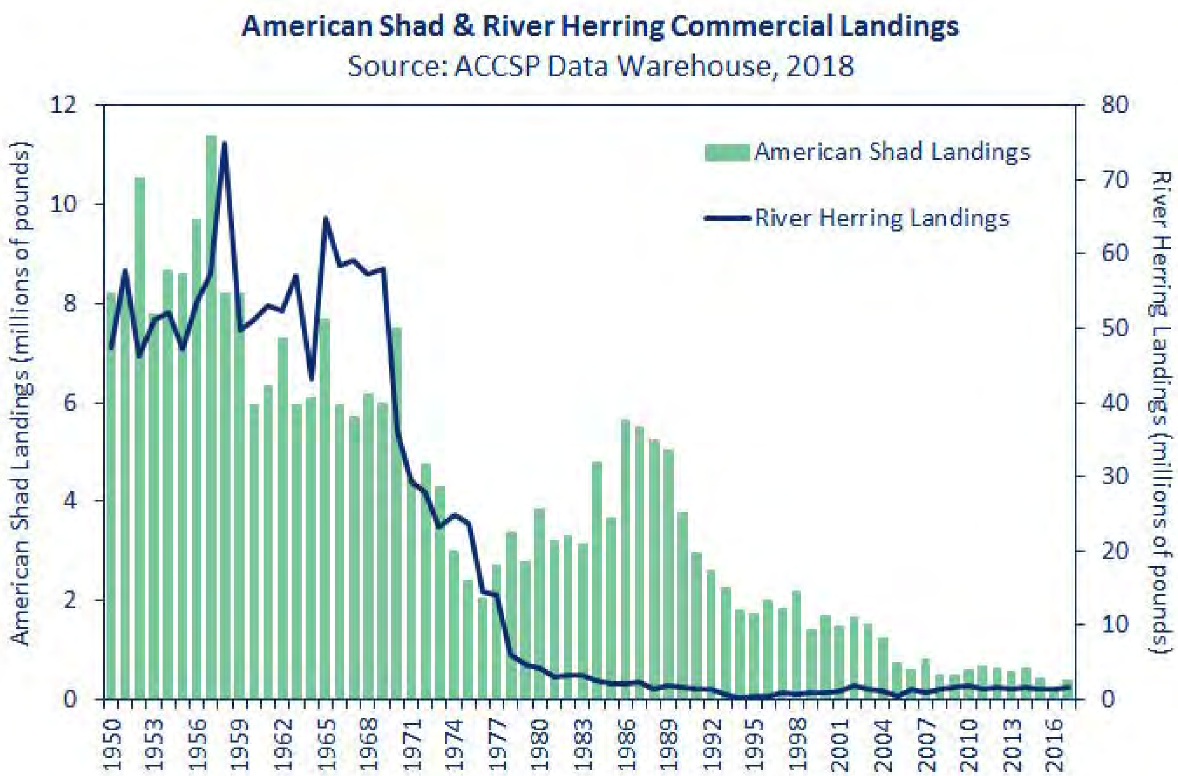


Figure 1-4. *American Shad & River Herring Commercial Landings, 1950-2017.*

reduced the spawning habitat for American Shad, river herring, and other migratory fish along the East Coast (Hardy 1999). The Lenape repeatedly petitioned to have mill dams removed or at least opened to allow migratory fish spawning runs to reach their camps (Becker 2006). In addition to a loss of spawning and rearing habitat, by the 1890s three to four million shad were taken annually in the commercial fishery, which was several times greater than any other Atlantic coast fishery (Mansueti & Kolb 1953).

The combination of dams and other impediments blocking spawning rivers, water pollution, and overfishing severely depleted shad and river herring populations by the turn of the 20th century. By the middle of the 20th century, water quality improvements and fisheries management actions led to the return of shad and other migratory fish to the river. However, commercial, and recreational fisheries returned only briefly and, by the late 1960s, commercial landings for both shad and river herring had declined dramatically (Figure 1-4).

Today, these populations remain at historically low levels and management actions have been taken in recent years in an effort to address this. In 2005, the directed ocean fishery for American Shad was closed and, in 2006, river herring were federally listed as species of concern. Both recreational and commercial fishing for river herring in the Delaware River Basin were closed in 2012 after the Atlantic States Marine Fisheries Commission (ASMFC) river herring stock assessment found that stocks along the coast were at near historic lows and remained depleted at the time of a subsequent update in 2017 (ASMFC 2012, 2017). The 2020 ASMFC stock assessment for American Shad found that the shad stock is also depleted and near historic lows (ASMFC 2020).

1.3 Report Structure

The Restoration Roadmap report is an action-oriented document that provides critical information about connectivity priorities for alosine restoration within the Delaware River Basin. As such, the report focuses on highlighting existing conditions, opportunities, and proposed actions along priority tributaries and does not include extensive background on the historic fisheries, alosine life histories, or additional threats beyond habitat fragmentation, though these areas are touched upon in the first few sections with references to relevant documents provided. Taken together, the priority actions listed in the report represent a basinwide strategy for reconnecting historic and high-quality habitat between the mainstem and Delaware River tributaries and seeks to galvanize partners and funders around a shared approach.

The roadmap contains seven sections and three appendices and a brief overview and direct links to each are included below for easy reference.

1 – Introduction

Section 1 includes background on the need for a restoration roadmap, historic fisheries in the Delaware, and an overview of the report content and sections.

2 – Species Overview & Habitat Suitability

Section 2 offers high-level information about the three species of interest—American Shad, Alewife, and Blueback Herring—and summarizes the approach and outcomes of the habitat suitability assessment completed for the priority tributaries.

3 – Beyond Dams: Restoration Challenges in the Delaware River Basin

Section 3 highlights additional challenges to restoration beyond habitat fragmentation caused by dams and other barriers, including threats specific to the Delaware basin as well as coastwide.

4 – Priority Tributaries and Actions

Section 4 contains most of the report content, with each Tier 1 priority tributary included as its own subsection that includes a table of priority actions, background on the watershed, alosine population status, opportunities, restoration potential, an overview of priority dams, and potential partners and stakeholders. Tiers 2 and 3 priority tributaries have reduced content and are included in Section 4.7.

4.1 – Schuylkill

4.2 – Brandywine

4.3 – White Clay

4.4 – Pequest

4.5 – Lehigh

4.6 – Neshaminy

4.7 – Tiers 2 & 3 Priority Tributaries

5 – Funding & Project Implementation Resources

Section 5 consists of key funding sources that can be used towards aquatic connectivity projects as well as links to useful project implementation resources.

6 – Additional Recommendations & Research Needs

Section 6 list research needs, monitoring recommendations, and basinwide recommendations.

7 – Literature Cited

Appendices

A - Appendix A includes Tier 1 Priority Dam fact sheets, photos, and aerial images.

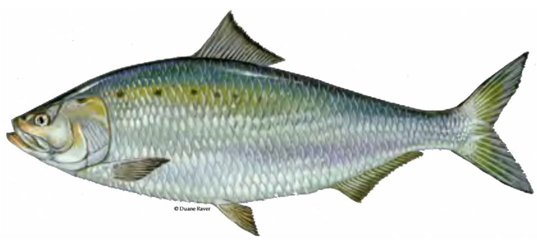
B - Appendix B includes a table with historic and current run information for American Shad, Alewife, and Blueback Herring in the basin.

C - Appendix C contains the full alosine habitat suitability assessment completed by the Academy of Natural Sciences of Drexel University.

Section 2

Species Overview & Habitat Suitability

2.1 Species Overview



American Shad.
Credit: Duane Raver, USFWS.

American Shad, *Alosa sapidissima*

American Shad are an anadromous, highly migratory, pelagic schooling species (Colette and Klein-MacPhee 2002). The species spends 4 to 5 years at sea, returning to freshwater river systems along the Atlantic coast of the United States to spawn. Their current native distribution extends from the St. Lawrence River in Canada to St. Johns River in Florida. American Shad begin their upstream migration in the spring with the peak historically occurring in May in the Delaware River (Walburg and Nichols 1967; Leggett and Whitney 1972). In the Delaware River, age at first maturity is between 3 to 6 years and repeat spawners make up less than 25% of the population (unpublished data in Hendricks et al. 2002). Ross et al. (1993) observed that the greatest level of spawning occurred where the water depth was less than 1 meter in the Delaware River.

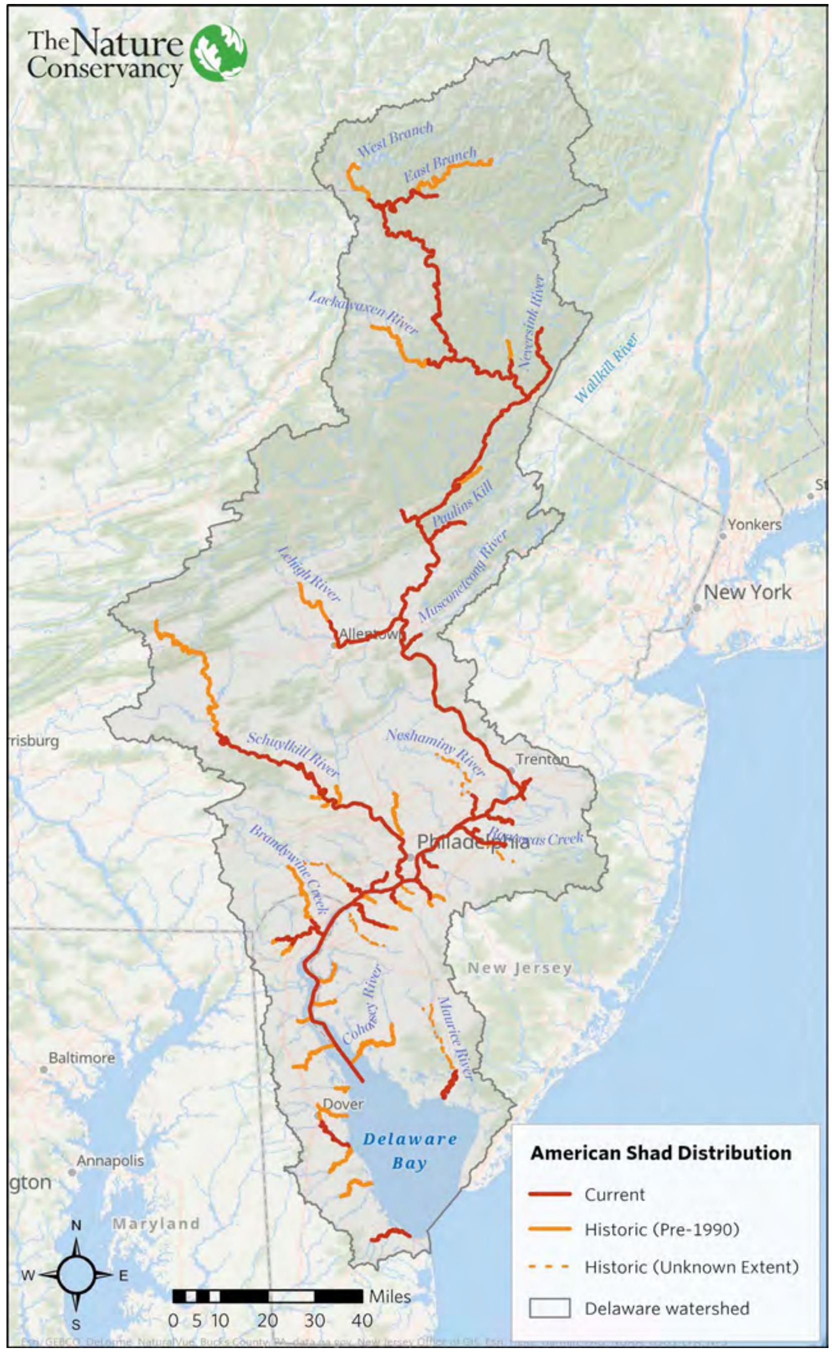


Figure 2-1. *Map of American Shad distribution in the Delaware basin. Refer to Appendix B for additional details on current and historic run information.*

Alewife. Credit: Duane Raver, USFWS.

Alewife, *Alosa pseudoharengus*

Alewife are a highly migratory, euryhaline, pelagic, schooling species of anadromous fish ranging from the Gulf of St. Lawrence and Nova Scotia (Winters et al. 1973) southward to North Carolina (Rulifson et al. 1994). The species spends the majority of its life at sea, returning to freshwater river systems along the Atlantic coast of the United States to spawn. Alewife usually spawn 3 to 4 weeks before Blueback Herring in areas where they co-occur and typically ascend the river when water temperatures reach 41°-50° F (Loesch 1987). Adult Alewife and Blueback Herring will typically enter the Delaware Basin to spawn beginning in early February with peak activity occurring during April. The adults emigrate downstream soon after spawning although a minority remains through the summer. Larvae will hatch and juveniles will maintain freshwater residence through November, although juvenile emigration can occur as early as the water temperatures decline through the fall. Once mature, adults will return to their natal streams to spawn. Many Alewives are repeat spawners, and although repeat spawning rates do not exist for the Delaware, studies from Virginia and Maryland indicated the percentage of repeat spawners ranged from 30-72% (Joseph and Davis 1965, Howell et al. 1990). Alewives are an import host fish for the alewife floater, *Anodonta implicata*, a species of freshwater mussel.

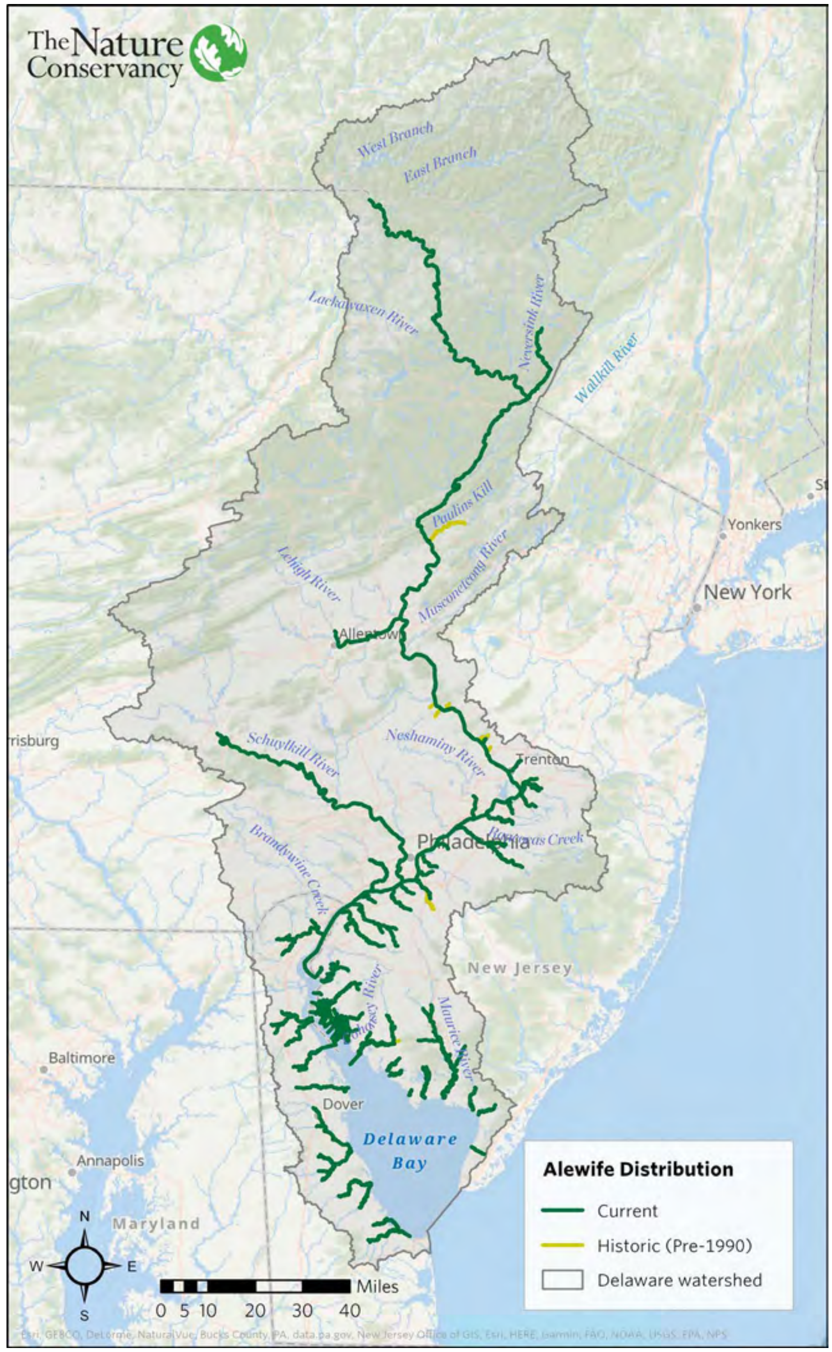


Figure 2-2. *Map of Alewife distribution in the Delaware basin.*
Refer to Appendix B for additional details on current and historic run information.

Blueback Herring.
Credit: Duane Raver, USFWS.

Blueback Herring, *Alosa aestivalis*

Blueback Herring are a highly migratory, euryhaline, pelagic, schooling species of anadromous fish ranging from the St. Johns River in Florida (Hildebrand 1963) to Cape Brenton, Nova Scotia (Bigelow and Schroeder 1953). The species spends the majority of its life at sea, returning to freshwater river systems along the Atlantic coast of the United States to spawn. Blueback Herring prefer spawning sites with fast currents and associated hard substrates (Loesch and Lund 1977). In the Delaware River, Chittenden (1972) found that the largest numbers of Blueback Herring appeared in late April near the head of tidewater and that chief spawning grounds in the Delaware River were located in the tidal portion of the river. Spawning extended about 105 kilometers above the tide. Along the coast, Blueback Herring are repeat spawners at an average rate of 30 to 40% (Richkus and DiNardo 1984); however, repeat spawning rates do not exist for the Delaware River. In laboratory experiments with juvenile Blueback Herring taken from the Delaware River, Chittenden (1972) found these juvenile fish to be highly tolerant of brackish water conditions. More recent studies also support this finding of a euryhaline tolerant species during its early life history stages (DiMaggio et al. 2016).

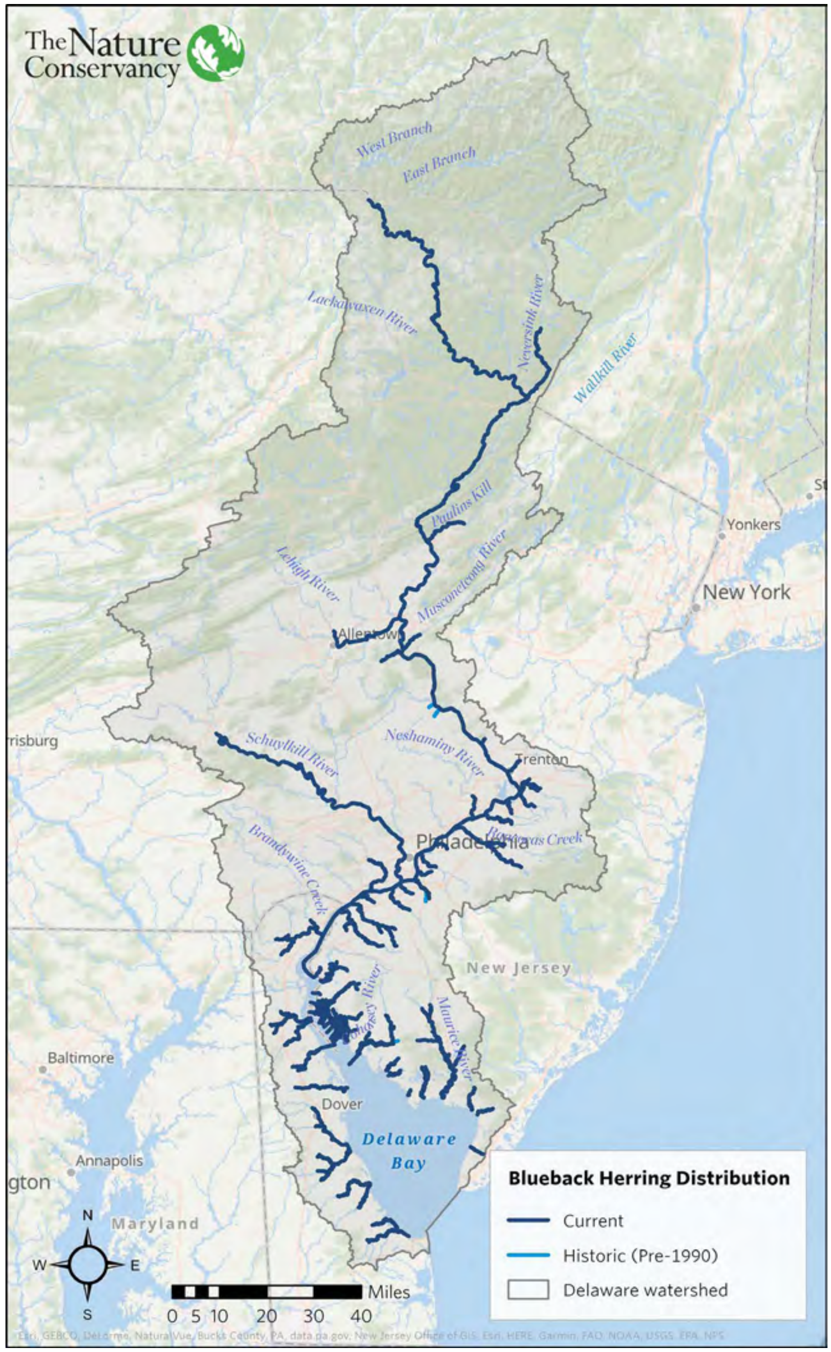


Figure 2-3. *Map of Blueback Herring distribution in the Delaware basin.*
Refer to Appendix B for additional details on current and historic run information.

2.2 Habitat Suitability

The Academy of Natural Sciences of Drexel University (ANS) assessed the habitat suitability for American Shad, Alewife, and Blueback Herring in 16 tributaries identified as having the most potential for alosine restoration (Figure 2-4). ANS compiled a total of 7.5 million records from 71 stream gages and imported these into the project database to calculate 49 metrics. These metrics were based primarily on temperature, but also included criteria for dissolved oxygen (D.O.) and pH. ANS assessed the suitability of habitat of priority tributaries for the spawning, egg, larval, and early juvenile stages of each alosine species using key habitat suitability criteria from Greene et al. (2009) (Table 2-1). For each priority tributary, ANS compiled temperature, dissolved oxygen, and pH data from existing sources (e.g., USGS gaging stations, government agencies, and public sources) to assess habitat quality for each species-stage combination. Following data compilation, data gaps were identified and overall habitat suitability for each alosine species was assessed where existing data allowed.

Metrics were compiled for each alosine species-stage combination for each priority tributary and used in a semi-quantitative assessment of habitat suitability (Table 2-1). For most priority tributaries, data from multiple gages were considered. Typically, gages on larger watersheds were weighted more heavily when subjectively assigning suitability categories for species-stage combinations.

Sixteen priority tributaries were assessed for their suitability to support twelve alosine species-stage combinations. Based on similarity, tributaries were grouped into four tiers for overall temperature suitability, three tiers for overall pH suitability, and two tiers for overall dissolved oxygen suitability (Table 2-2). Tiers were developed to ease interpretation and aid in relative comparisons among the 16 priority systems. Please refer to Appendix C for the complete report and results.

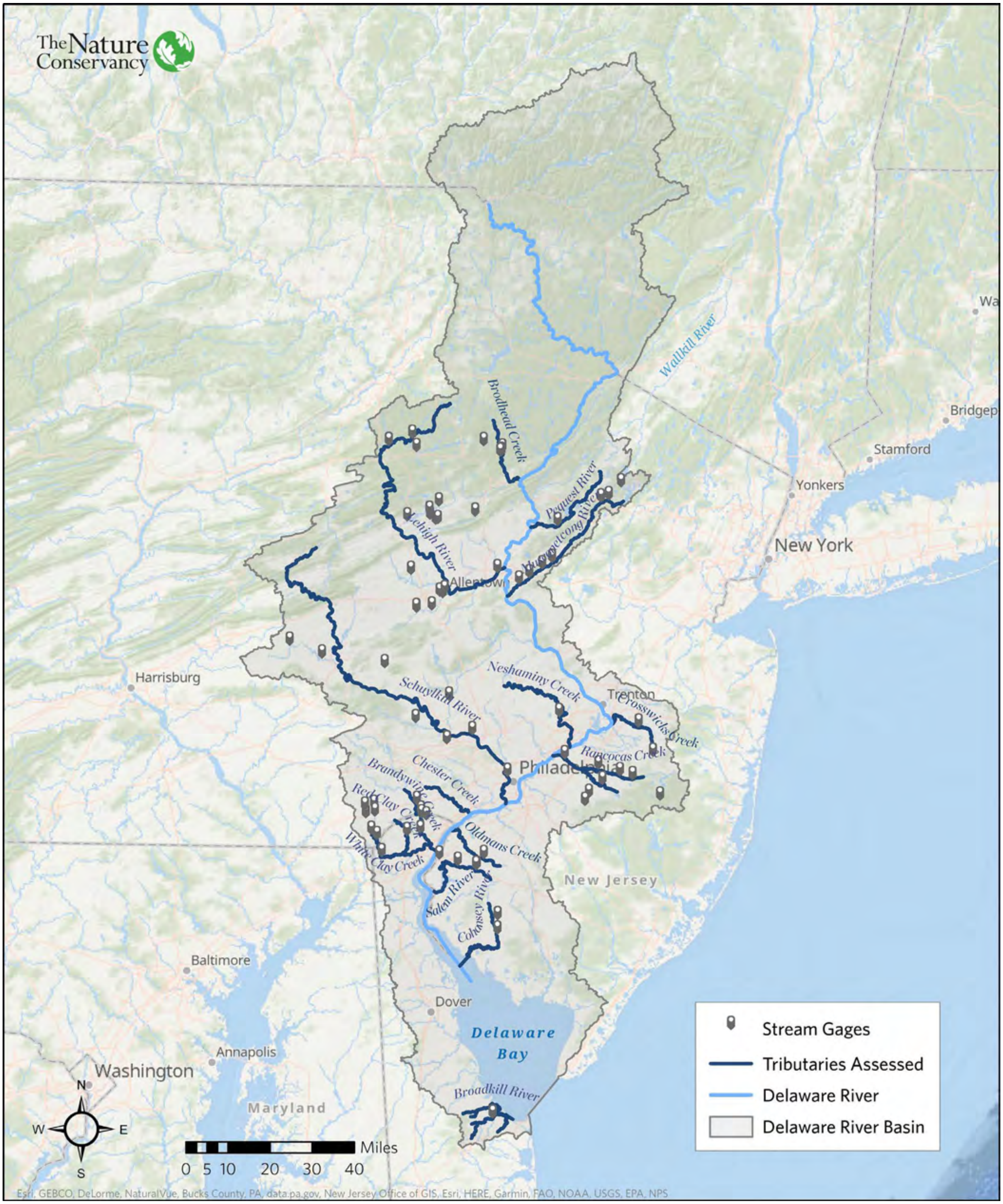


Figure 2-4. *Map of 16 priority tributaries assessed during habitat suitability assessment, including stream gages used for data.*

Species	Life Stage	Parameter	Description
American Shad	Early-juvenile	Dissolved Oxygen	Percentage of measurements during the Summer (July,Aug,Sept) that are at or above 5 mg/l dissolved oxygen.
		Temperature	Percentage of measurements during the Summer (July,Aug,Sept) that are within the optimum temperature (10-25°C) range.
		Temperature	Percentage of measurements during the Summer (July,Aug,Sept) that are within the tolerable temperature (3-35°C) range.
	Egg	Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (8-30°C) range.
		pH	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable pH (5.5-9.5) range.
		pH	Percentage of measurements during the Spring (Apr,May,June) that are within the average tolerable pH (6-8.5) range.
		Dissolved Oxygen	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.
	Larval	Dissolved Oxygen	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.
		pH	Percentage of measurements during the Spring (Apr,May,June) that are within the average tolerable pH (6.6-9.6) range.
		pH	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable pH (6.5-9.9) range.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (10-30°C) range.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (15-25°C) range.
	Spawning Adult	Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (8-26°C) range.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (14-24.5°C) range.
		Dissolved Oxygen	Percentage of measurements during the Spring (Apr,May,June) that are at or above 4 mg/l dissolved oxygen.

Table 2-1. *Description of metrics derived from Greene et al. (2009) used to assess habitat suitability for American Shad, Alewife, and Blueback Herring.*

Species	Life Stage	Parameter	Description
Alewife	Early-juvenile	Temperature	Percentage of measurements during the Summer (July,Aug,Sept) that are within the optimum temperature (15-20°C) range.
		Dissolved Oxygen	Percentage of measurements during the Summer (July,Aug,Sept) that are at or above 3.6 mg/l dissolved oxygen.
		Temperature	Percentage of measurements during the Summer (July,Aug,Sept) that are within the tolerable temperature (10-28°C) range.
	Egg	Dissolved Oxygen	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.
		pH	Percentage of measurements during the Spring (Apr,May,June) that are within the optimal pH (5-8.5) range.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (10.6-26.7°C) range.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (17.2-21.1°C) range.
	Larval	pH	Percentage of measurements during the Spring (Apr,May,June) that are within the optimal pH (5-8.5) range.
		Dissolved Oxygen	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (14-28°C) range.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (20-26°C) range.
		Dissolved Oxygen	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.
	Spawning Adult	Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (8-31°C) range.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (15-24°C) range.
		pH	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable pH (4.5-7.3) range.

Table 2-1 *(cont.). Description of metrics derived from Greene et al. (2009) used to assess habitat suitability for American Shad, Alewife, and Blueback Herring.*

Species	Life Stage	Parameter	Description
Blueback Herring	Early-juvenile	Temperature	Percentage of measurements during the Summer (July,Aug,Sept) that are within the optimum temperature (20-30°C) range.
		Temperature	Percentage of measurements during the Summer (July,Aug,Sept) that are within the tolerable temperature (11-32°C) range.
		Dissolved Oxygen	Percentage of measurements during the Summer (July,Aug,Sept) that are at or above 4 mg/l dissolved oxygen.
	Egg	pH	Percentage of measurements during the Spring (Apr,May,June) that are within the optimal pH (6-8) range.
		pH	Percentage of measurements during the Spring (Apr,May,June) that are within the suitable pH (5.7-8.5) range.
		Dissolved Oxygen	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (7-14°C) range.
	Larval	pH	Percentage of measurements during the Spring (Apr,May,June) that are within the optimal pH (6.5-8.0) range.
		pH	Percentage of measurements during the Spring (Apr,May,June) that are within the suitable pH (6.2-8.5) range.
		Dissolved Oxygen	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (13-28°C) range.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (13-27°C) range.
	Spawning Adult	Dissolved Oxygen	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.
		Temperature	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (20-25°C) range.
		pH	Percentage of measurements during the Spring (Apr,May,June) that are within the suitable pH (6-8) range.

Table 2-1 *(cont.). Description of metrics derived from Greene et al. (2009) used to assess habitat suitability for American Shad, Alewife, and Blueback Herring.*

Species	Life Stage	Cohansey River	Red Clay Creek	Brandywine Creek	White Clay Creek	Schuylkill River	Pequest River	Musconetcong River	Neshaminy Creek	Crosswicks Creek	Rancocas Creek	Lehigh River	Broadkill River	Salem River	Brodhead Creek	Chester Creek	Oldmans Creek
American Shad	Adult	O	O	O	O	O	O	O	O	O	O	O[2]	O	O[1]	S	-	-
	Egg	T	T	T	T	T	T	T	T	T	T	T	T	T	T	-	-
	Larval	O	O	O	O	O[2]	O	O	O	O	O	S	O	S[1]	S	-	-
	Juvenile	O	O	O	O	O[2]	O	O	O	O	O[2]	O	S	O	O	-	-
Alewife	Adult	O[2]	O	S	S	S[4]	O	O	S	S	S	O[2]	S	S	S	-	-
	Egg	S	S[1]	S[1]	S[1]	S[1]	S	S[1]	P	P	P	S[1]	S[1]	S[1]	P	-	-
	Larval	S[1]	S	S	S	S[1]	P	P	S	S	S	P	S	S[1]	P	-	-
	Juvenile	S[1]	P	P	P	P[5]	O	S	P	P	P	S	T	P	S	-	-
Blueback Herring	Adult	S[1]	S	S	S	S[1]	P	P	S	S[1]	S	P[3]	S	S[1]	P/I	-	-
	Egg	I	I	I	I	I	I	I	I	I	I	I	I	I	T	-	-
	Larval	T	T	T	T	T	T	T	T	T	T	T	T	T	I	-	-
	Juvenile	O	O	O	O	O	S	O	O	O	O	O	O	O	S	-	-
Temp Tiers		1	1	1	1	1	2	2	2	2	2	3	3	3	4	UA	UA
pH Tiers		UA	UA	2	UA	2	UA	UA	UA	UA	UA	1	1	3[6]	UA	UA	1[6]
D.O. Tiers		UA	UA	1	UA	1	UA	UA	UA	UA	UA	1	2	2[6]	UA	UA	UA

O optimal, optimal conditions; >50% of the time optimal
S suboptimal, optimal conditions; 25-50% of the time optimal
P poor, optimal conditions; <25% of the time optimal
T mostly tolerable condition; >50% of the time tolerable
I mostly intolerable conditions; <50% of the time tolerable
UA unable to assess; additional data needed

1 many years or gages indicate poor temperatures
2 many years or gages indicate suboptimal temperatures
3 some gages indicate mostly tolerable temperatures
4 some optimal temperatures in upper watershed
5 some suboptimal temperatures in upper watershed
6 based on 14-day continuous dataset

Table 2-2. *Summary of habitat suitability for American Shad, Alewife, and Blueback Herring in 16 tributaries identified as priorities for restoration. Conditions were determined by assessing metric scores for each species-stage within a tributary. Temperature, pH, and dissolved oxygen tiers represent subjective groupings with similar tributaries sharing numbers and shading, and lower numbers indicating better suitability.*

©Lyndon DeSalvo/TNC

Section 3

Beyond Dams: Restoration Challenges in the Delaware River Basin

While habitat fragmentation caused by dams and other barriers is a primary threat to alosines and the focus of this report, there are additional challenges to restoring these populations. This section provides a high-level overview of some of these challenges as well as specific threats to alosines in the Delaware basin and coastwide. For more information, refer to those resources cited throughout the section as well as the recently published paper by Hare et al. 2021 (link at right) that offers a holistic examination of challenges to river herring restoration coastwide.

Fishways

Technical fishways have been determined to be generally ineffective at passing American Shad (Haro & Santos 2012). Of the 45 priority dams identified through this project as priorities for alosine restoration, 11 have engineered fish passage, but there are additional fishways on other tributaries in the basin. Throughout this project we found that many of these fish ladders are not maintained or monitored—even during the spawning run season—and those that did have passage, often passed nominal numbers of fish. While the State of Pennsylvania has been a nationwide leader in dam removals, a few of these fish ladders and dams which have minimal maintenance and passage are actually owned by state conservation agencies and are located on tributaries that had sizable historic shad and river herring runs.

The States of New Jersey and Delaware are both utilizing eDNA technology to determine fish ladder effectiveness on their dams. Historically, fish ladders have been the tool of first choice when dealing with connectivity issues; however, fish ladders should be a tool of last resort as dam removal is the best fish passage technology (ASMFC 2010).

A Review of River Herring Science

In 2013, National Oceanic and Atmospheric Administration Fisheries established the Technical Expert Working Group (TEWG) to synthesize information about river herring and to provide recommendations to advance the science related to their restoration.

The result of this effort is a synthesis paper entitled "*A Review of River Herring Science in Support of Species Conservation and Ecosystem Restoration*" by Hare et al. (2021). It is a holistic examination of challenges of recovering river herring coastwide. The authors identify dam removal and increased stream connectivity as critical to river herring restoration. The paper is open access and can be found **here.**

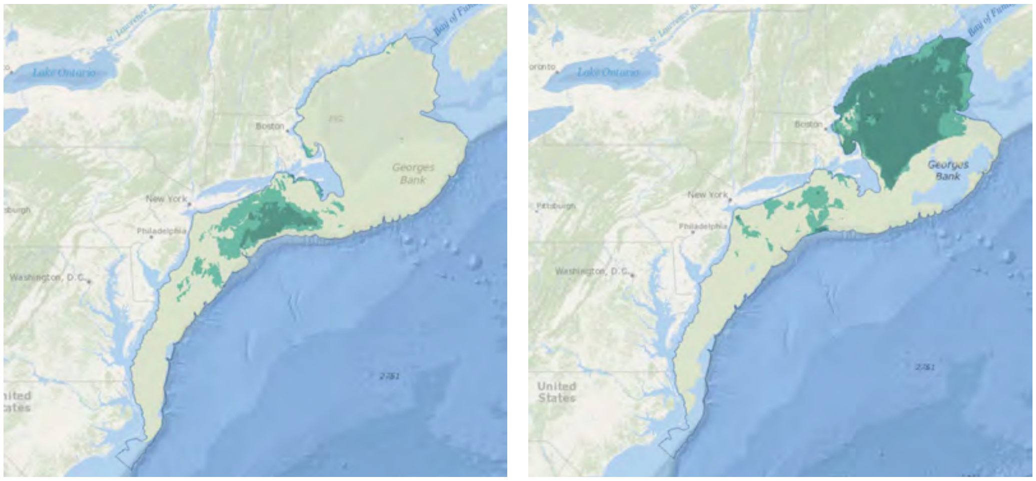


Figure 3-1. *Alewife biomass from spring in the 1970s (left) and 2010s. Credit: MARCO Mid-Atlantic Ocean Data Portal.*

Check out the ***MARCO Mid-Atlantic Ocean Data Portal*** *to explore the Fish Species Through Time map collection and view shifts to the distribution of Mid-Atlantic fish species over the last five decades.*

Changing Climate/Shifting Distributions

Anadromous fish species have been identified as being highly vulnerable to the cumulative effects of climate change (Hare et al. 2016) and other direct anthropogenic pressures. There is mounting evidence that climate change is altering the timing of migration and spawning cycles of anadromous fishes by shifting distributions, restricting suitable habitat, or shortening the window of time (i.e., phenophase) in which ideal conditions for those activities take place (Nye et al. 2009; Peer and Miller 2014; Lynch et al. 2015; Lombardo et al. 2020). Legett et al. 2021 found that water temperature was the most consistent predictor of both daily river herring presence-absence and abundance during migration in an analysis of twelve coastal streams in Massachusetts. In the Delaware River Basin, the alosine populations should be managed in a way that promotes and protects a diverse age structure and habitat utilization in order to "hedge our bets" against a single catastrophic event that can wipe out an entire year's cohort of shad and/or river herring.

Mid-Atlantic fish are expected to shift northward, eastward, and/or into deeper water in response to climate change (Nye et al. 2009; Pinsky et al. 2013). An analysis of federal Northeast Fisheries Science Center (NEFSC) bottom trawl survey data collected between 1972 and 2017 show a trend in alewife moving to waters farther north and further offshore from the 1970s to the present day (Figure 3-1). Shifting distribution can challenge documenting restoration succuss when factors in the marine environment may be driving changes to abundance and distribution of these species.

A population that utilizes the full extent of the mainstem as well as numerous tributaries of different size classes may have greater reproductive potential to protect against negative impacts from environmental disturbances (Hillborn et al. 2003, Schindler et al. 2010).

A diverse age structure and behavioral patterns within a population of migratory fish can help mitigate against stochastic or anthropomorphic effects and take advantage of ideal conditions for population recruitment (Kerr et al. 2010, Secor 2007).

Figure 3-2. *The Lehigh Canal in Easton, PA. The Chain Dam currently waters the canal, which is used as a cultural and recreational resource, and is the main reason why stakeholders have opposed removing the dam. Credit: Lyndon DeSalvo/TNC.*

Canals

Locally cherished historic canals have proven a significant barrier to advancing dam removal on priority river systems and therefore restoration of alosines. Although the original use for these canal systems is long gone, many of the canal towpaths have been turned into recreation trails along water-filled canals (Figure 3-2). Dams still provide the water to these canals and solutions to removing the dam while maintaining water in the canal have proven to be difficult to overcome. Innovative solutions to balance the needs of migratory fish passage and historic and recreational interests are needed.

Data Gaps

The continued decline of alosines suggests that critical information about the ecology and key habitat suitability metrics for these species remains unknown (Gahagan and Bailey 2020). Documenting the most important places for restoration is difficult without a clear picture of what constitutes high-quality habitat. In the Delaware River, there is a significant lack of Alewife and Blueback Herring life history data and what data do exist are dated. With climate change impacts and uncertainties, it is critical to improve basic life history knowledge and habitat suitably information for these species.

Impingement and Entrainment (I&E)

There are several large water intake systems at energy projects on the Delaware River. The Delaware River Fish and Wildlife Management Cooperative acquired 316b reports for five companies with cooling water intake structures (CWIS) on the Delaware River or its tributaries plus Annual Biological Monitoring Reports for the Salem Generating Station. These reports indicated that individual projects can entrain millions of alosine eggs and larvae annually and impinge tens of thousands of juveniles (J. Mohler pers. comm.). In a river system with numerous intake facilities that occur in spawning and nursery grounds for alosines, the cumulative impacts to the population could be substantial. Reporting of I&E losses are inconsistent. Consistent periodical assessments would aid in providing a better characterization of loss to this type of mortality and its potential impact on restoration of alosines in the basin.

Bycatch

Recent genetic studies have indicated that mid-Atlantic Blueback Herring stocks are being significantly impacted by bycatch in the Atlantic Herring Fishery and this bycatch may be impacting restoration efforts (Hasselman et al. 2016). Fisheries managers do not currently have enough data to determine biologically-based river herring and shad catch caps or to assess the potential effects of such catch caps on river herring and shad populations coastwide or in the Delaware River.

Predation

Flathead Catfish, Blue Catfish, Northern Snakehead, and Swamp Eels are only a few of the introduced species that may be causing increased predation on alosines in the Delaware River. The Philadelphia Water Department has documented Flathead Catfish inhabiting the fishway in Fairmount Dam, and these fish were likely targeting alosines as a food source during the spring spawning run. This type of threat is difficult to address and highlights the importance in ecosystem-based management in fisheries. Future studies such as stomach analysis on naturalized non-native species and the development of ecosystem level fish population models are critical to understanding if alosine populations are being impacted by abundant predator populations. Because the non-native piscivores have become widely established in the river system and prized by numerous groups of anglers, eradication of these species is unlikely.

Urbanization & Associated Flooding

Increasing urbanization and corresponding increases in impervious surfaces can significantly reduce the percentage of Alewife eggs and larvae that survive, and this may be especially true in smaller watersheds (Limburg and Schmidt, 1990, Uphoff 2011, Monteiro et al. 2020). For example, between 2000 and 2015, the population of the Brandywine-Christina watershed grew by 8%, with most of the growth occurring in Pennsylvania (Brandywine Conservancy 2018). This increase in impervious area combined with extreme storm events, such as Tropical Storm Ida in September 2021, has led to severe flooding particularly in the downstream urbanized section of the creek that runs through Wilmington, Del. This is not unique to the Brandywine watershed and highlights the need for a multifaceted approach to alosine restoration that includes a focus on water quality, protecting intact habitat, and restoring degraded streams (Figure 3-3).

Figure 3-3. *Fairmout Dam during Tropical Storm Ida, September 2021. The lower Schuylkill River severely flooded during Ida in September 2021 causing the Fairmount Dam to be completely submerged. During the storm, the fishway was damaged and may not be operational for the 2022 spawning runs. Credit: Lyndon DeSalvo/TNC.*

© Jason Fischer

Section 4

Priority Tributaries & Actions

Habitat fragmentation caused by over 1,400 dams and other barriers along tributaries throughout the Delaware River basin currently limits access to critical spawning and rearing habitat for alosines.

This project advances a targeted approach to improving aquatic connectivity for American Shad, Alewife, and Blueback Herring by prioritizing and evaluating barriers on rivers of historical significance and with suitable habitat conditions, while also considering project feasibility. Rather than select individual barriers scattered throughout the basin, the roadmap instead focuses on a set of priority tributaries—most of which have a suite of barriers along them. The proposed actions seek to address the collective impact resulting from improved connectivity at all sites, while also specifically addressing the first or the most downstream dam in the series, as "opening up" connectivity between the mainstem Delaware River and its tributaries is essential for re-establishing connectivity for migratory fish species. This approach not only leverages the ecological benefits of multiple restoration projects within a watershed, but it also leverages potential for shared funding and capacity needs by targeting a reduced number of systems.

The below section details the process of winnowing down from over 1,400 barriers basinwide to the 45 included as priorities in the roadmap, which are located along 13 tributary rivers and streams. These priority tributaries (and the dams along them) are further separated into three tiers, with Tier 1 being the highest priority. For these Tier 1 barriers, the report includes an in-depth assessment of existing conditions, including images and fact sheets, as well as necessary actions towards fish passage and habitat restoration. In some instances, the barrier may limit passage altogether whereas others may already have a fishway, but either not pass alosines at a sufficient rate to restore populations or need further study to understand current passage conditions. Some of the dams that restrict access to spawning habitat are obsolete and no longer serve their intended purpose; some are dangerous to human life, and others, not designed to withstand the increase flooding associated with climate change, pose risks to local communities. The roadmap also identifies additional benefits associated with dam removal and restoration and highlights these and other opportunities in each priority section.

Figure 4-1. *Restoration Roadmap process diagram.*

5.1 Process for Prioritization

Step 1: Synthesize Data

At the outset of the project, data was synthesized from existing plans and prioritizations related to aquatic connectivity across the four states of the basin including: *The Delaware River Basin American Shad Habitat Plan*, NFWF *River Herring Restoration Needs Report*, New York's Delaware River Barrier Prioritization, the New Jersey Statewide Dam Removal Partnership, the Brandywine Shad 2020 Collaboration, and the Pennsylvania Aquatic Connectivity Workgroup. Additional outreach to experts and practitioners was also conducted to update existing barrier information in the basin and identify current streams suitable for shad and/or river herring restoration. Using this updated dataset, barriers across the basin were prioritized using the Northeast Aquatic Barrier Prioritization Tool , which offers a landscape-scale ecological benefits assessment and is designed to support planners and managers in their efforts to target dam removals, fish passage improvements, and other aquatic connectivity projects where they can have the most benefit for migratory fish or other species of interest. The result provided a preliminary list of priority barriers for aquatic restoration across the Delaware River basin.

Step 2: Narrow Priorities

During Step 2, numerous one-on-one and small group discussions were held with key partners and stakeholders to further understand on-the-ground conditions and current species distribution throughout the watershed. This included state and federal agency officials, academic fishery experts, local watershed practitioners, and community members advancing aquatic connectivity efforts. Information on historical runs was also collected from historic fisheries reports, historic narratives, and previous assessments and then mapped with current distribution to view key barriers to upstream migration. The preliminary list of priority sites was then assessed against known historical and current runs of shad and river herring in the basin to further refine priorities. Feedback was solicited from the Delaware River Basin Fish and Wildlife Management Cooperative (Co-op) during this step to ensure priorities aligned with the expansive collective knowledge of its members. The result was a short list of priority tributaries and barriers to be further assessed in Steps 3 and 4, which happened concurrently.

Step 3: Investigate Priorities

In Step 3, priority barriers were investigated in-depth to better understand on-the-ground conditions and feasibility of options for improving connectivity at these sites. This involved discussions with partners, review of previous assessments and reports, and site visits to ascertain opportunities and challenges associated with each of the structures. Special attention was paid to engineering constraints, such as the existence of nearby infrastructure, stream gages, and as possible, the extent of legacy sediment behind the dam, permitting challenges associated with cultural resources and rare species, and existing uses, such as water supply or recreation. In some instances, site visits also helped to determine that certain structures were passable by alosines in typical spring flow conditions and did not constitute a barrier to passage. For instance, two barriers within the Crosswicks Creek watershed were deemed to be passable and therefore this system was removed from the final priority list (Figure 4-2). When feasible, meetings with dam owners also occurred to understand project feasibility and readiness for barrier removal or alternative fish passage options. Through this process and the concurrent habitat suitability assessment described below, the final list of priority tributaries and associated dams was developed for inclusion in the roadmap.

Step 4: Assess Habitat

The Academy of Natural Sciences (ANS) assessed the habitat suitability for American Shad, Alewife, and Blueback Herring in 16 tributaries identified as having the most potential for alosine restoration (priority tributaries). ANS assessed the suitability of habitat of priority tributaries for the spawning, egg, larval, and early-juvenile stages of each alosine species using key habitat suitability criteria from Greene et al. (2009). For each priority tributary, ANS compiled temperature, dissolved oxygen, and pH data from existing sources (e.g., USGS gaging stations, government agencies and public sources) to assess habitat quality for each species-stage combination. Following data compilation, ANS identified data gaps and assessed overall habitat suitability for each alosine species where existing data allowed. During this step, ANS determined that there was insufficient data to assess suitability for Oldmans Creek and that the Salem River and Brodhead Creek had the least suitable conditions as compared to the others and thus all three systems were removed as priorities. The full habitat suitability report is included as Appendix C.

Figure 4-2. *Walnford Dam on Crosswicks Creek. A side channel beside the historic gristmill was determined to allow for sufficient fish passage during a site visit. Credit: Lyndon DeSalvo/TNC.*

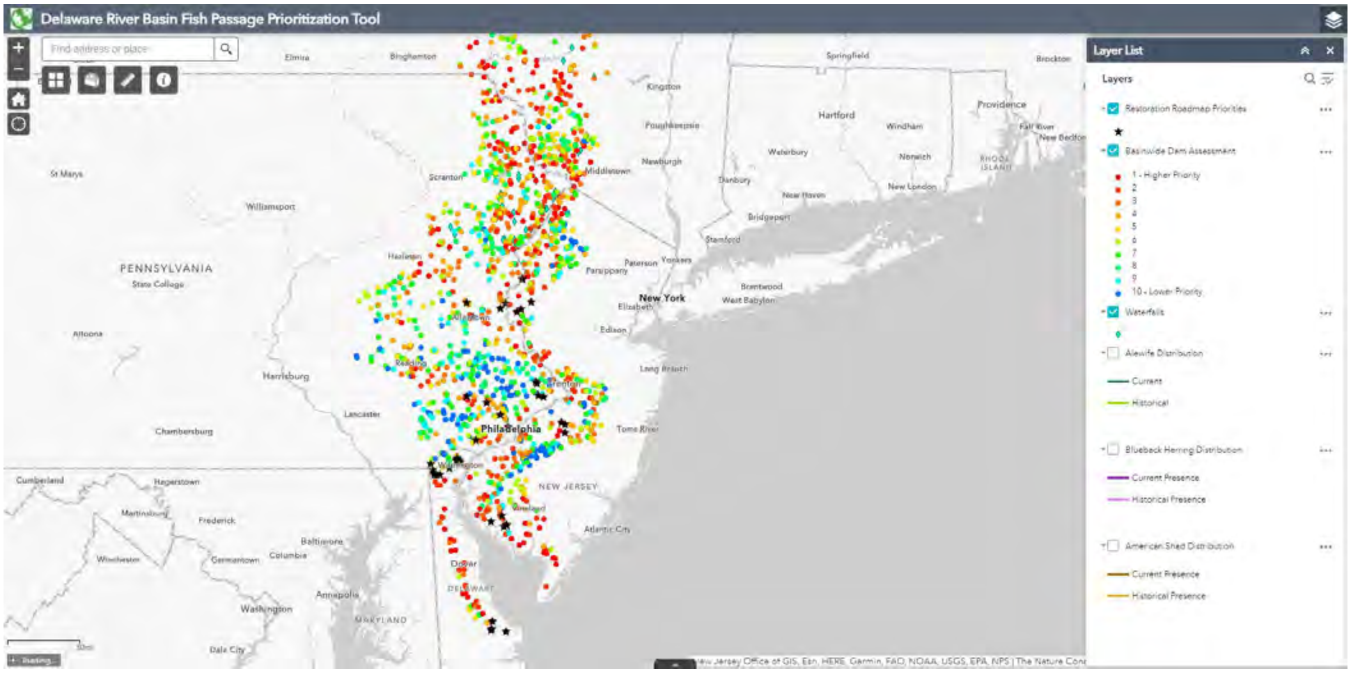


Figure 4-3. *Delaware River Basin Fish Passage Prioritization Tool.*

Delaware River Basin Fish Passage Prioritization Tool

The Delaware River Basin Fish Passage Prioritization Tool was developed in ArcGIS Online and allows users to explore an updated basinwide dams dataset, current and historic distribution of American Shad, Alewife, and Blueback Herring within the basin, and the priority dams identified in the Restoration Roadmap.

Click the link to explore:
https://maps.tnc.org/drbdams

Step 5: Finalize Roadmap

The final step was to develop the Restoration Roadmap, which consolidates information gathered in the previous steps and highlights key actions needed to address priority barriers for the restoration of alosines in the Delaware River Basin. This includes recommendations on funding needs, opportunity, potential for phasing projects, and key partners and stakeholders. Alongside the report is a Delaware River Basin Fish Passage Prioritization tool developed in ArcGIS Online that uses an updated basinwide dams dataset and includes information on fishways and barrier permeability (Figure 4-3). Users can customize an ecological benefits assessment using 12 pre-set aquatic connectivity and landscape-scale metrics determined to be most relevant to shad and river herring, as well as explore the known historic and current run information for these species and the priorities identified in the Restoration Roadmap.

Tier 1 - Highest Priority	Tier 2 - Priority	Tier 3 - Exploratory
Schuylkill River Brandywine Creek White Clay Creek Lehigh River Pequest River Neshaminy Creek	Musconetcong River Rancocas Creek Cohansey River East Branch Delaware River*	Red Clay Creek Broadkill River Chester Creek

Table 4-1. *Priority Tributaries for American Shad and river herring restoration in the Delaware River basin. *The East Branch Delaware River is included as a priority tributary with the aim of modifying releases from the Pepacton Reservoir to improve conditions for alosines.*

5.2 Priority Tributaries

Table 4-1 includes the list of Delaware River tributaries identified as priorities for American Shad and river herring restoration efforts. Those listed as Tier 1 are the highest priority and detailed at-length in this report, whereas Tier 2 are priority and Tier 3 are those with potential but in need of further exploration and scoping.

Notable Exceptions

Inevitably, the priority tributaries list excludes certain historically significant rivers or others with suitable habitat for various reasons. Without going into extensive detail, a few notable exceptions are listed below in upstream to downstream order with some of the rationale for omitting them from the list.

West Branch Delaware River – The Cannonsville Reservoir is currently critical to New York City's water supply and therefore dam removal is extremely unlikely and fish passage is unfeasible.

Lackawaxen River – The Lackawaxen was a historically significant shad stream and currently there are no barriers to passage in its lower section.

Mongaup River – The Mongaup currently has three hydropower dams that are in the process of FERC relicensing. Dam #2 is located at Mongaup Falls, which would most likely have been a natural barrier to upstream passage of alosines historically.

Paulins Kill – Dam removal efforts along the Paulins Kill have already led to the removal of the Columbia Lake Dam with plans well underway to remove the two next upstream dams. It was determined that by the time of report publication, these projects would have been fully funded and no longer warrant being listed as priorities; however, the Paulins Kill should be considered as a key monitoring site to measure pre- and post-dam removal effectivness.

Big Timber Creek – Despite historic and current alosine runs, Big Timber Creek was excluded due to extremely high levels of urbanization within the watershed and no barriers along its mainstem.

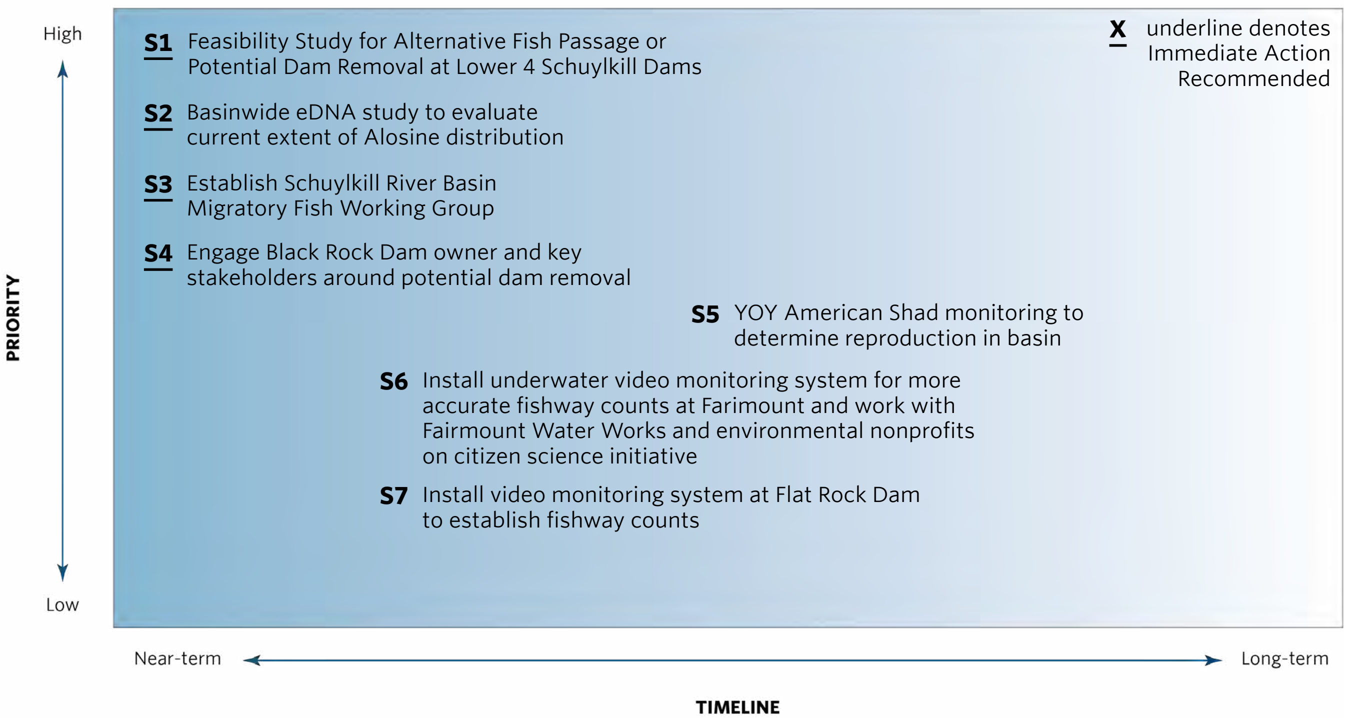
Raccoon Creek – The one dam that most greatly impacts alosines – the Mullica Hill Pond Dam – was recently reconstructed with the addition of a new fish ladder in 2019 and therefore was considered very unlikely for removal in the near-term.

Salem River – The Salem was included in the habitat suitability assessment, but it was determined that habitat upstream of the first barrier was unsuitable for alosines presumably due to high levels of nutrient deposition caused by agricultural uses in the headwaters.

Maurice River – A historically significant shad stream, the Maurice River was excluded because most of its tributary dams already have steeppass ladders and the Union Lake Dam, popular for recreation, is highly unlikely for removal and successful fish passage would likely require installation of a fish lift.

4.1 Schuylkill River

Priority Restoration Actions



Background

The Schuylkill River begins at its headwaters in the mountains near the tiny coal-region town of Tuscarora, PA and flows southeasterly for approximately 137 miles through Schuylkill, Berks, Montgomery, Chester, and Philadelphia Counties on its way to its confluence with the Delaware River in Philadelphia. Draining an area of about 1,916 square miles, the Schuylkill River is the largest tributary to the Delaware and was once home to the Delaware Lenape tribe who called it the *manaiunk* meaning "place where we go to drink" (Heckewelder and Du Ponceau 1834, 355). The Schuylkill River was renowned for its runs of shad and other migratory fish. American Shad historically migrated 120 miles upstream to Pottsville, Pa. and the spawning runs were estimated to be in the hundreds of thousands. An account by William Penn even mentions six hundred shad being taken with one swipe of the seine and written records describe numerous fisheries along the banks of the Schuylkill, with those at Manayunk and Long Ford being particularly sizeable (Penn 1685, Meehan 1893). Mill dams along tributary streams blocked historic fish runs relied upon by the Lenape and, in the mid-1700s, the so-called "fish wars" occurred when those operating freight canoes used for transporting goods clashed with fisherman who would place racks, weirs, and dams in the river causing the boats to overturn.

In 1820, the construction of the Fairmount Dam (Dam #1) nine miles from the mouth of the Schuylkill River—built both to provide slack water

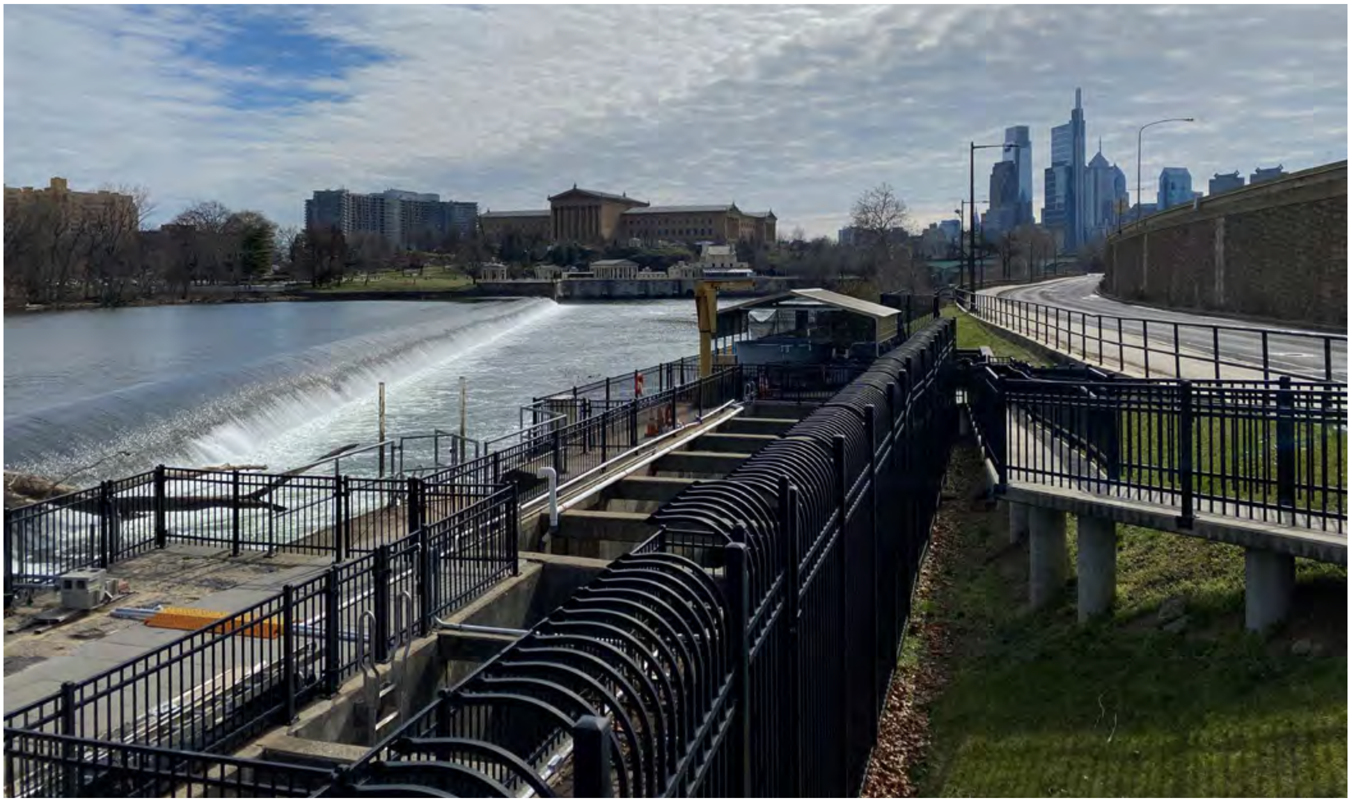


Figure 4-4. *Fairmount Dam fish ladder. Credit: Lyndon DeSalvo/TNC.*

to a section of canal and as a water supply for Philadelphia—effectively eliminated migratory fish runs in the tributary for 150 years (Sykes and Lehman 1957). An addition of a fishway (Figure 4-4) in 1979 was a result of cooperative efforts by Pennsylvania Fish and Boat Commission, United States Fish and Wildlife Service, and the City of Philadelphia following water quality improvements and the return of alosines to the tidal section of the river (DRBFWMC 1985). Restoration efforts over the last 40 years have included the removal of several mainstem dams and addition of fishways to many of the remaining dams. Currently there are six complete mainstem dams with removal planned for the New Kernsville Dam (Dam #5) in the next couple of years.

These restoration efforts have provided access through a series of fish ladders and, in theory, alosines have access to 100 miles of mainstem up to the New Kernsville Dam. However, only minimal passage is thought to be occurring due to insufficient passage rates at the four downstream dams. Single digit passage of shad at Black Rock Dam #4 (2011-16) has been documented (Normandeau Associates 2019). The extent of utilization by alosines in Schuylkill River tributaries is unknown at this time.

Population Status

Electrofishing gear is used to sample upstream migrating adult shad and river herring in the tidal reach below the Fairmount Dam to obtain annual estimates of relative abundance using CPUE. Annual passage counts at the Fairmount fishway average approximately 1,500 American Shad and the current run is estimated to Reading, Pa. (rm 75), with only a handful of shad making it upstream of Black Rock Dam (Dam #4) from 2011 to 2016. River

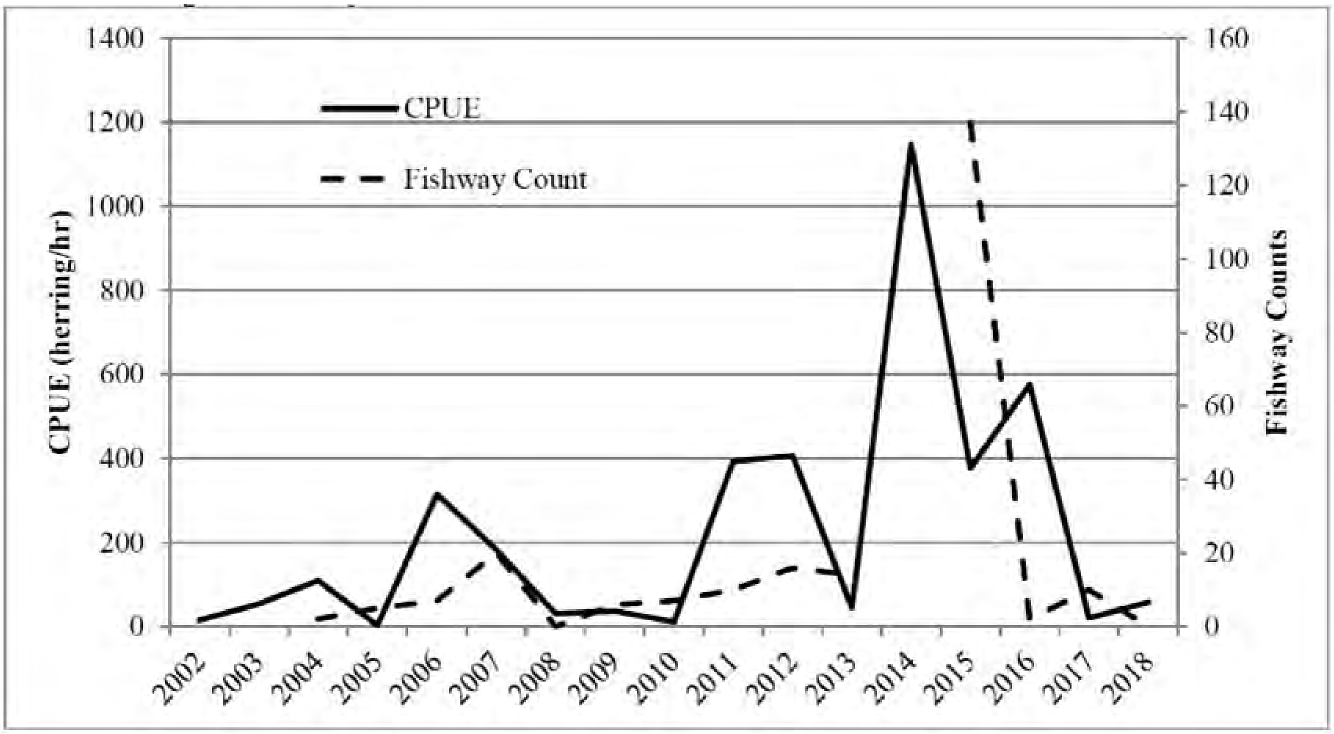


Figure 4-5. *Electrofishing CPUE (river herring/hr) and fishway video counts at Fairmount Dam. Credit: Philadelphia Water Department.*

herring relative abundance has been quantified by the Philadelphia Water Department during their springtime boat electrofishing surveys in the tidal reach of the Schuylkill River below Fairmount Dam and they also document successful river herring passage (total number) through the Fairmount fishway, (RM 8.5; Figure 4-5).

Successful passage of river herring through the Fairmount Fishway is nominal since monitoring commenced in 2004. The poor passage of river herring compared to the relative high abundance immediately below the fishway entrance suggests that restoration of these fishes to the Schuylkill River may be viable with improved passage.

Opportunity

Migratory fish restoration efforts in the Schuylkill watershed have diminished somewhat since the early 2000s when many mainstem dams were removed or had fish ladders added to them. However, the Schuylkill still offers a significant opportunity to restore alosine populations due to the extent of potential habitat and known historic capacity of the watershed, concerted efforts amongst partners to address water quality, and dam owner willingness to discuss fish passage improvements. In addition, widespread flooding along the lower Schuylkill in recent years has devastated many local communities and dam removal or alternative fish passage, along with other restoration efforts, may present an opportunity to help mitigate future impacts from flooding and enhance resiliency in the face of climate change impacts.

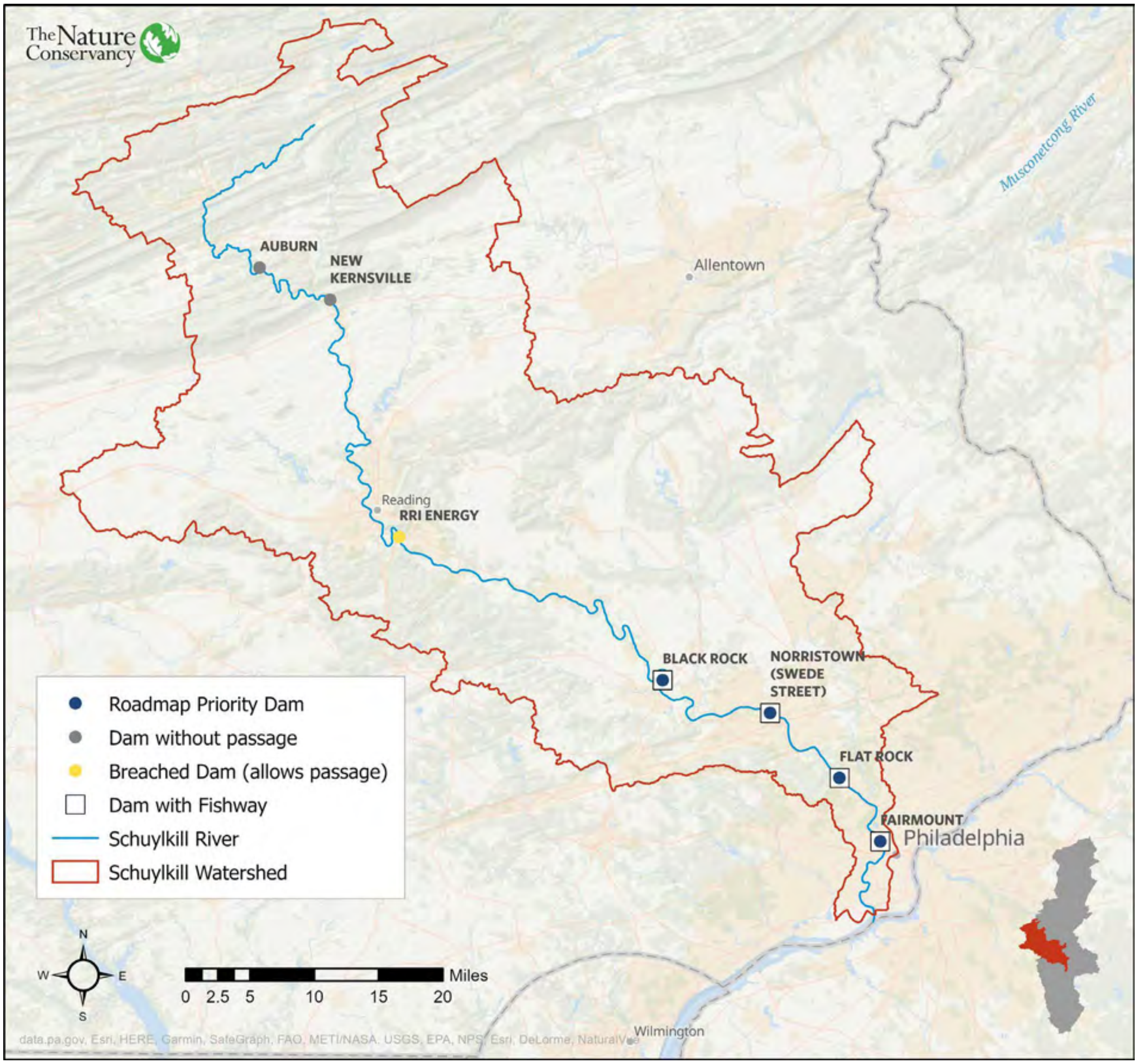


Figure 4-6. *Schuylkill River Mainstem Dams Map.*

Dam #	Unique ID	Dam Name	River Mile	Barrier Status
1	**PA_51-002**	**Fairmount Dam**	**8.7**	**Fishway**
2	**PA_PA00896**	**Flat Rock Dam**	**15.6**	**Fishway**
3	**PA_46-001**	**Norristown (Swede St) Dam**	**24.2**	**Fishway**
4	**PA_46-027**	**Black Rock Dam**	**37**	**Fishway**
5	PA_06-440	RRI Energy Dam	71	Breached
6	PA_06-434	New Kernsville Dam	100	Complete (removal planned)
7	PA_PA00670	Auburn Dam	111	Complete

Table 4-2. *Schuylkill River Mainstem Dams. Bolded dams with grey shading are priorities for restoration detailed at greater length in this report.*

Restoration Potential

The four lower run-of-the-river dams along the mainstem of the Schuylkill River are highlighted as some of the highest priority restoration sites in the Delaware River Basin. Detailed descriptions are below for each dam and dam fact sheets and photos can be found in Appendix A. Restoration goals for spawning adults in the Schuylkill River Watershed have ranged from 165,000-800,000 American shad annually (PFBC 2012, USFWS 1999). No restoration goals for river herring have been set. Although depressed coastwide populations certainly contribute to much lower-than-expected populations within the Schuylkill, insufficient passage at the fishways is a critical concern. A 2017 assessment completed by USFWS Northeast Region staff indicated that poor passage at these dams – Fairmount (rm 8.7), Flat Rock (rm 15.6), Norristown (rm 24.2), and Black Rock (rm 37) – restrict migratory fish runs and limit the recovery of self-sustaining populations within the watershed (USFWS 2017). Upstream of Black Rock Dam, only two complete barriers remain on the mainstem, and they are both former desilting dams owned by the PA DEP Bureau of Abandoned Mine Reclamation (BAMR). The New Kernsville Dam is located at river mile 100 and removal is already underway due to concerns about safety and liability. Auburn Dam is at river mile 111 and there are no current plans for removal or fish passage.

FACT SHEET

FAIRMOUNT DAM (Dam #1) is the first barrier within the Schuylkill watershed and was first installed in 1820 to provide a water supply to the growing city of Philadelphia in addition to watering the most downstream segment of the Schuylkill canal system. Originally consisting of 72 locks, the Schuylkill Canal was operational from the 1820s to the 1930s and used primarily to transport anthracite coal from the mines to the port and markets of Philadelphia. In 1945, the State of Pennsylvania initiated the Schuylkill River Project to remove silt build up behind the dams to desilting basins to address issues with water quality, flooding, and recreation. While this section of the canal has since been demolished, the Fairmount Dam is still necessary to prevent tidal influence from reaching two drinking water intakes upstream in Philadelphia and for the recreational rowing afforded in its impoundment. Additionally, the dam is on the National Register of Historic Places and is culturally significant due to its role in the development of Fairmount Park and the city itself.

Fairmount Dam. Credit: Lyndon DeSalvo/TNC.

The potential for alternative fish passage options and dam removal should be considered at Dams 1-4 and, in the near-term, technical fishways need to be better monitored and maintained. Fishways were added (or renovated, in the case of Fairmount) to these dams within the last 15 years at the same time as several mainstem dams were removed. While these restoration efforts have certainly improved access for migratory fish, technical issues, limited maintenance, and lack of monitoring at some fishways means that they continue to serve as significant barriers to upstream migration.

The Fairmount Dam fish ladder, initially installed in the 1970s, underwent major renovation in 2008 and the new vertical slot fish ladder has the capacity to pass 200,000 to 250,000 shad yearly, according to USFWS, but reaching these numbers would require a significant increase in the overall Delaware River basin shad population. Between 2009 and 2018, approximately 1,500 shad have been observed passing annually, a significant improvement over the few shad that passed prior to the renovation, but still far below expectations. The Philadelphia Water Department maintains and monitors the fishway and has noted several significant issues currently effecting alosine passage. In addition to depressed basinwide populations, lower than expected passage counts at the Fairmount fish ladder are likely due to issues with the attraction flow, turbulence between pools and at the observation window, and observed predation at the entrance and within the fishway. As of December 2021, the fish ladder was still inoperable due to damages caused by flooding during Tropical Storm Ida and may not be operable for the 2022 season.

FACT SHEET

FLAT ROCK DAM (Dam #2) was originally completed in 1818 by the Schuylkill Navigation Company to water a two-mile section of the Schuylkill canal system in Manayunk, now a neighborhood in Philadelphia. The Philadelphia Water Department, which owns the canal and locks, has initiated an approximately $15 million project to restore water flow to the canal—cut off for decades—to allow boating, improve water quality, and eliminate odors caused by fish kills. Efforts to restore the canal have been championed by historic preservationists and the Manayunk Development Corporation as this would preserve the only remaining section of the Schuylkill Navigation Canal from end-to-end in an area of the city currently experiencing an influx of development.

When PFBC documented American Shad at the Flat Rock Dam in 2002, it was the first time the species had been observed above Fairmount Dam since its construction in 1820. As a result, a vertical slot fishway with observation window was added on the west side of the dam, though monitoring has never occurred here. Due to its historic inclusion in the Schuylkill River Project, PA DEP's Bureau of Abandoned Mine Reclamation (BAMR) is the owner of the dam; however, BAMR is currently only able to provide minimal maintenance and repairs to the fishway. Due to this and challenges caused by the placement and design of the fishway, it is largely considered to be ineffective at passing American Shad and river herring.

FACT SHEET

NORRISTOWN DAM (Dam #3), also known as the Swede Street Dam, was originally constructed in 1836 by the Schuylkill Navigation Company. In 1923, the Philadelphia Electric Company (PECO)—now a

Flat Rock Dam. Credit: Lyndon DeSalvo/TNC.

Norristown (Swede St) Dam. Credit: Lyndon DeSalvo/TNC.

subsidiary of Exelon—took ownership of the dam to support its generating station on Barbadoes Island, located just upstream. Sections of the dam were rebuilt in the 1980s and 1990s following a breach and, in 1993, PECO transferred ownership of the dam to Montgomery County following the decommissioning of the Barbadoes Generating Station. Dam removal was considered by PECO at the time of ownership, but Montgomery County residents were adamant about preserving upstream recreation in the five-mile impoundment at the time. A Denil-style fishway with observation window was added to the south side of the dam in 2008, but monitoring has never occurred here, and any maintenance is likely intermittent. The expansive 900-foot-wide dam is known to create a problem for fish to find and utilize the fishway and a USFWS engineer noted debris buildup and technical issues with the fishway during a 2017 site visit.

FACT SHEET

BLACK ROCK DAM (Dam #4) was originally constructed in 1822 to water a section of the Schuylkill Navigation Canal between locks #60 and #61. The present dam was built in 1840, replacing the original, and still retains its rock-filled timber crib structure underneath a concrete cap that was added in the 1960s. In recent decades, the dam also supplied a water source to the Cromby Generating Station, a recently retired coal-fired power plant located upstream within the 2.9-mile-long impoundment. In the last few years, ownership of the generating station and the dam has transferred from Exelon to a developer that may not require the dam for water supply purposes. The restored section of canal is a popular recreational area with private residences located along its length. In 2017, a family of four boating down the Schuylkill were trapped in the turbulent waters at the bottom of the dam and required rescue.

A Denil-type fishway was added to the dam in 2008 with an observation window and video monitoring that allowed for fish passage counts from 2011 to

Black Rock Dam. Credit: Lyndon DeSalvo/TNC.

2016, which included a total of 11 American Shad and no documented river herring during this period. PFBC also noted that American Shad were present during June electrofishing in the next downstream pool below the dam.

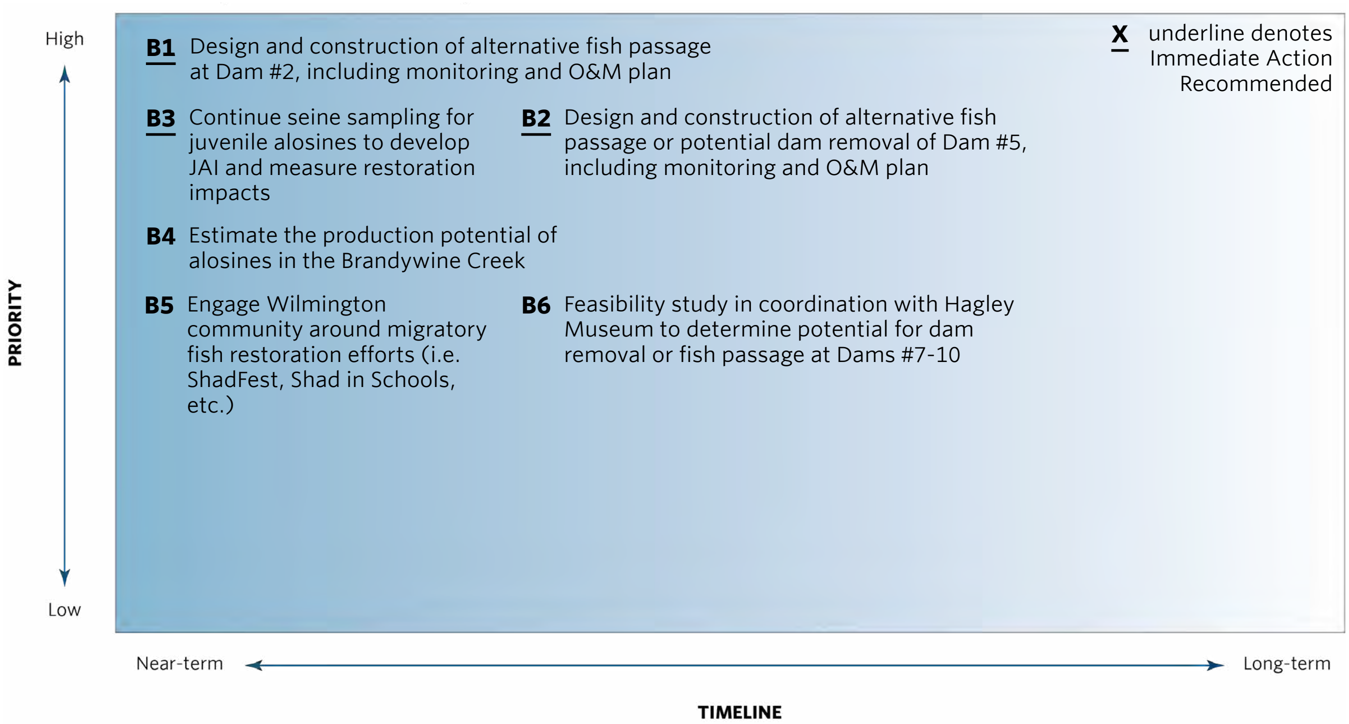
Potential Partners/Stakeholders:

While there are many partners working on various conservation and watershed issues in the Schuylkill watershed, in recent years there has been little attention to specifically addressing fish passage issues in the mainstem. We have identified some key stakeholders below that would be likely partners in building a coalition that would be key to any dam removal or fish passage improvement projects:

U.S. FISH AND WILDLIFE SERVICE, CITY OF PHILADELPHIA, PA BUREAU OF ABANDONED MINE AND RECLAMATION, SCHUYLKILL RIVER GREENWAYS, PA FISH AND BOAT COMMISSION, PARTNERSHIP FOR THE DELAWARE ESTUARY, AMERICAN RIVERS, PA DEPT. OF ENVIRONMENTAL PROTECTION, THE NATURE CONSERVANCY, NOAA FISHERIES, AMERICAN RIVERS, BLACK ROCK VOLUNTEER FIRE COMPANY, FRIENDSHIP FIRE COMPANY'S DIVE AND WATER RESCUE, USACE, PHILADELPHIA DISTRICT, USGS, ACADEMY OF NATURAL SCIENCES AT DREXEL, SCHUYLKILL ACTION NETWORK, SCHUYLKILL NAVY, PHILADELPHIA CANOE CLUB, MANAYUNK CANAL CORPORATION, UPPER MERION BOAT CLUB, MONTGOMERY COUNTY PARKS, SCHUYLKILL CANAL ASSOCIATION, FISHERMEN AND LOCAL COMMUNITIES

4.2 Brandywine Creek

Priority Restoration Actions



This section contains summary-level information about dam removal and fish passage efforts on the Brandywine Creek. For more detailed information, refer to the Brandywine Shad 2020 webpage.

Background

The Brandywine Creek watershed is the largest of the four major watersheds that comprise the Brandywine-Christina basin and spans approximately 325 square miles across both Pennsylvania and Delaware. The river itself originates in the Welsh Mountains of the Piedmont Province in southeastern Pennsylvania before flowing into New Castle County in Delaware, where it passes through Wilmington and then reaches the confluence with the Christina River a mile above the Delaware (Brandywine Conservancy 2005). As the steepest river in Delaware, the Brandywine was heavily utilized as a source of waterpower for mills in the colonial period, with as many as 100 mills at one time situated along the river (Brandywine Conservancy 2005).

In the late 1600s, it is estimated that the Brandywine-Christina watershed supported tens of thousands of American Shad and river herring prior to the damming of the rivers. However, as early as the 1700s, the Indigenous Lenape were complaining to commissioners in Pennsylvania that dams were preventing the rockfish and shad from "coming up" as formerly and causing great injury to their people (Weslager 1989, Schutt 2007). The proliferation of dams and water pollution effectively eliminated the runs in the watershed for over 200 years until the 1960s, when American Shad were once again discovered in the lower tidal section of the river. To restore shad and attract out-of-state anglers, bi-state restoration efforts took place in the 1960s and 1970s, which included adding fishways to the lower Brandywine dams and stocking shad fry upstream; however, these efforts were eventually discontinued due to diminishing shad runs with many of the antique ladders subsequently removed (Narvaez 2010, Park 2020, Hardy 1999).

The Brandywine Conservancy completed an American Shad restoration feasibility study for the Brandywine in 2005 that offered a detailed analysis of the 11 mainstem dams located within the state of Delaware and outlining dam removal and fish passage opportunities. In the last few years, these efforts have gained new momentum with the support of Brandywine Shad 2020 and a coalition of partners, and recent water quality improvements and dam removals have succeeded in reopening previously inaccessible reaches within this system. In July 2020, sampling below Broom Street Dam (Dam #2) in Wilmington confirmed American Shad were spawning in this section for the first time in more than 100 years following the removal of the West Street Dam (Dam #1) in 2019.

Population Status

DNREC performs annual sampling using a deep haul seine at five locations in the Christina River and one location in Brandywine Creek each summer to determine a juvenile abundance index (JAI) for shad and river herring in the Christina watershed (Figure 4-7; Park 2020). The four species targeted during this effort include American Shad, Hickory Shad, Alewife, and Blueback Herring. A large portion of the American Shad and most of the Blueback Herring were collected at the Brandywine Creek sampling location in 2017, though in subsequent years other sites have been more productive (Park and Stangl 2020). Haul seine sampling in 2020 produced 65 American Shad and 415 Blueback Herring from Brandywine Creek (Park and Stangl 2021).

Sampling has also occurred on the Brandywine pre- and post-removal of Dam #1. In spring 2016, the Delaware Division of Fish and Wildlife sampled the Brandywine Creek and counted three American Shad, two Hickory Shad, and 28 Striped Bass below Dam #1 on Market Street in Wilmington (UDWRC 2018). Following the removal of the dam in 2019, the area below Dam #2 was sampled in the summer of 2020 using a seine and 160 juvenile and 8 adult American Shad were collected, demonstrating multiple life stages were utilizing the newly available habitat (Figure 4-8; Hale 2020). No Alewife and Blueback Herring were collected during sampling, though fishermen have reported river herring upstream of the former Dam #1 site near the I-95 overpass (Desmond Kahn, pers. comm.). Additional sampling below and above Dam #2 is planned for future years to evaluate the effectiveness of the removal on fish movement and migration.

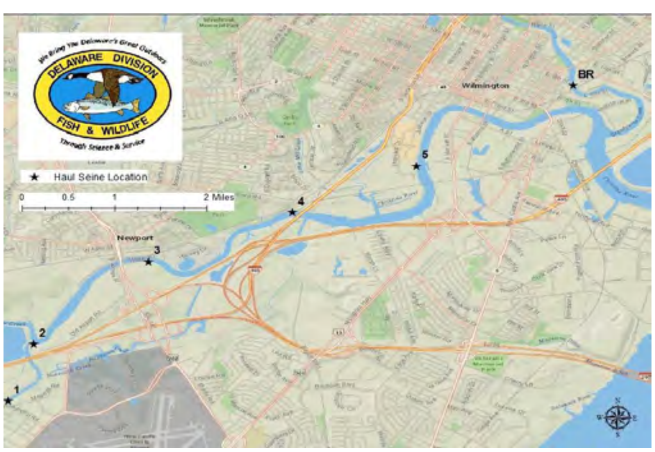


Figure 4-7. *Christina River haul seine site locations. Credit: DNREC.*

Figure 4-8. *Seine sampling on the Brandywine in summer 2020. Credit: Kim Hachadoorian/TNC.*

Opportunity

The Brandywine Creek presents a significant opportunity for alosine restoration efforts due to the historic and current presence of the species as well as the strong partnership that has coalesced to address barriers to migratory fish. The 2005 Brandywine Conservancy report and recent efforts by Brandywine Shad 2020 and a broad coalition of partners have spurred restoration efforts along the river with several dam removals already completed or planned for the next couple years. The various partners have also incorporated critical community engagement within these efforts, such as ShadFest, and have gained momentum from wide-ranging public support for the projects. The 2015 *River Herring Restoration Needs Report* by the Atlantic Coast Fish Habitat Partnership also highlighted that dam removals on the Brandywine should continue to be a priority for improved river herring access within the basin (Bowden et al. 2015).

The Christina-Brandywine River Remediation Restoration Resilience (CBR4) project also will benefit downstream habitat as partners are seeking to address legacy toxic contamination, restore the native ecology, and prepare for climate change and other threats in the lower Christina River and tidal Brandywine. More broadly, the governance structure of the Brandywine-Christina watershed, which includes three states, five counties and 55 municipalities, creates challenges owing to its complexity, yet offers opportunity for newfound collaboration and coordination particularly between the states of Pennsylvania and Delaware (UDWRC 2018).

Efforts to restore American Shad and other migratory fish to the Brandywine Creek and its tributaries have gained significant momentum in recent years with the support of a wide range of partners. Still, seven complete barriers remain and some of these are unlikely for removal due to either existing infrastructure needs or historic preservation reasons. Where dam removal is not an option, it is critical to ensure that any added fishways are very effective at passing alosines due to the potential cumulative impact of partial passability.

Restoration Potential

Of the ten remaining mainstem dams along the Brandywine Creek in Delaware, seven have been included as priorities in this report because they are complete barriers to passage. Dams 3, 9, and 11 were not detailed at length given they are either fully or partially breached and thought to be passable in certain conditions, though removal would certainly be beneficial. Descriptions are below for each priority dam and detailed dam fact sheets and photos can be found in Appendix A.

No restoration goals for American Shad and river herring have been established in the Brandywine Creek. Potential production estimates for American Shad can be found in the 1985 study *A Review and Recommendations Relating to Fishways Within the Delaware River Basin* commissioned by the Delaware River Basin Fish and Wildlife Management Cooperative. Using a coarse rule-of-thumb based on abundance data from the Connecticut River and available spawning habitat, the study estimated that potential shad production in the Brandywine Creek was between 9,400 and 26,600 fish if the eleven mainstem dams were addressed to allow fish passage. However, DNREC and partners are interested in developing a new estimate of production potential for alosines in the Brandywine based on the amount of suitable habitat and spawning potential using more specific stream data and ratios available in recent literature.

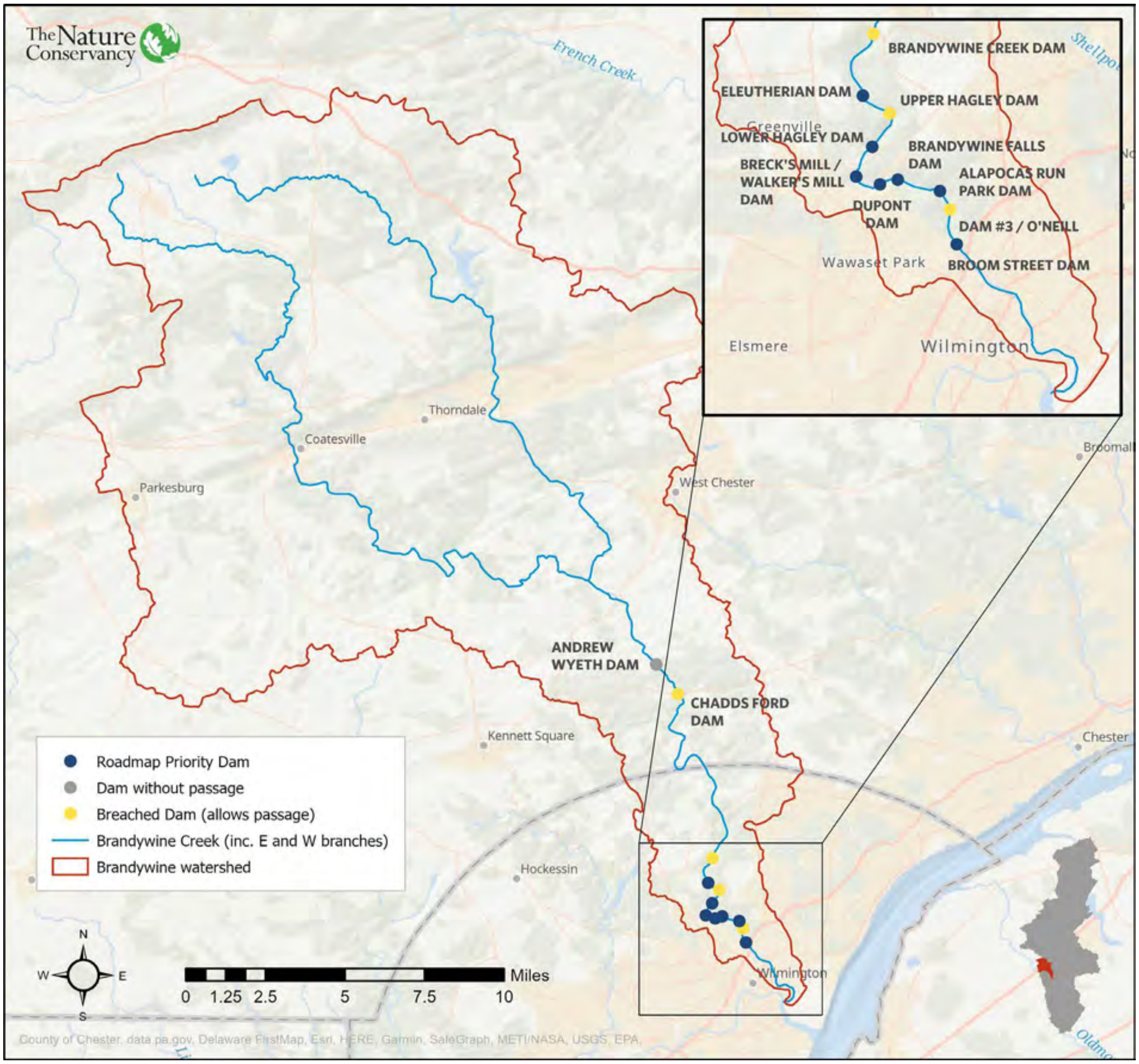


Figure 4-9. *Brandywine Creek Mainstem Dams Map.*

Dam #	Unique ID	Dam Name	River Mile	Barrier Status
1	*DE_14*	*West Street Dam*	*2.1*	*Removed 2019*
2	**DE_13**	**Broom Street Dam**	**2.9**	**Complete**
3	DE_12	Dam #3/O'Neill	3.4	Breached
4	**DE_11**	**Alapocas Run Park Dam**	**3.6**	**Complete (removal planned)**
5	**DE_10**	**Brandywine Falls Dam**	**4.2**	**Complete**
6	**DE_9**	**DuPont Dam**	**4.5**	**Complete (removal planned)**
7	**DE_7**	**Breck's Mill/Walker's Mill Dam**	**4.8**	**Complete**
8	**DE_6**	**Lower Hagley Dam**	**5.2**	**Complete**
9	DE_emadd02	Upper Hagley Dam	5.7	Partially breached
10	**DE_5**	**Eleutherian Dam**	**6.2**	**Complete**
11	DE_101	Brandywine Creek Dam	7.2	Partially breached
12	PA_1208921	Chadds Ford Dam	14.5	Breached (removal planned)
13	PA_15-018	Andrew Wyeth Dam	16	Complete
14	*PA_15-388*	*Lenape Dam*	*19*	*Removed 2021*

Table 4-3. *Brandywine Creek Mainstem Dams. Bolded dams with grey shading are priorities for restoration detailed at greater length in this report.*

FACT SHEET

BROOM STREET DAM (Dam #2) is owned by the City of Wilmington and is critical to the city's water supply, as the dam maintains a sufficient water level in the creek to support raw water intake upstream and via the adjacent mill race. Though not historic, the dam is located within the Brandywine Park and Kentmere Park Historic District and the original structure and raceway date back to 1762. An antique fish ladder was added to the dam in the 1960s to support anadromous fish restoration efforts, but it is ineffective, and the concrete dam currently is a complete barrier to migration. Following the removal of Dam #1 in 2019, the area below Dam #2 was sampled in the summer of 2020 using a seine and 160 juvenile and 8 adult American Shad were collected, demonstrating multiple life stages were utilizing the newly available habitat (Hale 2020). Due to its current use the dam is not being considered for removal. Brandywine Shad 2020 and partners are currently assessing alternative fish passage options—including a rock ramp or bypass—having received a 2021 NFWF grant to develop engineering and design.


Broom Street Dam. Credit: Brandywine Shad 2020.

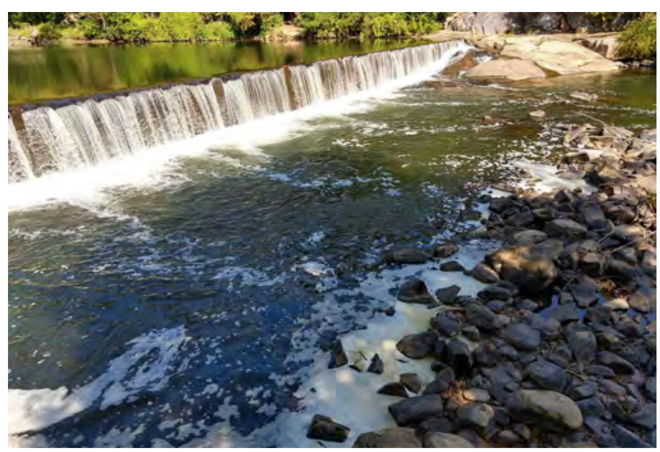
FACT SHEET

ALAPOCAS RUN DAM (Dam #4) is owned by the Delaware Department of Natural Resources and Environmental Control (DNREC) and is adjacent to Alapocas Run Park and Bancroft Mills. The concrete dam was historically used for water supply, but currently has no known use and there is a cavity in the center of the structure. Brandywine Shad 2020 received funding from NFWF in 2021 to remove the dam, which is estimated at a cost of approximately $400,000, and has already filed the required state and federal permits.


Alapocas Run Dam. Credit: Brandywine Shad 2020.

FACT SHEET

BRANDYWINE FALLS DAM (Dam #5) is located 4.2 miles upstream of the mouth of the Brandywine and is a stone and concrete structure that was previously used for mills and industrial water supply. Today, the dam is not used other than to supply water to a historic mill race that runs alongside the Brandywine Falls Condo Association property on the


Brandywine Falls Dam. Credit: Brandywine Shad 2020.

DuPont Dam. Credit: Brandywine Shad 2020.

Breck's Mill/Walker's Mill Dam. Credit: Brandywine Shad 2020.

Lower Hagley Dam. Credit: Brandywine Shad 2020.

south side of the river. In 2021, Brandywine Shad 2020 received NFWF funding to develop engineering and design to assess the potential for dam removal or alternative fish passage options at the site, including a natural bypass channel or rock ramp.

DUPONT DAM (Dam #6) is located at the DuPont Experimental Station and originally served to provide industrial water supply to the site, though it no longer is needed for this purpose. The dam is owned by the DuPont Company and has already been partially breached by previous storms. Still, the structure poses a significant barrier to fish passage and, in 2021, Brandywine Shad 2020 received NFWF funding to remove the dam, estimated at a cost of $200,000.

FACT SHEET

BRECK'S MILL/WALKER'S MILL DAM (Dam #7) is owned by the Hagley Museum and located within two historic districts. Once Victor du Pont's woolen mill, the dam is considered historic and still feeds two mill races with the corresponding historic mill buildings immediately adjacent on either side of the river (Canby 1941). While the Hagley Museum owns Breck's Mill and the land on the west side of the river, the east bank is owned by Walker's Mill Association, LLC.

FACT SHEET

LOWER HAGLEY DAM (Dam #8) is also owned by the Hagley Museum and is located within the Eleutherian Mills Historic District, recognized as a National Historic Landmark Area. The stone and concrete structure still feeds a historic mill race, and the museum considers the infrastructure critical to its storytelling.

FACT SHEET

FACT SHEET

ELEUTHERIAN DAM (Dam #10) is a historic dam owned by the Hagley Museum and located within the Eleutherian Mills Historic District, recognized as a National Historic Landmark Area. The original dam was likely built around 1800 and was critical to the du Pont family's production of gun powder throughout the nineteenth and early twentieth centuries. The structure has a timber spillway and was reconstructed within the past 15 years by Duffield Associates at a cost of $1,000,000 to the museum. There is a millrace on the western side of the creek and a channel on the eastern side and flow through these structures is supported by the dam.

Eleutherian Dam. Credit: Brandywine Shad 2020.

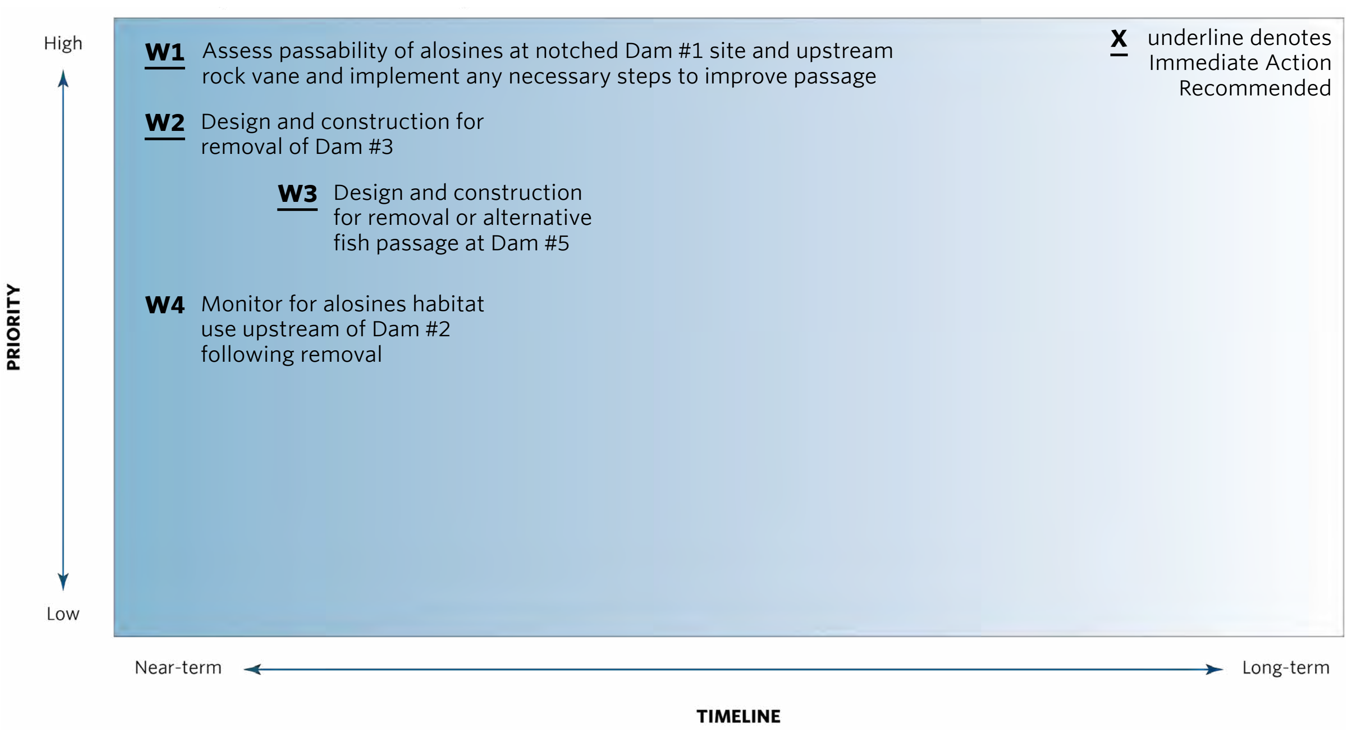
Potential Partners/Stakeholders:

The Brandywine Creek has a strong coalition of partners working towards improving fish passage in addition to broader watershed restoration efforts. Brandywine Shad 2020 is a cross-section of educational organizations, non-profits, governmental agencies, and private citizens whose shared goal is to restore the region's most historic fish, the American Shad, to the Brandywine River by returning the river to its free-flowing, pre-colonial state (UDWRC 2021). The below list includes key partners included in these efforts as well as additional stakeholders that can assist in achieving the action items identified at the beginning of this section:

BRANDYWINE SHAD 2020, UNIVERSITY OF DELAWARE WATER RESOURCES CENTER, DELAWARE NATURAL RESOURCES AND ENVIRONMENTAL CONTROL (DNREC), BRANDYWINE CONSERVANCY, HAGLEY MUSEUM AND LIBRARY, U.S. FISH AND WILDLIFE SERVICE, CITY OF WILMINGTON, BRANDYWINE RED CLAY ALLIANCE, DELAWARE NATURE SOCIETY, STROUD WATER RESEARCH CENTER, UPSTREAM ALLIANCE, THE CONSERVATION FUND, PA FISH AND BOAT COMMISSION, DELAWARE SEA GRANT, PARTNERSHIP FOR THE DELAWARE ESTUARY, AMERICAN RIVERS, PA DEPT. OF ENVIRONMENTAL PROTECTION, THE NATURE CONSERVANCY, NOAA FISHERIES, USACE PHILADELPHIA DISTRICT, USGS, FISHERMEN AND LOCAL COMMUNITIES

4.3 White Clay Creek

Priority Restoration Actions



Background

The White Clay Creek comprises one of the four major watersheds in the Christina River Basin and drains an area of 107 square miles including sections of Pennsylvania, Delaware, and a sliver of Maryland. The upper portion consists of the East, Middle, and West Branches, which come together in Chester County, Pa., before the creek crosses into Delaware flowing southeast through New Castle County and emptying into the Christina River and then the Delaware. Although there are few written records, American Shad and river herring were almost certainly present in the White Clay historically, with likely runs in the tens of thousands (Narvaez et al 2010). The Lenape are known to have inhabited the watershed around 10,000 years ago and the former settlement of *Opasiskunk*—situated at the confluence of the East and Middle branches of the White Clay Creek—was presumably at this location due in large part to the migratory fish that would have ascended the creek each spring (Narvaez et al 2010, PA DCNR 2021). In 1683, William Penn purchased a large tract of land from the Lenni Lenape Chief Kekelappen that covers the present-day White Clay Creek Preserve (however, further north in the Delaware watershed, Penn's descendants would later steal lands owned by the Lenape in what is referred to as the "Walking Purchase"). By the mid-1700s, European settlement here and along downstream sections of the creek undoubtedly eliminated migratory fish runs as dams were constructed to power local mills.

In 2010, efforts to restore American Shad and river herring to the White Clay Creek began in earnest with a report from the University of Delaware's

Water Resources Agency titled *Restoration of Shad and Anadromous Fish to the White Clay Creek National Wild and Scenic River: A Feasibility Report*. Sampling in the lower section of White Clay Creek had confirmed the presence of migratory fish, including significant numbers of alosines. The Byrnes Mill Dam, also known as White Clay Creek Dam #1, was removed in 2014 to restore migratory fish runs and marked the first recorded dam removal for fish passage in the state of Delaware. Funding from NFWF and other sources has been secured for the removal of additional dams on White Clay Creek, including the Red Mill (Dam #2), Paper Mill (Dam #4), and Deerfield (Dam #7) dams.

Today, nearly 200 miles of the White Clay Creek and its tributaries are protected as part of the National Wild and Scenic Rivers System and, when designated as such in 2000, it was the first time an entire watershed had been included rather than a single river corridor. Additionally, over 7,000 acres of land surrounding the creek is protected as part of the bi-state White Clay Creek Preserve and the watershed is renowned for its scenery, historic features, and recreational opportunities, including some of the best trout fishing in the area. The watershed also serves as a major drinking water source for approximately 120,000 people in Pennsylvania and Delaware.

Population Status

DNREC performs annual sampling using a deep haul seine at five locations in the Christina River and one location in Brandywine Creek each summer to determine a juvenile abundance index (JAI) for shad and river herring in the Christina watershed (Figure 4-7). The four species targeted during this effort include American Shad, Hickory Shad, Alewife, and Blueback Herring. Site 2 is located is at the confluence of the Christina River and White Clay Creek and is often the most productive (Park and Stangl 2020). Unfortunately, electrofishing for adult shad and river herring on White Clay Creek is not performed regularly given two previous years of sampling (2016 and 2017) failed to observe any alosine species between Dam #2 and the former Dam #1 site (Figure 4-10). The reason for this is unclear, but it is suspected that sediment may be blocking fish passage, especially during low tide (Park and Stangl 2021). In 2010, electrofishing conducted below Dam #1 returned significant numbers of alosines, particularly Hickory Shad and Alewives, and surveys of fishermen at the time confirmed that Hickory Shad were the most frequently caught species in the lower section of the White Clay (Narvaez et al 2010).

Opportunity

Since the 2010 report by University of Delaware's Water Resources Center, a group of partners has been working towards dam removal and fish passage efforts in the watershed. The 2015 *River Herring Restoration Needs Report* by the Atlantic Coast Fish Habitat Partnership also highlighted that dam removals on the White Clay Creek should continue to be a priority for improved river herring access within the basin (Bowden et al. 2015). Of the six remaining dams that are complete barriers to fish passage, four have received funding and are planned for removal. The remaining two need significant repairs or reconstruction and the owners appear willing to discuss potential removal so long as viable alternatives can be determined to replace existing infrastructure associated with the dams. Although not focused on fish passage specifically, the Christina-Brandywine River Remediation Restoration Resilience (CBR4) project also will benefit downstream habitat as partners are seeking to address legacy toxic contamination, restore the native ecology, and prepare for climate change as well as other threats in the lower Christina River in the section just below its confluence with the White Clay.

Restoration Potential

There are six remaining mainstem dams that serve as barriers to migratory fish on the White Clay Creek. The former Byrnes Mill Dam (Dam #1) was notched in 2014 to allow passage and Dam #6 was breached in previous storms and is considered passable. However, as noted above, the sediment issue at the site of former Byrnes Mill Dam needs to be further investigated and mitigated. In the past few years, funding has been secured for the removal of three additional dams (Dams #2, #4, and #7) and PA DCNR has plans to remove Dam #8 on the Pennsylvania side as well. Detailed descriptions for each dam are below and dam fact sheets and photos can be found in Appendix A. No numerical restoration goals for American Shad and river herring have been established for the White Clay Creek at this time.

FACT SHEET

RED MILL DAM (Dam #2) is currently the first barrier on the White Clay Creek given that the former Byrnes Mill Dam (Dam #1) was notched in 2014 to allow migratory fish passage. A dam has likely existed at this location for nearly 300 years as the dam was originally constructed to provide water to a raceway for Red Mill (a former gristmill) situated 60 feet upstream that is listed in the National Register of Historic Places. The current structure is a rockfill dam that is failing at several points and leading to severe downstream bank erosion and areas of upstream sediment deposition (Narvaez et al. 2010). The University of Delaware's Water Resources Agency received NFWF funding in 2019 to remove the dam, which is currently in process and should be completed by 2022. However, since the removal of Dam #1 on the White Clay, alosines have yet to be confirmed below the Red Mill Dam despite several monitoring efforts and it is suspected that sediment build up in the lower section of the creek near Dam #1 may be prohibiting passage upstream to the site.

Red Mill Dam. Credit: Jason Fischel.

Karpinski Park Dam. Credit: Jason Fischel.

FACT SHEET

KARPINSKI PARK DAM (Dam #3) is formed by a City of Newark sanitary sewer line that is approximately 18 to 20 inches in diameter and encased in concrete. The sewer main has eroded on the downstream side and the City is considering alternative replacement options, such as a sewer siphon or reburying the sewer below the streambed, that would remove the in-stream barrier to fish passage. The dam is easily accessible as it is located immediately adjacent to City of Newark parkland on both banks.

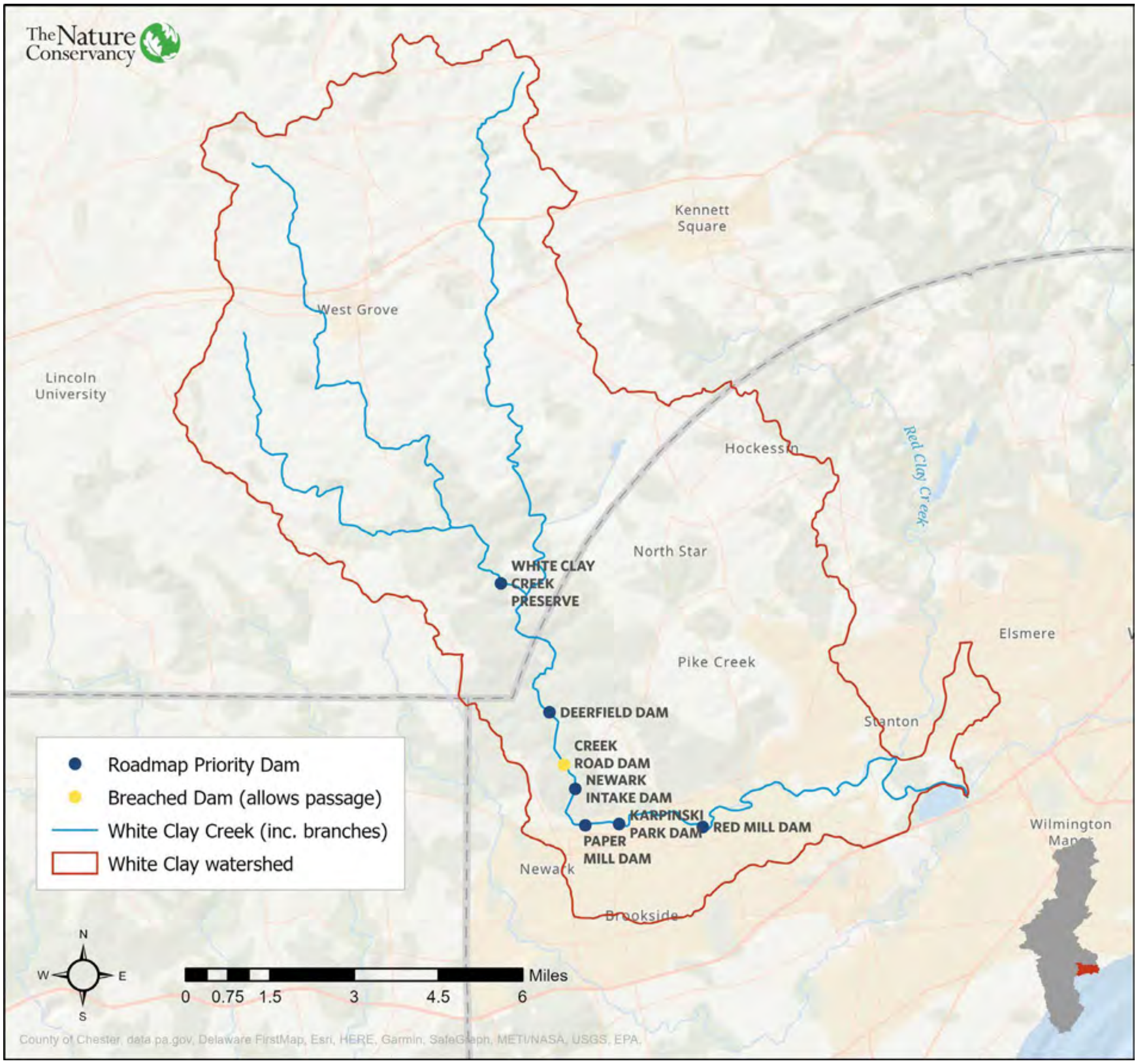


Figure 4-10. *White Clay Creek Mainstem Dams Map.*

Dam #	Unique ID	Dam Name	River Mile	Barrier Status
0		*TCS Suez Dam*	*0.6*	*Inflatable dam not deployed during spring migration*
1		*Byrnes Mill Dam*	*4.1*	*Removed 2014*
2	**DE_23**	**Red Mill Dam**	**6.7**	**Complete (removal planned)**
3	**DE_emadd05**	**Karpinski Park Dam**	**9.5**	**Complete**
4	**DE_22**	**Paper Mill Dam**	**10.1**	**Complete (removal planned)**
5	**DE_emadd06**	**Newark Intake Dam**	**11.1**	**Complete**
6	DE_emadd07	Creek Road Dam	11.6	Breached
7	**DE_emadd08**	**Deerfield Dam**	**12.7**	**Complete (removal planned)**
8	**PA_15-377**	**White Clay Creek Preserve Dam**	**16.2**	**Complete (removal planned)**

Table 4-4. *White Clay Creek Mainstem Dams. Bolded dams with grey shading are priorities for restoration detailed at greater length in this report.*

Paper Mill Dam. Credit: Jason Fischel.

Newark Intake Dam. Credit: Jason Fischel.

Deerfield Dam. Credit: Jason Fischel.

PAPER MILL DAM (Dam #4) is a concrete structure formerly associated with the National Vulcanized Fibre (NVF) company. Although the dam no longer serves its original purpose, it does function as a hydraulic control for a USGS gage station (White Clay Creek at Newark - 01478650) and is used to verify minimum flow requirements from the upstream Newark Intake Dam (Dam #5) as SUEZ North America has first rights of withdrawal at river mile 0.6 where they employ an inflatable dam. The dam is in poor condition and is anticipated for removal in 2022 following the placement of an adjacent pedestrian bridge and the re-gaging of the stream by USGS. New Castle Conservation District is managing the restoration project and has received funding from NFWF and the City of Newark.

FACT SHEET

NEWARK INTAKE DAM (Dam #5) is owned by the City of Newark and serves as an intake for the Curtis Water Treatment Plant, which provides water to approximately 40,000 customers in the northern section of Newark and surrounding areas. A dam was originally constructed at the site for the Curtis Paper Mill—in operation from 1789 to the late twentieth century—and the City still utilizes the mill race to transport water three-quarters of a mile from the dam to the treatment plant (LaPenta 2019). Water obtained from the White Clay Creek at this location is also used to fill the nearby Newark Reservoir, which has a capacity of 317 million gallons (City of Newark 2021). The concrete dam has had patchwork repairs but is in poor condition and will likely need to undergo significant reconstruction or removal in the near future. The City of Newark is supportive of fish passage efforts and has entertained installing a wellfield here like the one employed in the southern section of the city, though additional studies are needed.

FACT SHEET

DEERFIELD DAM (Dam #7) was originally built by the DuPont Company in 1955 to supply water for irrigation purposes to the adjacent Deerfield Golf Club, which has been owned and operated by the

FACT SHEET

State of Delaware since 2005. The golf course has an active water withdrawal permit and can pump 400 gallons per minute during the spring when flows are high to fill their pond for summer irrigation. During especially low flows as measured at the upstream USGS gage (01478500), the golf course is not able withdraw water from the White Clay Creek and must resort to the on-site pond or three groundwater wells. Located within the White Clay Creek State Park, the dam itself is in poor condition and has led to significant degradation of in-stream and riparian habitat. The dam and its impoundment contribute to thermal stress in a popular trout fishing location as well as sediment build up and braiding in the reach below the dam. In 2021, the New Castle Conservation District received NFWF funding for dam removal and restoration of a mile of river hydrology and stream habitat, which will reconnect over 9 miles of creek within the state park.

FACT SHEET

WHITE CLAY CREEK PRESERVE DAM (Dam #8) is the most upstream barrier on the White Clay before it splits into its Middle and West branches and is located within the White Clay Creek Preserve in Pennsylvania. The land that now forms the preserve and contiguous White Clay Creek State Park in Delaware was donated by the DuPont Company in 1984, which originally acquired the land to dam the White Clay Creek and form a reservoir—an idea that never came to fruition. The rockfill dam at this site is breached on its southern side but may still present a challenge to fish passage. Pennsylvania DCNR, which owns the dam, has indicated its intentions to remove the structure and included this in a list of 14 dams across the state that are part of a design/build contract.

White Clay Creek Preserve Dam. Credit: Jason Fischel.

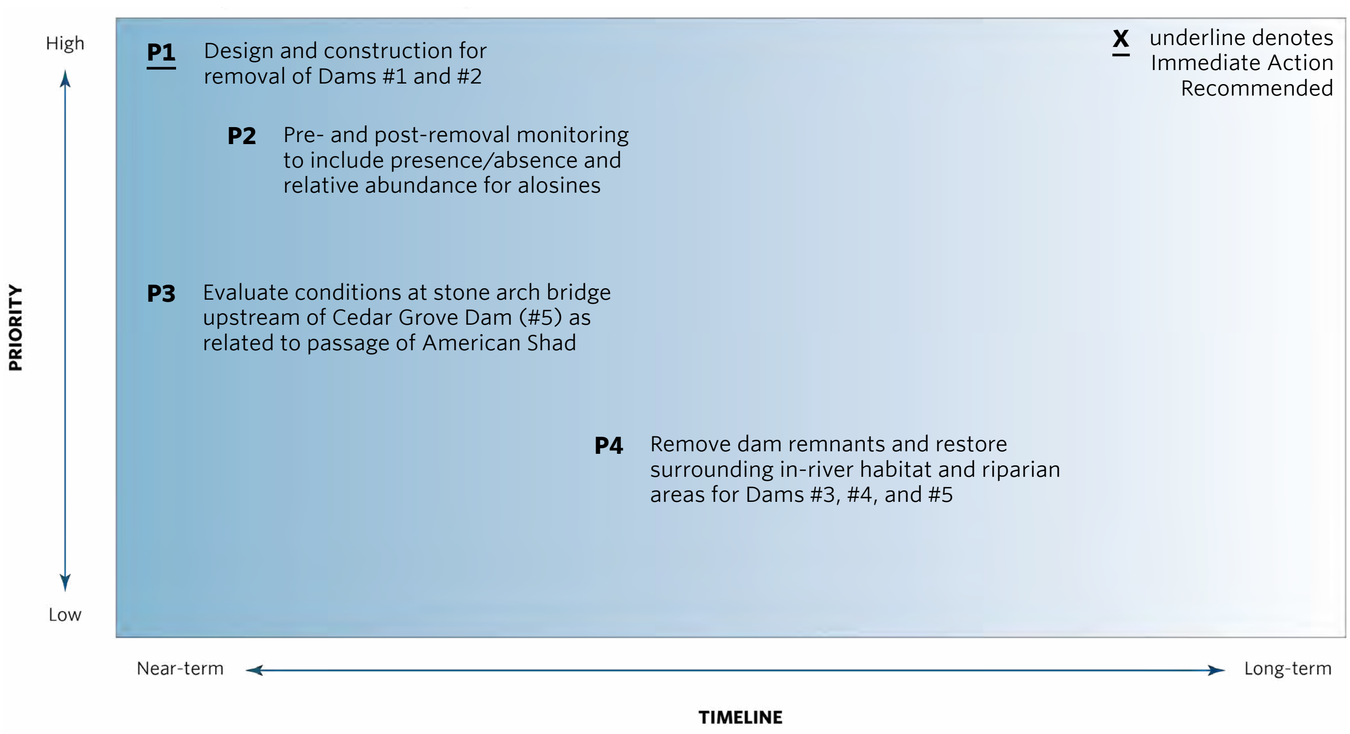
Potential Partners/Stakeholders:

The Brandywine-Christina watershed presents a great case study in multi-jurisdictional watershed management and collaboration as it includes three states, five counties, and 55 municipalities (UDWRC 2018). The White Clay has demonstrated how these efforts can prove fruitful given its designation as a Wild and Scenic River throughout much of the watershed and the development of a strong partnership amongst federal, state, and local agencies as well as nonprofit and for-profit organizations and local communities. The 2010 White Clay feasibility report assisted in strengthening this coalition of partners interested in water quality, dam removal, and migratory fish restoration efforts within the watershed. The below list includes active or potential partners that can assist in achieving the action items identified at the beginning of this section:

NEW CASTLE CONSERVATION DISTRICT, UNIVERSITY OF DELAWARE WATER RESOURCES CENTER, JASON FISCHEL – UNIVERSITY OF DELAWARE POSTDOCTORAL RESEARCHER, NATIONAL PARKS SERVICE, WHITE CLAY CREEK NATIONAL WILD & SCENIC RIVER, DNREC, USGS, NOAA FISHERIES, STROUD WATER RESEARCH CENTER, CITY OF NEWARK, PA DCNR, PA FISH AND BOAT COMMISSION, USFWS, WHITE CLAY WATERSHED ASSOCIATION, WHITE CLAY OUTFITTERS, TROUT UNLIMITED, FISHERMEN, AND LOCAL COMMUNITIES

4.4 Pequest River

Priority Restoration Actions



Background

The Pequest River is a 35.7-mile-long tributary to the Delaware River that enters at river mile 198 in Belvidere, NJ. The watershed encompasses approximately 158 square miles in the Appalachian Highlands region of northwestern New Jersey and includes portions of Warren and Sussex counties. The Pequest watershed is largely forested, with some agricultural lands, and generally has good water quality that supports rare species and naturally-reproducing trout populations (DRBC 2016). The Highlands region is popular for recreation and provides drinking water for millions of people, including many who live outside of the Delaware watershed (DRWI 2021).

No information related to historic shad and river herring runs was found for the Pequest River; however, it is likely that there was a historic run, at least in the lower section, given that the nearby Paulins Kill had a documented shad run prior to its damming (Cummings 1964). Historic eel weirs created by the Lenape and European settlers were also prevalent in the Pequest River, with some having been reconstructed in recent decades and still evident today (Hackettstown Life 2021). Current American Shad and river herring runs in the nearby Musconetcong River and Paulins Kill also affirm that the Pequest holds potential for restoration efforts given they have similar watershed characteristics.

The Pequest River has two intact run-of-river dams along its mainstem in downtown Belvidere within a half-mile of its confluence with the Delaware River. In 2017, the New Jersey Statewide Dam

Removal Partnership (NJSDRP), a collaboration of nonprofits and government agencies, reviewed a list of more than forty dams and ranked the removal of each in terms of ecological uplift, fish migration benefits, public safety, flooding, condition, and owner willingness to remove. The Upper and Lower E.R. Collins & Son dams (NJ_24-28 and NJ_24-29) were both ranked in the top ten considering dams across the entire state due to their proximity to the Delaware River, the expected ecological benefits, and potential to provide spawning habitat for migratory fish, specifically American Shad, Blueback Herring, Sea Lamprey, and American Eel. Apart from these and a few remnant dams just upstream of Belvidere, the Pequest River is free of obstructions for over 20 miles.

Population Status

The New Jersey Department of Environmental Protection (NJDEP) has recorded American Shad in the lower Pequest River from its confluence with the Delaware to the base of the Lower E.R. Collins & Son Dam (NJ_24-28) and, in 2005, acquired a 4.6-acre property in Belvidere along the two rivers that expanded fishing access adjacent to an already existing boat ramp (NJDEP 2005b). The NJDEP Bureau of Freshwater and Biological Monitoring has two long-term monitoring sites on the lower Pequest between Belvidere and the NJ Division of Fish and Wildlife Pequest Trout Hatchery where they monitor fish assemblages and assess overall stream health. The Academy of Natural Sciences also has a long-term monitoring site located near the hatchery. With the planned removal of the Lower and Upper E.R. Collins & Son Dams in Belvidere, these datasets will provide a good baseline to assess changes in fish assemblages following removal and a coordinated monitoring approach is being developed for pre- and post-project monitoring with relevant partners.

Opportunity

Currently, a coalition of partners, including The Nature Conservancy, NJDEP Division of Fish and Wildlife, USFWS, the Town of Belvidere, the NJSDRP, and the dam owners, are actively working towards removal of the first two dams and have received funding for design, permitting, and engineering to get the projects "shovel-ready" by 2023. In addition to the ecological uplift, the two dam removals on the Pequest River are also expected to result in the long-term socioeconomic benefits associated with reduced flooding in local residences and businesses. In this instance, flooding is a real impetus in moving these projects to construction and the Town of Belvidere is eager for the dams to be removed.

Restoration Potential

Upstream of Belvidere, the Pequest is free of complete obstructions for over 20 miles, until the Tranquility Mill Dam (NJ_21-15) in Andover Township, NJ. However, there are three remnant dams located along its lower section that should be considered following the removal of the Belvidere dams. These barriers—McMurtie & Co. Dam (NJ_24-30), No Name Dam (NJ_24-31), and Cedar Grove Dam (NJ_24-32)—are expected to allow passage of alosines in high flow conditions but removing the remaining dam sections and restoring the stream would improve fish passage, water quality, and habitat conditions. Just upstream, there is also a stone arch bridge that may present a barrier to alosines due to its low overhead and dark conditions, and this should be monitored as well. No restoration goals for American Shad and river herring have been established in the Pequest River.

FACT SHEET

LOWER E.R. COLLINS & SON DAM (Dam #1) is owned by the NJDEP Division of Fish and Wildlife and is the first blockage to migratory fish on the Pequest River. The removal of this dam along with the Upper E.R. Collins & Son Dam just upstream will increase migratory fish habitat—specifically

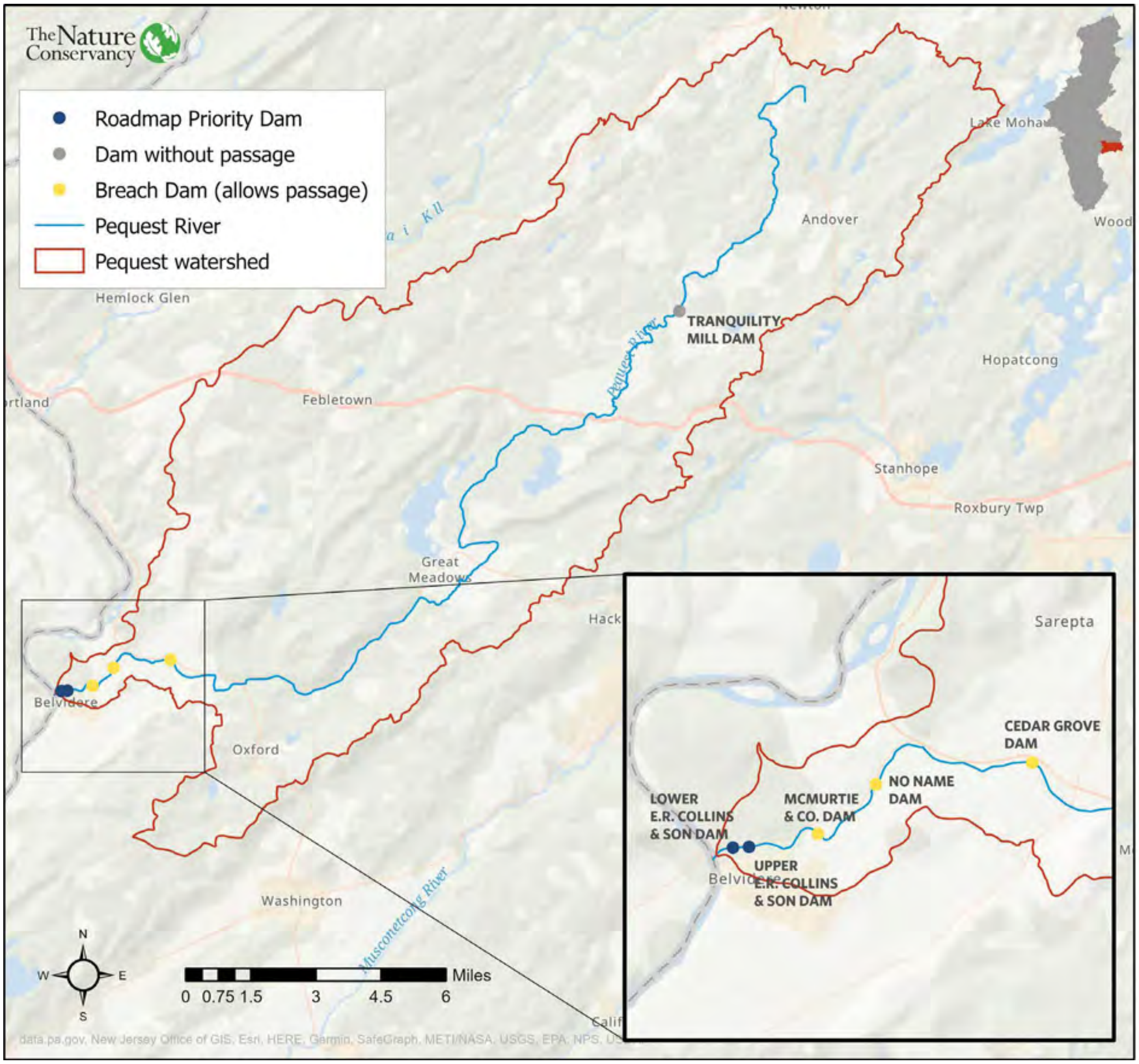


Figure 4-11. *Pequest River Mainstem Dams Map.*

Dam #	Unique ID	Dam Name	River Mile	Barrier Status
1	**NJ_24-28**	**Lower E.R. Collins & Son Dam**	**0.1**	**Complete**
2	**NJ_24-29**	**Upper E.R. Collins & Son Dam**	**0.2**	**Complete**
3	NJ_24-30	McMurtie & Co. Dam	1	Breached
4	NJ_24-31	No Name Dam	1.8	Breached
5	NJ_24-32	Cedar Grove Dam	3.5	Breached
6	NJ_21-15	Tranquility Mill Dam	24.5	Complete

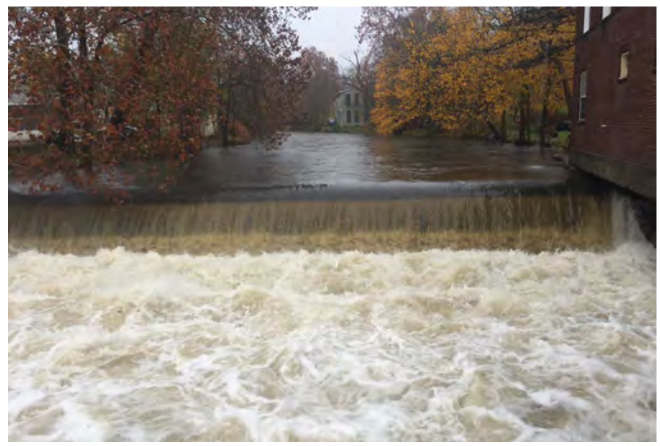
Table 4-5. *Pequest River Mainstem Dams. Bolded dams with grey shading are priorities for restoration detailed at greater length in this report.*

benefitting American Shad, Blueback Herring, Sea Lamprey, and American Eel—in addition to improving water quality and reducing hazardous flood impacts in downtown Belvidere. The Nature Conservancy, working closely with NJDEP Division of Fish and Wildlife, USFWS, the Town of Belvidere, and the NJSDRP, has received funding for engineering studies to develop design plans and necessary permitting for removal with the goal of initiating construction in 2023. The NJSDRP has also begun conversations with Norfolk Southern Rail to coordinate on necessary structural evaluations given a rail bridge is located just 50 feet upstream of the dam.

Lower E.R. Collins & Son Dam. Credit: TNC.

FACT SHEET

UPPER E.R. COLLINS & SON DAM (Dam #2) is located just upstream of the Greenwich-Market Street Bridge in downtown Belvidere and is situated between two commercial buildings on either bank of the river. Due to repeated flooding in downtown that is exacerbated by the dam, the Town of Belvidere—the dam owner—and additional stakeholders are supportive of removal and eager to move forward with construction. According to the township, there are six "severe repetitive loss" and 53 "repetitive loss" flood properties in Belvidere. Review of FEMA flood profiles indicate that removal of the Upper E.R. Collins & Son Dam will mitigate flooding for the 10-, 50- and 100-year floods by up to three feet. Removal of this dam along with the downstream dam will benefit migratory fish, public safety, and water quality. The Nature Conservancy has received funding for design, engineering, and permitting for the removal with plans to move to construction in 2024.



Upper E.R. Collins & Son Dam. Credit: TNC.

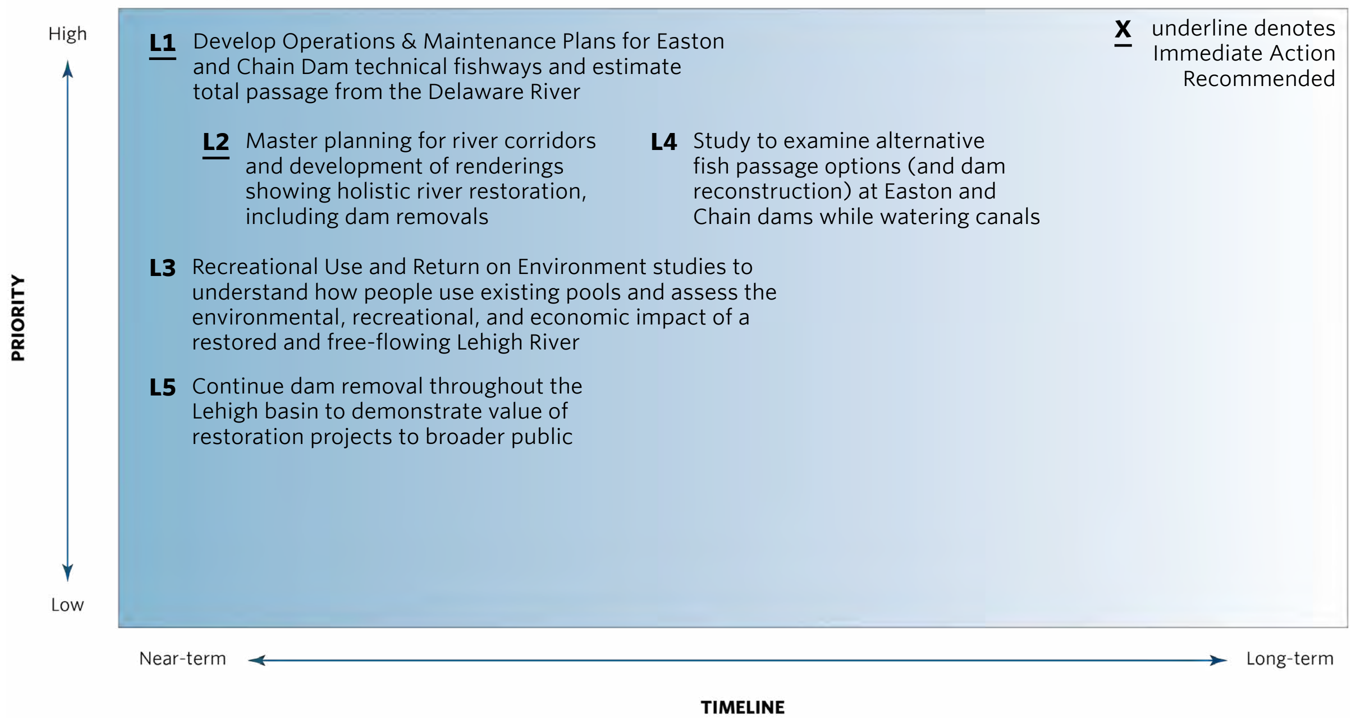
Potential Partners/Stakeholders

The New Jersey Statewide Dam Removal Partnership (SDRP) is a collaboration of nonprofits and government agencies that seeks to advance the removal of antiquated, dangerous, or ecologically detrimental dams. Its members meet quarterly to discuss beneficial dam removal projects and to exchange information regarding policy, regulatory issues, funding, and the practical considerations of dam removal. The SDRP is working closely with the Town of Belvidere to address the two downstream dams on the Pequest River. The below list of partners includes many of those active in the SDRP:

U.S. FISH AND WILDLIFE SERVICE, TOWN OF BELVIDERE, NEW JERSEY STATEWIDE DAM REMOVAL PARTNERSHIP, THE NATURE CONSERVANCY, NJ DIVISION OF FISH AND WILDLIFE, NOAA FISHERIES, USACE PHILADELPHIA DISTRICT, NJ DEPARTMENT OF ENVIRONMENTAL PROTECTION, USDA NATURAL RESOURCES CONSERVATION SERVICE, USGS, TROUT UNLIMITED, FISHERMEN AND LOCAL COMMUNITIES

4.5 Lehigh River

Priority Restoration Actions



Background

The Lehigh River is the second largest tributary to the Delaware with a watershed that encompasses 1,345 square miles of eastern Pennsylvania and contains more than 2,000 miles of tributary streams. Located upriver in the non-tidal reach of the Delaware River, the Lehigh enters the Delaware at Easton, Pa. (rm 184), flowing over 100 miles from its headwaters that form in the Pocono Mountains. The upper Lehigh watershed is largely forested and renowned for its spectacular scenery and exceptional water quality – earning it a state designation as a Scenic River. The area is popular for recreation, with some of the state's best cold-water fishing areas and whitewater rapids through Lehigh Gorge that rely in part on releases from the Francis E. Walter Dam—owned and operated by the US Army Corps of Engineers (USACE)—at river mile 77.6. The region's mining and industrial legacy is more evident in the middle and lower sections of the river as water quality deteriorates and there is continued influence from acid mine drainage (Arnold and Pierce 2007). Four dams located in this lower section and the surrounding urbanized areas contribute to the poor water quality and degraded habitat in addition to limiting the passage of alosines upriver.

Prior to the construction of a series of dams for supporting the Lehigh Coal and Navigation Canal system in the early 1800s, American Shad migrated at least 36 miles (58 km) upriver to Palmerton, Pa. where the Indigenous Lenape people annually harvested shad at the confluence of the Aquashicola Creek. Although no written record has been found

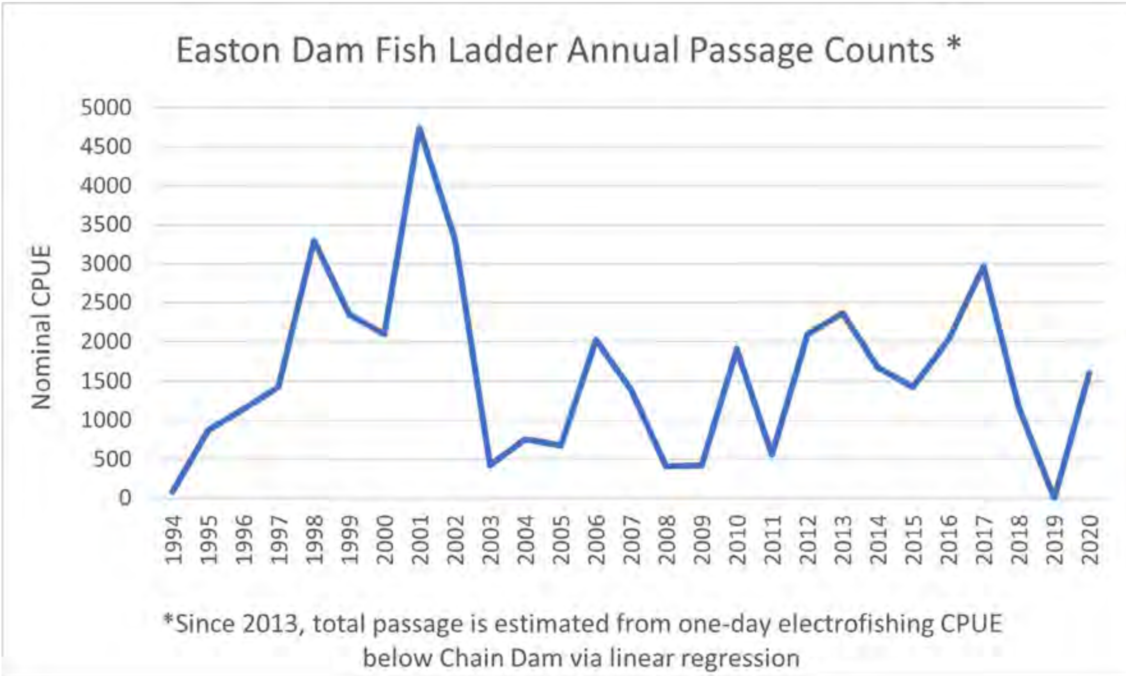


Figure 4-12. *Easton Dam Fish Ladder Annual Passage Counts and Estimates. Since 2013, total passage at Easton is estimated from one-day electrofishing CPUE below Chain Dam via linear regression. Data source: PFBC.*

documenting the occurrence of shad further upriver of Palmerton, Pa., it is reasonable to assume they continued their migrations for some distance upstream. "Plump hordes of spawning shad" were also recorded in Jordan Creek in Allentown in the 1740s and it is likely that they utilized many of the larger tributaries as well as the mainstem Lehigh while they remained accessible (Lehigh County Historical Society 1962). Construction of the Easton Dam (0 rm) in 1829 at the confluence of the Lehigh and Delaware rivers extirpated shad and river herring from the Lehigh River basin for 165 years until the subsequent installation of a fishway in 1994.

Today, four run-of-river dams are located on the Lehigh between its confluence with the Delaware and river mile 23.9, the last of which does not allow any fish passage; however, the mainstem is free of barriers upriver to the Francis E. Walter Dam at river mile 77.6. Improving and restoring aquatic connectivity at these lower four dams will be critical to reestablishing self-sustaining populations of American Shad and river herring within this watershed.

Population Status

Shad and river herring currently have access to the Northampton (Cementon) Dam at river mile 23.9 (rkm 38), though ineffective passage at the three downstream dams limits the run size. Fish passage counts via video monitoring at the Easton and Chain Dams occurred from 1995 to 2012, at which time funding was discontinued. Since 2013, fish passage at the Easton Dam is estimated based on a one-day electrofishing survey below Chain Dam using concurrent estimates of Easton Dam fishway counts and Lehigh River electrofishing from 1996 to 2012 (Figure 4-12). The Lehigh River is considered under restoration status for a self-sustaining migration of American Shad and, in 2013, PFBC imposed a catch and release only fishery (no harvest). River herring passage at Easton Dam is often nominal.

Opportunity

Wildlands Conservancy, in partnership with PFBC and KCI Engineering, led the Lehigh River Fish Passage Improvement Feasibility Study at the lower two Lehigh dams—Easton and Chain—that was completed in 2013. The study concluded that removal of the Easton and Chain dams was the only feasible option for restoring sustainable fish passage as the size and construction of the dams made rock ramps, partial removal, and natural fishways infeasible. The study involved a wide range of stakeholders, and at the time there was significant public opposition to the idea of removal as the dams are critical to watering sections of historic canals and are considered part of the city's aesthetics. During this project, the idea of dam removal or alternative fish passage at the lower Lehigh dams was revisited and it was generally acknowledged that the City of Easton and the wider community would need to support any such efforts for them to move forward.

Two planning studies completed since 2013 present opportunities for reimagining the lower Lehigh River and recommend actions that could benefit the Easton community and migratory fish. In 2016, the City published its updated *Easton 2035 Comprehensive Plan*, which recommends developing master plans for the city's river corridors. Such a planning process would bring together various stakeholders and re-envision what the river corridors could look like in the future, including the potential for holistic river restoration efforts and dam removal that are demonstrated using visual renderings. Delaware Canal 21's *Delaware Canal Vision Study* (2017) developed a sketch concept for the confluence of the Lehigh and Delaware rivers that proposes transforming the Easton Dam into a wing dam with a technical kayak park that would maintain water in the canal, promote tourism, and allow fish passage via the kayak channel. Outside-the-box ideas like this and others should be further studied to determine if there is potential to develop solutions that work for various stakeholder interests. This could incorporate a Recreational Use study to understand existing uses of the pools paired with a Return on Environment report to determine the overall environmental, recreational, and economic benefit of a free-flowing Lehigh River if the dams were to be removed or alternative options pursued. In September 2021, Tropical Storm Ida also caused severe damage to the length of the Delaware Canal, estimated between $5 to 8 million, presenting further opportunity to reassess the construction needs of centuries-old infrastructure in the future considering climate change impacts.

Various stakeholder groups are interested in re-envisioning the Lehigh riverfront and canals to meet the needs of the 21st century. There is a near-term opportunity to engage in wider efforts to develop plans for Easton's river corridors and map out a future for fish and people through a collaborative process that considers the potential environmental, economic, and visual impacts of a restored and free-flowing Lehigh River as well as alternative, outside-the-box approaches that satisfy multiple needs.

In the meantime, there is an opportunity to improve the functioning of the current technical fishways and several partners, including USFWS, PFBC, PA DCNR, and PA DEP, are actively working to develop operations and maintenance plans for the Easton and Chain fishways. The anticipated American Shad telemetry study will also be beneficial to understanding the movement of shad around the Easton Dam and whether they are able to find and navigate the fishway.

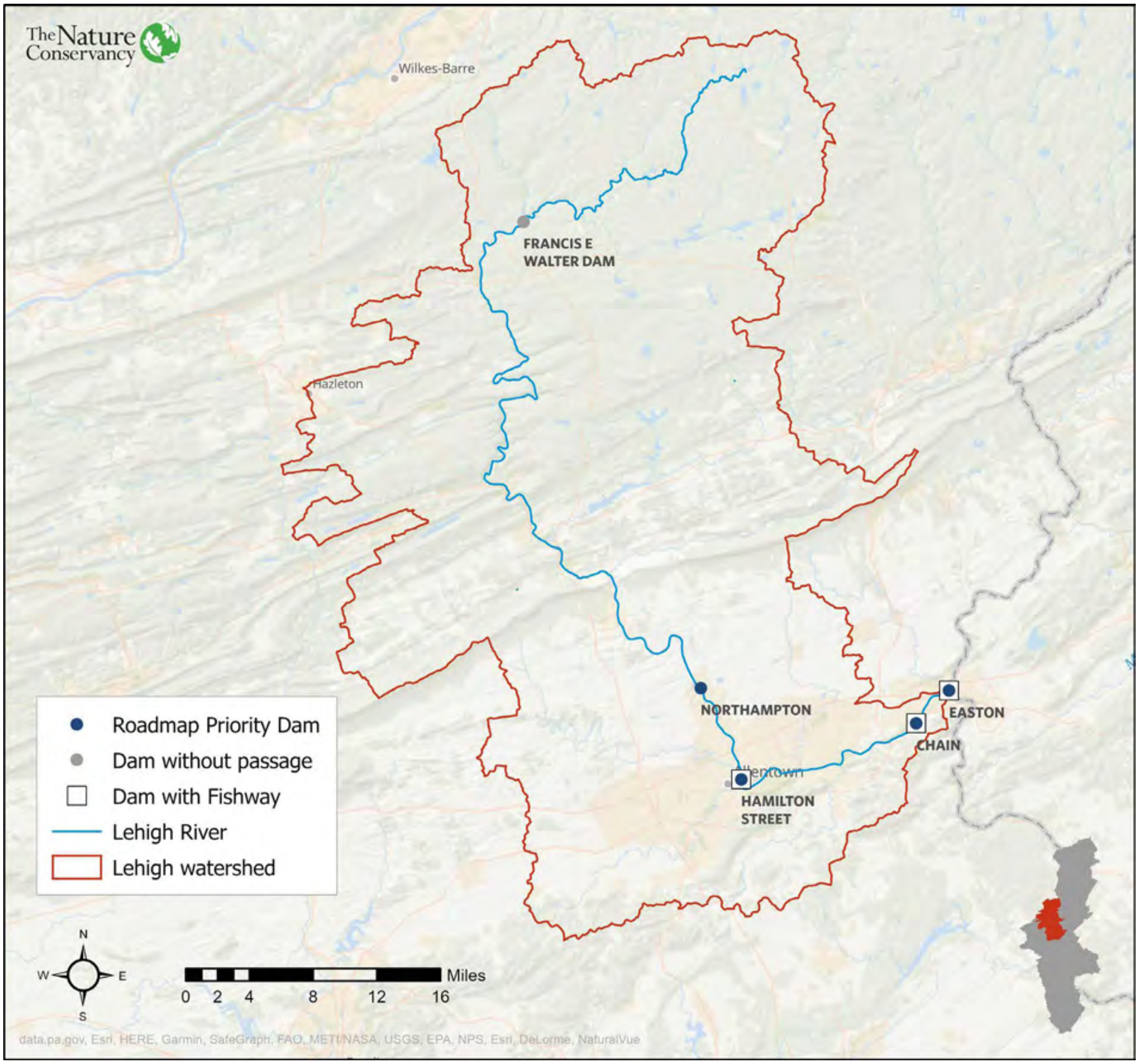


Figure 4-13. *Lehigh River Mainstem Dams Map.*

Dam #	Unique ID	Dam Name	River Mile	Barrier Status
1	**PA_48-012**	**Easton Dam**	**0.0**	**Fishway**
2	**PA_48-013**	**Chain Dam**	**3.2**	**Fishway**
3	**PA_39-009**	**Hamilton Street Dam**	**17**	**Fishway (dewatered)**
4	**PA_39-060**	**Northampton Dam**	**23.9**	**Complete**
5	PA_PA00008	Francis E. Walter Dam	77.6	Complete

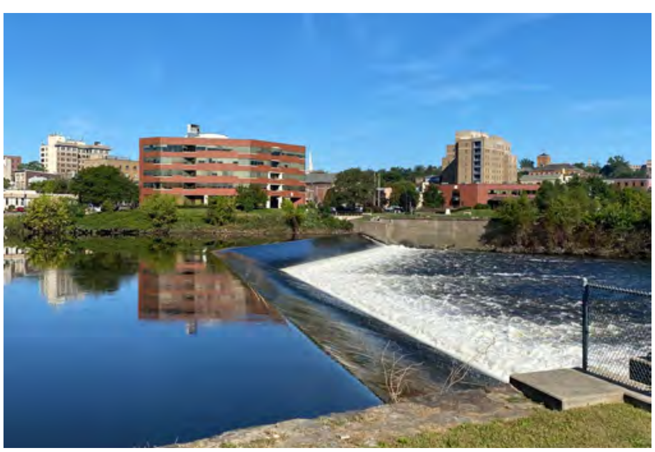
Table 4-6. *Lehigh River Mainstem Dams. Bolded dams with grey shading are priorities for restoration detailed at greater length in this report.*

Restoration Potential

The four run-of-the-river mainstem dams along the Lehigh River are highlighted as high priority restoration sites. Detailed descriptions are below for each dam and dam fact sheets and photos can be found in Appendix A. The Lehigh River shad spawning runs remain well below the original restoration goals of 165,000 – 465,000 wild shad annually (PFBC 1988). No restoration goals have been established for river herring in the Lehigh. Fish passage at the lower three dams via the constructed fish ladders are known to be insufficient based on previous fishway monitoring and a 2017 assessment completed by USFWS Northeast Region staff. To reach the 80-100% passage efficiency target for American Shad established by PFBC and to restore a self-sustaining population in the Lehigh, it is likely that dam removal or alternative fish passage options will be required. A major challenge in doing so is that each of these structures currently water historic canal segments—once vital to transporting anthracite coal from the region to Philadelphia and other cities—that have now become popular recreational sites and symbols of the community.

FACT SHEET

EASTON DAM (Dam #1) is located at the confluence of the Lehigh and Delaware rivers and was originally constructed in 1829 to provide water to the Delaware Canal. The Easton Dam still serves to water a portion of the nearly 60-mile-long canal—a National Historic Landmark owned and operated by the Pennsylvania Department of Conservation and Natural Resources (PA DCNR)—and a recent investment of $40 million was made to restore the canal and locks in the 2000s. While the dam was reconstructed in 1968 following a breach, the redesign maintained the timber crib structure at its core and placed a concrete cap overtop.



Easton Dam. Credit: Lyndon DeSalvo/TNC.

Case Study: Cuyahoga River Dam Removals

In 2020, the National Park Service removed two historic dams that watered a section of the Ohio & Erie Canal (a National Historic Landmark) to improve the health of the river and plans to install a pump to maintain water in the canal.

Learn more about the project **here**.

Owing to the advocacy of the Delaware River Shad Fishermen's Association, $3.3 million in state funding was appropriated for fishways on the Easton and Chain dams in 1989. In 1994, a vertical slot fishway was constructed on the southern side of the Easton Dam complete with an observation window and video surveillance, which allowed fish passage counts from 1995 to 2012 (Figure 4-12). American Shad and other anadromous species, including small numbers of river herring, were able to access historic habitat that they had been excluded from for over 150 years. Post-2012, total passage of American Shad through the Easton Dam fishway is estimated using a predictive regression relationship between total passage and a one-day electrofishing survey due to loss of funding for video monitoring. The 2013 feasibility study determined that full dam removal was the only viable option to significantly improve fish passage at Easton Dam; however, this option did not have the necessary support from the City of Easton to move forward with removal. Current efforts are underway to develop an Operations & Maintenance Plan and improve the functioning of the technical fishway.

FACT SHEET

CHAIN DAM (Dam #2)—also referred to as the Glendon Dam—is located three miles upstream of the Easton Dam and was constructed around the same time to water the most downstream segment of the Lehigh Canal system. In 1965, an ice floe along the Lehigh River caused the original Chain Dam to breach and it was eventually reconstructed in 1974. The former dam was located approximately 160′ upstream of the current structure and its remnants have not been fully removed from the riverbed. Today, the dam still waters over two miles of a fully restored section of the Lehigh Canal, included in the National Historic Register, and cultural offerings within the City of Easton's Hugh Moore Park, including the National Canal Museum and mule-powered boat rides along the canal, celebrate this history. While the dam is officially owned by PADEP, the agency has a binding agreement with the City of Easton and would need the city's buy-in as well as legislative support to entertain removal.

The vertical slot technical fishway was added to the dam in 1994 and is located on the north side of the river. PFBC fish passage counts from 1995 to 2012 at Easton and Chain Dams demonstrated approximately a 25% passage efficiency at Chain, with an average of 500 shad passing annually over the 15-year period. Today, the fishway is no longer monitored though DCNR staff are responsible for maintenance and operation of the fishway. Located just downstream of the dam, Palmer Pool is known to support American Shad spawning while significant sediment builds up just upstream contributes to poor water quality and proliferation of aquatic invasives, such as Eurasian watermilfoil. The 2013 feasibility study determined that full dam removal was the only viable option to significantly improve fish passage at Easton Dam; however, the City of Easton did not support removal at the time. Current efforts are underway to develop an Operations & Maintenance Plan and improve the functioning of the technical fishway.

Chain Dam. Credit: Lyndon DeSalvo/TNC.

Hamilton Street Dam. Credit: Lyndon DeSalvo/TNC.

FACT SHEET

HAMILTON STREET DAM (Dam #3) is in Allentown, Pa. and was originally constructed circa 1830 to feed a section of the Lehigh Coal and Navigation Canal. In 1984, the dam was reconstructed following a breach caused by ice floes in 1977 and a vertical slot fishway was added to the eastern side, beside the canal entrance. Ownership of the dam transferred to the City of Allentown at this time, though the municipality only recently realized it owned the structure and, as of 2020, has just begun to set aside annual funds towards maintenance. The impoundment created by the dam extends approximately 3.5 miles upstream and the Lehigh County Authority does have drinking water intakes located here, though the primary water source for the City of Allentown is the Little Lehigh Creek and two springs, with the Lehigh River serving as a back-up supply. The Lehigh County Authority's main wastewater treatment plant at Kline Island is also located just downstream of the dam at the mouth of the Little Lehigh. The dam is included in the current waterfront development plans and the community uses the impoundment for boating.

While American Shad have been recorded upstream of the Hamilton Street fishway, it is not consistently maintained and passes fish in relatively small numbers. The fishway does not have an observation window for monitoring purposes and no fish passage counts have been recorded here. During a 2021 site visit, the fishway was found to be dewatered and in relatively poor condition.

Northampton Dam. Credit: Lyndon DeSalvo/TNC.

NORTHAMPTON DAM (Dam #4), also referred to as the Cementon Dam, was constructed in 1927 and creates an impoundment extending approximately one mile upstream. The section of river above Cementon is greatly impacted by abandoned mine drainage due to inputs from several tributaries—including Sandy Run, Buck Mountain Creek, Black Creek, and Nesquehoning Creek—some of which are still devoid of fish. The adjacent Lafarge Holcim cement manufacturing plant currently relies on the dam for its water supply and determined that groundwater alone would not be capable of providing sufficient water for its daily operations. The Northampton Borough Municipal Authority (NMBA) Water Treatment Plant is also located upstream of the dam and may rely on the impoundment for its intake.

No fish passage is present at the Northampton Dam. While American Eel and Sea Lamprey are not typically impeded by the dam, American Shad and other migratory fish are unable to pass and have been documented in the tailrace and downstream Hokendauqua Creek Pool by anglers and PFBC electrofishing surveys. Enabling fish passage here would open an additional 54 miles of the mainstem to the Francis E. Walter Dam.

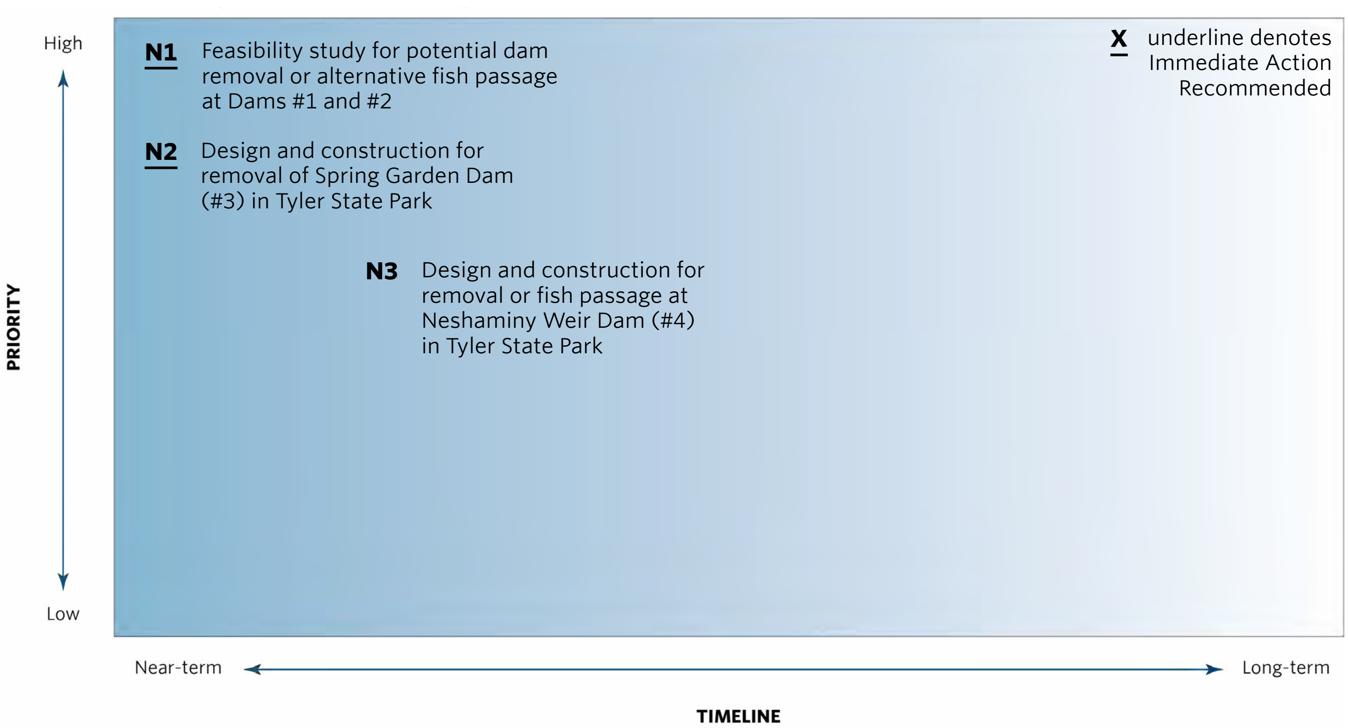
Potential Partners/Stakeholders

The 2013 feasibility study brought together a broad range of stakeholders interested in fish passage efforts and overall river restoration in the Lehigh River basin. The below list captures this cross-cutting group of partners – including governmental agencies, non-profit organizations, recreational groups, and technical experts – critical to moving forward on any dam removal and fish passage improvement projects:

WILDLANDS CONSERVANCY, U.S. FISH AND WILDLIFE SERVICE, CITY OF EASTON, PA FISH AND BOAT COMMISSION, PA DEPT. OF ENVIRONMENTAL PROTECTION, PA DEPARTMENT OF CONSERVATION & NATURAL RESOURCES, USACE PHILADELPHIA DISTRICT, DELAWARE RIVER BASIN COMMISSION, THE NATURE CONSERVANCY, NOAA FISHERIES, AMERICAN RIVERS, DELAWARE RIVER SHAD FISHERMEN'S ASSOCIATION, NURTURE NATURE CENTER, DELAWARE & LEHIGH NATIONAL HERITAGE CORRIDOR, CANAL 21, FRIENDS OF THE DELAWARE CANAL, LEHIGH VALLEY PLANNING COMMISSION, CITY OF ALLENTOWN, LAFARGE-HOLCIM, EASTON WHITEWATER, LAFAYETTE COLLEGE, LEHIGH UNIVERSITY, LEHIGH COUNTY CONSERVATION DISTRICT, HERITAGE CONSERVANCY, TROUT UNLIMITED, NORTHAMPTON BOROUGH MUNICIPAL AUTHORITY, TRI-BORO SPORTSMEN CLUB, FISHERMEN AND LOCAL COMMUNITIES

4.6 Neshaminy Creek

Priority Restoration Actions



Background

Neshaminy Creek flows 40 miles from the borough of Chalfont, where its north and west branches merge, to its confluence with the Delaware in Bensalem, Pa. at river mile 115.5. Located primarily within Bucks County in southeastern Pennsylvania, the watershed drains an area of approximately 236 square miles and is located just north of Philadelphia. The Lenape called the stream "*Nesha-men-ning*," which translated to "the double drinking place" or "where we can drink twice" owing to two freshwater springs near one of their villages (McCarren 1972). During the 1700s, mills and farms grew along the creek, and it became an important area for commerce and transportation. Flooding has historically been an issue within the watershed – with notably large floods in 1833 and 1865 that destroyed several bridges and dams – and is made even worse today by the high percentage of impervious surface caused by increasing development.

Amongst Pennsylvania's tributaries to the Delaware, the Neshaminy was one of four historically significant streams for American Shad and river herring – alongside the Schuylkill, Lehigh, and Lackawaxen Rivers – according to a 1985 report by the Delaware River Basin Fish and Wildlife Management Cooperative (DRBFWMC 1985). In 1683, William Penn signed a treaty with Chief Tamanend of the Lenape granting Penn rights to the lands along the Neshaminy Creek and south to the Pennypack Creek (Wiencke 2021). Europeans quickly settled the area and, sometime prior to 1725, a mill dam was erected near the present day Hulmeville Dam (rm 6.2), which “prevented shad running up which greatly offended the Holland settlers of North and Southampton who made several attempts to tear it away” (Davis 1905, 20). The extent of the historic shad run prior to the damming of the creek is unknown, but Gay also noted that shad frequented the lower section of this creek for spawning in the late 1800s (Gay 1892).

Population Status

The lower, tidal section of the Neshaminy and upstream to the Hulmeville Dam are recognized as an important nursery area for Alosines. During 2014 Largemouth Bass surveys, PFBC noted young-of-year American Shad, Alewife, and Blueback Herring (the latter of which was listed as abundant) in the 2.5-mile section of the creek from the I-95 bridge to the mouth (PFBC 2014). Fishermen are known to catch American Shad below the base of the dam and Blueback Herring and Alewife are occasionally targeted here by people using illegal sabiki rigs (Tyler Grabowski, pers. comm.). During 2021 sampling for a Northern Snakehead diet study, Academy of Natural Sciences staff also noted a lot of juvenile Alosines were present (David Keller, pers. comm.). Currently, there are no population estimates for the Alosine populations in the Neshaminy Creek.

Opportunity

While there is not currently an active partnership working towards aquatic connectivity in the Neshaminy watershed, there is certainly opportunity to address the mainstem dams via removal or added fish passage. Two of the dams lie within Tyler State Park and PA DCNR is already seeking to remove the Spring Garden Dam (Dam #3) as it is a liability and has no current use. In addition, significant flooding along the lower Neshaminy in recent years has devastated many Bucks County communities and dam removal or alternative fish passage, along with other restoration efforts and enhanced stormwater management, may present an opportunity to help mitigate future impacts from flooding and enhance resiliency in the face of climate change impacts.

Restoration Potential

No restoration goals for American Shad and river herring have been established in the Neshaminy Creek. Potential production estimates for American Shad can be found in the 1985 study *A Review and Recommendations Relating to Fishways Within the Delaware River Basin* commissioned by the Delaware River Basin Fish and Wildlife Management Cooperative. Using a coarse rule-of-thumb based on abundance data from the Connecticut River and available spawning habitat, the study estimated that potential shad production in the Neshaminy Creek was between 14,200 and 40,200 fish if the lower three mainstem dams were addressed.

The Neshaminy Creek has four dams along its lower section between its mouth at Bensalem, Pa. and upstream to Tyler State Park in Newtown, Pa. that are identified as priorities. Detailed descriptions are below for each dam and dam fact sheets and photos can be found in Appendix A. None of these dams currently allows for passage of Alosines, despite the Hulmeville Dam being listed as a priority for fish passage in the 1985 report. Restoration efforts would also need to extend beyond dam removal and fish passage to address additional challenges associated with wastewater and stormwater discharge, chemical contaminants, severe flooding, streambank erosion, and sedimentation.

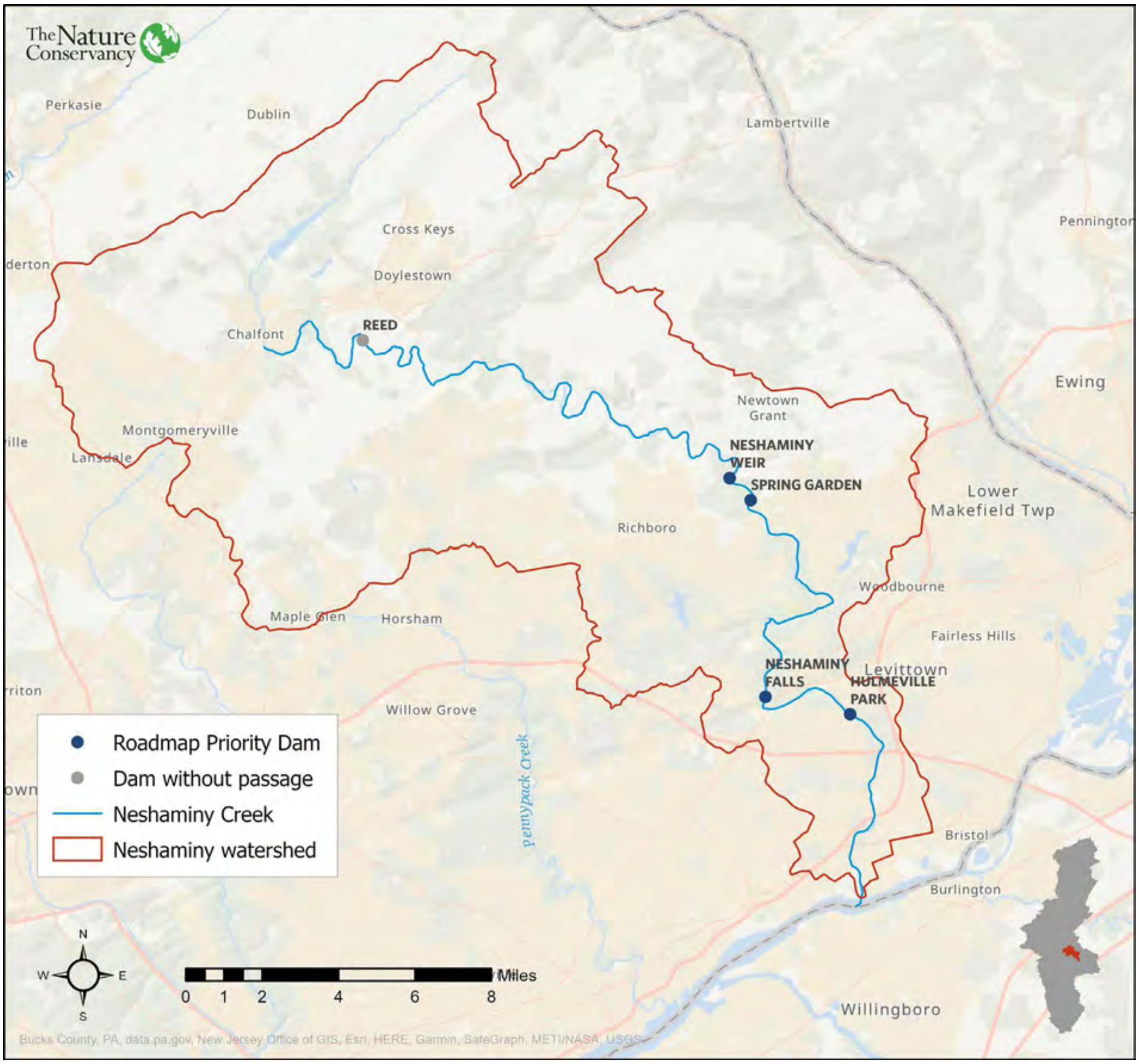
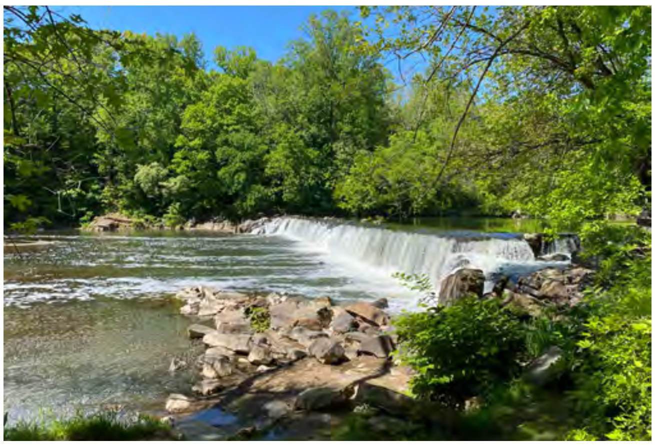


Figure 4-14. *Neshaminy Creek Mainstem Dams Map.*

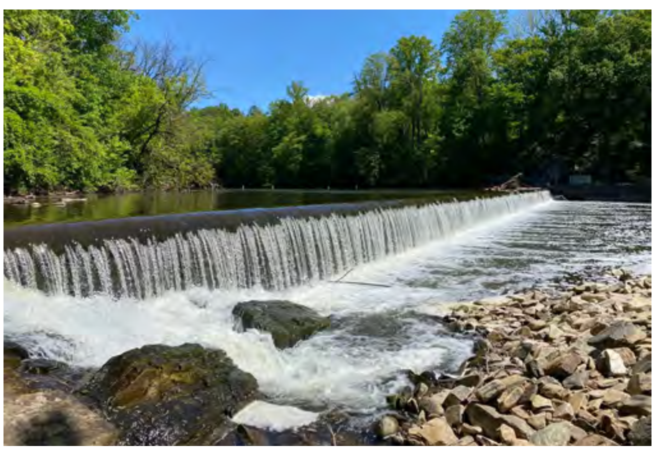
Dam #	Unique ID	Dam Name	River Mile	Barrier Status
1	**PA_09-084**	**Hulmeville Park Dam**	**6.2**	**Complete**
2	**PA_09-003**	**Neshaminy Falls Dam**	**9**	**Complete**
3	**PA_09-083**	**Spring Garden Dam**	**17.5**	**Complete**
4	**PA_09-167**	**Neshaminy Weir Dam**	**18.5**	**Complete**
5	PA_09-141	Reed Dam	35	Complete

Table 4-7. *Neshaminy Creek Mainstem Dams. Bolded dams with grey shading are priorities for restoration detailed at greater length in this report.*

None of the mainstem dams on the Neshaminy Creek currently allows for fish passage despite it being a historically significant shad stream and recognized as a nursery for alosines in its lower section today. There is a significant opportunity to restore aquatic connectivity within this system while also expanding restoration activities to address other critical issues within the watershed including flooding, streambank erosion, and sedimentation.



Hulmeville Park Dam. Credit: Lyndon DeSalvo/TNC.



Neshaminy Falls Dam. Credit: Lyndon DeSalvo/TNC.

HULMEVILLE PARK DAM (Dam #1) is a rockfill dam constructed at a natural pinch point in the Neshaminy that utilizes natural rock outcroppings on its southern portion. A dam has likely existed in this section of river for over 300 years as the Hulmeville, Pa. website mentions a plaster-mill that was built prior to 1725 near the current Hulmeville Rd/Route 513 bridge just downstream that prevented the historic shad run. PFBC and local fishermen have documented American Shad and River Herring at the base of the dam, which does not allow for fish passage, and in the lower tidal section of the Neshaminy, considered a nursery for Alosines. The neighboring Neshaminy Shore Picnic Park utilizes the upstream impoundment for recreational boating.

FACT SHEET

NESHAMINY FALLS DAM (Dam #2) is owned by Aqua Pennsylvania and used to intake surface water for treatment at their Neshaminy Falls Water Treatment Plant, which has a capacity of 15 million gallons per day (MGD). The original dam supported a grist mill and later recreational boating as part of Neshaminy Falls Grove, described as "a miniature Coney Island with a carousel, scenic creek railway, fun houses, shooting galleries, wheel games, side shows, motorboat rides, a roller-skating pavilion, ballroom and band shell" (LaVO 2017). The current masonry dam does not allow for fish passage and the local flooding and streambank erosion are evidenced by silt islands located just below the dam where Japanese Knotweed and other invasive plants have proliferated.

FACT SHEET

FACT SHEET

SPRING GARDEN DAM (Dam #3) is an arch-shaped, concrete dam located within Tyler State Park that does not currently allow for fish passage. The dam was likely originally connected to the Spring Garden Mill located just downstream near the Route 332 bridge, though it has since been rebuilt. Currently, the impoundment formed by the dam supports recreational boating in Tyler State Park; however, PA DCNR, the owner of the dam, considers it a liability due to unauthorized swimming at the location and is currently seeking funds for removal.

Spring Garden Dam. Credit: Lyndon DeSalvo/TNC.

FACT SHEET

NESHAMINY WEIR DAM (Dam #4) is also located within Tyler State Park and owned by PA DCNR. The dam is only 2-3 feet high and situated beside a boat house where DCNR rents kayaks and canoes to park visitors. Although the dam may be passable in high flows, a nature-like fishway could easily be added here to facilitate passage of Alosines if the lower Neshaminy Creek dams were to be addressed. A pedestrian walkway just downstream of the dam passes over the creek but allows for fish passage via a canoe bypass.

Neshaminy Weir Dam. Credit: Lyndon DeSalvo/TNC.

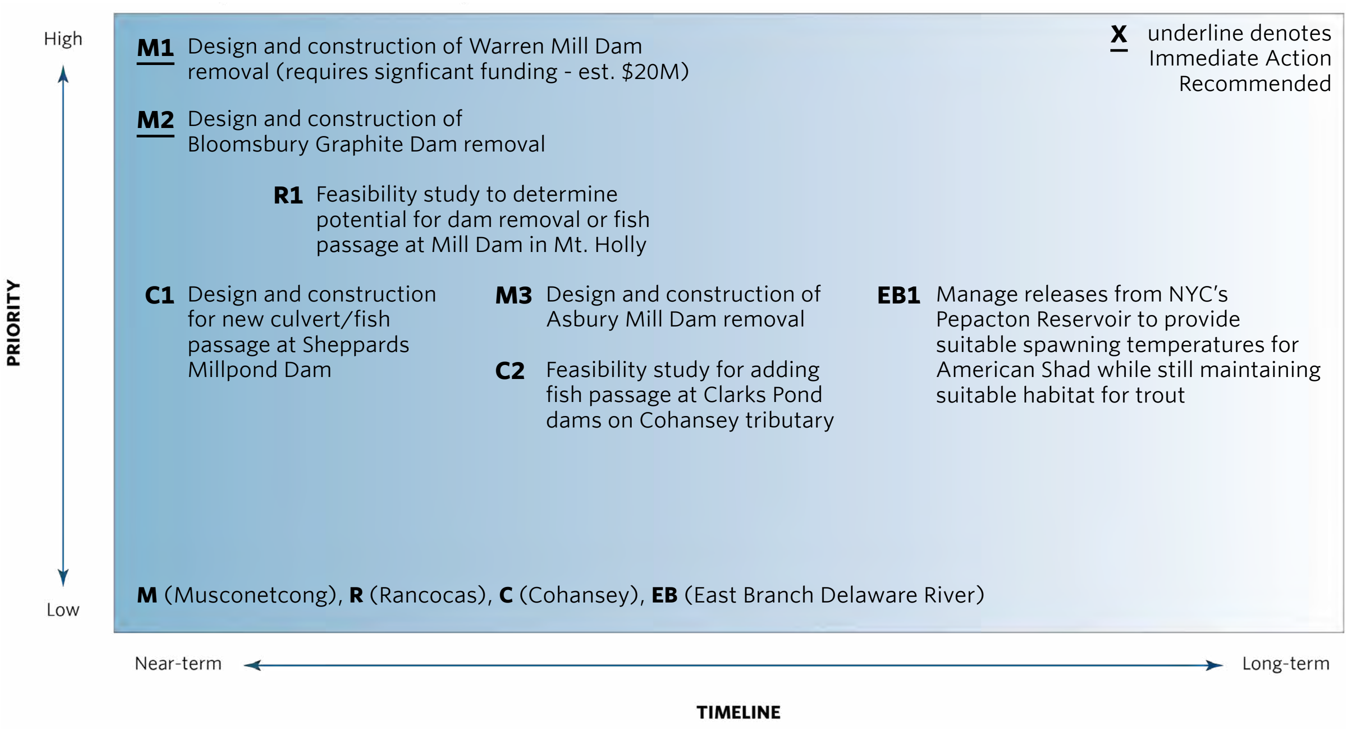
Potential Partners/Stakeholders

There are not currently any significant efforts to address fish passage on the mainstem of the Neshaminy Creek. We have identified some key stakeholders below that would be likely partners in building a coalition that would be key to any dam removal or fish passage improvement projects:

U.S. FISH AND WILDLIFE SERVICE, PA FISH AND BOAT COMMISSION, PA DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES, BUCKS COUNTY CONSERVATION DISTRICT, NESHAMINY CREEK WATERSHED ASSOCIATION, AQUA AMERICA, AMERICAN RIVERS, PA DEPT. OF ENVIRONMENTAL PROTECTION, THE NATURE CONSERVANCY, NOAA FISHERIES, USACE PHILADELPHIA DISTRICT, USGS, ACADEMY OF NATURAL SCIENCES AT DREXEL, PARTNERSHIP FOR THE DELAWARE ESTUARY, NESHAMINY SHORE PICNIC PARK, FISHERMEN AND LOCAL COMMUNITIES

4.7 Tiers 2 & 3 Priority Tributaries

Tier 2 Priority Restoration Actions



Tier 2 Tributaries

Tributaries and watersheds listed as Tier 2 are priority for American Shad and river herring restoration efforts. In some instances, dams may already have fish passage, but further assessment may be needed to determine current passage rates and conditions.

Musconetcong River

The Musconetcong River Restoration Partnership has been actively working to remove dams and restore migratory fish habitat in the Musconetcong watershed for the past couple decades, having removed five dams along the mainstem between 2008 and 2016. In 2017, American Shad were observed at the base of the Warren Mill Dam following the removal of the downstream Hughesville Dam in 2016 and it is expected that Blueback Herring also utilize the newly available habitat (MWA 2021). A coalition of partners are working to remove the next three upstream dams, all of which were ranked in the top ten statewide by the New Jersey Statewide Dam Removal Partnership due to the expected ecological benefits and potential to provide spawning habitat for migratory fish. While there are no historic records of alosines utilizing the Musconetcong, the current use by these species, active partnerships, and high-quality habitat elevates this as a priority system for restoration efforts. In addition, a section of the Musconetcong is designated as a Wild and Scenic River and, upon removal of the three dams, the lower section could be designated part of the Wild

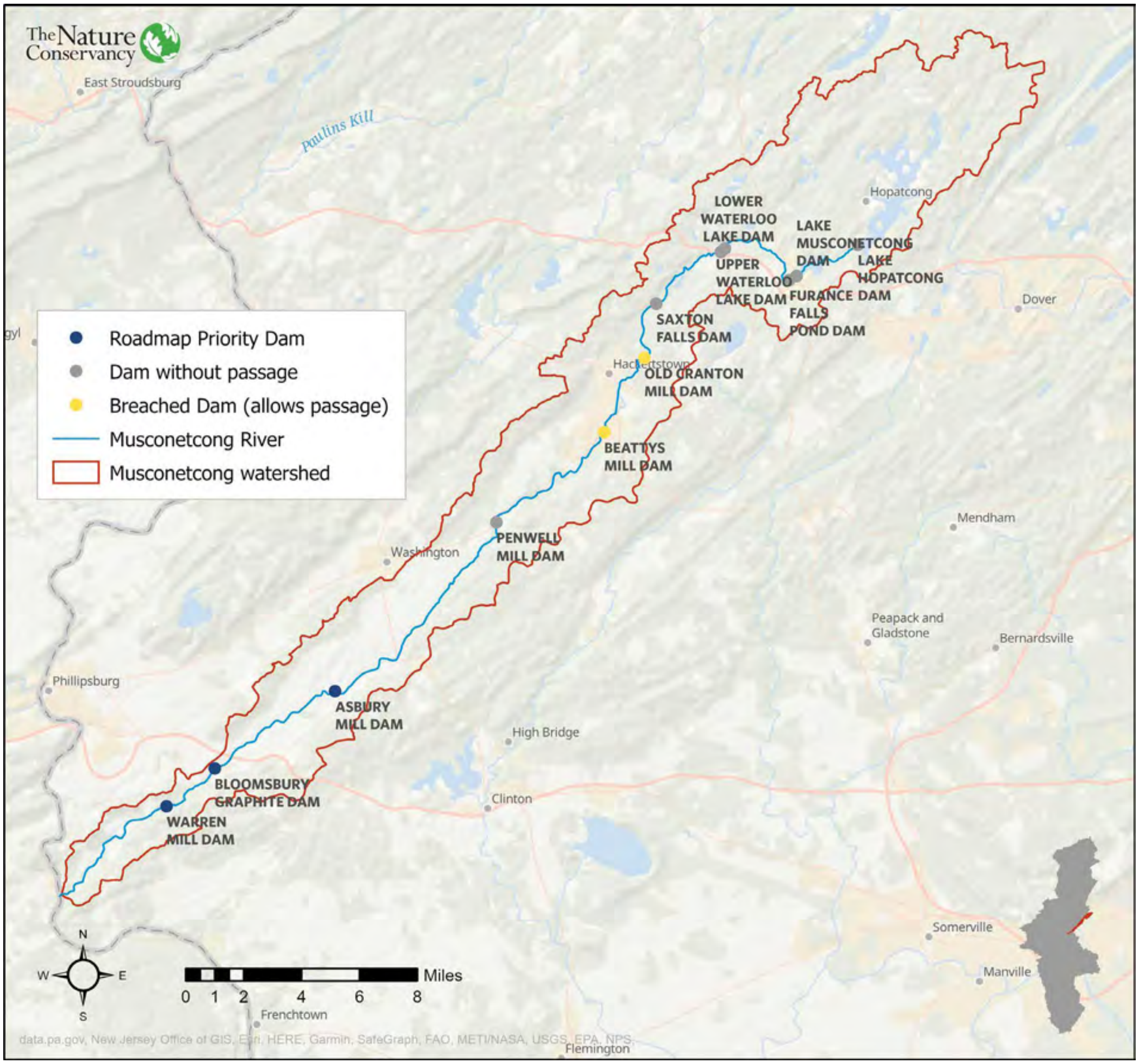


Figure 4-15. *Musconetcong River Mainstem Dams Map.*

Dam #	Unique ID	Dam Name	River Mile	Barrier Status
1		*Riegelsville Mill Dam*	*0.8*	*Removed 2011*
2		*Finesville Dam*	*1.6*	*Removed 2011*
3		*Hughesville Dam*	*4.5*	*Removed 2016*
4	**NJ_NJ00765**	**Warren Mill Dam**	**5.5**	**Complete**
5	**NJ_24-6**	**Bloomsbury Graphite Dam**	**7.8**	**Complete (removal planned)**
6	**NJ_NJ00581**	**Asbury Mill Dam**	**13.4**	**Complete**
7	NJ_NJ00781	Penwell Mill Dam	22.5	Complete
8	NJ_24-36	Beattys Mill Dam	30	Breached (removal planned)
** Additional mainstem dams exist upstream of Beattys Mill Dam as shown on map.*				

Table 4-8. *Musconetcong River Mainstem Dams. Bolded dams with grey shading are priorities for restoration detailed at greater length in this report.*

Warren Mill Dam. Credit: Musconetcong Watershed Association.

Bloomsbury Graphite Dam. Credit: NJ DEP.

and Scenic River system. In 2020, the Musconetcong Watershed National Water Trail was also designated in the National Trails System and would benefit further from dam removals to improve in-stream connectivity for recreational boating.

WARREN MILL DAM (Dam #4), also known as the Warren Glen Dam, is the lowest remaining barrier to migratory fish passage on the Musconetcong River following the removal of three downstream dams in the last decade. Built in 1916, the 37.5-foot High Hazard Class I Dam is vulnerable to a "Sunny Day" breach with four known leaks and poses a significant hazard to downstream residents and property. The dam is co-owned by International Process Plants and Equipment (IPPE) and the New Jersey Division of Fish and Wildlife, with both owners supportive of removal efforts. The major challenge to removal is the estimated cost at $20 million due in large part to the sediment impounded behind the dam, which may exceed 300,000 cubic yards (USACE 2019).

The Musconetcong Watershed Association, NJDEP, USFWS, and others are currently in the process of completing necessary design and engineering studies to move the project forward. With the Warren Mill Dam removed, the NJ Field Office of the US Fish & Wildlife Service indicates that a total of 8 stream miles and 100 acres of migratory fish habitat will have been restored in the Lower Musconetcong River watershed, and resiliency to extreme weather events will improve for downstream residents and employers by eliminating the risk of flooding and property damage from failure of a High Hazard dam (MWA 2021).

BLOOMSBURY GRAPHITE DAM (Dam #5) is a run-of-river dam located approximately 7.8 miles upstream from the confluence of the Musconetcong with the Delaware River. Currently, the USACE and NJDEP are partnering on the cost share for the design and removal of the dam, with construction planned for 2022. Removal of the dam would result in numerous environmental benefits including restoration of free-flowing conditions, free passage of aquatic organisms, and improved aquatic habitat (NJDEP 2018). Dam removal would also improve public safety by eliminating drowning risks at the dam and allowing unimpeded passage for recreational boats.

ASBURY MILL DAM (Dam #6) is the third remaining upstream barrier on the Musconetcong River. The twin dam structure is integrated with the adjacent Main Street bridge and currently USFWS and the Musconetcong Watershed Association are undergoing a flow study to develop concepts for dam removal.

Asbury Mill Dam. Credit: NJ Skylands.

Rancocas Creek

The Rancocas Creek watershed is located almost entirely in Burlington County, NJ and drains an area of approximately 360 square miles, extending from the headwaters of its north and south branches in the Pinelands region through south central New Jersey before entering the Delaware River in the tidal section at river mile 111 (rkm 179). The Rancocas was a historically significant shad stream and noted amongst a handful of other tidal tributaries as supporting extensive shad runs at the end of the 19th century. American Shad were known to run 15 to 20 miles upstream and extended into the northern and southern branches of the Rancocas watershed (PA State Commissioners of Fisheries 1896). Since 1975, regular monitoring by NJ Division of Fish and Wildlife has confirmed spawning Alewife and Blueback Herring in the mainstem and its two branches, and recent seining has also confirmed American Shad are present as well (NJDEP 2012).

Since the mid-1990s, the Rancocas watershed has been a focus of shad and river herring restoration efforts and, although there are no dams on the 8 miles of mainstem, there have been previous efforts to remove the most downstream dams on its North and South branches. Of the dams listed as priorities within the watershed, only the Mill Dam is a complete barrier without fish passage. The Smithville and Vincentown Mill dams both have steeppass fishways, though the current passage efficiency is unknown, and this should be a priority to better understand current conditions. All three of the dams are also located within local historic districts.

Mill Dam. Credit: Lyndon DeSalvo/TNC.

MILL DAM (North Branch Dam #1) is the first downstream barrier on the North Branch Rancocas Creek and currently does not allow fish passage. In the 1990s, USFWS and USACE specifically looked at the possibility of dam removal or added fish passage at the Mill Dam, which is owned by the

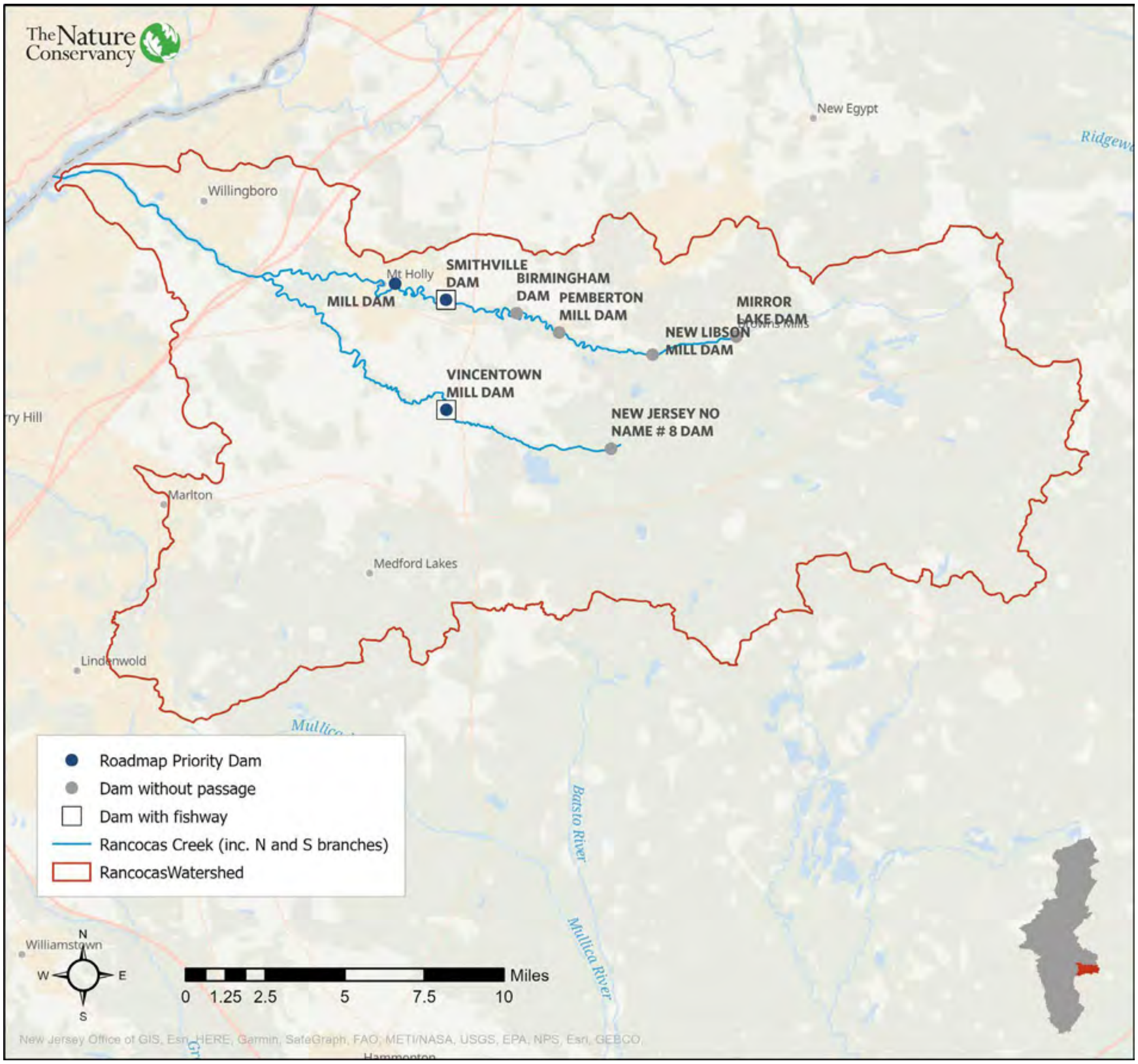


Figure 4-16. *Rancocas Creek North and South Branch Dams Map.*

Dam #	Unique ID	Dam Name	River Mile	Barrier Status
NB1	**NJ_NJ00540**	**Mill Dam**	**6.3**	**Complete**
NB2	**NJ_NJ00043**	**Smithville Dam**	**9.7**	**Fishway**
NB3	NJ_32-6	Birmingham Dam	13	Complete
NB4	NJ_32-3	Pemberton Mill	15.7	Complete
NB5	NJ_NJ00601	New Lisbon Dam	19.5	Complete
NB6	NJ_NJ00458	Mirror Lake Dam	22.2	Complete
SB1	**NJ_NJ00396**	**Vincentown Mill Dam**	**11.4**	**Fishway**
SB2	NJ_NJ00534	New Jersey No Name #8 Dam	17.4	Complete

Table 4-9. *Rancocas Creek Dams on North and South Branches. Bolded dams with grey shading are priorities for restoration detailed at greater length in this report.*

Township of Mount Holly, but significant public opposition squashed the project at the time. In 2017, the New Jersey Statewide Dam Removal Partnership (NJSDRP), a collaboration of nonprofits and government agencies, reviewed a list of more than forty dams and ranked the removal of each in terms of ecological uplift, fish migration benefits, public safety, flooding, condition, and owner willingness to remove. The Mill Dam was ranked in the top ten considering dams across the entire state due to their proximity to the Delaware River, the expected ecological benefits, and potential to provide spawning habitat for migratory fish. Given the presence of Northern Snakeheads below Mill Dam, there is some concern about the potential for dam removal to open additional habitat to this invasive species particularly as it connects to the Pine Barrens. The structure is also located within the Mount Holly Historic District, listed with local significance in the National Register of Historic Places (Ref #73001084).

SMITHVILLE DAM (North Branch Dam #2) is a 10-foot-high structure with timber cribbing that is owned by Burlington County and classified as a High-Hazard dam. The original structure was built around 1780, with significant repairs made since, the most recent in 1980. The dam is located within the Historic Smithville Park and Mansion property and is listed with local significance in the National Register of Historic Places (Ref #77000856). In a 2004 report by the Interagency Waterway Infra-structure Improvement Task Force, the Smithville Dam was listed as the only major flood control structure on the North Branch of the Rancocas. The dam currently has a steeppass fish ladder; however, passage efficiency is unknown and requires further study.

Smithville Dam. Credit: Google Earth.

Vincentown Mill Dam. Credit: Google Earth.

VINCENTOWN MILL DAM (South Branch Dam #1) is the first downstream barrier on the South Branch Rancocas Creek and owned by the Township of Southampton. Originally built in 1891, the dam was replaced in 2005 following damage during a July 2004 storm event that caused severe flooding and dam failures in several local watersheds. The High-Hazard dam was reconstructed to include a steeppass fish ladder; however, passage efficiency is unknown and requires further study. The structure is located within the Vincentown Historic District and is listed with local significance in the National Register of Historic Places (Ref #87002107).

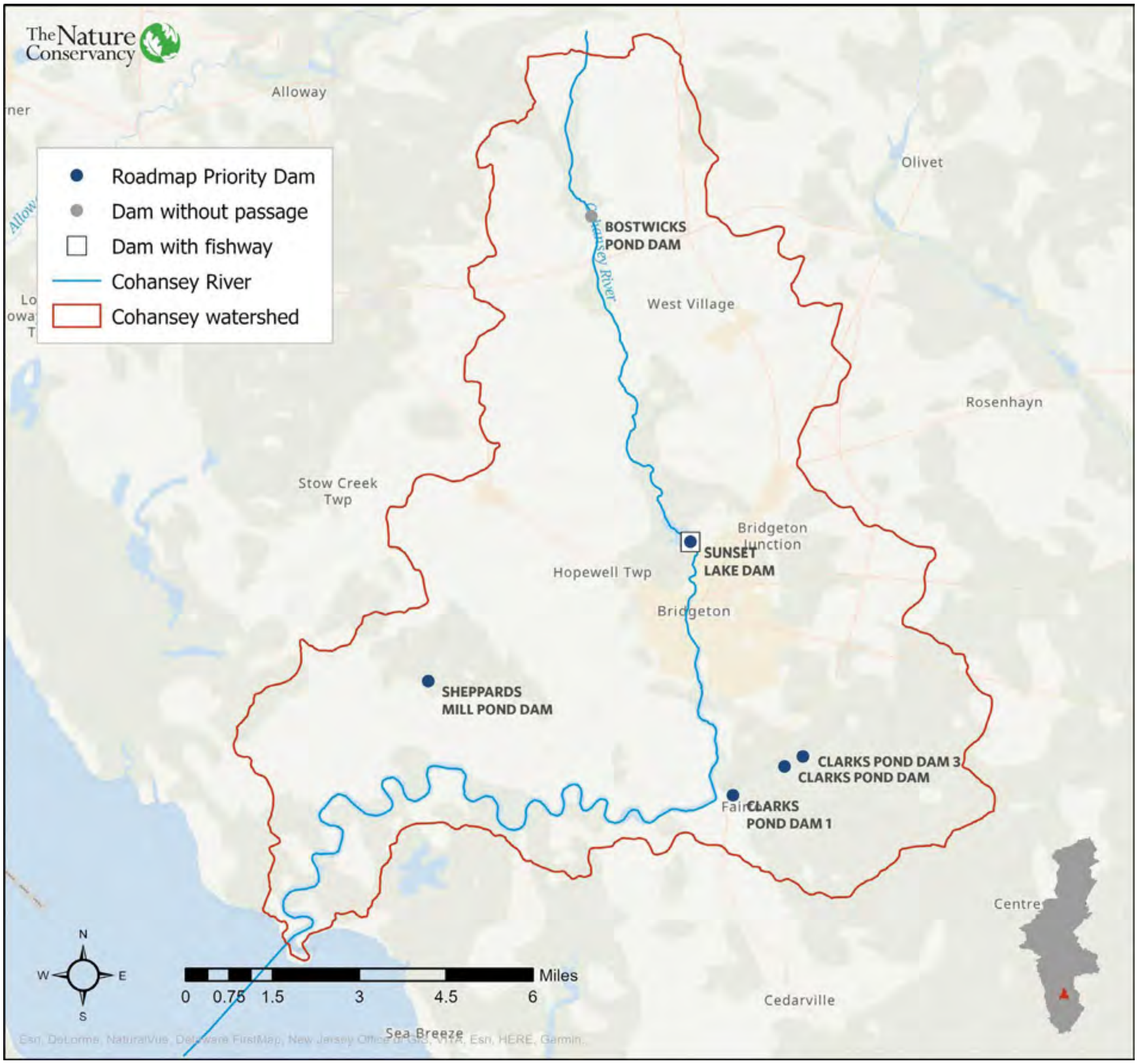


Figure 4-17. *Cohansey River Mainstem Dams and Priority Dams Map.*

Dam #	Unique ID	Dam Name	River Mile	Barrier Status
1	**NJ_NJ00063**	**Sunset Lake Dam**	**23.3**	**Fishway**
2	**NJ_NJ00065**	**Seeley's Mill Pond Dam**	**27**	**Breached 2012 (since removed)**
3	NJ_NJ00039	Bostwicks Pond Dam	30	Complete
MC1	NJ_NJ00072	Sheppards Mill Pond Dam	Tributary	Complete
CP1	DRB_3211	Clarks Pond Dam 1	Tributary	Complete
CP2	NJ_NJ00071	Clarks Pond Dam 2	Tributary	Complete
CP3	**DRB_3212**	**Clarks Pond Dam 3**	**Tributary**	**Complete**

Table 4-10. *Cohansey River Mainstem Dams and Key Tributary Dams. Bolded dams with grey shading are priorities for restoration detailed at greater length in this report.*

Cohansey River

The Cohansey River is in the southwestern part of New Jersey and empties into the Delaware Bay at river mile 38 (rkm 61). In 1896, the Cohansey ranked third in New Jersey as a shad-producing stream yielding 21,850 fish, surpassed only by the Hudson and Delaware rivers, and shad were known to run 20 miles upstream to Bridgeton (Stevenson 1898). While there is no current American Shad run in the Cohansey, there is a confirmed river herring presence, with the steeppass fish ladder at Sunset Lake Dam considered to be one of the most effective fishways in the state (ASFMC 2017). A 2012 storm breached the dam, which was reconstructed in 2015, as well as two upstream dams on the mainstem that are not planned for reconstruction (Seeley's Mill Pond Dam and Silver Lake Dam). However, the Cohansey watershed is included as a priority system due to the opportunity to reconnect critical habitat for river herring within its tributaries, as well as by assessing current passage at the Sunset Lake fish ladder to determine if any improvements are warranted.


Sunset Lake Dam. Credit: Lyndon DeSalvo/TNC.

Sheppards Mill Pond Dam. Credit: Google Earth.

SUNSET LAKE DAM (Dam #1) and the associated raceway were repaired in 2015 following severe damage during a 2012 storm that breached the dam and drained the 94-acre lake. A dam has likely existed at this site since approximately 1815, when the Cumberland Nail & Ironworks built a mill on this site and the impounded lake quickly became a popular recreational spot, with the Tumbling Dam Amusement Park established here in the 1890s. Today, Sunset Lake is still popular for recreation, including boating and largemouth bass fishing, and dam removal is extremely unlikely especially considering the recent reconstruction. In 1997, PSE&G added an Alaskan steeppass fish ladder to the dam, and this has historically been very successful in passing Alewife and Blueback Herring (ASFMC 2017). It is recommended that passage rates are reassessed at this site to verify that the fish ladder is still effective.

SHEPPARDS MILL POND DAM (Mill Creek Dam #1) is located along the Mill Creek tributary to the Cohansey. The original structure was constructed in 1885 and is currently owned by the New Jersey Division of Fish & Wildlife. In 1978, river herring were confirmed at this dam and the later construction of a culvert allowed tidal fluctuations upstream of the site as well as some movement of diadromous fish. However, a recent storm breached the culvert, which was replaced with a structure that currently restricts fish passage and tidal flow.

Clarks Pond Dam #1. Credit: Lyndon DeSalvo/TNC.

Clarks Pond Dam #2. Credit: Lyndon DeSalvo/TNC

Clarks Pond Dam #3. Credit: Google Earth.

CLARKS POND DAM 1 (Clarks Pond Dam #1) is the first of three barriers on the Mill Creek tributary that passes through the Clarks Pond Fish and Wildlife Management Area. In 1978, river herring were confirmed at this site by Zich during his statewide anadromous fish inventory (Zich 1978). Currently, the downstream dam and pond closest to the Cohansey River is privately owned and does not provide any fish passage. The structure is integrated with Bridgeton Fairton Rd and prevents tidal influence upstream.

CLARKS POND DAM 2 (Clarks Pond Dam #2) is owned by the New Jersey Division of Fish and Wildlife and is located within the Clarks Pond Fish and Wildlife Management Area. The dam is integrated into Clarks Pond Road and currently does not allow for fish passage.

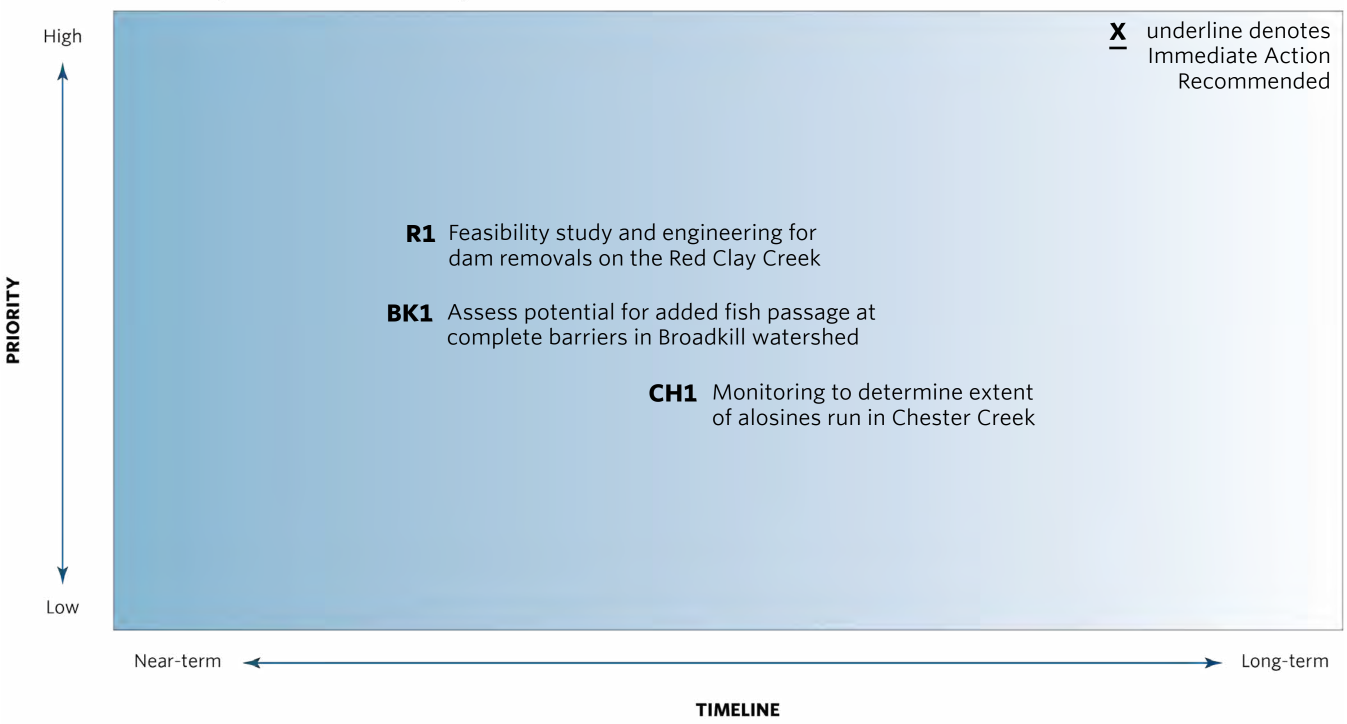
CLARKS POND DAM 3 (Clarks Pond Dam #3) is owned by the New Jersey Division of Fish and Wildlife and is located within the Clarks Pond Fish and Wildlife Management Area. The dam is integrated into Burlington Road and currently does not allow for fish passage.

Formed by the Downesville Dam, the Pepacton Reservoir supplies drinking water for New York City. Credit: Wikimedia Commons.

East Branch Delaware River

The East Branch was a historically significant American Shad stream with reports of shad migrating 42 miles (68 km) upriver to the former town of Shavertown (Bishop 1936), which is now submerged beneath New York City's Pepacton Reservoir. Most of the East and West branches of the Delaware no longer support shad spawning runs due to the cold-water releases from the New York City reservoirs and direct loss of habitat due to the reservoirs themselves (Chittenden 1976). However, there have been reports from fishermen of shad as far as 15.5 mi (25 km) up the East Branch, to the confluence with the Beaver Kill. Chittenden (1976) reported that shad ran 3.7 miles up the Beaver Kill, an East Branch tributary, but it is unclear whether they spawn there. Other reports have shad going as far as a mile up into the Little Beaver Kill, a tributary of the Beaver Kill (McPhee 2005). Today, the East Branch is utilized as nursery habitat though the extent probably varies with temperature in any given year and warrants further study. Pepacton's Downesville Dam tailwaters are specifically managed for sustaining trout and hinder the ability of shad to utilize much of the East Branch for spawning. Unlike all the other tributaries listed as priority in the Roadmap, the East Branch is unique in that dam removal and fish passage is not the focus; instead, there is potential to manage releases from the Downesville Dam/Pepacton Reservoir to provide more suitable temperatures to support spawning of American Shad while still providing suitable habitat for trout.

Tier 3 Priority Restoration Actions



Tier 3 Tributaries

Tributaries listed as Tier 3 are potential priorities for American Shad and river herring restoration, but in need of further exploration and scoping to determine current run extents and project feasibility.

Red Clay Creek

The Red Clay Creek is included as a potential priority tributary in part due to the opportunity for a truly watershed-scale effort around aquatic connectivity given active partnerships are already working towards dam removal and fish passage in the White Clay and Brandywine creeks. Despite being an essential dead zone for fish in the mid-20th-century due to high zinc levels from the National Vulcanized Fiber (NVF) facility in Yorklyn, the Red Clay has been cleaned up considerably in recent years and is once again designated a trout-stocking stream. DNREC is interested in a feasibility study looking at dam removal and restoration potential. There are currently 12 dams on the Red Clay Creek, but many of these are already breached or owned by the State of Delaware, so opportunity for removal may be high. Dam #1 likely presents the biggest obstacle to removal given it is located immediately underneath a CSX railway bridge and therefore should be the principle focus during the feasibility study.

Red Clay Dam #1. Credit: Jason Fischel.

Broadkill Creek

The Broadkill Creek watershed may present an opportunity for river herring restoration efforts given the current fishway at Wagamons Pond has the highest annual counts of Blueback Herring as compared to other steeppass ladders in Delaware (Boucher and Stangl 2020). The Diamond Pond Dam upstream of Wagamons, as well as the Red Mill Pond Dam on the Martin Branch and Waples Pond Dam on Primehook Creek, are all complete barriers and so fish passage may be warranted if this watershed does support higher river herring runs than other tributaries within the state of Delaware. DNREC is currently undergoing an eDNA study with the Smithsonian Environmental Research Center to determine how well each fish ladder performs based on abundance of alosines immediately downstream. This study may offer critical information about the river herring run size in the Broadkill and whether it should be prioritized for restoration efforts. American Shad were not known to be in the Broadkill prior to being stocked there in the 1880s (Stevenson 1898); however, anglers have recorded shad in the Wagamons Pond spillway below the fish ladder in recent years and it is believed they are not able to pass the current steeppass fish ladder (Jones 1999). Additionally, much of the downstream watershed is protected as it falls within the Prime Hook National Wildlife Refuge offering high-quality habitat.

Chester Creek

Chester Creek historically had an American Shad run prior to the establishment of mills and damming of the river in the 17th and 18th centuries (Pennsylvania State Commissioners of Fisheries 1896). Indeed, an account from 1683 mentions the fish as ‘exceedingly plentiful’ with fishermen taking ‘600 at a draught’ and six shad purchased for a shilling (Martin 1877). Shad were unknown to utilize the Chester Creek in recent years until PFBC biologists documented numerous shad fingerlings in the Chester/Upland portion of the watershed in 2007. American Shad were collected at two lower sites at river miles 2.45 and 2.85, which are both tidally influenced, so there is some question as to whether they were produced in Chester Creek of “rode” in with the tide. At the time, no shad were documented just below the Rockdale Dam at river mile 6.6, but it would be useful to determine if American Shad and river herring access the creek to this point as it is the most downstream barrier to passage.

© Penobscot Trust

Section 5

Funding & Project Implementation Resources

5.1 Major Funding and Technical Assistance Sources for Dam Removal/ Barrier Mitigation in the Delaware Basin

The cost of a dam removal or other improvements to fish passage can range from the tens of thousands to million of dollars. Identifying potential funding sources early in any fish passage improvement project is critical to success. In the Delaware River basin there is significant funding available for fish passage improvement projects. In addition, the 2021 Infrastructure and Investment Act will also provide an enormous boost to the amount and availability of aquatic connectivity funding nationwide.

Delaware Watershed Conservation Fund

The 2016 Delaware River Basin Conservation Act established the Delaware River Basin Restoration Program and in 2018 the National Fish and Wildlife Foundation launched the Delaware Watershed Conservation Fund in partnership with the U.S. Fish and Wildlife Service. In 2020 the USFWS awarded more than $8 million for restoration projects in the basin. Requests for proposals are generally announced annually in late winter. A 1:1 non-federal match is required.

National Fish Passage Program (NFPP)

The National Fish Passage Program in the Northeast provides roughly $1 million to restoration projects annually, mostly through financial assistance awards to partners. Funds can be used for project design or construction. Although there is no upper limit on awards, typical project funding is $50-$75,000 and strives to achieve a 1:1 match from federal or non-federal sources.

2021 Infrastructure and Investment Act

Significantly increases the availability of funding for aquatic connectivity projects:

- Increased funding for **NOAA's Community-based Restoration Program (CRP)** which will receive $400 million over the next five years that can be used for dam removals.
- Established the **National Culvert Replacement Program**, which will provide $1 billion over five years to states, tribal nations, and local governments to repair or remove culverts to ease passage for endangered and threatened fish.
- Provides $7 billion for the **U.S. Army Corps of Engineers** for infrastructure funding which includes funding of projects under Section 206 Aquatic Ecosystem Restoration Program.

Atlantic Coast Fish Habitat Partnership (ACFHP)

Federal funding through America's Conservation Enhancement (ACE) is available through the National Fish Habitat Partnership (NFHP). Past awards range between $90,000 –$225,000 annually. A 1:1 non-federal match is required.

Bring Back the Native Fish

NFWF program with USFWS and USFW funding supports projects benefitting native fish of eastern U.S. rivers, especially river herring and American Shad in the Chesapeake and Delaware watersheds. Awards are generally between $50,000-$100,000. A 1:1 non-federal match is required.

United States Army Corps of Engineers (USACE)

The Philadelphia District of the U.S. Army Corps of Engineers covers the entire Delaware River watershed. Section 206 of the Water Resources Development Act of 1996, the Corps may plan, design, and build projects to restore aquatic ecosystems for fish and wildlife. The cost-sharing requirement for 206 projects is 50 percent of the feasibility cost after the first $100,000 in federal expenditures and 35 percent of the project implementation costs if a feasible plan is identified.

NOAA's Community-Based Habitat Restoration Program (CRP)

Provides funding and technical assistance for restoration projects that ensure fish have access to high-quality habitat. The goal of these projects is to recover and sustain fisheries—particularly those species managed by NOAA Fisheries, or those listed as endangered or threatened under the Endangered Species Act. Applicants are encouraged to demonstrate a 1:1 non-federal match for NOAA funds. Minimum award of $75,000 and to $3 million for a three-year award.

National Coastal Resilience Fund (NCRF)

Provides funding for planning, design, and restoration of natural and nature-based solutions to help protect coastal communities from the impacts of storms, floods, and other natural hazards and enable them to recover more quickly and enhance habitats for fish and wildlife. This funding source provides significant funding towards, site assessment, preliminary and final designs.

State Specific Funding

Pennsylvania

H2O PA – High Hazard Unsafe Dam Projects

Pennsylvania Department of Community & Economic Development, provides single-year or multi-year grants to the state, independent agencies, municipalities, or municipal authorities for High-Hazard Unsafe Dams. Funds projects which involve the repair, rehabilitation, or removal of all or a part of a high hazard unsafe dam. A minimum of $500,000 or more and a maximum of $20 million for any project. Multi-year grants may not be given for more than (6) six years.

Community Conservation Partnerships Program

Department of Conservation and Natural Resources (DCNR), funds dam removals under its River Conservation Grants section. Requires 1:1 Match.

PFBC Technical Assistance Program

Habitat Enhancement and Restoration for Streams & Lakes, Pennsylvania Fish and Boat Commission, provides technical assistance in review, planning and implementation of fish habitat restoration projects.

Growing Greener Watershed Restoration and Protection

PA Department of Environmental Protection's Growing Greener Plus Grants Program has funded dam removals. Strong emphasis on improved water quality. Eligible applicants including counties, authorities and other municipalities; county conservation districts; watershed organizations; and other organizations involved in watershed restoration.

New Jersey

New Jersey Dam Restoration and Inland Water Projects Loan Program

New Jersey Department of Environmental Protection. Provide loans to assist local government units, private lake associations or similar organizations in the funding of a dam restoration project or an inland waters project. Application periods are established from time to time based upon availability of funds in the program

Natural Resource Restoration Grants

New Jersey Department of Environmental Protection. Natural Resource Damage (NRD) settlements obtained by NJ DEP are routinely granted out to enhance natural resources including dam removals.

New York

Department of Environmental Conservation Grant Opportunity High Hazard Dam Rehabilitation Grant

DEC's High-Hazard Dam Rehabilitation program is funded through FEMA's Rehabilitation of High Hazard Potential Dams (HHPD) grant program. The 2021 funding round is closed, but additional rounds are expected.

5.2 Project Implementation Resources

Removing Small Dams: A Basic Guide for Project Managers, American Rivers

River Restoration Tools and Resources, American Rivers

Frequently Asked Questions on Removal of Obsolete Dams, Environmental Protection Agency

Guidelines for Dam Decommissioning Projects, United States Society on Dams.

Dam Removal Analysis Guidelines for Sediment, U.S. Department of the Interior, Bureau of Reclamation Technical Service Center

New Jersey Dams, The New Jersey Statewide Dam Removal Partnership (SDRP)

Clearinghouse for Dam Removal Information (CDRI), Calisphere, University of California

Determination of Compensatory Mitigation Credits for the Removal of Obsolete Dams and Other Structures from Rivers and Streams, Regulatory Guidance Letter: U.S. Army Corp of Engineers.

Dam Removal and the Federal Role, Congressional Research Service. 2021

Planning and implementing small dam removals: lessons learned from dam removals across the eastern United States, Tonitto, C., Riha, S.J.. 2016 Sustain. Water Resour. Manag. 2, 489–507

Section 6

Additional Recommendations & Research Needs

While Section 4 includes detailed actions and recommendations to enhance aquatic connectivity efforts along priority tributaries, there are additional monitoring and research needs relevant to the entire basin included in this section that are likewise critical to restoring shad and river herring. Taken together, these recommendations are the “roadmap” and outline crucial next steps to improving access to high-quality spawning and rearing habitat for these species in addition to elevating our understanding of their life histories, habitat use, production potential, and mortality. Throughout the project, it became clear that there is a significant need for more robust and continuous monitoring to better document alosine distribution and measure the impact of dam removal and restoration efforts. The following recommendations and research needs are those considered most important to addressing knowledge gaps and should be implemented in tandem with aquatic connectivity projects.

6.1 Additional Recommendations

1. **Develop a monitoring collaborative focused on a small set of effective Sentinel Monitoring Sites.** Select a small set of sites for population, demographics, water quality monitoring and status for all three species. Monitoring efforts should focus on tributaries undergoing restoration activities and ones that have long-term monitoring data sets that could be improved or expanded. A collaborative could pool resources and funding. Interpreting monitoring data is challenged by short-term efforts or loss of years due to loss of funding.
2. **Increase number and spatial extent of continuous water quality monitoring stations.** Habitat suitability was difficult to assess across the basin due to the lack of continuous pH and dissolved oxygen data. Aside from the larger systems (e.g. Schuylkill), standardized water quality data were lacking in the medium to small tributaries. Collecting real-time water quality information is critically important for assessing suitability as well as documenting change and trends in a changing climate.
3. **Increase the project lengths allowed in Delaware Watershed Conservation Fund.** In order to create sustainable efforts around monitoring and stakeholder collaboration, two- or even three-year projects are not enough to create the momentum needed to move the needle on the recovery of these species.

6.2 Research Needs

1. **Investigate fish ladder effectiveness across the basin.**
2. **Improve knowledge of habitat suitability and general life history characteristics of Alewife and Blueback Herring in the basin. This should include, but not be limited to the following: percentage of repeat spawners, age, and size.**
3. **Better document extent of distribution of Alewife and Blueback Herring and habitat use throughout the basin.**
4. **Estimate the production potential of American Shad and river herring in the Delaware mainstem and tributaries by determining the amount of available spawning habitat for each species.**
5. **Conduct age assessment of historical American Shad scales and otoliths to better track mortality rates and repeat spawning rates.**

Section 7

Literature Cited

Arnold, D. A. and Pierce, D. J. 2007. Lehigh River Fisheries Management Plan. Division of Fisheries Management, Pennsylvania Fish and Boat Commission.

Arnold, D. A. 2000. Lehigh River American shad: The first six years. Pennsylvania Angler and Boater 69(3): 18-21.

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

ASMFC (Atlantic States Marine Fisheries Commission). 2012 River Herring Benchmark Stock Assessment Report: Volume I and Volume II. Atlantic States Marine Fisheries Commission. Washington, D.C

ASMFC (Atlantic States Marine Fisheries Commission). 2020 American Shad Benchmark Stock Assessment and Peer Review Report. Prepared by the ASMFC American Shad Stock Assessment Review Panel. Retrieved from: http://www.asmfc.org/uploads/file/5f43ca4eAmShadBenchmarkStockAssessment_PeerReviewReport_2020_web.pdf

ASMFC (Atlantic States Marine Fisheries Commission). 2017 River Herring Stock Assessment Update, Volume II: State-Specific Reports. Prepared by the ASMFC River Herring Stock Assessment Review Panel. Retrieved from: http://www.asmfc.org/uploads/file/59c2ac1fRiverHerringStockAssessmentUpdateVolumeII_State-Specific_Aug2017.pdf

Becker, M. J. 2006. Anadromous Fish and the Lenape. Pennsylvania Archaeologist, 76(2), 28-40. Retrieved from http://digitalcommons.wcupa.edu/anthrosoc_facpub/55

Bigelow, H. B., and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildlife Service Fisheries Bulletin 53, Washington, D.C.

Bishop, S.C. 1935. The Shad Fisheries of the Delaware.

Boucher, J. and Stangl, M. 2020. Anadromous Species Investigations, Study 2: Shad and Herring Research, Activity 5: Delaware Fish Ladder Operation, Maintenance and Biological Monitoring. Delaware Division of Fish and Wildlife, DNREC.

Bowden, A. A. 2013. Towards a comprehensive strategy to recover river herring on the Atlantic seaboard: lessons from Pacific salmon. ICES (International Council for the Exploration of the Sea) Journal of Marine Science 71: 666–671.

Bowden, A. A., M. DeLucia, L. N. Havel, E. H. Martin, C.A. Patterson, and C. Shumway. 2015. River Herring Restoration Needs. The Atlantic Coast Fish Habitat Partnership final report to National Fish and Wildlife Foundation (Grant No.: 36719). Atlantic States Marine Fisheries Commission, Arlington, Virginia.

Brandywine Conservancy. 2005. The Restoration of American Shad to the Brandywine River: A Feasibility Study.

Boucher and Stangl. 2020. Anadromous Species Investigations, Study 2: Shad and Herring Research, Activity 5: Delaware Fish Ladder Operation, Maintenance and Biological Monitoring. Delaware Division of Fish and Wildlife, DNREC.

Canby, Henry S. 1941. The Brandywine. Farrar & Rinehart.

Cargill, J., P. Boettcher, S. Peterson, and T. Keyser. 2020. Brandywine River Dams: Analysis of Chemical Contaminants in Sediments. Watershed Assessment & Management Section and Remediation Section, DNREC.

Chittenden , M. E., JR. 1969. Life history and ecology of the American shad, Alosa sapidissima, in the Delaware River. Ph.D. Thesis, Rutgers Univ., New Brunswick, N.J., 458 p

Chittenden, M. E., Jr. 1972. Salinity tolerance of young blueback herring, Alosa aestivalis. Trans Am Fish Soc 101(1):123–125

Chittenden, M. E., Jr. 1976. Present and historical spawning grounds and nurseries of American Shad, *Alosa sapidissima, in the Delaware River. In Fishery Bulletin 74: 343-352.*

City of Newark, DE. 2021, November 8. 2021 Annual Water Quality Report. Retrieved from: https://newarkde.gov/ArchiveCenter/ViewFile/Item/6968

Colette, B. B., and G. Klein-MacPhee, editors. 2002. Bigelow and Schroeder's fishes of the Gulf of Maine, 3rd edition. Smithsonian Institution Press, Washington, D.C.

Collier, P. & Webb, Robert & Schmidt, Jc. (1996). Dams and Rivers: A Primer on the Downstream Effects of Dams. U.S. Geological Survey Circular. 1126.

Compton, K. R. 1963. Angler harvest comparisons on the fly-fishing only and open fishing stretches of the Big Flatbrook. D.J. Job Compl. Rep. State N.J. Proj. F-20-R-1, 37 p.

Cummings, Warren D. 1964. Sussex County: A History. Newton, New Jersey: Newton Rotary Club. Retrieved from: http://archiver.rootsweb.com/th/read/NJSUSSEX/2002-09/1032918263

Davis, W. W. H. 1905. The History of Bucks County, Pennsylvania, Chapter XI, Middletown, 1692. From the Discovery of the Delaware to the Present Time. 1876 and 1905 editions.

DiMaggio, M. A., T. S. Breton, L. W. Kenter, C. G. Diessner, A. I. Burgess, and D. L. Berlinsky. 2016. The effects of elevated salinity on river herring embryo and larval survival. Environmental Biology of Fishes 99: 451–461

DNREC (Delaware Department of Natural Resources and Environmental Control). 2005. Delaware Bay and Estuary Assessment Report. 171 pp.

DRBC (Delaware River Basin Commission). 2016. Lower Delaware River Special Protection Waters Assessment of Measurable Changes to Existing Water Quality, Round 1: Baseline EWQ (2000-2004) vs. Post-EWQ (2009-2011). Delaware River Basin Commission, DRBC/NPS Scenic Rivers Monitoring Program, West Trenton, NJ. Authors: Robert Limbeck, Eric Wentz, Erik Silldorff, John Yagecic, Thomas Fikslin, Namsoo Suk.

DRBFWMC (Delaware River Basin Fish and Wildlife Management Cooperative). 1985. A Review and Recommendations Relating to Fishways within the Delaware Basin.

DRBFWMC (Delaware River Basin Fish and Wildlife Management Cooperative). 2017. Delaware River Sustainable Fishing Plan for American Shad. Submitted to the Atlantic States Marine Fisheries Commission Shad and River Herring Management Board.

DRBFWMC (Delaware River Basin Fish and Wildlife Management Cooperative). 2019. Delaware, Lehigh and Schuylkill Rivers American Shad, Hickory Shad and River Herring Annual Report for 2018 Submitted to the Atlantic States Marine Fisheries Commission Shad and River Herring Management Board.

DRWI (Delaware River Watershed Initiative). 2021. *New Jersey Highlands.* Retrieved from: https://4states1source.org/our-work/new-jersey-highlands-3/

Eagle Creek Renewable Energy. 2020. Final License Application II: Mongaup River Hydroelectric Projects.

Enterline, C. L., B. C. Chase, J. M. Carloni, and K. E. Mills. 2012a. A Regional Conservation Plan for Anadromous Rainbow Smelt in the U.S. Gulf of Maine. Maine Dept, of Marine Resources. 96 pp.

Fowler, H.W. 1907. Records of Pennsylvania Fishes. In The American Naturalist 41.481: 5-21. University of Chicago Press.

Gahagan, B., and M. M. Bailey, 2020. Surgical Implantation of Acoustic Tags in American Shad to Resolve Riverine and Marine Restoration Challenges. Marine and Coastal Fisheries Dynamics Management and Ecosystem Science. 12:5

Gay, J. 1892. The shad streams of Pennsylvania. In Report of the State Commissioners of Fisheries for the years 1889-90-91. Harrisburg, Pa., pp. 151-187.

Graf, W. L. 1999. Dam nation: A geographic census of American dams and their large-scale hydrologic impacts. Water Resources Research 351305-1311.

Greene, K. E., J. L. Zimmerman, R. W. Laney, and J. C. Thomas-Blate. 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, Washington, D.C.

Hackettstown Life. 2021. *Pequest River fishing weirs.* Retrieved from: http://www.hackettstownlife.com/forum/730511

Hale, Edward A. 2020. An Annual Report Examining the Recovery of Diadromous Fishes in the Brandywine Creek, DE, 2020. Delaware Sea Grant.

Hardy, C. A., 1999. Fish or Foul: A History of the Delaware River Basin Through the Perspective of the American Shad, 1682 to the Present. Pennsylvania History, 66(4), 506-534. Retrieved from: https://digitalcommons.wcupa.edu/hist_facpub/

Hare, J.A., D. L. Borggaard, M. A. Alexander, M. M. Bailey, A. A. Bowden, K. Damon-Randall, J. T Didden, D.J. Hasselman, T. Kerns, R. McCrary, S. McDermott, J.A. Nye, J. Pierce, E. T. Schultz, J.D. Scott, C. Starks, K. Sullivan, and M. Tooley. 2021. A Review of River Herring Science in Support of Species Conservation and Ecosystem Restoration. Marine and Coastal Fisheries. 13. 627-664.

Hare, J. A., Morrison, W. E., Nelson, M. W., Stachura, M. M., Teeters, E. J., Griffis, R. B., Alexander, M. A., Scott, J. D., Alade, L., Bell, R. J., Chute, A. S., Curti, K. L., Curtis, T. H., Kircheis, D., Kocik, J. F., Lucey, S. M., McCandless, C. T., Milke, L. M., Richardson, D. E., Robillard, E., ... Griswold, C. A. 2016. A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. PloS one, 11(2).

Haro A, Castro-Santos T. 2012. Passage of American Shad: paradigms and realities. Marine and Coastal Fisheries. 4:252–261.

Heckewelder, J. and Du Ponceau, P.S. 1834. Names Which the Lenni Lenape or Delaware Indians, Who Once Inhabited This Country, Had Given to Rivers, Streams, Places, &c. &c. within the Now States of Pennsylvania, New Jersey, Maryland, and Virginia. Transactions of the American Philosophical Society 4:351-396.

Heritage Conservancy. 2004. Lower Neshaminy Creek Watershed Conservation Plan.

Hildebrand, S. F. 1963. Family Clupeidae. Pages 257-454 in H. B. Bigelow, editor. Fishes of the Western North Atlantic, part 3. Sears Foundation for Marine Research, Yale University, New Haven, Connecticut.

Hilborn, R., Quinn, T. P., Schindler, D. E., & Rogers, D. E. (2003). Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences of the United States of America, 100(11): 6564–6568.

Hendricks, M. L., R. L. Hoopes, D. A. Arnold, and M. L Kaufman. 2002. Homing of hatchery reared American shad to the Lehigh River, a tributary to the Delaware River. North American Journal of Fisheries Management 22: 243-248.

Horwitz, R.J., D. Keller, S. Moser and P. Overbeck. 2008. Neversink Shad Study, Final Report. Submitted to The Nature Conservancy, Patrick Center for Environmental Sciences. The Academy of Natural Sciences. 23pp.

Horwitz, R., P. Overbeck, D. Keller, S. Moser. 2014. Fish inventories of Delaware Water Gap National Recreation Area and Upper Delaware Scenic and Recreational River. Natural Resource Report NPS/ERMN/NRR—2014/864. National Park Service, Fort Collins, Colorado.

Howell, M. H., J. P. Mowrer, R. J. Hochberg, A. A. Jarzynski, and D. R. Weinrich. 1990. Investigation of anadromous alosines in Chesapeake Bay. Maryland Department of Natural Resources, Annapolis, Maryland.

Interagency Waterway Infrastructure Improvement Task Force. 2004. Summary of Findings. New Jersey.

Jones, W. J. 1999. Establishment of River Herrings in a Southern Delaware Impoundment: Evaluation of Fish Passage and Predation. Thesis submitted to the Faculty of the Graduate School of the University of Maryland Eastern Shore.

Joseph, E. B., and J. Davis. 1965. A progress report to the herring industry. Virginia Institute of Marine Science, Special Science Report No. 51, Gloucester Point, Virginia.

KCI Technologies, Inc. 2013. Lehigh River Fish Passage Improvement Feasibility Study: Easton & Chain Dams, Easton, Pennsylvania.

Kerr, L ., S. X. Cadrin, D.H. Secor. 2010. The role of spatial dynamics in the stability, resilience, and productivity of an estuarine fish population. Ecological applications. 20: 497-507.

LaPenta, Dante. 2019, October 22. *Ghosts of Land Use Past*. UDaily, University of Delaware. Retrieved from: https://www.udel.edu/udaily/2019/october/removing-milldams-impact-water-quality/

LaVO, Carl. 2017, May 22. *When fame and fortune excited Bucks County and beyond at Neshaminy Falls.* Bucks County Courier Times: Levittown, PA.

Leggett, W. C., and R. R. Whitney. 1972. Water temperature and the migrations of American Shad. Fisheries Bulletin 70: 659-670.

Lehigh County Historical Society. 1962. Proceedings of the Lehigh County Historical Society – v. 24: James Allen; builder of Trout Hall.

Limburg, K.E. & J. R. Waldman. 2009. Dramatic Declines in North Atlantic Diadromous Fishes. BioScience 59 (11): 955–965. https://doi.org/10.1525/bio.2009.59.11.7

Loesch, J.G. 1987. Overview of life history aspects of anadromous alewife and blueback herring in freshwater habitats. American Fisheries Society Symposium 1:89-103.

Loesch, J.G., and Lund, W.A. 1977. A contribution to the life history of the blueback herring, Alosa aestivalis. Trans. Am. Fish. Soc. 106: 583–589.

Lombardo, S. M., J. A. Buckel, E. F. Hain, E. H. Griffith, and H. White. 2020. Evidence for temperature-dependent shifts in spawning times of anadromous Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*). Canadian Journal of Fisheries and Aquatic Sciences 77: 741– 751.

Lynch, P. D., J. A. Nye, J. A. Hare, C. A. Stock, M. A. Alexander, J. D. Scott, K. L. Curti, and K. Drew. 2015. Projected ocean warming creates a conservation challenge for river herring populations. ICES Journal of Marine Science 72:374–387.

Mansueti I, R., and H. Kolb. 1953. A historical review of the shad fisheries of North America. In Chesapeake Bio. Lab. Pub. 97. 293 p.

Martin, E. H. and C. D. Apse. 2011. Northeast Aquatic Connectivity: An Assessment of Dams on Northeastern Rivers. The Nature Conservancy, Eastern Freshwater Program.

Martin, J. H. 1877. Chester (and its vicinity) Delaware County, in Pennsylvania; with Genealogical Sketches of Some Old Families. William H. Pile & Sons: Philadelphia. 530 pp.

McCarren, Edward F. 1972. Water Quality of Streams in the Neshaminy Creek Basin, Pennsylvania. Geological Survey Water-Supply Paper 1999-O, U.S. Department of the Interior. Prepared in cooperation with the Commonwealth of Pennsylvania Department of Environmental Resources.

McPhee, J. 2002. The Founding Fish. Farra, Staus and Giroux, New York, NY.

Meehan, W. E. 1893. Fish, fishing, and fisheries of Pennsylvania. Harrisburg: E.K. Meyers, state printer.

Monteiro Pierce, R., K. E. Limburg, D. Hanacek, and I. Valiela. 2020. Effects of urbanization of coastal watersheds on growth and condition of juvenile Alewives in New England. Canadian Journal of Fisheries and Aquatic Sciences 77:594–601.

MWA (Musconetcong Watershed Association). 2021. Removing Warren Mill Dam at Warren Glen, New Jersey. Retrieved from: https://b1b55b96-5eeb-4a1a-b931-a05860df756c.filesusr.com/ugd/79d237_525f38c51b5d42acabed3beeb2de5aca.pdf

Narvaez, M.C. et al. 2010. Restoration of Shad and Anadromous Fish to the White Clay Creek National Wild and Scenic River: A Feasibility Report. University of Delaware, Water Resources Agency.

Narvaez, M. and A. Homsey. 2016. White Clay Creek State of the Watershed Report. University of Delaware, Water Resources Agency.

NJDEP (New Jersey Department of Environmental Protection). 2005a. Locations of Anadromous American Shad and River Herring during their Spawning Period in New Jersey's Freshwaters including known Migratory Impediments and Fish Ladders. Division of Fish and Wildlife, Bureau of Freshwater Fisheries. Retrieved from: https://www.njfishandwildlife.com/pdf/anadromouswaters.pdf

NJDEP (New Jersey Department of Environmental Protection). 2005b, May 17. DEP Increases Public Access to Fishing Waters Through Acquisition of Belvidere Property. Retrieved from: https://www.nj.gov/dep/newsrel/2005/05_0061.htm

NJDEP (New Jersey Department of Environmental Protection), 2012. Investigation and Management of Anadromous Fisheries: Inventory and Status of Anadromous Clupeid Spawning Migrations in New Jersey Freshwaters (2002 – 2007). New Jersey Division of Fish and Wildlife. Division of Fish and Wildlife, Bureau of Freshwater Fisheries. Prepared by Smith, C.

NJDEP (New Jersey Department of Environmental Protection). 2018, July 6. Bloomsbury Dam Removal. Retrieved from: https://www.state.nj.us/dep/nrr/restoration/bloomsbury-dam.html

NJDEP (New Jersey Department of Environmental Protection), Division of Fish and Wildlife, Bureau of Freshwater Fisheries. 2019. American Shad Officially Documented Upstream of Former Columbia Lake Dam. New Jersey Division of Fish and Wildlife. Retrieved from: https://www.njfishandwildlife.com/news/2019/paulinskillshad2.htm

Normandeau Associates. 2019. Total number of individuals by taxon observed immigrating through the Black Rock Dam Fish Ladder, April through June, 2011 through 2016. *LGS Fish Community Review.*

Nye, J. A., J. S. Link, J. A. Hare, and W. J. Overholtz. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the northeast United States continental shelf. Marine Ecology Progress Series 393:111–129

Park, I.A. and M.J. Stangl. 2020. Anadromous Species Investigations, Study 2: Shad and Herring Research, Activity 4: Adult alosine abundance, juvenile alosine abundance and American Shad nursery habitat evaluation in the Christina system (Project Number F19AF00074 (F-47-R-29)) submitted to the U.S.F.W.S. Sport Fish Restoration Program.

Park, I.A. and M.J. Stangl. 2021. Anadromous Species Investigations, Study 2: Shad and Herring Research, Activity 4: Adult alosine abundance, juvenile alosine abundance and American Shad nursery habitat evaluation in the Christina system (Project Number F19AF00074 (F-47-R-30)) submitted to the U.S.F.W.S. Sport Fish Restoration Program

Peer, A. & Miller, Thomas. 2014. Climate Change, Migration Phenology, and Fisheries Management Interact with Unanticipated Consequences. North American Journal of Fisheries Management. 34: 10.

Penn, William. 1685. Of the Produce of Our Waters. A further account of the province of Pennsylvania and its improvements for the satisfaction of those that are adventurers, and enclined to be so. Ann Arbor: Text Creation Partnership, 2021. Retrieved from: http://name.umdl.umich.edu/A54140.0001.001

PA DCNR (Pennsylvania Department of Conservation & Natural Resources). 2021, November 12. History of White Clay Creek Preserve. Retrieved from: https://www.dcnr.pa.gov/StateParks/FindAPark/WhiteClayCreekPreserve/Pages/History.aspx

PA DEP (Pennsylvania Department of Environmental Protection). 2021. Neshaminy Creek Fish Advisory. Retrieved from: https://www.dep.pa.gov/About/Regional/SoutheastRegion/Community%20Information/Pages/Neshaminy-Creek-Fish-Advisory.aspx

PFBC (Pennsylvania Fish and Boat Commission). 1988. Strategic Fishery Management Plan for American Shad Restoration in the Schuylkill and Lehigh river basins. Pennsylvania Fish & Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

PFBC (Pennsylvania Fish and Boat Commission). 2011. Delaware River Management Plan. A management plan focusing on the large river habitats of the West Branch Delaware River and Non-tidal reach of the Delaware River of Pennsylvania. Retrieved From: https://www.fishandboat.com/Fish/Fisheries/DelawareRiver/Documents/delaware_river_plan.pdf

PFBC (Pennsylvania Fish and Boat Commission). 2012. Next Steps in American Shad Restoration in Pennsylvania. Presentation at the 2012 Watershed Congress at Montgomery County Community College. Retrieved from: https://www.delawareriverkeeper.org/sites/default/files/resources/Reports/Next_Ste ps_in_American_Shad_Restoration_in_Pennsylvania.pdf

PFBC (Pennsylvania Fish and Boat Commission). 2014. Darby and Neshaminy Creeks 2014 Tidal Largemouth Bass Surveys. Retrieved from: https://pfbc.pa.gov/images/reports/2015bio/6x08_28darbynesh.pdf

Pennsylvania State Commissioners of Fisheries. 1896. Report of the State Commissioners of Fisheries for the Year 1896. Clarence M. Busch: Harrisburg.

Pinsky M.L, B. Worm, M.J. Fogarty, J.L Sarmiento, and S.A. Levin. 2013. Marine taxa track local climate velocities. Science 341(6151):1239-1242.

Richardson, B.M. C.P. Stence, M.W. Baldwin, and C.P. Mason. 2009. Restoration of Hickory Shad in three Maryland Rivers. Maryland Department of Natural Resources. Annapolis, MD.

Richkus, W. A., and G. DiNardo. 1984. Current status and biological characteristics of the anadromous alosid stocks of the eastern United States: American shad, hickory shad, alewife, and blueback herring. Atlantic States Marine Fisheries Commission Interstate Fisheries Management Program, Washington, D.C.

Ross, R. M., R. M Bennett, and T. W. H. Backman. 1993. Habitat use and spawning adult, egg, and larval American shad in the Delaware River. Rivers 4: 227-238.

Rulifson, R. A., M. T. Huish, and R. W. Thoesen. 1994. Status of anadromous Alosa along the east coast of North America. Pages 134-159 in J. E. Cooper, R. T. Eades, R. J. Klauda, and J. G. Loesch, editors. Proceedings of the Anadromous Alosa Symposium, American Fisheries Society, Bethesda, Maryland.

Schindler, D.E, R. Hilborn, B. Chasco, C.P. Boatwright, T.P. Quinn, L.A. Rogers and M.S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465: 609–612.

Schutt, A. 2007. Peoples of the River Valleys: The Odyssey of the Delaware Indians. University of Pennsylvania Press. 264 p.

Secor, D.H. 2007. The year-class phenomenon and the storage effect in marine fishes. Journal of Sea Research. 57: 91-103.

Stevenson, C. H. 1899. The shad fisheries of the Atlantic coast of the United States. Pages 101–269 in G.M. Bowers. Report of the U.S. Commission of Fish and Fisheries, part 24. U.S. Commission of Fish and Fisheries, Washington, D.C

Stich, D. S., Sheehan, T. F., and Zydlewski, J. D. (2019). A dam passage performance standard model for American shad. Can. J. Fish. Aquat. Sci. 76, 762–779. doi: 10.1139/cjfas-2018-0008

Sykes, J.E. and Lehman, B.A. 1957. Past and Present Delaware River Shad Fishery and Considerations for its Future. U.S. Department of the Interior. Washington, DC.

USACE (U.S. Army Corps of Engineers) 2019, July 16. Musconetcong River Habitat Connectivity Feasibility Study. USACE Philadelphia District. Retrieved from: https://www.nap.usace.army.mil/Missions/Factsheets/Fact-Sheet-Article-View/Article/1906318/musconetcong-river-habitat-connectivity-feasibility-study/

UDWRC (University of Delaware Water Resources Center). 2015. Restoration of American Shad to the Brandywine River.

UDWRC (University of Delaware Water Resources Center). 2018. Brandywine-Christina State of the Watershed Report, 2018.

UDWRC (University of Delaware Water Resources Center). 2021, November 10. *Brandywine Shad 2020.* University of Delaware Water Resources Center. Retrieved from: https://www.wrc.udel.edu/public-service/brandywine-shad-2020/

Uphoff, J. H. Jr., M. McGinty, R. Lukacovic, J. Mowrer, and B. Pyle. 2011. Impervious surface, summer dissolved oxygen, and fish distribution in Chesapeake Bay subestuaries: linking watershed development, habitat conditions, and fisheries management. North American Journal of Fisheries Management 31:554–566.

USFWS. (U.S. Fish and Wildlife Service). 2017. PA Technical Fishways: USFWS Fish Passage Engineering Assessments.

USFWS (U.S. Fish and Wildlife Service). 1999. Restoring anadromous fishes to the Schuylkill River basin. Fact Sheet.

Walburg, C. H., and P. R. Nichols. 1967. Biology and management of the American shad and status of the fisheries, Atlantic coast of the United States, 1960. U.S. Fish and Wildlife Service Special Science Report for Fisheries 550.

Weslager C. A. 1989. “The Delaware Indians: A History” Rutgers University Press, New Brunswick, NJ 546 pp.

Wiencke, Gus. 2021. *Chief Tamanend.* Upper Southampton Township. Retrieved from: https://www.ustwp.org/government/boards-commissions/historical-advisory-board/chief-tamanend/

Winters, G. H., J. A. Moores, and R. Chaulk. 1973. Northern range extension and probably spawning of gaspereau (Alosa pseudoharengus) in the Newfoundland area. Journal of the Fisheries Research Board of Canada 30: 860-861.

Zich H. E. 1978. New Jersey Anadromous Fish Inventory: Information on Anadromous Clupeid Spawning in New Jersey. New Jersey Department of Environmental Protection, Bureau of Fisheries. Lebanon, New Jersey.

Zydlewski J., Stich D. S., Roy S., Bailey M., Sheehan T. and Sprankle K. 2021. What Have We Lost? Modeling Dam Impacts on American Shad Populations Through Their Native Range. Front. Mar. Sci. 8:734213. doi: 10.3389/fmars.2021.734213

Appendix A

Tier 1 Priority Dam Fact Sheets

This appendix contains relevant information about Tier 1 priority dams listed in a single-page fact sheet format for easy reference in addition to a photo and aerial image of the structure to provide further context. Information included in this section was compiled from a variety of sources, including on-the-ground site visits, conversations with key stakeholders and dam owners, previous reports and barrier prioritizations, the National Register of Historic Places (NRHP), the United States Army Corps of Engineers' National Inventory of Dams (NID) database, and more. While extensive, the information should not be considered exhaustive and is intended to provide a snapshot of each dam's ownership, condition, and current uses.

Dam Name	Fairmount Dam
Unique ID	PA_51-002
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.967154, -75.186036
Address (access)	Fairmount Fish Ladder, Martin Luther King Jr Dr, Philadelphia, PA 19131
Town	Philadelphia
County	Philadelphia
State	PA
River/Stream	Schuylkill River
River Mile	8.7
HUC-12	City of Philadelphia-Schuylkill River (020402031008)
Dam Drainage (sq mi)	1,916
CURRENT USE & OWNERSHIP	
Owner Name	City of Philadelphia (managed by Philadelphia Water Department - PWD)
Public/Private	Public
Primary Purpose	Water supply (public), Recreation
Relevant Neighboring Properties	Fairmount Water Works; MLK Jr. Drive; Fairmount Park
Historic Designation	Dam is relevant to two National Historic Landmarks and within Fairmount Park. • Fairmount Water Works (NRHP Ref #76001662) - National Historic Landmark • Boat House Row (NRHP Ref # 87000821) – National Historic Landmark • Fairmount Park (NRHP Ref # 72001151) - PHMC "Commonwealth Treasure"
Key Uses	Provides impoundment for 2 drinking water intakes at Queen Lane and Belmont for PWD, dam prevents tidal fluctuation upstream and potential for saltwater intrusion.
CONSTRUCTION & CONDITION	
Year Completed	1820 (original), 1927
Barrier Type	Low-head dam
Material	Concrete
Height (ft)	31.5 (10.5' crest elevation)
Length (ft)	1,204
Capacity (ac-ft)	3,683
Condition	Satisfactory
Hazard Class (Last Inspection)	Significant (3/4/2019)
Adjacent Infrastructure	*Bridges* (10): Spring Garden St, MLK Jr. Dr, Girard Ave/US-13, Pennsylvania Railroad, Connecting Railway Bridge, Columbia Railroad Bridge/CSX, Strawberry Mansion Bridge, Philadelphia and Reading Railroad, Bridge at West Falls/CSX, Falls Rail Bridge/CSX, Twin Bridges/US-1, Falls Bridge, City Ave Bridge; *Utilities*: Numerous stormwater outfalls; *Other*: USGS gage (01474500)
Sediment	Sediment build-up in Schuylkill Rowing Basin spurred 2020 dredging project, but only 5% complete as of summer 2021. Plans to remove 60,000 cubic yards of sediment.
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	Vertical slot fishway
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey, Striped Bass, White Perch
Aquatic Federal T & E Species	None
Next Upstream Barrier	Flat Rock Dam (PA_PA00896)
Next Downstream Barrier	None
SITE CONSIDERATIONS	
Recreation - Rowing with Boathouse Row an iconic location for university boathouses. Dam is also part of city aesthetics and cultural history of Fairmount Park founding.	

Fairmount Dam. Credit: Lyndon DeSalvo/TNC.

Fairmount Dam aerial. Credit: Google Earth.

Dam Name	**Flat Rock Dam**
Unique ID	PA_PA00896
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.038333, -75.246667
Address (access)	Flat Rock Park, 122 River Rd, Gladwyne, PA 19035
Town	Philadelphia
County	Philadelphia
State	PA
River/Stream	Schuylkill River
River Mile	15.6
HUC-12	Plymouth Creek-Schuylkill River (020402031007)
Dam Drainage (sq mi)	1,809
CURRENT USE & OWNERSHIP	
Owner Name	PA DEP – Bureau of Abandoned Mine Reclamation (BAMR)
Public/Private	Public
Primary Purpose	Recreation
Relevant Neighboring Properties	PaperWorks Industries, Apex Apartments
Historic Designation	Dam feeds the Manayunk Canal and is the northern boundary of historic district. • Manayunk Main Street Historic District (NRHP Ref # 83002274)
Key Uses	Upstream rowing in impoundment. Dam also waters Manayunk Canal.
CONSTRUCTION & CONDITION	
Year Completed	1818 (original); 1977
Barrier Type	Low-head dam
Material	Concrete
Height (ft)	21
Length (ft)	520
Capacity (ac-ft)	1,500
Condition	Fair
Hazard Class (Last Inspection)	Low (11/9/17)
Adjacent Infrastructure	*Bridges*: Fayette Street Bridge, Pearl Harbor Memorial Bridge/US-476, Upper Merion & Plymouth Rail Bridge; *Utilities*: Numerous stormwater outfalls; *Other*: Manayunk Canal, USGS Gage (01473800)
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	Vertical slot fishway
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey, Striped Bass, White Perch
Aquatic Federal T & E Species	None
Next Upstream Barrier	Norristown (Swede St) Dam (PA_46-001)
Next Downstream Barrier	Fairmount Dam (PA_51-002)
SITE CONSIDERATIONS	
Canal - Planned $14-16 million investment in canal and lock restoration by PWD. *Recreation* - Basin formed by dam used for upstream rowing in Conshohocken. Campaign to build a boathouse at Flat Rock Park by some in Lower Merion, but significant opposition from nearby neighbors. *Energy* - Philadelphia Energy Authority has considered potential for hydropower in canal.	

Flat Rock Dam. Credit: Lyndon DeSalvo/TNC.

Flat Rock Dam aerial. Credit: Google Earth.

Dam Name	Norristown (Swede Street) Dam
Unique ID	PA_46-001
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.1104939, -75.3473831
Address (access)	Norristown Fish Passage, 300-318 Merion St, Bridgeport, PA 19405
Town	King of Prussia
County	Montgomery
State	PA
River/Stream	Schuylkill River
River Mile	24.2
HUC-12	Plymouth Creek-Schuylkill River (020402031007)
Dam Drainage (sq mi)	1,765
CURRENT USE & OWNERSHIP	
Owner Name	Montgomery County, Parks & Heritage Services
Public/Private	Public
Primary Purpose	Water Supply (public); Recreation
Relevant Neighboring Properties	Upper Merion Boat Club, Montgomery County – Barbadoes Island, SEPTA
Historic Designation	N/A
Key Uses	Rowing in impoundment.
CONSTRUCTION & CONDITION	
Year Completed	1836 (original); 1984 & 1994 (reconstructed sections)
Barrier Type	Low-head dam with a north and south section at slightly different angles that meet obliquely in the middle of the river
Material	Concrete and earthen
Height (ft)	12
Length (ft)	900
Capacity (ac-ft)	2,355
Condition	Satisfactory
Hazard Class (Last Inspection)	Low (6/6/2018)
Adjacent Infrastructure	*Bridges*: DeKalb Veterans Memorial Bridge/US 202, Bridgeport Bridge/SEPTA, Norfolk Southern Rail Bridge, Dannehower Bridge/US 202, CSX Stony Creek Branch Rail Bridge, Haws Avenue Bridge, Schuylkill River Crossing Complex/US 422, Sullivan's Bridge/PA 363; *Utilities*: Pennsylvania American Water Intake and Treatment Plant; *Other*: USGS gage (01473500)
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	Denil fishway
Diadromous Fish	American Shad, Alewife, Blueback Herring, American Eel, Sea Lamprey
Aquatic Federal T & E Species	None
Next Upstream Barrier	Black Rock Dam (PA_46_027)
Next Downstream Barrier	Flat Rock Dam (PA_PA00896)
SITE CONSIDERATIONS	
Water Supply - Pennsylvania American Water intake located in impoundment. Norristown, PA sources drinking water from Schuylkill. *Fishway* - The shape and length of the dam create a problem for fish to find and utilize the fishway. *Recreation* - Upstream slack water is popular for water recreation – dragon boat racing and rowing. *Other* - Former coal-fired power plant on Barbadoes Island, immediately upstream of the dam	

Norristown Dam. Credit: Lyndon DeSalvo/TNC.

Norristown Dam aerial. Credit: Google Earth.

Dam Name	Black Rock Dam
Unique ID	PA_46-027
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.148221, -75.506215
Address (access)	Gate to fishway, Black Rock Rd, Phoenixville, PA 19460
Town	Phoenixville
County	Montgomery
State	PA
River/Stream	Schuylkill River
River Mile	37
HUC-12	Mingo Creek-Schuylkill River (020402031006)
Dam Drainage (sq mi)	1,296
CURRENT USE & OWNERSHIP	
Owner Name	WP Cromby, LLC
Public/Private	Private
Primary Purpose	Industrial water supply (formerly to Cromby Generating Station – not currently in use)
Relevant Neighboring Properties	Black Rock Sanctuary, Chester County; Lock 60 Recreation Area, Montgomery County
Historic Designation	Dam waters section of Schuylkill Canal and Black Rock Bridge is in impoundment. • Schuylkill Navigation Canal, Oakes Reach Section (NRHP Ref# 88000462) – State designation • Black Rock Bridge (NRHP Ref # 88000735) – State designation
Key Uses	Provides water to canal. Public water supply intake in impoundment.
CONSTRUCTION & CONDITION	
Year Completed	1825 (original); 1840; 1960s
Barrier Type	Low head dam with timber crib
Material	Rock-filled timber crib with concrete cap
Height (ft)	11
Length (ft)	400
Capacity (ac-ft)	221
Condition	Satisfactory
Hazard Class (Last Inspection)	Low (7/27/2018)
Adjacent Infrastructure	*Bridges*: Black Rock Bridge/PA 113, Black Rock Tunnel Bridge, Cromby and Mingo Rail Bridge; *Utilities*: Phoenixville Boro Water Plant; *Other*: Schuylkill Canal and lock system
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	Denil fishway
Diadromous Fish	American Shad, Alewife, Blueback Herring, American Eel, Sea Lamprey
Aquatic Federal T & E Species	None
Next Upstream Barrier	New Kernsville Dam (PA_06-434)
Next Downstream Barrier	Norristown (Swede Street) Dam (PA_46-001)
SITE CONSIDERATIONS	
Owner seems interested in possibility of transferring ownership or dam removal. Does not appear to want the upkeep and liability attached to the dam. *Risk & Safety* - A family of four in a boat was trapped and required rescue on the dam in 2017. *Water Supply* - Supplied water to former Cromby Generating Station, but likely no longer needed for water supply to new development proposed here. Phoenixville Boro Water Plant is located upstream of dam along impoundment with two intakes.	

Black Rock Dam. Credit: Lyndon DeSalvo/TNC.

Black Rock Dam aerial. Credit: Lyndon DeSalvo/TNC.

Dam Name	**Broom Street Dam**
Unique ID	DE_13
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.758762, -75.555172
Address (access)	1704 N Park Dr, Wilmington, DE 19806
Town	Wilmington
County	New Castle
State	DE
River/Stream	Brandywine Creek
River Mile	2.9
HUC-12	Lower Brandywine Creek (020402050403)
Dam Drainage (sq mi)	321
CURRENT USE & OWNERSHIP	
Owner Name	City of Wilmington
Public/Private	Public
Primary Purpose	Water Supply
Relevant Neighboring Properties	Brandywine Park
Historic Designation	In historic district, but dam is not listed as historic. • Brandywine Park and Kentmere Parkway (NRHP # 81000192) – Local
Key Uses	Supplies water for City of Wilmington intake.
CONSTRUCTION & CONDITION	
Year Completed	1762 (original)
Barrier Type	Mill dam
Material	Concrete
Height (ft)	7
Length (ft)	176
Capacity (ac-ft)	Unknown
Condition	Satisfactory
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	*Bridges*: I-95/Rte 202 Bridge; *Other*: Mill race; *Utilities*: City of Wilmington water supply intake
Sediment	Estimated sediment accumulation between 9,800-23,300 cubic yards (DNREC-WATAR 2020).
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	None
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Dam #3 (O'Neill)
Next Downstream Barrier	N/A
SITE CONSIDERATIONS	
Dam has a mill race that is necessary intake for City of Wilmington water supply. There is a non-functioning fish ladder at the dam that was installed in the 1990s.	

Broom Street Dam. Credit: Brandywine Shad 2020.

Dam aerial. Credit: Google Earth.

Dam Name	Alapocas Run Park Dam
Unique ID	DE_11
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.768452, -75.559234
Address (access)	100-200 Mill Rd, Wilmington, DE 19806
Town	Wilmington
County	New Castle
State	DE
River/Stream	Brandywine Creek
River Mile	3.6
HUC-12	Lower Brandywine Creek (020402050403)
Dam Drainage (sq mi)	320
CURRENT USE & OWNERSHIP	
Owner Name	DNREC
Public/Private	Public
Primary Purpose	Water supply (historic)
Relevant Neighboring Properties	Alapocas Run Park, Bancroft Mills
Historic Designation	Dam is not historic but within historic district: • Bancroft and Sons Cotton Mills (NRHP #84000439) - State
Key Uses	None
CONSTRUCTION & CONDITION	
Year Completed	1878
Barrier Type	Mill dam
Material	Concrete
Height (ft)	4
Length (ft)	150
Capacity (ac-ft)	Unknown
Condition	Poor. Center of dam is damaged with cavity.
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	Bancroft Mills building
Sediment	Estimated sediment accumulation between 2,600-19,300 cubic yards (DNREC-WATAR 2020). Known former source of PCBs adjacent to Dam #4.
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Brandywine Falls Dam (DE_10)
Next Downstream Barrier	Dam #3/O'Neill (DE_12)
SITE CONSIDERATIONS	
Alapocas Run enters Brandywine River just downstream of the dam on the eastern side. Known former source of PCBs adjacent to Dam #4. There is a non-functioning fish ladder at the dam that was installed in the 1990s.	

Alapocas Run Park Dam. Credit: Brandywine Shad 2020.

Alapocas Run Park Dam aerial. Credit: Google Earth.

Dam Name	**Brandywine Falls Dam** *(aka Rockford Dam)*
Unique ID	DE_10
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.770509, -75.569233
Address (access)	35 Brandywine Falls Rd, Wilmington, DE 19806
Town	Wilmington
County	New Castle
State	DE
River/Stream	Brandywine Creek
River Mile	4.2
HUC-12	Lower Brandywine Creek (020402050403)
Dam Drainage (sq mi)	318
CURRENT USE & OWNERSHIP	
Owner Name	DNREC/Brandywine Falls Condo Association
Public/Private	Public/Private
Primary Purpose	Water supply (historic)
Relevant Neighboring Properties	Brandywine Falls Condo Association, Alapocas Run Park
Historic Designation	Dam is not historic but within historic district: • Bancroft and Sons Cotton Mills (NRHP #84000439) - State
Key Uses	Waters mills race adjacent to private condos.
CONSTRUCTION & CONDITION	
Year Completed	c.1800 (original); 1878 (current)
Barrier Type	Mill dam
Material	Stone, concrete
Height (ft)	10
Length (ft)	200
Capacity (ac-ft)	Unknown
Condition	Good
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	Mill race
Sediment	Estimated sediment accumulation up to 32,600 cubic yards (DNREC-WATAR 2020).
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	DuPont Dam (DE_9)
Next Downstream Barrier	Alapocas Run Park Dam (DE_11)
SITE CONSIDERATIONS	
Access to the dam via the eastern side within the park will be challenging due to topography.	

Brandywine Falls Dam. Credit: Brandywine Shad 2020.

Brandywine Falls Dam aerial. Credit: Google Earth.

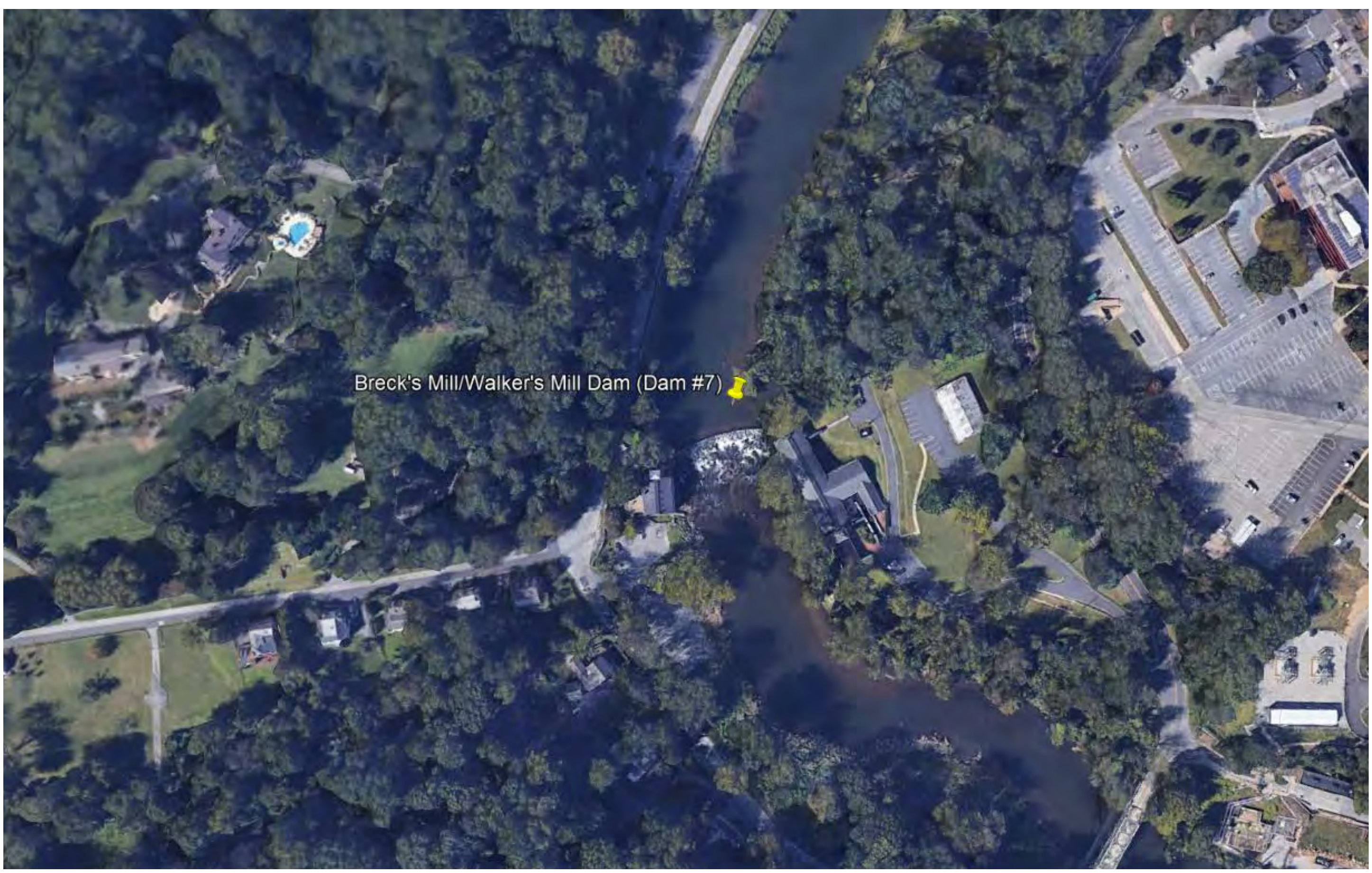
Dam Name	DuPont Dam
Unique ID	DE_9
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.769416, -75.573825
Address (access)	Dupont Experimental Station, Creek Rd, Wilmington, DE 19806
Town	Wilmington
County	New Castle
State	DE
River/Stream	Brandywine Creek
River Mile	4.5
HUC-12	Lower Brandywine Creek (020402050403)
Dam Drainage (sq mi)	318
CURRENT USE & OWNERSHIP	
Owner Name	DuPont Company
Public/Private	Private
Primary Purpose	Water supply (historic)
Relevant Neighboring Properties	Rockford Park, DuPont Experimental Station
Historic Designation	N/A
Key Uses	None
CONSTRUCTION & CONDITION	
Year Completed	1824
Barrier Type	Mill dam
Material	Stone, concrete
Height (ft)	6
Length (ft)	182
Capacity (ac-ft)	Unknown
Condition	Poor. Breached at multiple points.
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	USGS gage (01481500)
Sediment	Estimated sediment accumulation between 1,200-16,600 cubic yards (DNREC-WATAR 2020).
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Breck's Mill/Walker's Mill Dam (DE_7)
Next Downstream Barrier	Brandywine Falls Dam (DE_10)
SITE CONSIDERATIONS	

DuPont Dam. Credit: Brandywine Shad 2020.

DuPont Dam aerial. Credit: Google Earth.

Dam Name	**Breck's Mill/Walker's Mill Dam**
Unique ID	DE_7
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.770999, -75.579009
Address (access)	Breck's Mill, 1-99 Stone Block Row, Wilmington, DE 19807
Town	Wilmington
County	New Castle
State	DE
River/Stream	Brandywine Creek
River Mile	4.8
HUC-12	Lower Brandywine Creek (020402050403)
Dam Drainage (sq mi)	318
CURRENT USE & OWNERSHIP	
Owner Name	Hagley Museum / Walker's Mill Association, LLC
Public/Private	Private
Primary Purpose	Mill (historic)
Relevant Neighboring Properties	Hagley Museum, Breck's Mill, Walker's Mill
Historic Designation	Dam is considered historic and located within historic districts • Brandywine Powder Mills District (NRHP #84000819) - State • Breck's Mill Area – Henry Clay Village Historic District (NRHP #87000683) - State
Key Uses	Waters two mill races. Historic dam part of Hagley Museum.
CONSTRUCTION & CONDITION	
Year Completed	1815 (original)
Barrier Type	Mill dam
Material	Stone, concrete
Height (ft)	6
Length (ft)	156
Capacity (ac-ft)	Unknown
Condition	Satisfactory
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	*Buildings*: Breck's Mill, Walker's Mill buildings; *Other*: USGS gage (01481500)
Sediment	Estimated sediment accumulation between 3,000-52,200 cubic yards (DNREC-WATAR 2020).
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Lower Hagley Dam (DE_6)
Next Downstream Barrier	DuPont Dam (DE_9)
SITE CONSIDERATIONS	
Adjacent historic mill buildings and two mill races.	

Breck's Mill/Walker's Mill Dam. Credit: Brandywine Shad 2020.



Breck's Mill/Walker's Mill Dam aerial. Credit: Google Earth.

Dam Name	Lower Hagley Dam
Unique ID	DE_6
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.776453, -75.575306
Address (access)	Hagley Museum, 200 Hagley Creek Rd, Wilmington, DE 19807
Town	Wilmington
County	New Castle
State	DE
River/Stream	Brandywine Creek
River Mile	5.2
HUC-12	Lower Brandywine Creek (020402050403)
Dam Drainage (sq mi)	317
CURRENT USE & OWNERSHIP	
Owner Name	Hagley Museum
Public/Private	Private
Primary Purpose	Mill (historic)
Relevant Neighboring Properties	Hagley Museum
Historic Designation	Dam is historic and part of National Historic Landmark Area • Eleutherian Mills Historic District (NRHP #66000259)
Key Uses	Waters historic mill race on Hagley Museum property.
CONSTRUCTION & CONDITION	
Year Completed	1802
Barrier Type	Mill dam
Material	Stone, concrete
Height (ft)	8
Length (ft)	215
Capacity (ac-ft)	Unknown
Condition	Satisfactory
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	Mill race
Sediment	Estimated sediment accumulation between 8,300-28,500 cubic yards (DNREC-WATAR 2020).
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Upper Hagley Dam (DE_emadd02)
Next Downstream Barrier	Breck's Mill/Walker's Mill Dam (DE_7)
SITE CONSIDERATIONS	
The dam is located within a National Historic Landmark Area.	

Lower Hagley Dam. Credit: Brandywine Shad 2020.

Lower Hagley Dam aerial. Credit: Google Earth.

Dam Name	Eleutherian Dam
Unique ID	DE_5
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.785739, -75.577591
Address (access)	Hagley Library, 298 Buck Rd, Wilmington, DE 19807
Town	Wilmington
County	New Castle
State	DE
River/Stream	Brandywine Creek
River Mile	6.2
HUC-12	Lower Brandywine Creek (020402050403)
Dam Drainage (sq mi)	315
CURRENT USE & OWNERSHIP	
Owner Name	Hagley Museum
Public/Private	Private
Primary Purpose	Mill (historic)
Relevant Neighboring Properties	Hagley Museum
Historic Designation	Dam is historic and part of National Historic Landmark Area • Eleutherian Mills Historic District (NRHP #66000259)
Key Uses	Waters historic mill race on Hagley Museum property.
CONSTRUCTION & CONDITION	
Year Completed	1802 (original); 2009 (current)
Barrier Type	Mill dam
Material	Timber, stone
Height (ft)	3
Length (ft)	126
Capacity (ac-ft)	Unknown
Condition	Excellent. Recently rebuilt.
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	Mill race, channel
Sediment	Estimated sediment accumulation between 1,600-7,100 cubic yards (DNREC-WATAR 2020).
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Brandywine Creek Dam (DE_101)
Next Downstream Barrier	Upper Hagley Dam (DE_emadd02)
SITE CONSIDERATIONS	
The dam was rebuilt in 2009 at a cost of $1 million using historic methods and building materials. The dam is located within a National Historic Landmark Area.	

Eleutherian Dam. Credit: Brandywine Shad 2020.

Eleutherian Dam aerial. Credit: Google Earth.

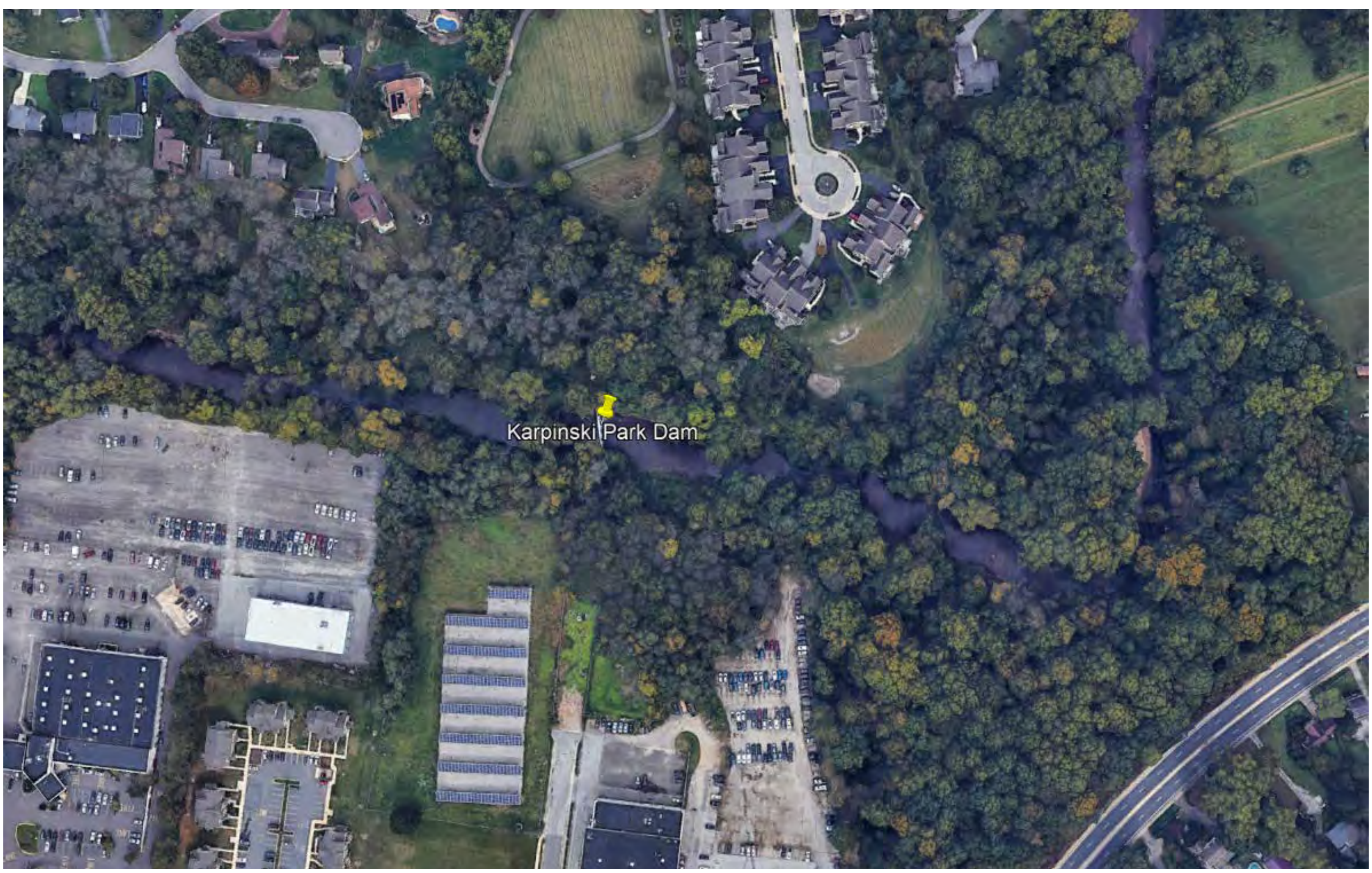
Dam Name	**Red Mill Dam**
Unique ID	DE_23
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.689287, -75.709745
Address (access)	A2Z Paintball, Red Mill Rd, Newark, DE 19711
Town	Newark
County	New Castle
State	DE
River/Stream	White Clay Creek
River Mile	6.7
HUC-12	Upper White Clay Creek (020402050306)
Dam Drainage (sq mi)	75
CURRENT USE & OWNERSHIP	
Owner Name	Mac Shar Enterprises
Public/Private	Private
Primary Purpose	Mill (historic)
Relevant Neighboring Properties	Windy Mill (New Castle County), A2Z Paintball, Red Mill Farm
Historic Designation	Dam feeds mill race relevant to adjacent historic site. • England House and Mill (NRHP Ref #72001597) - State
Key Uses	None
CONSTRUCTION & CONDITION	
Year Completed	1730s (original)
Barrier Type	Mill dam
Material	Rockfill
Height (ft)	3
Length (ft)	140
Capacity (ac-ft)	Unknown
Condition	Poor. The dam is failing at several points leading to downstream bank erosion and areas of upstream sediment deposition.
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	*Utilities*: New Castle County sewer lines downstream of dam
Sediment	2010 study noted sediment deposition upstream of Red Mill Dam.
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey
Aquatic Federal T & E Species	Bog Turtle, *Glyptemys muhlenbergii*
Next Upstream Barrier	Karpinski Park Dam (DE_emadd05)
Next Downstream Barrier	None
SITE CONSIDERATIONS	
Sediment accumulation is an issue in the lower section of White Clay Creek. Stroud and USGS are currently completing studies to better understand the sources of sediment.	

Red Mill Dam. Credit: Jason Fischel.

Red Mill Dam aerial. Credit: Google Earth.

Dam Name	Karpinski Park Dam
Unique ID	DE_emadd05
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.68991, -75.737637
Address (access)	Karpinski Park, Newark, DE 19711
Town	Newark
County	New Castle
State	DE
River/Stream	White Clay Creek
River Mile	9.5
HUC-12	Upper White Clay Creek (020402050306)
Dam Drainage (sq mi)	70
CURRENT USE & OWNERSHIP	
Owner Name	City of Newark
Public/Private	Public
Primary Purpose	Sewer main
Relevant Neighboring Properties	Karpinski Park (City of Newark)
Historic Designation	N/A
Key Uses	Barrier formed by sewer main.
CONSTRUCTION & CONDITION	
Year Completed	Unknown
Barrier Type	Sewer Main
Material	Concrete
Height (ft)	4
Length (ft)	75
Capacity (ac-ft)	Unknown
Condition	Concrete-encased sewer main that has eroded on the downstream side.
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	*Utilities*: City of Newark sewer main
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey
Aquatic Federal T & E Species	Bog Turtle, *Glyptemys muhlenbergii*
Next Upstream Barrier	Paper Mill Dam (DE_22)
Next Downstream Barrier	Red Mill Dam (DE_23)
SITE CONSIDERATIONS	
Adjacent site was formerly used as a landfill/dump site, so will need to be considered during any removal/ reconstruction.	

Karpinski Park Dam. Credit: Jason Fischel.



Karpinski Park Dam aerial. Credit: Google Earth.

Dam Name	Paper Mill Dam
Unique ID	DE_22
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.689463, -75.749031
Address (access)	Curtis Mill Park, 299 Paper Mill Rd #287, Newark, DE 19711
Town	Newark
County	New Castle
State	DE
River/Stream	White Clay Creek
River Mile	10.1
HUC-12	Upper White Clay Creek (020402050306)
Dam Drainage (sq mi)	69
CURRENT USE & OWNERSHIP	
Owner Name	City of Newark
Public/Private	Public
Primary Purpose	Mill (historic)
Relevant Neighboring Properties	Curtis Mill Park (City of Newark); electrical substation
Historic Designation	Dam is not historic. Paper Mill Road Bridge (immediately downstream of dam) is eligible for listing in the NRHP.
Key Uses	Pools water for USGS gage.
CONSTRUCTION & CONDITION	
Year Completed	1845
Barrier Type	Mill dam (historic)
Material	Concrete
Height (ft)	6
Length (ft)	160
Capacity (ac-ft)	Unknown
Condition	Poor. Breached at multiple points.
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	*Utilities*: USGS Gage (01478650); *Other*: City of Newark sewer line crosses downstream at multiple point.
Sediment	Little sediment built up behind dam.
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel
Aquatic Federal T & E Species	Bog Turtle, *Glyptemys muhlenbergii*
Next Upstream Barrier	Newark Intake Dam (DE_emadd06)
Next Downstream Barrier	Karpinski Park Dam (DE_emadd05)
SITE CONSIDERATIONS	
Utilities - Dam used as weir for USGS gage to ensure City is meeting minimum flow requirements as TCS Suez had first rights of withdrawal. USGS will re-gage and is not concerned with dam removal. Sewer crossing just downstream of dam may continue to pool water here. Bedrock is exposed so scouring is not a concern.	

Paper Mill Dam. Credit: Jason Fischel.

Paper Mill Dam aerial. Credit: Google Earth.

Dam Name	Newark Intake Dam
Unique ID	DE_emadd06
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.698909, -75.752429
Address (access)	White Clay Creek State Park, 997-1099 Creek Rd, Newark, DE 19711
Town	Newark
County	New Castle
State	DE
River/Stream	White Clay Creek
River Mile	11.1
HUC-12	Upper White Clay Creek (020402050306)
Dam Drainage (sq mi)	67.5
CURRENT USE & OWNERSHIP	
Owner Name	City of Newark
Public/Private	Public
Primary Purpose	Water Supply
Relevant Neighboring Properties	Curtis Water Treatment Plant, Newark Reservoir, White Clay Creek State Park
Historic Designation	N/A
Key Uses	Supplies mill race for half of Newark's drinking water supply.
CONSTRUCTION & CONDITION	
Year Completed	1789 (original)
Barrier Type	Mill dam
Material	Concrete
Height (ft)	10
Length (ft)	150
Capacity (ac-ft)	Unknown
Condition	Poor. Deterioration evident.
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	Mill race
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey
Aquatic Federal T & E Species	Bog Turtle, *Glyptemys muhlenbergii*
Next Upstream Barrier	Creek Road Dam (DE_emadd07)
Next Downstream Barrier	Paper Mill Dam (DE_22)
SITE CONSIDERATIONS	

Water supply - City of Newark relies on this dam and associated mill race for half of its water supply. Th City is open to the idea of dam removal and possibly sourcing using a wellfield. *Risk & Safety* - University of Delaware student died at dam during flood event.

Newark Intake Dam. Credit: Jason Fischel.

Newark Intake Dam aerial. Credit: Google Earth.

Dam Name	Deerfield Dam
Unique ID	DE_emadd08
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.718626, -75.761231
Address (access)	White Clay Creek State Park, Wedgewood Road, Newark, DE 19711
Town	Newark
County	New Castle
State	DE
River/Stream	White Clay Creek
River Mile	12.7
HUC-12	Upper White Clay Creek (020402050306)
Dam Drainage (sq mi)	65.5
CURRENT USE & OWNERSHIP	
Owner Name	DNREC
Public/Private	Public
Primary Purpose	Water Supply
Relevant Neighboring Properties	Deerfield Golf Club
Historic Designation	N/A
Key Uses	Supplies water for state-owned golf course.
CONSTRUCTION & CONDITION	
Year Completed	1955
Barrier Type	Rockfill
Material	Rockfill
Height (ft)	6
Length (ft)	125
Capacity (ac-ft)	Unknown
Condition	Poor. Breached in multiple locations. Large boulders were placed on top of dam since initial construction.
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	Abandoned building.
Sediment	Sediment accumulation upstream of dam. Braiding below dam extends for 1,000 feet and is degrading habitat.
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey
Aquatic Federal T & E Species	Bog Turtle, *Glyptemys muhlenbergii*
Next Upstream Barrier	White Clay Creek Preserve Dam (PA_15-377)
Next Downstream Barrier	Creek Road Dam (DE_emadd07)
SITE CONSIDERATIONS	
Large boulders were placed on top of dam since initial construction and will likely be retained on site following planned removal due to their size. Immediately adjacent to the dam is an abandoned building owned by the State of Delaware and the Tri-Valley Trail.	

Deerfield Dam. Credit: Jason Fischel.

Deerfield Dam aerial. Credit: Google Earth.

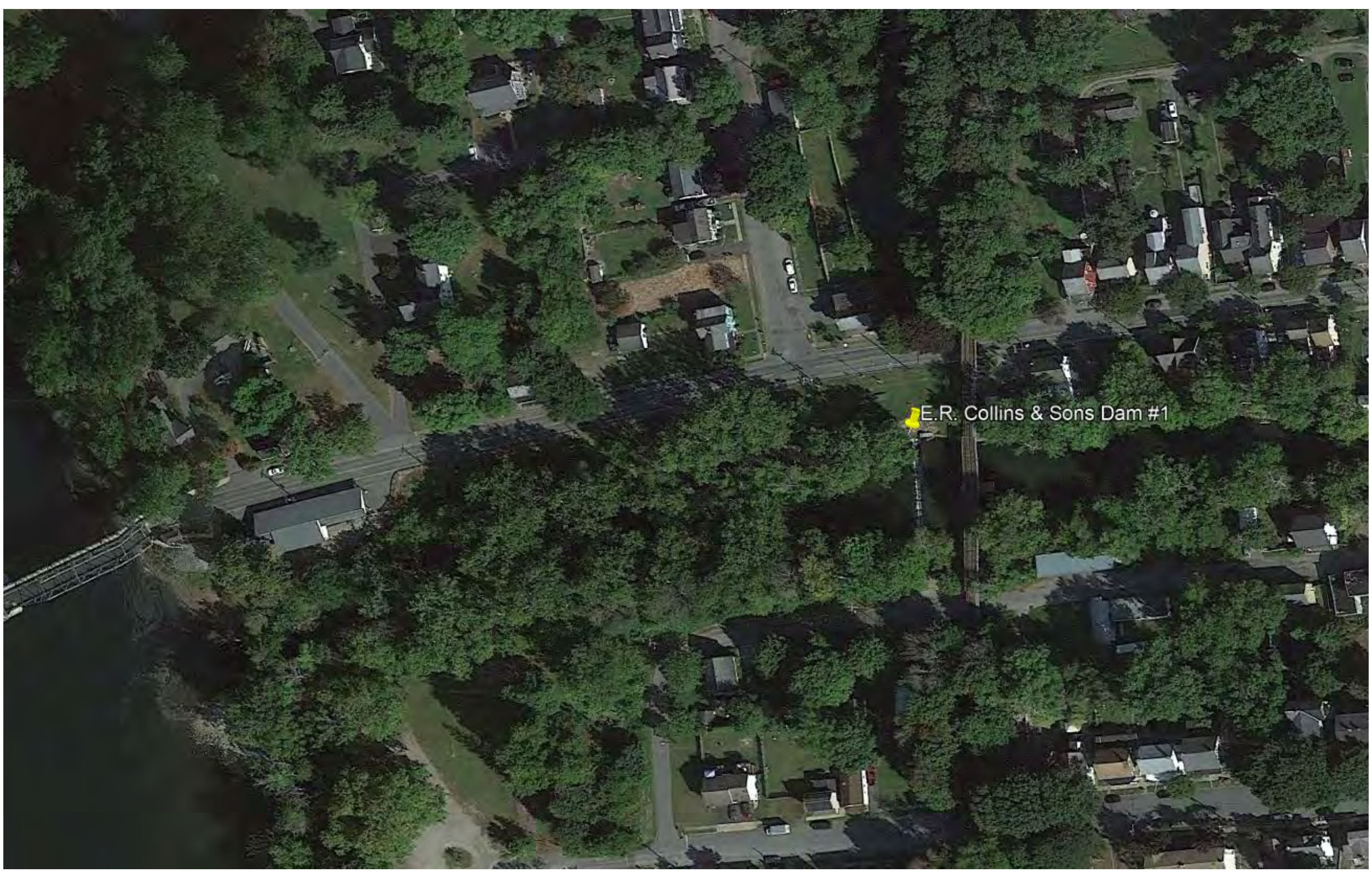
Dam Name	White Clay Creek Preserve Dam
Unique ID	PA_15-377
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	39.751804, -75.777927
Address (access)	398-328 London Tract Rd, Landenberg, PA 19350
Town	Landenberg
County	Chester
State	PA
River/Stream	White Clay Creek
River Mile	16.2
HUC-12	Upper White Clay Creek (020402050306)
Dam Drainage (sq mi)	25.5
CURRENT USE & OWNERSHIP	
Owner Name	PA DCNR
Public/Private	Public
Primary Purpose	Recreation
Relevant Neighboring Properties	White Clay Creek Preserve
Historic Designation	N/A
Key Uses	None
CONSTRUCTION & CONDITION	
Year Completed	Unknown
Barrier Type	Rockfill
Material	Stone
Height (ft)	3
Length (ft)	120
Capacity (ac-ft)	Unknown
Condition	Breached
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	None
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Hickory Shad, American Eel, Sea Lamprey
Aquatic Federal T & E Species	Bog Turtle, *Glyptemys muhlenbergii*
Next Upstream Barrier	None before split between East and Middle branches
Next Downstream Barrier	Deerfield Dam (DE_emadd08)
SITE CONSIDERATIONS	
Removal planned and funded by State of Pennsylvania - included in 14 dams across PA that are part of design/build contract for removals.	

White Clay Creek Preserve Dam. Credit: Jason Fischel.

White Clay Creek Preserve Dam aerial. Credit: Google Earth.

Dam Name	Lower E.R. Collins & Son Dam
Unique ID	NJ_24-28
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.829395, -75.080830
Address (access)	213-99 Water St, Belvidere, NJ 07823
Town	Belvidere
County	Warren
State	NJ
River/Stream	Pequest River
River Mile	0.1
HUC-12	Lower Pequest River (020401050204)
Dam Drainage (sq mi)	158
CURRENT USE & OWNERSHIP	
Owner Name	NJDEP Division of Fish and Wildlife
Public/Private	Public
Primary Purpose	Mill (historic)
Relevant Neighboring Properties	NJDEP Belvidere Fishing Access Area
Historic Designation	Dam is near local historic district: • Belvidere Historic District (NRHP Ref # 80002525) - Local
Key Uses	None
CONSTRUCTION & CONDITION	
Year Completed	c. 1800 (original)
Barrier Type	Low-head dam
Material	Timber
Height (ft)	7
Length (ft)	145
Capacity (ac-ft)	Unknown
Condition	Satisfactory
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	*Bridges*: Norfolk Southern Rail Bridge, Greenwich-Market Street Bridge
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, American Eel, Sea Lamprey
Aquatic Federal T & E Species	Dwarf Wedgemussel, *Alasmidonta heterodon*
Next Upstream Barrier	Upper E.R. Collins & Son Dam (NJ_24-29)
Next Downstream Barrier	N/A
SITE CONSIDERATIONS	
Given proximity to Norfolk Southern Rail Bridge, dam removal requires structural evaluation of the bridge.	

Lower E. R. Collins & Son Dam. Credit: TNC.



Lower E.R. Collins & Son Dam aerial. Credit: Google Earth.

Dam Name	Upper E.R. Collins & Son Dam
Unique ID	NJ_24-29
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.829478, -75.078264
Address (access)	S Water St, Belvidere, NJ 07823
Town	Belvidere
County	Warren
State	NJ
River/Stream	Pequest River
River Mile	0.2
HUC-12	Lower Pequest River (020401050204)
Dam Drainage (sq mi)	158
CURRENT USE & OWNERSHIP	
Owner Name	Private owner
Public/Private	Private
Primary Purpose	Hydroelectric (historic)
Relevant Neighboring Properties	2-10 Market St (2103_11_2); 3 Greenwich St (2103_11_38)
Historic Designation	Dam is located within the local historic district: • Belvidere Historic District (NRHP Ref # 80002525) - Local
Key Uses	None
CONSTRUCTION & CONDITION	
Year Completed	c. 1800 (original)
Barrier Type	Mill dam, Ogee
Material	Concrete
Height (ft)	7
Length (ft)	85
Capacity (ac-ft)	Unknown
Condition	Satisfactory
Hazard Class (Last Inspection)	N/A
Adjacent Infrastructure	*Bridges*: Greenwich-Market Street Bridge, Hardwick-Prospect Street Bridge; *Other*: Two buildings associated with dam: 2-10 Market St, 3 Greenwich St
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, American Eel, Sea Lamprey
Aquatic Federal T & E Species	Dwarf Wedgemussel, Alasmidonta heterodon
Next Upstream Barrier	Tranquility Mill Dam (NJ_21-15)
Next Downstream Barrier	Lower E.R. Collins & Son Dam (NJ_24-28)
SITE CONSIDERATIONS	

Flooding - Dam is exacerbating local flooding in the surrounding area and is a priority for removal by the dam owner and the Town. Given proximity to Greenwich-Market Street Bridge and abutment to two buildings, dam removal requires evaluation of structures.

Upper E.R. Collins & Son Dam. Credit: TNC.

Upper E.R. Collins & Son Dam aerial. Credit: Google Earth.

Dam Name	**Easton Dam**
Unique ID	PA_48-012
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.688421, -75.206279
Address (access)	Easton Dam, D & L Trail - Lehigh Canal Towpath, Easton, PA 18042
Town	Easton
County	Northampton
State	PA
River/Stream	Lehigh River
River Mile	0.0
HUC-12	Lehigh River-Delaware River (020401060813)
Dam Drainage (sq mi)	1,373
CURRENT USE & OWNERSHIP	
Owner Name	PA Department of Conservation and Natural Resources (DCNR)
Public/Private	Public
Primary Purpose	Historic (canal); Recreation
Relevant Neighboring Properties	Delaware Canal State Park (PA DCNR); Scott Park (City of Easton)
Historic Designation	Dam is within National Register boundaries of the Lehigh Canal: Easton Section and necessary for watering of Delaware Division of the Pennsylvania Canal. • Lehigh Canal: Eastern Section Glendon and Abbott Street Industrial Sites (NRHP Ref #78002437) • Delaware Division of the Pennsylvania Canal (NRHP Ref #74001756) – National Historic Landmark
Key Uses	Waters Delaware Canal. Boating in upstream impoundment.
CONSTRUCTION & CONDITION	
Year Completed	1829 (original), 1968 (current)
Barrier Type	Stone
Material	Stone, Masonry, Timber Crib (core)
Height (ft)	30
Length (ft)	600
Capacity (ac-ft)	1,033
Condition	Satisfactory
Hazard Class (Last Inspection)	Low (11/12/20)
Adjacent Infrastructure	*Bridges*: Black River and Western Railroad Bridge No. 77 (Easton Viaduct over 3rd Street), Dr. George S. Smith Bridge (3rd Street / S.R. 611), Eastern and Northern EA - 77A Bridge (near 9th Street); *Utilities*: 2 main sewer lines (upstream, in-river), 42 stormwater outfalls; *Other*: Delaware Canal
Sediment	Sediment depth 1,500 feet upstream of the dam is approximately 5′, with mostly sand and coarse gravel noted in 2012 analysis.
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	Vertical slot fishway
Diadromous Fish	American Shad, Alewife, Blueback Herring, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Chain Dam (PA_48-013)
Next Downstream Barrier	N/A
SITE CONSIDERATIONS	
Recreation, Cultural - Previous efforts at dam removal met significant opposition due to canal linkage, recreation, and city aesthetics. Tropical Storm Ida in September 2021 caused an estimated $5-8M in damages to the Delaware Canal. Delaware Canal 21 is currently launching a financial study to determine how to finance necessary improvements.	

Easton Dam. Credit: Lyndon DeSalvo/TNC.

Easton Dam aerial. Credit: Google Earth.

Dam Name	**Chain Dam** *(aka Glendon Dam)*
Unique ID	PA_48-013
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.659221, -75.245142
Address (access)	D&L Trail: Nat'l Canal Museum Spur, Easton, PA 18042
Town	Easton
County	Northampton
State	PA
River/Stream	Lehigh River
River Mile	3.2
HUC-12	Lehigh River-Delaware River (020401060813)
Dam Drainage (sq mi)	1,360
CURRENT USE & OWNERSHIP	
Owner Name	PA Department of Environmental Protection / City of Easton*
Public/Private	Public
Primary Purpose	Historic (canal); Recreation
Relevant Neighboring Properties	Hugh Moore Park (City of Easton); National Canal Museum (D&L NHC); Riverview Park (Palmer Township)
Historic Designation	Dam waters Lehigh Canal: Easton Section and Chain Bridge footing and piers are upstream in impoundment. • Lehigh Canal: Eastern Section Glendon and Abbott Street Industrial Sites (NRHP Ref #78002437) • Chain Bridge (NRHP Ref #74001798)
Key Uses	Boating in impoundment. Waters Lehigh Canal.
CONSTRUCTION & CONDITION	
Year Completed	1820s (original); 1974 (current)
Barrier Type	Ogee, Stone
Material	Stone, Concrete
Height (ft)	20
Length (ft)	700
Capacity (ac-ft)	1,197
Condition	Satisfactory
Hazard Class (Last Inspection)	Low (11/12/20)
Adjacent Infrastructure	*Bridges*: Glendon Hill Road Bridge, Glendon-Wilson Bridge (25th Street / S.R. 2012), Gene Hartzell Memorial Bridge (S.R. 33); *Utilities*: 12 stormwater outfalls; *Other*: Lehigh Canal, USGS gage (01454700 Lehigh River at Glendon, PA)
Sediment	Bed of Eurasian milfoil at upstream side of fish ladder.
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	Vertical slot fishway
Diadromous Fish	American Shad, Alewife, Blueback Herring, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Hamilton Street Dam (PA_39-009)
Next Downstream Barrier	Easton Dam (PA_48-012)
SITE CONSIDERATIONS	
Recreation, Cultural - Slack water feeds Lehigh Canal and necessary for mule-drawn boat rides by National Canal Museum. Bethlehem Boat Club interest in maintaining pool. *Energy* - Preliminary proposals and provisional license granted by FERC for low-impact hydropower on Lehigh Canal. *Risk & Safety* - In 2014, drowning of fisherman in contact. Concerns with safety. *While DEP is owner of dam, agency would require City of Easton approval prior to alteration or dam removal.	

Chain Dam. Credit: Lyndon DeSalvo/TNC.

Chain Dam aerial. Credit: Google Earth.

Dam Name	**Hamilton Street Dam** *(aka Allentown Dam)*
Unique ID	PA_39-009
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.60675, -75.454417
Address (access)	S Albert St, Allentown, PA 18109
Town	Allentown
County	Lehigh
State	PA
River/Stream	Lehigh River
River Mile	17
HUC-12	Lehigh River-Delaware River (020401060813)
Dam Drainage (sq mi)	1,030
CURRENT USE & OWNERSHIP	
Owner Name	City of Allentown
Public/Private	Public
Primary Purpose	Historic (canal); Recreation; Water supply*
Relevant Neighboring Properties	America on Wheels Museum; Pennsylvania Power & Light Company substation
Historic Designation	Dam waters section of Lehigh Canal included in National Historic Register. • Lehigh Canal: Allentown to Hopeville Section (NRHP Ref # 79002307)
Key Uses	Boating in impundment. Waterfront development along basin.
CONSTRUCTION & CONDITION	
Year Completed	1830 (original); 1984 (current)
Barrier Type	Gravity
Material	Concrete
Height (ft)	14
Length (ft)	490
Capacity (ac-ft)	50
Condition	Satisfactory
Hazard Class (Last Inspection)	Low (3/11/21)
Adjacent Infrastructure	*Bridges*: Hamilton Street Bridge, Union Blvd-Tilghman St Bridge, American Parkway Bridge, Lehigh Valley Thruway/Rt 22 Bridge; *Utilities*: Lehigh County Authority Drinking Water Intakes; Lehigh County Authority Wastewater Treatment Plant; PPL Substation; *Other*: Lehigh Canal
Sediment	Coal silt settled here following the flooding of the former Treichlers Dam located up-stream in 1981.
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	Vertical slot fishway (dewatered during 2021 visit)
Diadromous Fish	American Shad, Alewife, Blueback Herring, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Cementon Dam (PA_39-060)
Next Downstream Barrier	Chain Dam (PA_48-013)
SITE CONSIDERATIONS	
Water supply - Lehigh County Authority has main WWTP just downstream of dam and also uses Lehigh River as backup water supply (presumably with intakes in dam impoundment). *Cultural, Economic Development* - Large mixed-use development – "The Waterfront" – under construction along 26 acres of Lehigh River banks within dam impoundment. Slack water feeds Lehigh Canal. *Energy* - Preliminary proposals and provisional license granted by FERC for low-impact hydropower on Lehigh Canal. *Risk & Safety* - Some concerns about risk and safety, especially given inadequate maintenance.	


Hamilton Street Dam. Credit: Lyndon DeSalvo/TNC.

Hamilton Street Dam aerial. Credit: Google Earth.

Dam Name	**Northampton Dam** *(aka Cementon Dam)*
Unique ID	PA_39-060
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.689193, -75.502724
Address (access)	5101-5105 Main St, Whitehall, PA 18052
Town	Northampton
County	Lehigh
State	PA
River/Stream	Lehigh River
River Mile	23.9
HUC-12	Fireline Creek-Lehigh River (020401060804)
Dam Drainage (sq mi)	943
CURRENT USE & OWNERSHIP	
Owner Name	LaFarge Holcim Corporation
Public/Private	Private
Primary Purpose	Water supply
Relevant Neighboring Properties	LaFarge North American Cement Plant; Canal Street Park (Northampton Borough)
Historic Designation	N/A
Key Uses	Lafarge cement company uses this as water supply for daily operations
CONSTRUCTION & CONDITION	
Year Completed	1927
Barrier Type	Low-head dam
Material	Concrete
Height (ft)	8
Length (ft)	280
Capacity (ac-ft)	50
Condition	Satisfactory
Hazard Class (Last Inspection)	Low (1/23/20)
Adjacent Infrastructure	*Bridges*: Main St/PA-329 Bridge; *Utilities*: NBMA Water Treatment Plant
Sediment	Upriver abandoned mine drainage inputs mean that sediment behind dam likely contains metal pollution.
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, American Eel, Sea Lamprey, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Francis E. Walter Dam (PA_PA00008)
Next Downstream Barrier	Hamilton Street Dam (PA_39-009)
SITE CONSIDERATIONS	
Water supply - Northampton Borough Municipal Authority (NMBA) Water Treatment Plant has intake upstream of dam. *Fish passage* - American Shad are present in tailrace of dam and Hokendauqua Creek pool located one mile downstream. American eels and sea lamprey not typically impeded by lack of fish passage at Northampton due to relatively high flows.	

Northampton Dam. Credit: Lyndon DeSalvo/TNC.

Northampton Dam aerial. Credit: Google Earth.

Dam Name	Hulmeville Park Dam
Unique ID	PA_09-084
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.1432609, -74.916193
Address (access)	Neshaminy Shore Picnic Park, 13 Beaver St, Hulmeville, PA 19047
Town	Bensalem
County	Bucks
State	PA
River/Stream	Neshaminy Creek
River Mile	6.2
HUC-12	Core Creek-Neshaminy Creek (020402010303)
Dam Drainage (sq mi)	224
CURRENT USE & OWNERSHIP	
Owner Name	Neshaminy Shore Picnic Park / Bucks County
Public/Private	Private / Public
Primary Purpose	Recreation; Mill (historic)
Relevant Neighboring Properties	Juniper Village at Bucks County
Historic Designation	Dam is located near (but outside) historic district • Hulmeville Historic District (NRHP Ref# 86001677) – Local
Key Uses	Boating in upstream impoundment.
CONSTRUCTION & CONDITION	
Year Completed	1720 (original);
Barrier Type	Run-of-river dam
Material	Rockfill
Height (ft)	12
Length (ft)	210
Capacity (ac-ft)	123
Condition	Fair
Hazard Class (Last Inspection)	Low (6/30/17)
Adjacent Infrastructure	*Bridges*: Route 513/Hulmeville Rd bridge, Route 1/Lincoln Highway bridge, Old Lincoln Highway bridge, SEPTA West Trenton Line Rail Bridge; *Other:* Old stone walls (possible canal or foundations from former mill buildings) located on north side near parking area.
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American shad, Alewife, Blueback Herring, American Eel, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Neshaminy Falls Dam (PA_09-003)
Next Downstream Barrier	N/A
SITE CONSIDERATIONS	
Recreation - Dam provides slack water for recreational boating at Neshaminy Shores Picnic Park (listed as owner in USACE National Inventory of Dams); however, Bucks County owns streambank and surrounding parcels.	

Hulmeville Park Dam. Credit: Lyndon DeSalvo/TNC.

Hulmeville Park Dam aerial. Credit: Google Earth.

Dam Name	Neshaminy Falls Dam
Unique ID	PA_09-003
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.150117, -74.956615
Address (access)	Neshaminy Falls Station, 4255 E Bristol Rd, Bensalem, PA 19020
Town	Langhorne
County	Bucks
State	PA
River/Stream	Neshaminy Creek
River Mile	9
HUC-12	Core Creek-Neshaminy Creek (020402010303)
Dam Drainage (sq mi)	211
CURRENT USE & OWNERSHIP	
Owner Name	Aqua Pennsylvania, Inc.
Public/Private	Private
Primary Purpose	Water Supply (public), Recreation
Relevant Neighboring Properties	N/A
Historic Designation	N/A
Key Uses	Aqua PA public water intake.
CONSTRUCTION & CONDITION	
Year Completed	1909
Barrier Type	Run-of-river dam
Material	Masonry
Height (ft)	14
Length (ft)	290
Capacity (ac-ft)	260
Condition	Satisfactory
Hazard Class (Last Inspection)	Low (6/30/2017)
Adjacent Infrastructure	*Bridges*: SEPTA West Trenton Rail Bridge, Brownsville Rd Bridge; *Utilities*: Aqua PA Water intake and transmission mains, Aqua PA Water Treatment Plant
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, Americal Eel, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Spring Garden Dam (PA_09-083)
Next Downstream Barrier	Hulmeville Dam (PA_09-084)
SITE CONSIDERATIONS	
Water supply - Water treatment plant underwent $25 million upgrade from 2009-2013; has intake from dam.	

Neshaminy Falls Dam. Credit: Lyndon DeSalvo/TNC.

Neshaminy Falls Dam aerial. Credit: Google Earth.

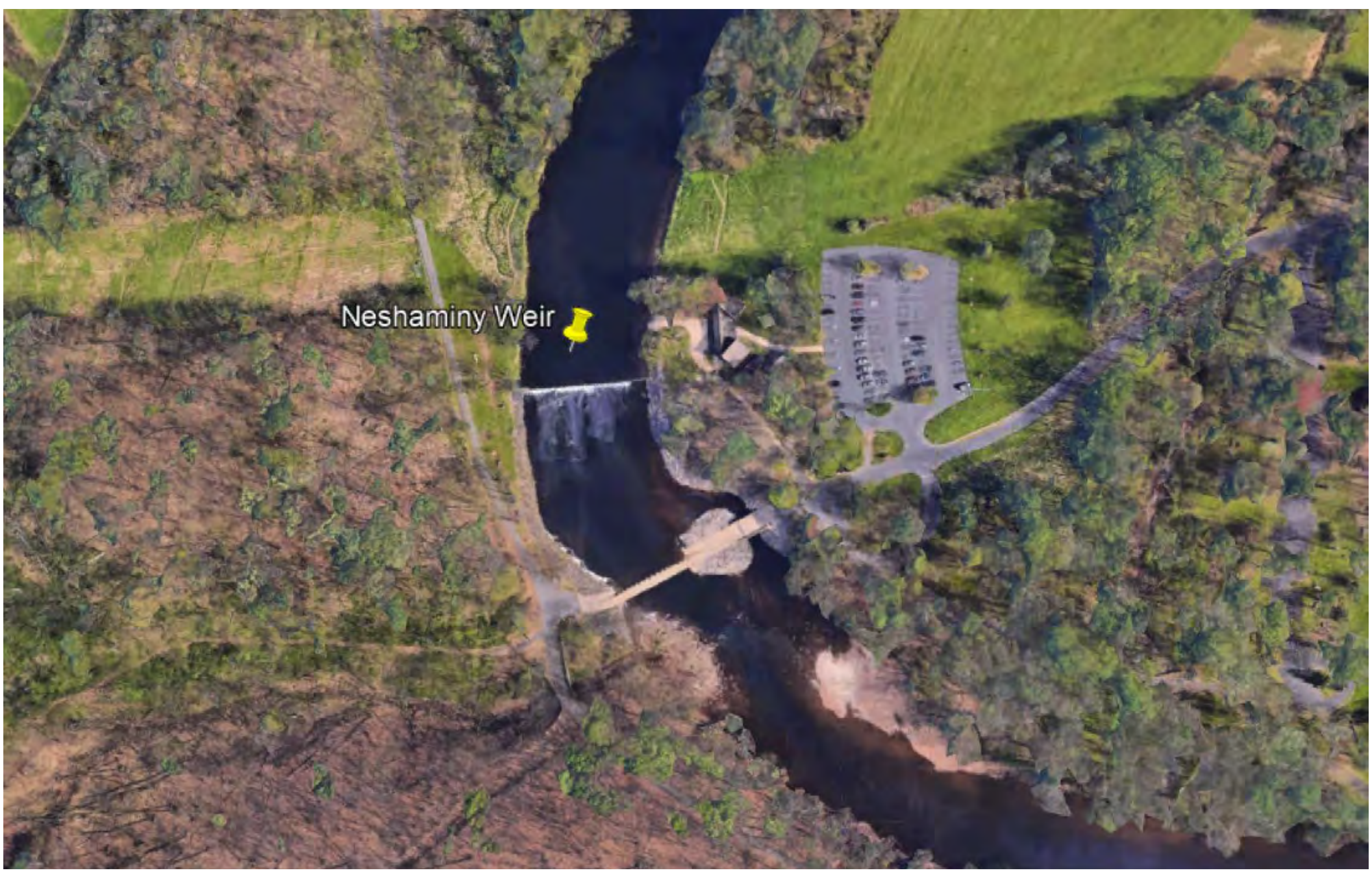
Dam Name	Spring Garden Dam
Unique ID	PA_09-083
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.224714, -74.963755
Address (access)	Fisherman's Parking Lot – Tyler State Park, Northampton Township, PA 18940
Town	Newtown
County	Bucks
State	PA
River/Stream	Neshaminy Creek
River Mile	17.6
HUC-12	Mill Creek-Neshaminy Creek (020402010301)
Dam Drainage (sq mi)	165
CURRENT USE & OWNERSHIP	
Owner Name	PA DCNR
Public/Private	Public
Primary Purpose	Recreation
Relevant Neighboring Properties	Tyler State Park
Historic Designation	N/A
Key Uses	Boating in upstream impoundment.
CONSTRUCTION & CONDITION	
Year Completed	1920
Barrier Type	Run-of-river dam; arch shape
Material	Concrete
Height (ft)	9
Length (ft)	275
Capacity (ac-ft)	112
Condition	Satisfactory
Hazard Class (Last Inspection)	Low (6/18/2018)
Adjacent Infrastructure	*Bridges*: Route 322/Richboro Rd Bridge (Downstream), Main Park Rd/Dairy Hill Trail Bridge
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American shad, Alewife, Blueback Herring, American Eel, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Neshaminy Weir Dam (PA_09-167)
Next Downstream Barrier	Neshaminy Falls Dam (PA_09-003)
SITE CONSIDERATIONS	
Risk & Safety - PA DCNR considers the dam a liability and is seeking funds for removal.	

Spring Garden Dam. Credit: Lyndon DeSalvo/TNC.

Spring Garden Dam aerial. Credit: Google Earth.

Dam Name	Neshaminy Weir Dam
Unique ID	PA_09-167
LOCATION & HYDROGRAPHY	
Coordinates (Lat, Lon)	40.233086, -74.974240
Address (access)	Tyler State Park – Boathouse Parking Lot, Newtown, PA 18940
Town	Newtown
County	Bucks
State	PA
River/Stream	Neshaminy Creek
River Mile	18.6
HUC-12	Mill Creek-Neshaminy Creek (020402010301)
Dam Drainage (sq mi)	164
CURRENT USE & OWNERSHIP	
Owner Name	PA DCNR
Public/Private	Public
Primary Purpose	Recreation
Relevant Neighboring Properties	Bucks County Community College
Historic Designation	N/A
Key Uses	Used for non-motorized boating.
CONSTRUCTION & CONDITION	
Year Completed	1980
Barrier Type	Run-of-river dam
Material	Stone
Height (ft)	2-3
Length (ft)	170
Capacity (ac-ft)	Unknown
Condition	Good
Hazard Class (Last Inspection)	Low (N/A)
Adjacent Infrastructure	*Bridges*: Main Park Rd/Dairy Hill Trail Bridge, Schofield Ford Covered Bridge
Sediment	Unknown
AQUATIC CONNECTIVITY & FISH PASSAGE	
Fish Passage	No
Diadromous Fish	American Shad, Alewife, Blueback Herring, American eel, Striped Bass
Aquatic Federal T & E Species	None
Next Upstream Barrier	Reed Dam (PA_09-141)
Next Downstream Barrier	Spring Garden Dam (PA_09-083)
SITE CONSIDERATIONS	
Recreation - Boat launch just upstream of dam; road crossing/walkway (with AOP) just downstream of dam to access other areas of Tyler State Park.	

Neshaminy Weir Dam. Credit: Lyndon DeSalvo/TNC.



Neshaminy Weir Dam aerial. Credit: Google Earth.

Appendix B

Current and Historic American Shad, Alewife, and Blueback Herring Distribution in the Delaware Basin

The current and historic distribution information for Alewife, American Shad, and Blueback Herring was collected as part of the Restoration Roadmap project and should not be considered comprehensive. The information was compiled from historic fisheries reports, current monitoring efforts, conversations with partners, and previous datasets. Data sources are listed within the table and cited in full in Section 7.

Delaware River Tributaries	RKM	Pre-1950 Shad Run	1950-1990 Shad Run	1990-2020 Shad Run	Pre-1950 AW Run	1950-1990 AW Run	1990-2020 AW Run	Pre-1950 BBH Run	1950-1990 BBH Run	1990-2020 BBH Run	Relevant Barriers	Comments	Data Sources (links to soures included here or as reference listed in literature cited section)
West Branch Delaware (NY)	532	Y (24km)	Y	N							Cannonsville Dam (NY_119-2889)	Historic shad runs up to at least Deposit, NY. Cold tailwaters from NYC reservoirs create unsuitable conditions for shad.	Sykes & Lehman 1957; Bishop 1935; Gay 1892; Mansueti & Kolb 1953; Chittenden 1969
East Branch Delaware (NY)	532	Y (68km)	Y	Y							Downsville Dam (NY_146-1429)	Historic shad runs as far upstream as Downesville and within 30 miles of headwaters. Shad present in East Branch during 1959-62 surveying. Cold tailwater from NYC reservoir and distance upstream probably varies with water temperatures.	Sykes & Lehman 1957; Bishop 1935; Pennsylvania Fisheries Report 1896; PFBC 2011;
Beaver Kill (NY)		Y		Y (6km)							None	Chittenden (1976) reported shad 6km up Beaver Kill; and others reported shad 1km up Little Beaver Kill (tributary). Excellent water quality and undammed on its mainstem.	Chittenden 1976; Bishop 1935;
Lackawaxen River (PA)	447	Y		Y	Y*			Y*			Wooln Mill Dam (PA_64-053); Lake Wallenpaupack Dam (PA_52-051)	Thousands of shad noted in Lackawaxen in 1891 following installation of fishway at Lackawaxon Dam, as far as 25-30 miles above dam. Current fishing log mentions shad throughout Pike County section of Lackawaxen - likely a minor run today. 1985 Coop fishways report mentions Lackawaxen as 1/4 key shad streams and probably river herring as well. Flow alteration due to releases from Lake Wallenpaupack.	Gay 1892; DRBFWMC 1985;
Mongaup River (NY)	420	Y		Y (7.5km)							Rio Dam (NY_149-0086); Mongaup Falls Dam (NY_148-0130)	Hydroelectric dams (currently in process of relicensing for 2022). Supports minor shad run in lower reach below Rio Dam. Mongaup Falls was almost certainly a natural barrier prior to hydroelectric dams. Estimated 237 AMS were counted during American eel surveying in 2018.	Eagle Creek RE relicensing report 2020: https://www.eaglecreekre.com/facilities/operating-facilities/mongaup-river-hydroelectric-system/mongaup-river-relicensing-information ; National Park Service (Jessica Newbern - pers. comm.)
Neversink River (NY)	408	Y (below Cuddebackville Dam)	Y (below Cuddebackville Dam)	Y(14km+)							None	Small seine shad fishery in early 1800s. All historic mainstream habitat accessible and shad spawning run confirmed. Cuddebackville Dam removed in 2004 at RKM 16. High quality habitat.	Howritz et al. 2008; Gumaer 1890;
Adams Creek	386			Y*								Shad were found in Adams Creek according to ANS Delaware River (NPS) Gap Fisheries report (based on a survey by Chittenden in early 1990's). Likely lower 1/2 mile because high gradient stream.	Horwitz et al. 2014
Flat Brook (NJ)	362	Y (10km)		Unknown?								Minor shad run.	Compton 1963
Brodhead Creek (PA)	343			Y							Brodheads Creek Dam (PA_1195188); Mill Creek Rd Dam in East Stroudsburg; McMichael Creek Mill Dam (PA_45-029)	Current fishing logs mention shad in lower reaches. Brodheads Creek Dam is breached and shad able to pass upstream to Mill Creek Rd Dam in East Stroudsburg. Exceptional water quality; prone to flooding.	http://www.paflyfish.com/forums/Open-Forums/Warm-Water---Salt-Water-Fly-Fishing/Shad-on-the-Brodhead/16,46369.html
Paulins Kill (NJ)	333	Y		Y (16km)	Y			Y		Y	Paulina Lake Dam (NJ_NJ00170); County Line Dam (NJ_21-33)	Historic shad run documented in 1700s prior to damming of river. Current shad run up to Paulina Lake dam following removal of Columbia Lake Dam in 2018. TNC and partners looking to remove next two dams, the Paulina Lake and County Line.	NJ Freshwater Fisheries Report 2017: https://www.njfishandwildlife.com/pdf/fwfisheries/reports/annualreport17_appendices.pdf ; Cummings 1964
Pequest River (NJ)	318			Y							E.R. Collins & Sons Dam (NJ_24-28); E.R. Collins & Sons Dam (NJ_24-29);	Shad are in lower Pequest near confluence with Delaware River. Lower dams in Belvidere block shad and cause flooding issues.	https://www.nj.gov/dep/newsrel/2005/05_0061.htm
Lehigh River (PA)	295	Y (58km+)		Y (38km?)			Y?			Y?	Easton Dam (PA_48-012); Chain Dam (PA_48-013); Hamilton Street Dam (PA_39-009); Cementon Dam (PA_39-060)	Historic fisheries with large run prior to construction of dams and canals. Current shad distribution possible to Northampton Dam (38km) where there is no fish passage. Lower three dams have fishways, but they are somewhat ineffective. Additional habitat impacts include: lack of riparian vegetation (lower section); sediment deposition (lower section); metal contaminants. Easton averaged 1459 shad passing fish ladder from 2004-2018 (Post 2012 data is estimated from electro-fishing below dam). Shad juveniles present. River herring present in low numbers.	PFBC 2012; Arnold and Pierce 2007
Jordan Creek (PA)		Y										Shad - "plump hordes of spawning shad" noted along Jordan St in Allentown in 1740s. Jordan Creek Dams removed in 2013.	Annual Proceedings of the Lehigh County Historical Society 1962; https://www.wfmz.com/features/historys-headlines/historys-headlines-gone-fishin/article_a3f0e7bc-2f2d-11eb-805f-3b54263a1546.html
Little Lehigh Creek (PA)		Y										Shad - "plump hordes of spawning shad" noted along Jordan St in Allentown in 1740s. Little Lehigh Creek Dams removed in 2013.	Annual Proceedings of the Lehigh County Historical Society 1962; https://www.wfmz.com/features/historys-headlines/historys-headlines-gone-fishin/article_a3f0e7bc-2f2d-11eb-805f-3b54263a1546.html
Musconetong River (NJ)	281	?		Y (9.5km)			?			Y	Warren Mill Dam (NJ_NJ00765); Bloomsbury Dam (NJ_24-6); Asbury Mill Dam (NJ_NJ00581)	5 dams removed between 2008-2016 by Musconetcong Watershed Partnership. Support from state and dam owner for removal of Warren Mill Dam, which has been reported as a safety hazard since 1981 and has shad at base. Cost of ~$20M to remove due to sediment buildup behind dam. Upstream designated as Wild and Scenic River. Blueback herring also present downstream of Warren Mill Dam.	https://www.state.nj.us/dep/nrr/restoration/bloomsbury-dam.html; USFWS (Danielle Mcculloch - pers. comm.); The Nature Conservancy
Cooks Creek (PA)	280								Y	Y		Workers at paper plant near the mouth would catch Blueback Herring using screens. Known spawning. Dam was removed near confluence with Del Riv in early 2000s	PFBC (Mike Kauffman - pers. comm.)

Delaware River Tributaries	RKM	Pre-1950 Shad Run	1950-1990 Shad Run	1990-2020 Shad Run	Pre-1950 AW Run	1950-1990 AW Run	1990-2020 AW Run	Pre-1950 BBH Run	1950-1990 BBH Run	1990-2020 BBH Run	Relevant Barriers	Comments	Data Sources (links to soures included here or as reference listed in literature cited section)
Gallows Run (PA)	277								Y?	Y?		Blueback Herring believed to be present here in 2000s, but questionable source (fisherman). Gallows Run is not blocked by the canal as are some other streams.	PFBC (Mike Kauffman - pers. comm.)
Tohickon Creek (PA)	253.5								Y		Myers Dam (PA_09-020); Nockamixon (PA_PA00734)	Blueback Herring were present in Geddes Run in early 1980s. Law enforcement case where people were successfully brush seining for herring. Releases from Nockamixon Reservoir (Nockamixon Dam) popular for whitewater.	PFBC (Mike Kauffman - pers. comm.)
Paunnacussing Creek (PA)	251								Y		Solebury Farm (PA_09-015)	Blueback Herring spawning run here until mid-1990s. Property owner on north side of creek would document spawning runs.	PFBC (Mike Kauffman - pers. comm.)
Lockatong Creek (PA)	248					Y						Alewife confirmed at Lockatong Creek above Rt 29 in 1976.	Zich 1978
Fiddlers Creek	231					Y						Alewife confirmed at Rt 29 (mouth) in 1975.	Zich 1978
Jacobs Creek (NJ)	226					Y						Alewife confirmed at Rt 29 (mouth) in 1975.	Zich 1978; NJ DEP 2020
Assunpink Creek (NJ)	215					Y						RH - alewife confirmed in 1975 at Warren Street in Trenton; American eel confirmed in NJFW IBI on Shabakunk Ck in 2014	Zich 1978; NJFW IBI 2014
Crosswicks Creek (NJ)	206	Y		Y	Y		Y	Y		Y	Gropp Lake Dam (NJ_NJ00235)	Crosswicks was clear for fish passage in mainstem in late 1800s. Creek is generally in good condition. American Shad run in lower section of river. Alewife and Blueback Herring confirmed in 1975, and also in 2007 at Rt 206.	Zich 1978; Fowler 1907; NJFW 2012;
Blacks Creek (NJ)	206	Y		Y	Y		Y				Dunns Mill Dam (NJ_28-11)	Alewife and American Shad confirmed at West Burlington St in 2007.	NJDEP 2012;
Assiscunk Creek (NJ)	191	Y		Y	Y		Y				None	Water quality generally good and no dams evident in watershed. Shad and Alewife confirmed at Rt 130 in 2004.	Zich 1978; NJDEP 2005a, 2012;
Neshaminy Creek (PA)	186	Y		Y	Y*		Y	Y*	Y	Y	Hulmeville Park Dam (PA_09-084); Neshaminy Falls Dam (PA_09-003; Spring Garden (PA_09-083); Neshaminy Weir Dam (PA_09-167)	Gay 1892 writes that shad frequent this stream. American Shad, Alewife, and Blueback Herring run up to base of Hulmeville Park Dam and spawn in lower section of river. YOY shad and river herring documented in 2014 and 2017 (with Blueback Herring noted as abundant). Considered important nursery habitat for alosines. Creek is suceptible to flooding, sewage discharge, and sediment and nutrient loading.	Gay 1892; DRBFMC 1985; PFBC Darby + Neshaminy LMB Survey 2014; PFBC https://pfbc.pa.gov/images/reports/2015bio/6x08_28darbynesh.pdf (Tyler Grabowski, John Buzzar - pers. comm.); ANS (Dave Keller - pers. comm.);
Rancocas Creek (NJ)	179	Y (25km+)	Y	Y (2014)	Y		Y	Y		Y	Mill Dam (NJ_NJ00540); Smithville Dam (NJ_NJ00043); Vincentown Mill Dam (NJ_NJ00396); Kirbys Mill Dam (NJ_NJ00634)	Listed as good shad river in 1896 PA Fisheries Report with runs 15-20 miles up. American Shad in Rancocas between Centreton and Rancocas Park around 1950. Largest watershed in south central NJ. 2013 and 2014 NJ F&W seine samples found juvenile shad in Rancocas. Mill Dam at Mt Holly is impassable. Fowler Fishes of New Jersey 1900-1908 report Alewife in Rancocas to Hainesport; NJFW sampling confirmed spawning Alewife and Blueback Herring in Rancocas and two branches in 2014 (and since 1975).	Pennslyvania Fisheries Report 1896;; Mansueti & Kolb 1953; ANS (Dave Keller - pers. comm.); Fowler 1907; NJDEP (pers. comm.)
North Branch Rancocas Creek (NJ)							Y			Y		Alewife in North Branch in 1975.	Zich 1978
South Branch Rancocas Creek (NJ)					Y		Y	Y		Y		Alewife and Blueback Herring in South Branch in 1975.	Zich 1978
Pennsauken Creek (NJ)	169	?		N	Y			Y		Y	Moorestown Dam (NJ_NJ00635)	Small watershed with impacts from nutrients, PCBs. Blueback Herring confirmed at RR Bridge Crossing in 1997.	NJFW 2012;
Cooper River (NJ)	163	Y		Y	Y			Y		Y	Cooper River Parkway (Kaighn Ave) Dam (NJ_NJ00393); Cooper River Lake Dam (Cuthbert Ave); Wallworth Pond Dam (NJ_31-58); Evans Pond Dam (NJ_NJ00394)	Listed as good shad river in 1896 PA Fisheries Report. Fish ladder at Cooper River Lake with confirmed American Shad. Blueback Herring confirmed at NB at Park Blvd in 2016	Zich 1978; NJDEP 2012; Pennslyvania Fisheries Report 1896; NJ F&W (Brian Neilan - pers. comm.)
Newton Creek (NJ)	155.5						Y			Y	Newton Lake Dam (NJ_31-74) - *has fish passage*	River herring confirmed at Newton Lake Dam in 2003.	NJDEP (pers. comm.)
Big Timber Creek (NJ)	154	Y (25km+)		Y	Y		Y	Y		Y	Blackwood Lake Dam (NJ_NJ00800); Laurel Springs Dam (NJ_NJ00400)	Listed as great shad river in 1896 PA Fisheries Report with runs 15-20 miles up and fisheries.10,400 shad yield in 1896. Fowler Fishes of New Jersey 1900-1908 reported Alewife in south branch to Blackwood; 2003 - American Shad, Alewife, and Blueback Herring confirmed at Clements Bridge Rd. Historic water quality issues, development, Tidal Gate at Glendora. No dams before split into South and North branches.	Zich 1978; Fowler 1907; NJDEP 2012; Pennslyvania Fisheries Report 1896; Stevenson 1898; NJ F&W (Brian Neilan - pers. comm.)
Schuylkill River (PA)	149	Y (193km+)	Y (post-1979)	Y (2018)		Y	Y		Y	Y	Fairmount Dam (PA_51-002); Flat Rock Dam (PA_PA00896); Norristown Dam (PA_46-001); Black Rock Dam (PA_46_027) - all have fish passage however only Fairmount is maintained and monitored; New Kernsville Dam (PA_PA00723); Auburn Dam (PA_PA00670)	Shad historically migrated 193km up the Schuylkill to Pottsville, PA. Passage issues at lower 4 dams with fishways. In 2018, only 624 shad passed Fairmount fishway, with average of 1460 annually between 2009-2019. Invasives (Bluehead catfish; Northern snakeheads) prey on migrating Alosines below Fairmount Dam. Single digit passage of shad at Black Rock Dam (2011-18). Juvenile shad present. Alewife and Blueback Herring present at Fairmount in 1970s; limited passage currently with 140 river herring passing in 2015.	DRBFWMC,2019; PFBC 2012; DRBFWMC 1985; PFBC (Ben Lorson, Josh Tryninewski - pers. comm.); PWD (Joe Perillo - pers. comm.)
Wissahickon Creek (PA)		Y (Ambler, PA)									Grant Street Dam (PA_15-019); Robeson-Vandaren Mill Upper (PA_51-018)	History of Ambler document notes shad fishing as far as Ambler, PA. Habitat impacts include elevated nutrients, siltation, low DO, oil & grease, pathogens, non-native and invasive riparian species. Two dams right near confluence with Schuylkill. Flooding an issue.	2010 Wissahickon Creek Feasibility Study; Early History of Ambler, 1682-1888

Delaware River Tributaries	RKM	Pre-1950 Shad Run	1950-1990 Shad Run	1990-2020 Shad Run	Pre-1950 AW Run	1950-1990 AW Run	1990-2020 AW Run	Pre-1950 BBH Run	1950-1990 BBH Run	1990-2020 BBH Run	Relevant Barriers	Comments	Data Sources (links to soures included here or as reference listed in literature cited section)
Perkiomen Creek (PA)		Y									Wetherill Dam (PA_46-050); Indian Head Dam (PA_46-051)	Historic shad fishery located at mouth of Perkiomen Creek. Wetherill Dam used for water supply and is barrier to passage.	Pennslyvania Fisheries Report 1896;
Pickering Creek (PA)		Y									Pickering Creek Dam (PA_1194555)	Fishery at mouth of Pickering Creek in 1730s. Pickering Creek Dam (water supply) completely cuts off watershed.	Pennslyvania Fisheries Report 1896;
French Creek (PA)		Y									Phoenixville Dam (PA_15-200)	Shad fishery mentioned in 1896 PA Fisheries report.	Pennslyvania Fisheries Report 1896;
Woodbury Creek (NJ)	147	Y			Y					Y	Woodbury Creek Dam (NJ_NJ00398) *- has fish passage*	Listed as good shad river in 1896 PA Fisheries Report. Lowermost dam has fish ladder. Smaller watershed. Blueback Herring confirmed here in 2004. ANS noted juvenile alosines during summer 2021 sampling.	Zich 1978; NJDEP 2012; Pennslyvania Fisheries Report 1896;; ANS (Dave Keller - pers. comm.)
Mantua Creek (NJ)	144	Y		Y	Y		Y	Y			Bethel Lake Dam (NJ_NJ00406)	2,000 shad reported in 1896; Zich confirmed them in Mount Royal in lower section of Mantua Creek. Shad occupy lower part of river. Fowler Fishes of New Jersey 1900-1908 report Alewife in Mantua Creek to Wenonah;Alewife and Blueback Herring in Mantua to NJ Turnpike Bridge in 1978. Alewife confirmed at Mantua Ave in 2007.	Zich 1978, Fowler 1907; NJFW 2012; Stevenson 1898;
Darby Creek (PA)	138		N	Y			Y			Y	None	Barriers have been removed. Snakeheads present in Darby. Shad found at 84th St Bridge in John Heinz National Wildlife Refuge in 2010. Likely minor/limited to lower part. YOY Blueback Herring observed during electrofishing in 2014 by PFBC; ANS noted juvenile alosines during summer 2021 sampling.	PFBC Darby + Neshaminy LMB Survey 201: https://pfbc.pa.gov/images/reports/2015bio/6x08_28darbyn esh.pdf; PFBC (Mike Kauffman, John Buzzar - pers. comm.); ANS (Dave Keller - pers. comm.)
Chester Creek (PA)	133.5	Y		Y							Rockdale Dam (PA_23-004)	Shad noted as plentiful in account from 1683. 2007/2008 PFBC Surveys: numerous American shad fingerlings, one striped bass fingerling, and blue crabs in Chester Creek. American shad utilize the Chester/Upland portion of Chester Creek as nursery water and migrate to the Atlantic Ocean in fall. Chester Creek had been previously unknown as American shad nursery water.	Pennslyvania Fisheries Report 1896; PA Fish and Boat Commission 2007-2008 Fisheries Report: https://pfbc.pa.gov/images/fisheries/afm/2008/6x09_08ww cw.htm
Repaupo Creek (NJ)	132.5	Y									Warrington Mill Dam (NJ_NJ00114)	Shown as historic run in 1985 Coop Fishways Report. Flood gate at mouth.	DRBFWMC 1985
Raccoon Creek (NJ)	128	Y		Y	Y		Y	Y			Mullica Hill Pond Dam (NJ_NJ00639) - has fish passage	Historic shad fishery, with 4,800 shad reported in 1896. American Shad confirmed at Rt 130 in 1994. Fowler Fishes of New Jersey 1900-1908 reported Alewife in Raccoon to Bridgeport. Blueback Herring at Swedesboro in 1975. Alewife confirmed in 2005 at Tomlin Station Rd and 2007 at Mullica Hill Pond. ANS noted juvenile alosines during summer 2021 sampling.	Zich 1978, Fowler 1900; NJDEP 2012; Pennslyvania Fisheries Report 1896; Stevenson 1898; ANS (Dave Keller pers. comm.)
Oldmans Creek (NJ)	122	Y		N	Y		Y				Harrisonville Dam (NJ_NJ00105)	Listed as good shad river in 1896 PA Fisheries Report. No American Shad found in recent sampling. Alewife at Rt 74 in 1974 and at Pedricktown Rd in 2007. Upper part of watershed has agricultural impacts.	Zich 1978; NJDEP 2012; Pennslyvania Fisheries Report, 1896;
Christina River (DE)	113	Y		Y (2018)			Y (2018)			Y (2018)	Christina Lake Dam (DE_18); aka Smalleys Pond Dam; Cooch's Mill Dam (DE_24)	Historic fisheries, with 2,900 shad in 1896. Haul seine sampling in lower Christina River and tidal Brandywine returns YOY American Shad, Blueback Herring, and Alewife.	Pennslyvania Fisheries Report 1896;; Park and Stangl 2021;
Brandywine Creek (DE)		Y		Y	Y		Y (reported in 2020 at Dam #2)			Y	Broom Street Dam (DE_13); Dam #3/O'Neill (DE_12); Alapocas Run Park Dam (DE_11); Brandywine Falls Dam (DE_10); DuPont Dam (DE_8/DE_9); Breck's Mill/Walker's Mill Dam (DE_7); Lower Hagley Dam (DE_6); Upper Hagley Dam (DE_emadd02); Eleutherian Dam (DE_5); Brandywine Creek/Rocklands Mill Dam (DE_101)	Historically supported very large shad runs. Currently supports a very small run, but YOY shad were found below Broom Street Dam following removal of West Street Dam (Dam #1) in 2019. Dam removals and fishways planned for remaining 10 dams. Algal buildup due to dams. Fishermen reported Alewife run to I-95 bridge in March 2020.	Park 2021; Gay 1892; PA Fish and Boast Commission 2007-2008 Fisheries Report: https://pfbc.pa.gov/images/fisheries/afm/2008/6x09_08ww cw.htm; Brandywine Shad 2020
White Clay Creek (DE)		Y		Y (6.5km)	Y		Y				Red Mill Dam (DE_23); Karpinski Park Dam (DE_emadd05); Paper Mill Dam (DE_22); Newark Intake Dam (DE_emadd06); Creek Road Dam (DE_emadd07); Deerfield Dam (DE_emadd08); White Clay Creek Preserve (PA_15-377)	Historic shad run and abundant alosines (including American Shad, Blueback Herring, and Alewife) during sampling in 2010. Byrnes Mill Dam removed in 2014, but reports that shallow depths and sediment might still impede fish passage here, especially during low tides. No shad present between removed Byrnes Mill Dam and existing Red Mill Dam in 2016+2017 during sampling. Dam removals and fishways planned for next 4 dams, with high potential for improving passage.	Park and Stangl 2021; (Mike Stangl - pers. comm.)
Salem River (NJ)	94	Y		N	Y						Flood gates	Listed as good shad river, with 8,000 shad in 1896. Alewife at Beaverdam in 1976. Multiple flood gates near confluence with Delaware. Upper part of watershed has agricultural impacts.	Zich 1978; NJDEP 2012; Stevenson 1898; Pennslyvania Fisheries Report, 1896;
Alloway Creek (NJ)	87	Y		N (?)	Y	Y					Alloway Lake Dam (NJ_NJ00038), Elkinton Pond Dam (NJ_NJ00102)	300 shad yield in 1896. Alewife confirmed in 1974 at Alloway Lake Dam and Elkinton Pond Dam.	Zich 1978; NJDEP 2012; Stevenson 1898;
Appoquinmink River (DE)	82	Y		?			Y			Y	Noxontown Pond Dam (DE_36); Silver Lake Dam (DE_35) - have fish passage	350 shad yield in 1896. Two American Shad caught in 2017 approximately 1.2 km downriver of the spillway, which is just above the Rt 1/Rt 13 bridges. ZAlewife and Blueback Herring pass the fishway in low numbers. Water quality: DO, nutrients.	Boucher and Stangl 2020; DNREC (Mike Stangl - pers. comm.)
Blackbird Creek (DE)	81	Y		?							Blackbird Pond Dam (DE_38)	Current status unknown. Water quality: DO, nutrients.	

Delaware River Tributaries	RKM	Pre-1950 Shad Run	1950-1990 Shad Run	1990-2020 Shad Run	Pre-1950 AW Run	1950-1990 AW Run	1990-2020 AW Run	Pre-1950 BBH Run	1950-1990 BBH Run	1990-2020 BBH Run	Relevant Barriers	Comments	Data Sources (links to soures included here or as reference listed in literature cited section)
Duck Creek / Smyrna River (DE)	72	Y		?							Duck Creek Pond (DE_40), Lake Como Dam (DE_41)	Current Status unknown. Fisheries on Duck Creek at Smyrna and Walker in 1896 yielded 1,500 shad. Water quality: DO, nutrients	Stevenson 1899;
Stow Creek (NJ)	68						Y			Y	Davis Millpond Dam ()	Alewife confirmed at Davis Millpond Dam in 2004 and Blueback Herring confirmed at Jericho Pond Dam in 2003.	NJDEP 2012
Cohansey Creek (NJ)	61	Y		N?	Y	Y	Y	Y	Y	Y	Sunset Lake Dam (NJ_NJ00063); Sheppards Mill Pond Dam (NJ_NJ00072); Clarks Pond Dam (NJ_NJ00071)	Cohansey used to be third largest shad fishery in the state, after Hudson and Delaware. 21,850 shad yield in 1896. No current shad run. Alewife and Blueback Herring confirmed at Sunset Lake Dam in 1974. Fish ladder at Sunset Lake Dam (built by PSEG) said to pass more Alewife than other Estuary tribs. Blueback Herring confirmed in 2004.	Report of the Commissioner - United States Commission of Fish and Fisheries: https://ia802707.us.archive.org/5/items/reportofcommissi181892unit/reportofcommissi181892unit.pdf : Zich 1978, ASMFC 2017; Stevenson 1898; NJ F&W Marine Fisheries (Brian Neilan - pers. comm.)
Leipsic River (DE)	55	Y		?			Y			Y	Garrisons Lake Dam (DE_43) - has fish passage, Masseys Mill Pond Dam (DE_42)	Current status unknown. Fisheries from mouth to city of Leipsic yielded about 3,000 shad in 1896. No shad recorded at Garrisons Lake Dam. Alewife and Blueback Herring pass fishway in low numbers. Water quality: nutrients DO.	Boucher and Stangl 2020; Stevenson 1899;
Cedar Creek (NJ)	53						Y			Y	Cedar Lake Dam (NJ_NJ00069)	Alewife and Blueback Herring confirmed at Cedar Lake Dam in 2004.	NJDEP 2012: https://www.njfishandwildlife.com/pdf/fwfisheries/reports/annualreport12.pdf
Little River (DE)	45	Y		?							None	Current status unknown. Considered an important shad stream in 1940s. Undammed.	Mansueti & Kolb 1953
St. Jones River (DE)	38	Y		Y*			Y			Y	Silver Lake Dam (DE_45); Moores Lake Dam (DE_47) - have fish passage	Shad fisheries in 1896 at Lebanon, Cherrytree Landing, and Dover took about 3000 shad. 2 AMS found in fish ladder at Moore's lake 2012. Blueback Herring and Alewife pass Silver Lake Dam fishway in low numbers. Water quality: nutrients, DO.	Boucher and Stangl 2020; Stevenson 1899;
Murderkill River (DE)	37	Y		?			Y			Y	Courseys Pond Dam (DE_54); McColleys Pond Dam (DE_55); McGinnis Pond Dam (DE_51) - have fish passage	Shad fisheries at Fredericka in 1896 yielded 8,700 shad. Current status unknown, but no shad recorded at fish ladders. A total of 244 Blueback Herring and 131 Alewife were passed (Courseys Pond Dam) in 2017, with 1,364 Blueback Herring and 42 Alewife in 2018, and 358 Blueback Herring and 1 Alewife in 2019. Water quality: nutrients, DO.	Boucher and Stangl 2020; Stevenson 1899;
Maurice River (NJ)	34	Y	Y (1950, 1978)	Y*	Y		Y	Y		Y	Union Lake Dam (NJ_NJ00448); Willow Grove Dam (NJ_NJ00040); Rainbow Lake Dam (NJ_NJ00751) - have fish passage	Historically supported extensive shad fisheries. Current status unclear - juveniles caught in seine 2013-15, but none in 2016. Shad believed to be present in lower section of river. Union Lake Dam has fish passage but is ineffective at passing alosines. Sampling from 2013-2016 demonstrates both adult and juvenile Blueback Herring and Alewife in Maurice below Union Lake.	NJDEP, NJFWS 2012: https://www.njfishandwildlife.com/pdf/fwfisheries/reports/annualreport12.pdf ; DRBFWMC 2019; NJ F&W Marine Fisheries (Brian Neilan - pers. comm.)
West Creek (NJ)	25					Y	Y				West Creek Dam (NJ_NJ00629)	Alewife confirmed in 1974 at Rt 47, but none present in 2004 sampling at West Creek Dam. NJ DEP distribution data shows river herring past Hand Mill Dam.	Zich 1978; NJDEP 2005a
Dennis Creek (NJ)	23						Y				Johnson Pond Dam (NJ_NJ00128)	Alewife confirmed at Dennisville Lake (Johnson Pond) in 2013.	NJF&W 2012: https://www.njfishandwildlife.com/pdf/fwfisheries/reports/annualreport12.pdf
Mispillion River (DE)	19	Y		?			Y			Y	Silver Lake Dam (DE_61) - has fish passage; Haven Lake Dam (DE_60); Marshall Millpond Dam (DE_62)	Current Status Unknown. Shad fishery in 1896 at and around Milford, DE yielded 50,000 shad. Blueback Herring and Alewife pass Silver Lake Dam fishway in low numbers. No shad found at Silver Lake fish ladder. Water quality: nutrients, DO.	Boucher and Stangl 2020; Stevenson 1899;
Broadkill River (DE)	0	Y		Y			Y			Y	Wagamons Pond Dam (DE_69) - has fish passage; Diamond Pond Dam (DE_68); Red Mill Pond Dam (DE_71)	Shad were not present before being stocked here in 1880s.No shad in recent samples, though AMS recorded in spillway by anglers. A total of 1,164 Blueback Herring and 9 Alewife were passed in 2017, increasing to 2,594 Blueback Herring and 142 Alewife in 2018. In 2019 passage of Blueback herring increased to 3,481 while only 1 Alewife passed.Water quality: DO, nutrients.	Boucher and Stangl 2020; Stevenson 1899; Mansueti & Kolb 1953;

Appendix C

Alosine Habitat Suitability Assessment in Tributaries Identified for Restoration in the Delaware River Basin

The Academy of Natural Sciences of Drexel University (ANS) assessed the habitat suitability for American Shad, Alewife, and Blueback Herring in 16 tributaries identified as having the most potential for alosine restoration. The full report is included in this appendix.

Alosine habitat suitability in tributaries identified for restoration in the Delaware River Basin: an application of temperature, dissolved oxygen, and pH criteria

Report to:

The Nature Conservancy

Award ID: A105719

Subaward Number: SA040120_A105719

David H. Keller

Patrick Center for Environmental Research
The Academy of Natural Sciences of Drexel University
1900 Benjamin Franklin Parkway
Philadelphia, PA 19103

September 30, 2021

Introduction

The Academy of Natural Sciences (ANS) assessed the habitat suitability for American Shad, Alewife and Blueback Herring in 16 tributaries identified as having the most potential for alosine restoration (priority tributaries). ANS assessed the suitability of habitat of priority tributaries for the spawning, egg, larval, and early-juvenile stages of each alosine species. We identified and compiled key habitat suitability criteria from Greene et al. (2009). For each priority tributary, ANS compiled temperature, dissolved oxygen and pH data from existing sources (e.g., USGS gaging stations, government agencies and public sources) to assess habitat quality for each species-stage combination. Following data compilation, we identified data gaps and assessed overall habitat suitability for each alosine species where existing data allowed.

This report contains:

1. A habitat suitability assessment of priority tributaries where barriers were identified by The Nature Conservancy (TNC). Streams were characterized using key habitat criteria for American Shad and river herring species. Criteria focused mostly on temperature-based metrics, but dissolved oxygen and pH-based metrics were used as well.
2. An identification of data gaps and assessment of overall habitat suitability for each alosine species-stage combination where existing data allowed.

Methods

Identifying priority tributaries for restoration

A list of priority tributaries was provided by TNC following a review of available literature and meetings with regional managers (Table 1).

Source of habitat suitability criteria

We reviewed literature for potential biocriteria to use for assessing tributary suitability for Alosines. Greene et al. (2009) provided a detailed summary of stage specific habitat suitability requirements for each alosine species-stage combination. This was the primary source of stage specific suitability criteria. Additional review of literature published after Greene et al. (2009) was also reviewed to identify other criteria. Our goal was not to exhaustively review the literature, rather to identify habitat suitability criteria or associations that could be acquired from readily available published and/or public sources. The metrics and criteria developed and applied here are not exhaustive.

Development of habitat suitability metrics

A total of 49 water quality-based habitat suitability measures were developed for American Shad, Alewife, and Blueback Herring, using stage specific temperature, dissolved oxygen, and pH optima and tolerances summarized by Greene et al. (2009) (Table 2). Of these metrics, 42 were unique, and 7 duplicated criteria used for another species-stage (e.g., egg, larval, and early-juvenile stage American Shad had the same dissolved oxygen criteria, and so one metric for this parameter was used to assess suitability). Variables such as depth and substrate and other variables identified by Greene et al. (2009) were not used to assess suitability because they were difficult or problematic to calculate from readily available datasets. Metrics were calculated using continuous datasets from stream gages that provided a sufficient number of measurements for characterizing the parameter and period identified in the metric description (Table 2).

Data acquisition and management

We acquired all USGS continuous temperature, dissolved oxygen, and pH data from gages listed within the priority tributaries identified by TNC (Table 1 and 3). Gages containing current water quality data were identified by reviewing all gages listed on the "National Water Information System: Web Interface" website (https://waterdata.usgs.gov/nwis/rt) from December 2020 to January 2021. Additionally, the USGS mapper tool was used to review and identify any relevant gage data that was not shown on the National Water Information System. In addition, temperature data were acquired from modelmywatershed.org. Datasets were identified by reviewing monitoring locations on the program's map tool. Datasets were plotted and reviewed for data completeness and reasonableness. All datasets within the priority tributaries were downloaded providing the data were reasonable (did not have erroneous data or obvious outliers). Obvious outliers, flagged, and erroneous data were removed. Most datasets were of good quality, requiring little to no modification. A few of the datasets identified were not downloaded because they did not meet the criteria stated above. All "Model My Watershed" datasets were downloaded from modelmywatershed.org January to February 2021 (Table 3).

We acquired data from NJDEP DWM&S Continuous Data Monitoring Portal (https://njdep.rutgers.edu/continuous/) in April 2021. These data characterized short periods of time (typically multiple weeks) and were not suitable for fully characterizing seasonal conditions. However, these data were useful in identifying poor habitat suitability conditions that existed during these time periods (e.g., see Salem River suitability).

Data were housed in a custom-made database using Microsoft (MS) Access. Queries were written to calculate metrics. Query outputs were imported into MS Excel spreadsheets to create tables for assessing suitability in 16 priority tributaries that were identified by The Nature Conservancy (Table 1).

Results and Discussion

Habitat suitability metrics

We compiled a total of 7.5 million records from 71 stream gages and imported these into the project database to calculate 49 metrics. These metrics were based primarily on temperature, but also included criteria for dissolved oxygen and pH.

Data gaps

We found adequate temperature, pH, and dissolved oxygen data at 14, 6, and 5 tributaries, respectively (Table 1). The majority of the 16 priority tributaries lacked continuous pH and dissolved oxygen data. When available, dissolved oxygen and pH data were limited spatially within tributaries; typically, available at one location and at the largest gage in the tributary (Table 3; see Appendix 1-28). Continuous pH and dissolved oxygen data were available for four of the larger priority tributaries identified; the Schuylkill River, Lehigh River, Brandywine Creek, and the Broadkill River. Continuous pH and dissolved oxygen monitoring at other locations within these priority tributaries would be useful to provide improved spatial coverage to better assess suitability. For example, the variability observed in water temperatures among the upper and lower Schuylkill River, suggests dissolved oxygen conditions may not be uniform. Also, additional continuous pH and dissolved oxygen monitoring in the 11 priority tributaries lacking these data, and temperature monitoring in some others, would be useful to better characterize and assess suitability for alosines.

For two tributaries, Chester Creek and Oldmans Creek, little to no adequate data for calculating metrics were available (Table 1). Monitoring temperature, pH, and dissolved oxygen in these priority tributaries is needed to assess suitability for alosines. Additional descriptions of data gaps are provided in the "*Suitability of habitat for Alosines by priority tributary"* section below.

Although modelmywatershed.org provided useful datasets for assessing temperature suitability, the site did not provide any standardized quality assurance of datasets at the time of this work. Therefore, all data from modelmywatershed.org were considered provisional or raw. Additionally, some of these data required post processing to remove obvious outliers.

Suitability of habitat for Alosines by priority tributary

Metrics were compiled for each alosine species-stage combination for each priority tributary and used in a semi-quantitative assessment of habitat suitability (Table 1). For most priority tributaries, data from multiple gages were considered. Typically, gages on larger watersheds were weighted more heavily when subjectively assigning suitability categories for species-stage combinations.

Sixteen priority tributaries were assessed for their suitability to support twelve alosine species-stage combinations. A narrative interpretation of the habitat suitability and data gaps for each species-stage combination by priority tributary is summarized below and in Table 1. Based on similarity, tributaries were grouped into four tiers for overall temperature suitability, three tiers for overall pH suitability, and two tiers for overall dissolved oxygen suitability (Table 1). Tiers were developed to ease interpretation and aid in relative comparisons among the 16 priority tributaries.

1. Schuylkill River

American Shad

a. Spawning adult

1. Temperature – Spring water temperatures were optimal for adult spawning at all gages and during all years, except in Philadelphia at gage

1474500 in 2020. At this gage, in 2020, temperatures were within the optimal range only 47.2% of the time (Appendix 1 and 2).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 100% of the time (Appendix 3).

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for egg development 99.1-100% of the time, with 7 out of 9 springs assessed being suitable 100% of the time (Appendix 3).

3. pH – The pH in the Schuylkill River was within the average tolerable (6.0-8.5) and tolerable (5.5-9.5) ranges for American Shad eggs 85.1-100% and 100% of the time, respectively. The pH was within the average tolerable range >90% of time 4 out of 9 springs assessed (Appendix 4). These data suggest that, in most years, there are substantial periods of time with intolerable pH conditions for egg development (Appendix 4).

c. Larvae

1. Temperature – Overall, spring water temperatures were optimal for larval development at most gages and in most years. However, some gages did indicate suboptimal conditions (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for larval development 99.1-100% of the time, with 7 out of 9 springs assessed being suitable 100% of the time (Appendix 3).

3. pH – The pH in the Schuylkill River was within the average tolerable (6.6-9.6) and tolerable (6.5-9.9) ranges of American Shad larvae 100% of the time (Appendix 4).

d. Early-juvenile

1. Temperature - Overall, summer water temperatures were optimal for early-juvenile development at most gages and in most years. However, some gages did indicate suboptimal conditions (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 97.3-100% of the time, with 6 out of 9 springs assessed being suitable 100% of the time (Appendix 3).

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Spring temperatures were suboptimal for adult spawning. However, some upper portions of the watershed, near Reading and Bernville, PA, provided optimal conditions for Alewife spawning (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 99.1-100% of the time, with 7 out of 9 springs assessed being suitable 100% of the time (Appendix 3).

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Spring temperatures were suboptimal for egg development and provided poor suitability at many gages and in any years (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for egg development 99.1-100% of the time, with 7 out of 9 springs assessed being suitable 100% of the time (Appendix 3).

3. pH – The pH in the Schuylkill River was within the optimal (5.0-8.5) range for Alewife egg development 83.2-100% of the time (Appendix 4). The pH was within the optimal range >90% of time 4 out of 9 springs assessed, and >80% in all 9 springs assessed (Appendix 4).

c. Larvae

1. Temperature - Spring temperatures were suboptimal for larval development and provided poor suitability at many gages and in many years (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for larval development 99.1-100% of the time, with 7 out of 9 springs assessed being suitable 100% of the time (Appendix 3).

3. pH – The pH in the Schuylkill River was within the optimal (5.0-8.5) range for Alewife larval development 83.2-100% of the time (Appendix 4). The pH was within the optimal range >90% of time 4 out of 9 springs assessed, and >80% in all 9 springs assessed (Appendix 4).

d. Early-juvenile

1. Temperature - Overall, summer water temperatures were poor for early-juvenile development at most gages and in most years. However, some gages did indicate suboptimal conditions in the upper portion of the watershed near Bernville and Phoenixville, PA. (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for early-juvenile development 100% of the time (Appendix 3).

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Overall, spring water temperatures were suboptimal for adult spawning at most gages and in most years. However, some gages did indicate poor conditions (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 99.1-100% of the time, with 7 out of 9 springs assessed being suitable 100% of the time (Appendix 3).

3. pH – The pH on the Schuylkill River was within the optimal (6.5-8.0) and suitable (6.0-8.0) ranges for spawning adult Blueback Herring 73.0-99.3% (Appendix 4). Only 4 out of 9 springs were optimal >90% of the time (Appendix 4). Although, conditions were optimal most of the time in all springs assessed, the pH conditions were less suitable relative to other tributaries (Table 1).

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development at most gages and in most years; note that only 1

tributary exhibited mostly tolerable temperatures for egg development (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 99.1-100% of the time, with 7 out of 9 springs assessed being suitable 100% of the time (Appendix 3).

3. pH – The pH on the Schuylkill River was within the optimal (6.0-8.0) and suitable (5.7-8.5) ranges for Blueback Herring eggs 73.0-99.3% and 83.2-100% of the time, respectively (Appendix 4). Only 4 out of 9 springs were optimal >90% of the time (Appendix 4). Although, conditions were optimal most of the time in all springs assessed, the pH conditions were less suitable relative to other tributaries (Table 1).

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 99.1-100% of the time, with 7 out of 9 springs assessed being suitable 100% of the time (Appendix 3).

3. pH – The pH on the Schuylkill River was within the optimal (6.5-8.0) and suitable (6.2-8.5) ranges for Blueback Herring larval development 73.0-99.3% and 83.2-100% of the time, respectively (Appendix 4). Only 4 out of 9 springs were optimal >90% of the time (Appendix 4). Although, conditions were optimal most of the time in all springs assessed, the pH conditions were less suitable relative to other tributaries (Table 1).

d. Early-juvenile

1. Temperature – Overall, summer water temperatures were optimal for early-juvenile development at most gages and in most years (Appendix 1 and 2 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for early-juvenile development 99.8-100% of the time, with 7 out of 9 springs assessed being suitable 100% of the time (Appendix 3).

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

2. Brandywine Creek

American Shad

a. Spawning adult

1. Temperature – Spring temperatures at most gages were optimal for adult spawning (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 100% of the time (Appendix 7).

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen - – Dissolved oxygen conditions were suitable for egg development 100% of the time (Appendix 7).

3. pH – The pH in the Brandywine River was within the average tolerable (6.0-8.5) and tolerable (5.5-9.5) ranges for American Shad eggs 85.7-100% and 100% of the time, respectively. The pH was within the average tolerable range >90% of time 15 out of 20 springs assessed (two gages with 10 springs each; Appendix 8). These data suggest that, in some years, there are periods of time with intolerable pH conditions for egg development (Appendix 8).

c. Larvae

1. Temperature – Overall, spring water temperatures were optimal for larval development at most gages and in most years (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for larval development 100% of the time (Appendix 7).

3. pH – The pH in the Brandywine River was within the average tolerable (6.6-9.6) and tolerable (6.5-9.9) ranges for American Shad larvae 99.9-100% and 100% of the time, respectively (Appendix 8).

d. Early-juvenile

1. Temperature - Summer water temperatures were optimal for early-juvenile development at all gages and years assessed (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for early-juvenile development 100% of the time (Appendix 7).

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Spring temperatures were suboptimal for adult spawning (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen - – Dissolved oxygen conditions were suitable for spawning 100% of the time (Appendix 7).

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Overall, spring temperatures were suboptimal for egg development, with poor conditions at some gages and in some years (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for egg development 100% of the time (Appendix 7).

3. pH – The pH in the Brandywine River was within the optimal (5.0-8.5) range for Alewife egg development 85.7-100% of the time (Appendix 8). The pH was within the optimal range >90% of time 5 out of 20 springs assessed (two gages with 10 springs each; Appendix 8). These data indicated optimal conditions for egg development in all years assessed (Appendix 8).

c. Larvae

1. Temperature – Overall, spring water temperatures were suboptimal for larval development (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for larval development 100% of the time (Appendix 7).

3. pH – The pH in the Brandywine River was within the optimal (5.0-8.5) range for Alewife larval development 85.7-100% of the time (Appendix 8). The pH was within the optimal range >90% of time 5 out of 20 springs assessed (two gages with 10 springs each; Appendix 8). These data indicated optimal conditions for larval development in all years assessed (Appendix 8).

d. Early-juvenile

1. Temperature - Overall, summer water temperatures were poor for early-juvenile development (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for early-juvenile development 100% of the time (Appendix 7).

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Overall, spring water temperatures were suboptimal for adult spawning at most gages and in most years (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 100% of the time (Appendix 7).

3. pH – The pH on the Brandywine River was within the optimal (6.5-8.0) and suitable (6.0-8.0) ranges for spawning adult Blueback Herring 64.4-98.8% of the time (Appendix 8). Only 3 out of 20 springs were optimal >90% of the time (two gages with 10 springs each; Appendix 8). Although, conditions were optimal most of the time in all springs assessed, the pH conditions were less suitable relative to other tributaries (Table Trib 3).

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development at most gages and in most years; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for egg development 100% of the time (Appendix 7).

3. pH – The pH on the Brandywine River was within the optimal (6.0-8.0) and suitable (5.7-8.5) ranges for Blueback Herring eggs 64.9-98.8% and 85.7-100% of the time, respectively (Appendix 8). Only 3 out of 20 springs were optimal >90% of the time (two gages with 10 springs each; Appendix 8). Although, conditions were optimal most of the time in all springs assessed, the pH conditions were less suitable relative to other tributaries (Table 1).

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for larval development 100% of the time (Appendix 7).

3. pH – The pH on the Brandywine River was within the optimal (6.5-8.0) and suitable (6.2-8.5) ranges for Blueback Herring larval development 64.9-98.8% and 85.7-100% of the time, respectively (Appendix 8). Only 3 out of 20 springs were optimal >90% of the time (two gages with 10 springs each; Appendix 8). Although, conditions were optimal most of the time in all springs assessed, the pH conditions were less suitable relative to other tributaries (Table 1).

d. Early-juvenile

1. Temperature – Overall, summer water temperatures were optimal for early-juvenile development at most gages and in most years (Appendix 5 and 6 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for early-juvenile development 100% of the time (Appendix 7).

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

3. White Clay Creek

American Shad

a. Spawning adult

1. Temperature – Spring temperatures were optimal for adult spawning at all gages and in all years (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were optimal for larval development at all gages and in all years (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Summer water temperatures were optimal for early-juvenile development at all gages and years assessed (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Overall, spring temperatures were suboptimal for adult spawning in most years. However, optimal conditions occurred in some years and at some gages (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Overall, spring temperatures were suboptimal for egg development, with poor conditions at some gages and in some years (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Overall, spring temperatures were suboptimal for larval development, and provided poor suitability at some gages or years (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Overall, summer water temperatures were poor for early-juvenile development (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Overall, spring water temperatures were suboptimal for adult spawning at most gages and in most years (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development at most gages and in most years; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Overall, summer water temperatures were optimal for early-juvenile development at most gages and in most years (Appendix 9 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

4. Red Clay Creek

American Shad

a. Spawning adult

1. Temperature – Spring temperatures were optimal for adult spawning for both years assessed (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 10 and Table 1).

2. Dissolved Oxygen

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were optimal for larval development for both years assessed (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Summer water temperatures were optimal for early-juvenile development for both years assessed (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Spring temperatures were optimal for adult spawning in the two years of gage data assessed (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Overall, spring temperatures were suboptimal for egg development, with one year exhibiting poor conditions (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring temperatures were suboptimal for larval development (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Overall, summer water temperatures were poor for early-juvenile development (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Overall, spring water temperatures were suboptimal for adult spawning at most gages and in most years (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development at most gages and in most years; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Overall, summer water temperatures were optimal for early-juvenile development at most gages and in most years (Appendix 10 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

5. Lehigh River

American Shad

a. Spawning adult

1. Temperature – Overall, spring temperatures were optimal for adult spawning; however, many gages indicated suboptimal conditions (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 100% of the time (Appendix 14).

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for egg development 100% of the time (Appendix 14).

3. pH – The pH on the Lehigh River was within the average tolerable (6.0-8.5) and tolerable (5.5-9.5) ranges for American Shad eggs 95.8-100% and 100% of the time, respectively (Appendix 15).

c. Larvae

1. Temperature – Overall, spring water temperatures were suboptimal for larval development at most gages and in most years (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for larval development 100% of the time (Appendix 14).

3. pH – The pH on the Lehigh River was within the average tolerable (6.6-9.6) and tolerable (6.5-9.9) ranges for American Shad larvae 100% of the time (Appendix 15).

d. Early-juvenile

1. Temperature – Summer water temperatures were optimal for early-juvenile development at all gages and in all years (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for early-juvenile development 100% of the time (Appendix 14).

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Overall, spring temperatures were optimal for adult spawning; however, many gages and years indicated suboptimal conditions (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 100% of the time (Appendix 14).

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Overall, spring temperatures were suboptimal for egg development, with some years and gages exhibiting poor conditions (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for egg development 100% of the time (Appendix 14).

3. pH – The pH on the Lehigh River was within the optimal (5.0-8.5) range for Alewife egg suitability 98.5-100% of the time, with 7 out of 10 springs being optimal 100% of the time (Appendix 15).

c. Larvae

1. Temperature – Spring temperatures were poor for larval development (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for larval development 100% of the time (Appendix 14).

3. pH – The pH on the Lehigh River was within the optimal (5.0-8.5) range for Alewife egg suitability 98.5-100% of the time, with 7 out of 10 springs being optimal 100% of the time (Appendix 15).

d. Early-juvenile

1. Temperature – Spring temperatures tended to be suboptimal for early-juvenile development with poor years at some gages (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for early-juvenile development 100% of the time (Appendix 14).

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Spring temperatures were poor for adult spawning and some gages indicated only mostly tolerable temperatures (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 100% of the time (Appendix 14).

3. pH – The pH on the Lehigh River was within the optimal (6.5-8.0) and suitable (6.0-8.0) ranges for spawning adult Blueback Herring 86.4-100% of the time, with only 3 out of 10 springs being optimal 100% of the time (Appendix 15).

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for egg development 100% of the time (Appendix 14).

3. pH – The pH on the Lehigh River was within the optimal (6.0-8.0) and suitable (5.7-8.5) ranges for Blueback Herring egg development 86.4-100% and 98.5-100% of the time, respectively (Appendix 15). The pH

was within the optimal range >90% of the time 9 out of 10 springs assessed (Appendix 15).

c. Larvae

1. Temperature – Overall, spring water temperatures were tolerable for larval development (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for larval 100% of the time (Appendix 14).

3. pH – The pH on the Lehigh River was within the optimal (6.5-8.0) and suitable (6.2-8.5) range for larval development of Blueback Herring 86.4-100% and 98.5-100% of the time, respectively (Appendix 15). The pH was within the optimal range >90% of the time 9 out of 10 springs assessed (Appendix 15).

d. Early-juvenile

1. Temperature – Overall, summer water temperatures were optimal for early-juvenile development. However, suboptimal or poor conditions were observed for some gages in some years (Appendix 11, 12, and 13 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for early-juvenile development 100% of the time (Appendix 14).

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

6. Neshaminy Creek

American Shad

a. Spawning adult

1. Temperature – Spring temperatures were optimal for adult spawning for both years assessed (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Overall, spring water temperatures were optimal for larval development (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Summer water temperatures were optimal for early-juvenile development for both years assessed (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Overall, spring water temperatures were suboptimal for adult spawning (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – On average, spring water temperatures were poor for egg development (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were suboptimal for larval development (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data
3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Spring water temperatures were poor for early-juvenile development (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Overall, spring water temperatures were suboptimal for adult spawning (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Overall, summer water temperatures were optimal for early-juvenile development (Appendix 16 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

7. Crosswicks Creek

American Shad

a. Spawning adult

1. Temperature – Spring temperatures were optimal for adult spawning at both gages assessed (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Overall, spring water temperatures were optimal for larval development (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Summer water temperatures were optimal for early-juvenile development at both gages assessed (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Overall, spring water temperatures were suboptimal for adult spawning (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – On average, spring water temperatures were poor for egg development (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were suboptimal for larval development (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Spring water temperatures were poor for early-juvenile development (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Overall, spring water temperatures were suboptimal for adult spawning (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Overall, summer water temperatures were optimal for early-juvenile development (Appendix 17 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

8. Pequest River

American Shad

a. Spawning adult

1. Temperature – Spring temperatures were optimal for adult spawning for all years assessed (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were optimal for larval development in all years assessed (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Summer water temperatures were optimal for early-juvenile development in all years assessed (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Spring temperatures were optimal for adult spawning for all years assessed (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Overall, spring temperatures were suboptimal for egg development (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Overall, spring temperatures were poor for larval development (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Overall, summer temperatures were optimal for early-juvenile development (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Spring water temperatures were mostly poor for adult spawning (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Summer water temperatures were suboptimal for early-juvenile development in most years assessed (Appendix 18 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

9. Musconetcong River

American Shad

a. Spawning adult

1. Temperature – Spring temperatures were optimal for adult spawning for all years assessed (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were optimal for larval development in at the largest gage for which there was data; suboptimal conditions were found at smaller gage, further upstream, on a tributary to the Musconetcong (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Summer water temperatures were optimal for early-juvenile development in all years and gages assessed (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – On average, spring temperatures were optimal for adult spawning (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Overall, spring temperatures were suboptimal for egg development, however, one gage indicated poor conditions (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Overall, spring temperatures were poor for larval development (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Overall, summer temperatures were suboptimal for early-juvenile development (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Spring water temperatures were mostly poor for adult spawning (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 19 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Summer water temperatures were mostly optimal for early-juvenile development, however, poor conditions were observed at some gages on smaller tributaries (Appendix 19 and Table 1). Poorer conditions are presumably due to colder water temperatures maintained by groundwater inputs.

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

10. Brodhead Creek

American Shad

a. Spawning adult

1. Temperature – Spring water temperatures were suboptimal for spawning adults (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were suboptimal for larval American Shad (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Summer water temperatures were optimal for early-juvenile American Shad (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Spring water temperatures were suboptimal for spawning adults (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Spring water temperatures were poor for egg development and were within the tolerable range 60.5% of the time, on average (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring temperatures were poor for larval development and mostly intolerable at the post larval stage (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – On average, summer temperatures were suboptimal for early-juvenile development, although, 1 gage did indicate mostly optimal temperatures (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Spring water temperatures were poor and mostly intolerable for Blueback Herring spawning (Appendix 20 and Table 1). Temperatures in Brodhead Creek were the least suitable for Blueback Herring spawning relative to other tributaries assessed.

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

b. Egg

1. Temperature – Spring water temperatures were mostly tolerable for egg development. Brodhead Creek was the only tributary assessed where gages indicated mostly tolerable temperatures for egg development (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were intolerable for larval development (Appendix 20 and Table 1). Brodhead Creek was the only tributary assessed where gages indicated mostly intolerable temperatures for larval development (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – On average, summer temperatures were suboptimal for early-juvenile development, although, 1 gage did indicate mostly optimal temperatures (Appendix 20 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

11. Rancocas Creek

American Shad

a. Spawning adult

1. Temperature – On average, spring water temperatures were mostly optimal for American Shad spawning (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – On average, spring water temperatures were optimal for larval development (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Overall, spring water temperatures were optimal for early-juvenile development; however, many years and gages indicated suboptimal temperatures (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Spring water temperatures were suboptimal for spawning adults (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Across all gages, spring water temperatures were poor for egg development (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Overall, spring water temperatures were suboptimal for larval development (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Spring water temperatures were poor for early-juvenile development (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Overall, spring water temperatures were suboptimal for adult spawning at most gages and in most years (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development at most gages and in most years; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Overall, summer water temperatures were optimal for early-juvenile development at most gages and in most years (Appendix 21, 22, and 23 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

12. Oldmans Creek

American Shad

a. Spawning adult

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Jun 30 to July 14, 2016, showed that pH ranged 7.11-7.45 and averaged 7.32. Assuming these values are relatively stable throughout the year, these data indicate that the Oldmans Creek pH is likely within the average tolerable (6.0-8.5) and tolerable (5.5-9.5) ranges for American Shad eggs.

c. Larvae

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Jun 30 to July 14, 2016, showed that pH ranged 7.11-7.45 and

averaged 7.32. Assuming these values are relatively stable throughout the year, these data indicate that the Oldmans Creek pH is likely within the average tolerable average tolerable (6.6-9.6) and tolerable (6.5-9.9) ranges of American Shad larvae.

d. Early-juvenile

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Jun 30 to July 14, 2016, showed that pH ranged 7.11-7.45 and averaged 7.32. Assuming these values are relatively stable throughout the year, these data indicate that Oldmans Creek pH is likely within the optimal (5.0-8.5) range for Alewife egg suitability.

c. Larvae

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Jun 30 to July 14, 2016, showed that pH ranged 7.11-7.45 and averaged 7.32. Assuming these values are relatively stable throughout the

year, these data indicate that Oldmans Creek pH is likely within the optimal (5.0-8.5) range for larval Alewife suitability.

d. Early-juvenile

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Jun 30 to July 14, 2016, showed that pH ranged 7.11-7.45 and averaged 7.32. Assuming these values are relatively stable throughout the year, these data indicate that Oldmans Creek pH is likely within the optimal (6.5-8.0) and suitable (6.0-8.0) range for spawning adult Blueback Herring.

b. Egg

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Jun 30 to July 14, 2016, showed that pH ranged 7.11-7.45 and averaged 7.32. Assuming these values are relatively stable throughout the year, these data indicate that Oldmans Creek pH is likely within the optimal (6.0-8.0) and suitable (5.7-8.5) range for Blueback Herring eggs.

c. Larvae

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Jun 30 to July 14, 2016, showed that pH ranged 7.11-7.45 and averaged 7.32. Assuming these values are relatively stable throughout the year, these data indicate that Oldmans Creek pH is likely within the optimal (6.5-8.0) and suitable (6.2-8.5) range for larval Blueback Herring.

d. Early-juvenile

1. Temperature – unable to assess; insufficient data

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

13. Chester Creek

Unable to assess; insufficient data or no data acquired.

14. Salem River

American Shad

a. Spawning adult

1. Temperature – Spring water temperatures were within the tolerable range for American Shad spawning during the three years for which there were data at gage KCCR1S, a gage on a tributary to the upper Salem River near Woodstown, NJ (Appendix 24). However, this location presented optimal spawning temperatures only 30.9% of the time in 2020. These data indicate that the suitability of water temperature for spawning at this location are variable and present suboptimal more than optimal conditions in some years.

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature - Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 24 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Aug 24 to Sept 7, 2017, showed that pH ranged 6.43-6.84 and averaged 6.62. Assuming these values are relatively stable throughout the year, these data indicate that the upper Salem River pH is likely within the average tolerable (6.0-8.5) and tolerable (5.5-9.5) ranges for American Shad eggs.

c. Larvae

1. Temperature – Spring water temperatures were usually within the tolerable range for American Shad larvae during the three years for which there were data at gage KCCR1S, (Appendix 24). However, this location presented optimal spawning temperatures only 19.0% of the time in 2020. These data indicate that the suitability of water temperature for eggs at this location is variable and presents poor more than optimal conditions in some years.

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Aug 24 to Sept 7, 2017, showed that pH ranged 6.43-6.84 and averaged 6.62. Assuming these values are relatively stable throughout the year, these data indicate that the upper Salem River pH is near the lower limit for the average tolerable (6.6-9.6) and tolerable (6.5-9.9) ranges of American Shad larvae.

d. Early-juvenile

1. Temperature - NJDWM&S continuous water monitoring data indicated that the upper Salem River temperature was suitable and within the optimum range for early-juvenile stage American Shad (i.e., 10-25°C). During a 14-day period from Aug 24 to Sept 7, 2017, temp ranged from 17.06 to 22.90°C and averaged 19.96 °C. This portion of the Salem River had optimal temperatures for early-juvenile stage American Shad 100% of the time based on the 14-day dataset. Temperature data from gage KCCR1S, a tributary to the upper Salem River at Woodstown, NJ also showed temperatures to be mostly within the tolerable and optimal ranges, indicating temperatures to be mostly optimal for early-juvenile development (Appendix 24).

2. Dissolved Oxygen - NJDWM&S continuous water monitoring data indicated that the upper Salam River was not suitable for early-juvenile stage American Shad (i.e., the DO was <5mg/l). During a 14-day period from Aug 24 to Sept 7, 2017, DO ranged from 0.85 to 5.91 mg/l and averaged 3.75 mg/l. This portion of the Salem River was suitable for

early-juvenile stage American Shad 15% of the time based on the 14-day dataset.

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Spring water temperatures were suboptimal for Alewife spawning (Appendix 24 and Table 1). Water temperatures were mostly within the tolerable range for Alewife spawning during the three years for which there were data at gage KCCR1S, a gage on a tributary to the upper Salem River near Woodstown, NJ (Appendix 24). However, this location presented suboptimal spawning temperatures during most of 2018 and 2020. These data indicate that the suitability of water temperature for spawning at this location are suboptimal.

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature - Water temperatures were mostly within the tolerable range for Alewife eggs during the three years for which there were data at gage KCCR1S, a gage on a tributary to the upper Salem River near Woodstown, NJ (Appendix 24). However, this location presented suboptimal and poor temperatures for egg development (Appendix 24 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Aug 24 to Sept 7, 2017, showed that pH ranged 6.43-6.84 and averaged 6.62. Assuming these values are relatively stable throughout the year, these data indicate that the upper Salem River pH is likely within the optimal (5.0-8.5) range for Alewife egg suitability.

c. Larvae

1. Temperature - Water temperatures were within tolerable ranges for Alewife larvae two out of three years for which there were data at gage KCCR1S, a gage on a tributary to the upper Salem River near

Woodstown, NJ (Appendix 24). In 2020, this gage recorded temperatures that were tolerable for larvae only 30.9% of the time (Appendix 24). This location presented suboptimal temperatures for larvae in two out of three years. These data indicate that the suitability of water temperature for larvae at this location are highly variable and suboptimal about half of the time.

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Aug 24 to Sept 7, 2017, showed that pH ranged 6.43-6.84 and averaged 6.62. Assuming these values are relatively stable throughout the year, these data indicate that the upper Salem River pH is likely within the optimal (5.0-8.5) range for larval Alewife suitability.

d. Early-juvenile

1. Temperature - NJDWM&S continuous water monitoring data indicated that the upper Salem River temperature was within the tolerable range for early-juvenile stage Alewife (i.e., 10-28ºC) 100% of the time based on the 14-day dataset. During a 14-day period from Aug 24 to Sept 7, 2017, temp ranged from 17.06 to 22.90ºC and averaged 19.96ºC. This portion of the Salem River had optimal temperatures for early-juvenile stage Alewife (15-20ºC) 56% of the time based on the 14-day dataset.

Water temperatures were mostly within the tolerable range for early-juvenile development during the three years for which there were data at gage KCCR1S, a gage on a tributary to the upper Salem River near Woodstown, NJ (Appendix 24). However, this location presented poor temperatures for early-juvenile development during all three years. These data indicate that the suitability of water temperature for early-juveniles at this location are poor.

2. Dissolved Oxygen - NJDWM&S continuous water monitoring data indicated that the upper Salem River was often not suitable for early-juvenile stage Alewife (i.e., the DO was <3.6 mg/l). During a 14-day period from Aug 24 to Sept 7, 2017, DO ranged from 0.85 to 5.91 mg/l and averaged 3.75 mg/l. This portion of the Salem River was suitable for early-juvenile stage Alewife 55% of the time based on the 14-day dataset.

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Spring water temperatures were mostly within the tolerable range for Blueback Herring spawning during two of three years for which there were data at gage KCCR1S, a gage on a tributary to the upper Salem River near Woodstown, NJ (Appendix 24). However, this location presented suboptimal temperatures during most of 2019, and mostly intolerable temperatures in 2020. These data indicate that the suitability of water temperature for spawning at this location are more poor to suboptimal than optimal.

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Aug 24 to Sept 7, 2017, showed that pH ranged 6.43-6.84 and averaged 6.62. Assuming these values are relatively stable throughout the year, these data indicate that the upper Salem River pH is likely within the optimal (6.5-8.0) and suitable (6.0-8.0) range for spawning adult Blueback Herring.

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for Blueback Herring eggs during two of three years for which there were data at gage KCCR1S, a gage on a tributary to the upper Salem River near Woodstown, NJ (Appendix 24). These data indicate that water temperatures for Blueback Herring eggs are not suitable at this location.

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Aug 24 to Sept 7, 2017, showed that pH ranged 6.43-6.84 and averaged 6.62. Assuming these values are relatively stable throughout the year, these data indicate that the upper Salem River pH is likely within the optimal (6.0-8.0) and suitable (5.7-8.5) range for Blueback Herring eggs.

c. Larvae

1. Temperature – Most water temperatures were mostly tolerable for Blueback Herring larvae during two of three years for which there were data at gage KCCR1S, a gage on a tributary to the upper Salem River near Woodstown, NJ (Appendix 24). This location presented mostly intolerable temperatures for larvae during 2020. These data indicate that water

temperatures for Blueback Herring eggs are mostly tolerable, with intolerable years.

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – NJDWM&S continuous water monitoring data during a 14-day period from Aug 24 to Sept 7, 2017, showed that pH ranged 6.43-6.84 and averaged 6.62. Assuming these values are relatively stable throughout the year, these data indicate that the upper Salem River pH is likely within the optimal (6.5-8.0) and suitable (6.2-8.5) range for larval Blueback Herring.

d. Early-juvenile

1. Temperature - NJDWM&S continuous water monitoring data indicated that the upper Salem River temperature was within the tolerable range for early-juvenile stage Blueback Herring (i.e., 11-32ºC) 100% of the time based on the 14-day dataset. During a 14-day period from Aug 24 to Sept 7, 2017, temp ranged from 17.06 to 22.90 ºC and averaged 19.96 ºC. This portion of the Salem River had optimal temperatures for early-juvenile stage Blueback Herring (20-30 ºC) 44% of the time based on the 14-day dataset.

Summer water temperatures were optimal for Blueback Herring early-juvenile development during the three years for which there were data at gage KCCR1S, a gage on a tributary to the upper Salem River near Woodstown, NJ (Appendix 24).

2. Dissolved Oxygen - NJDWM&S continuous water monitoring data indicated that the upper Salem River was often not suitable for early-juvenile stage Blueback Herring (i.e., the DO was <4.0 mg/l). During a 14-day period from Aug 24 to Sept 7, 2017, DO ranged from 0.85 to 5.91 mg/l and averaged 3.75 mg/l. This portion of the Salem River was suitable for early-juvenile stage Blueback Herring 47% of the time based on the 14-day dataset.

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

15. Cohansey River

American Shad

a. Spawning adult

1. Temperature – Spring temperatures were optimal for adult spawning for both gages and all years assessed (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Spring water temperatures were tolerable for eggs, and like all other priority tributaries assessed (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were optimal for larval development for most years and at both gages assessed (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature - Summer water temperatures were optimal for early-juvenile development for most years and at both gages assessed (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Overall, spring water temperatures were optimal for adult spawning. However, suboptimal and poor temperatures occurred in some years at one gage (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Overall, spring water temperatures were suboptimal for egg development (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Overall, spring water temperatures were suboptimal for larval development. However, poor temperatures occurred at one gage in all three years assessed (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Overall, spring water temperatures were suboptimal for early-juvenile development. However, poor temperatures occurred at one gage in all three years assessed (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Overall, spring water temperatures were suboptimal for adult spawning at most gages and in most years. However, poor temperatures occurred at one gage in all three years assessed (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development at both gages and in most years; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – unable to assess; insufficient data

d. Early-juvenile

1. Temperature – Overall, summer water temperatures were optimal for early-juvenile development at both gages and in most years (Appendix 25 and Table 1).

2. Dissolved Oxygen – unable to assess; insufficient data

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

16. Broadkill River

American Shad

a. Spawning adult

1. Temperature – Most spring water temperatures were within the tolerable range for American Shad spawning during the four years for which there were data (Appendix 26). This gage indicated that spawning temperatures were optimal 60.1-73.7% and tolerable 84.0-92.5% of the time. These data indicate that the suitability of water temperature for spawning at this location is optimal most springs, but present intolerable and suboptimal conditions for substantial periods of time each spring (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for spawning 84.7-100% of the time (Appendix 27).

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

b. Egg

1. Temperature – Water temperatures were within the tolerable range for American Shad eggs 100% of the time, indicating suitable conditions (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen concentrations were suitable for egg development 64.0-96.6% of the time. These data indicate that dissolved oxygen concentrations may be unsuitable for long periods of time during some years (Appendix 27).

3. pH – The pH on the Broadkill was within the average tolerable (6.0-8.5) and tolerable (5.5-9.5) ranges for American Shad eggs 100% of the time (Appendix 28).

c. Larvae

1. Temperature – Most water temperatures were within the tolerable range for larval American Shad during the four years for which there were data (Appendix 26). Overall, spring water temperatures were optimal for larval development (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen concentrations were suitable for larval development 64.0-96.6% of the time. These data indicate that dissolved oxygen concentrations may be unsuitable for long periods of time during some years (Appendix 27).

3. pH – The pH on the Broadkill was within the average tolerable (6.6-9.6) and tolerable (6.5-9.9) ranges of American Shad larvae 99.9-100% of the time (Appendix 28).

d. Early-juvenile

1. Temperature – Although water temperatures were within the tolerable range for early-juvenile American Shad during all four years for which there were data, temperatures were suboptimal as well. These data indicate that the spring water temperature for early-juvenile American Shad are tolerable but suboptimal most of the time (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen conditions were suitable for juvenile American Shad 23.7-51.1% of the time (Appendix 27). These data indicate that dissolved oxygen conditions are not suitable for juvenile American Shad most of the time during most years.

3. pH – Not assessed at this stage. Metrics developed for egg and larval stages.

Alewife

a. Spawning adult

1. Temperature – Most water temperatures were within the tolerable range for American Shad spawning during the four years for which there were data (Appendix 26). However, these data indicated that spawning temperatures were optimal only 24.8-50.3% of the time. These data indicate that water temperatures are suboptimal most of the time (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen concentrations were suitable for spawning, egg, and larval development 64.0-96.6% of the time. These data indicate that dissolved oxygen concentrations may be unsuitable for long periods of time during some years (Appendix 27).

3. pH – Little information given by Greene et al. 2009; top end of range seems low, see egg and larval ranges.

b. Egg

1. Temperature – Most water temperatures were within the tolerable range for American Shad eggs during the four years for which there were data (Appendix 26). However, this gage indicated that temperatures were optimal 17.3-37.5% and tolerable 89.7-94.6% of the time. These data indicate that the water temperatures for egg development are intolerable on occasion and suboptimal to poor most of the time (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen concentrations were suitable for spawning, egg, and larval development 64.0-96.6% of the time. These data indicate that dissolved oxygen concentrations may be unsuitable for long periods of time during some years (Appendix 27).

3. pH – The pH of the Broadkill was optimal for egg development 100% of the time (Appendix 28).

c. Larvae

1. Temperature– Most water temperatures were within tolerable ranges but were suboptimal most of the time (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen concentrations were suitable for spawning, egg, and larval development 64.0-96.6% of the time. These data indicate that dissolved oxygen concentrations may be unsuitable for long periods of time during some years (Appendix 27).

3. pH – The pH of the Broadkill was optimal for larval development 100% of the time (Appendix 28).

d. Early-juvenile

1. Temperature – Most water temperatures were within the tolerable range for early-juvenile Alewife during the four years for which there were data (Appendix 26). However, these data indicated that temperatures were optimal 0.0-8.7% and tolerable 69.3-85.1% of the time (Appendix 26). These data indicate that the water temperatures for early-juvenile Alewife were intolerable for substantial periods of time and suboptimal 91.3% of the time (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen concentrations were suitable for early-juvenile Alewife 54.2-87.5% of the time. These data indicate that dissolved oxygen concentrations may be unsuitable for long periods of time during some years (Appendix 27).

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

Blueback Herring

a. Spawning adult

1. Temperature – Spring water temperatures were tolerable 82.7-89.8% of the time, and only optimal 20.8-48.3% of the time. These data indicated suboptimal to poor temperatures for spawning and intolerable conditions at times (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen concentrations were suitable for spawning, egg, and larval Blueback Herring 64.0-96.6% of the time. These data indicate that dissolved oxygen concentrations may be unsuitable for moderate periods of time during some years (Appendix 27).

3. pH – The pH of the Broadkill was optimal for Blueback Herring spawning 99.4- 100% of the time (Appendix 28).

b. Egg

1. Temperature – Spring water temperatures were mostly intolerable for egg development; note that only 1 tributary exhibited mostly tolerable temperatures for egg development (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen concentrations were suitable for spawning, egg, and larval Blueback Herring 64.0-96.6% of the time. These data indicate that dissolved oxygen concentrations may be unsuitable for moderate periods of time during some years (Appendix 27).

3. pH – The pH of the Broadkill was optimal for Blueback Herring egg development 99.4-100% of the time (Appendix 28).

c. Larvae

1. Temperature – Spring water temperatures were tolerable for larval development (Appendix 26 and Table 1). Temperatures for larval Blueback Herring development were tolerable 84.8-96.5% of the time.

2. Dissolved Oxygen – Dissolved oxygen concentrations were suitable for spawning, egg, and larval Blueback Herring 64.0-96.6% of the time. These data indicate that dissolved oxygen concentrations may be unsuitable for moderate periods of time during some years (Appendix 27).

3. pH – The pH of the Broadkill was optimal for Blueback Herring larval development 99.4-100% of the time (Appendix 28).

d. Early-juvenile

1. Temperature – Overall, summer water temperatures were optimal for early-juvenile development at most gages and in most years (Appendix 26 and Table 1).

2. Dissolved Oxygen – Dissolved oxygen concentrations were suitable for early-juvenile Blueback Herring 42.3-78.5% of the time. These data indicate that dissolved oxygen concentrations may be unsuitable for long periods of time during some years (Appendix 27).

3. pH – Not assessed at the juvenile stage. Metrics developed for egg and larval stages.

References

Greene, K. E., J. L. Zimmerman, R. W. Laney, and J. C. Thomas-Blate. 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, Washington, D.C.

Model My Watershed (modelmywatershed.org) downloaded February 2021

National Water Information System: Web Interface (https://waterdata.usgs.gov/nwis/rt) downloaded January 2021.

NJDEP DWM&S Continuous Data Monitoring Portal (https://njdep.rutgers.edu/continuous/) downloaded April 2021.

Tables

Table 1. Summary of habitat suitability for American Shad, Alewife, and Blueback Herring in 16 tributaries identified as priorities for restoration. Conditions were determined by assessing metric scores for each species-stage within a tributary. Temperature, pH, and dissolved oxygen tiers represent subjective groupings with similar tributaries sharing numbers and shading, and lower numbers indicating better suitability.

Species	Stage	Cohansey River	Red Clay Creek	Brandywine Creek	White Clay Creek	Schuylkill River	Pequest River	Musconetcong River	Neshaminy Creek	Crosswicks Creek	Rancocas Creek	Lehigh River	Broadkill River	Salem River	Brodhead Creek	Chester Creek	Oldmans Creek
American Shad	adult	O	O	O	O	O	O	O	O	O	O	O[2]	O	O[1]	S	-	-
	egg	T	T	T	T	T	T	T	T	T	T	T	T	T	T	-	-
	larval	O	O	O	O	O[2]	O	O	O	O	O	S	O	S[1]	S	-	-
	juvenile	O	O	O	O	O[2]	O	O	O	O	O[2]	O	S	O	O	-	-
Alewife	adult	O[2]	O	S	S	S[4]	O	O	S	S	S	O[2]	S	S	S	-	-
	egg	S	S[1]	S[1]	S[1]	S[1]	S	S[1]	P	P	P	S[1]	S[1]	S[1]	P	-	-
	larval	S[1]	S	S	S	S[1]	P	P	S	S	S	P	S	S[1]	P	-	-
	juvenile	S[1]	P	P	P	P[5]	O	S	P	P	P	S	T	P	S	-	-
Blueback	adult	S[1]	S	S	S	S[1]	P	P	S	S[1]	S	P[3]	S	S[1]	P/I	-	-
	egg	I	I	I	I	I	I	I	I	I	I	I	I	I	T	-	-
	larval	T	T	T	T	T	T	T	T	T	T	T	T	T	I	-	-
	juvenile	O	O	O	O	O	S	O	O	O	O	O	O	O	S	-	-
Temperature tiers		1	1	1	1	1	2	2	2	2	2	3	3	3	4	UA	UA
pH tiers		UA	UA	2	UA	2	UA	UA	UA	UA	UA	1	1	3 [6]	UA	UA	1 [6]
Dissolved Oxygen tiers		UA	UA	1	UA	1	UA	UA	UA	UA	UA	1	2	2 [6]	UA	UA	UA

O optimal, optimal conditions; >50% of the time optimal
S suboptimal, optimal conditions; 25-50% of the time optimal
P poor, optimal conditions; <25% of the time optimal
T mostly tolerable condition; >50% of the time tolerable
I mostly intolerable conditions; <50% of the time tolerable
UA unable to assess; addition data needed
1 many years or gages indicate poor temperatures
2 many years or gages indicate suboptimal temperatures
3 some gages indicate mostly tolerable temperatures
4 some optimal temperatures in upper watershed
5 some suboptimal temperatures in upper watershed
6 based on 14-day continuous dataset

Table 2. Description of metrics derived from Greene et al. (2009) used to assess habitat suitability for American Shad, Alewife, and Blueback Herring.

Species	Stage	Parameter	Metric Name	Description	Notes
American Shad	early-juvenile	Dissolved Oxygen	ALSAPJuvSumDO	Percentage of measurements during the Summer (July,Aug,Sept) that are at or above 5 mg/l dissolved oxygen.	Same metric for egg, larvae, and early-juvenile
American Shad	early-juvenile	Temperature	ALSAPJuvSumTempOpt	Percentage of measurements during the Summer (July,Aug,Sept) that are within the optimum temperature (10-25^{o}C) range.	
American Shad	early-juvenile	Temperature	ALSAPJuvSumTempTol	Percentage of measurements during the Summer (July,Aug,Sept) that are within the tolerable temperature (3-35^{o}C) range.	
American Shad	egg	Temperature	ALSAPEggSprTempTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (8-30^{o}C) range.	
American Shad	egg	pH	ALSAPEggpHTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable pH (5.5-9.5) range.	
American Shad	egg	pH	ALSAPEggpHAveTol	Percentage of measurements during the Spring (Apr,May,June) that are within the average tolerable pH (6-8.5) range.	
American Shad	egg	Dissolved Oxygen	ALSAPEggLarvDO	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.	Same metric for egg, larvae, and early-juvenile
American Shad	larval	Dissolved Oxygen	ALSAPEggLarvDO	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.	Same metric for egg, larvae, and early-juvenile
American Shad	larval	pH	ALSAPLarvpHAveTol	Percentage of measurements during the Spring (Apr,May,June) that are within the average tolerable pH (6.6-9.6) range.	
American Shad	larval	pH	ALSAPLarvpHTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable pH (6.5-9.9) range.	
American Shad	larval	Temperature	ALSAPLarvSprTempTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (10-30^{o}C) range.	
American Shad	larval	Temperature	ALSAPLarvSprTempOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (15-25^{o}C) range.	

Table 2 cont'd. Description of metrics derived from Greene et al. (2009) used to assess habitat suitability for American Shad, Alewife, and Blueback Herring.

Species	Stage	Parameter	Metric Name	Description	Notes
American Shad	spawning adult	Temperature	ALSAPSpawnTempTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (8-26^{o}C) range.	
American Shad	spawning adult	Temperature	ALSAPSpawnTempOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (14-24.5^{o}C) range.	
American Shad	spawning adult	Dissolved Oxygen	ALSAPSpawnDO	Percentage of measurements during the Spring (Apr,May,June) that are at or above 4 mg/l dissolved oxygen.	
Alewife	early-juvenile	Temperature	ALPSEJuvSumTempOpt	Percentage of measurements during the Summer (July,Aug,Sept) that are within the optimum temperature (15-20^{o}C) range.	
Alewife	early-juvenile	Dissolved Oxygen	ALPSEJuvSumDO	Percentage of measurements during the Summer (July,Aug,Sept) that are at or above 3.6 mg/l dissolved oxygen.	
Alewife	early-juvenile	Temperature	ALPSEJuvSumTempTol	Percentage of measurements during the Summer (July,Aug,Sept) that are within the tolerable temperature (10-28^{o}C) range.	
Alewife	egg	Dissolved Oxygen	ALPSESpawnEggLarvDO	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.	same metric for egg, larvae, and spawning
Alewife	egg	pH	ALPSEEggLarvpHOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimal pH (5-8.5) range.	
Alewife	egg	Temperature	ALPSEEggTempTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (10.6-26.7^{o}C) range.	
Alewife	egg	Temperature	ALPSEEggTempOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (17.2-21.1^{o}C) range.	
Alewife	larval	pH	ALPSEEggLarvpHOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimal pH (5-8.5) range.	egg and larvae pH criteria is the same
Alewife	Postlarvae	Dissolved Oxygen	ALPSESpawnEggLarvDO	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.	same metric for egg, larvae, and spawning

Table 2 cont'd. Description of metrics derived from Greene et al. (2009) used to assess habitat suitability for American Shad, Alewife, and Blueback Herring.

Species	Stage	Parameter	Metric Name	Description	Notes
Alewife	Postlarvae	Temperature	ALPSEPosLarvTempTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (14-28^{o}C) range.	
Alewife	Postlarvae	Temperature	ALPSEPosLarvTempOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (20-26^{o}C) range.	
Alewife	Prolarvae	Dissolved Oxygen	ALPSESpawnEggLarvDO	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.	same metric for egg, larvae, and spawning
Alewife	Prolarvae	Temperature	ALPSEProLarvTempTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (8-31C) range.	
Alewife	Prolarvae	Temperature	ALPSEProLarvTempOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (15-24^{o}C) range.	
Alewife	spawning adult	pH	ALPSESpawnpHTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable pH (4.5-7.3) range.	Little information; top end of range seems low; see egg range.
Alewife	spawning adult	Temperature	ALPSESpawnTempTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (7-27.8^{o}C) range.	
Alewife	spawning adult	Dissolved Oxygen	ALPSESpawnEggLarvDO	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.	same metric for egg, larvae, and spawning
Alewife	spawning adult	Temperature	ALPSESpawnTempOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (13-20^{o}C) range.	
Blueback Herring	early-juvenile	Temperature	ALAESJuvSumTempOpt	Percentage of measurements during the Summer (July,Aug,Sept) that are within the optimum temperature (20-30^{o}C) range.	
Blueback Herring	early-juvenile	Temperature	ALAESJuvSumTempTol	Percentage of measurements during the Summer (July,Aug,Sept) that are within the tolerable temperature (11-32^{o}C) range.	
Blueback Herring	early-juvenile	Dissolved Oxygen	ALAESJuvSumDO	Percentage of measurements during the Summer (July,Aug,Sept) that are at or above 4 mg/l dissolved oxygen.	Same metric for egg, larvae, and early-juvenile

Table 2 cont'd. Description of metrics derived from Greene et al. (2009) used to assess habitat suitability for American Shad, Alewife, and Blueback Herring.

Species	Stage	Parameter	Metric Name	Description	Notes
Blueback Herring	egg	pH	ALAESEggpHOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimal pH (6-8) range.	
Blueback Herring	egg	pH	ALAESEggpHSuit	Percentage of measurements during the Spring (Apr,May,June) that are within the suitable pH (5.7-8.5) range.	
Blueback Herring	egg	Dissolved Oxygen	ALAESSpawnEggLarvDO	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.	same as used for Alewife
Blueback Herring	egg	Temperature	ALAESEggTempTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (7-14^{o}C) range.	
Blueback Herring	larval	pH	ALAESLarvpHOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimal pH (6.5-8.0) range.	
Blueback Herring	larval	pH	ALAESLarvpHSuit	Percentage of measurements during the Spring (Apr,May,June) that are within the suitable pH (6.2-8.5) range.	
Blueback Herring	larval	Dissolved Oxygen	ALAESSpawnEggLarvDO	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.	same as used for Alewife
Blueback Herring	larval	Temperature	ALAESLarvTempTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (13-28^{o}C) range.	
Blueback Herring	spawning adult	Temperature	ALAESSpawnTempTol	Percentage of measurements during the Spring (Apr,May,June) that are within the tolerable temperature (13-27^{o}C) range.	
Blueback Herring	spawning adult	Dissolved Oxygen	ALAESSpawnEggLarvDO	Percentage of measurements during the Spring (Apr,May,June) that are at or above 5 mg/l dissolved oxygen.	same as used for Alewife
Blueback Herring	spawning adult	Temperature	ALAESSpawnTempOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum temperature (20-25^{o}C) range.	
Blueback Herring	spawning adult	pH	ALAESSpawnpHSuit	Percentage of measurements during the Spring (Apr,May,June) that are within the suitable pH (6-8) range.	

Table 2 cont'd. Description of metrics derived from Greene et al. (2009) used to assess habitat suitability for American Shad, Alewife, and Blueback Herring.

Species	Stage	Parameter	Metric Name	Description	Notes
Blueback Herring	spawning adult	pH	ALAESSpawnpHOpt	Percentage of measurements during the Spring (Apr,May,June) that are within the optimum pH (6.5-8) range.	

Table 3. Description of gages used to calculate metrics and assess habitat suitability for American Shad, Alewife, and Blueback Herring.

priority tributary	gageIDfull	GageID	gage location	watershed area (mi^2)	latitude	longitude	Notes
Brandywine Creek	01481000	1481000	Brandywine Creek at Chadds Ford, PA	287.0	39.8698328	-75.5932623	
Brandywine Creek	01481500	1481500	Brandywine Creek at Willmington, DE	314.0	39.7695	-75.5766944	
Brandywine Creek	BEAV_MS2	3			39.836731	-75.574524	many sparce periods, but useful
Brandywine Creek	PALM_MS3	12			39.82377	-75.57156	do not use for spring
Brandywine Creek	ROCK_US3	16			39.816792	-75.550789	
Brandywine Creek	BCWC_12S	2			39.822251	-75.821078	many sparce periods
Brandywine Creek	CR_Lloyd	4			39.84895	-75.82512	many sparce periods
Brandywine Creek	WCD696	22			39.8548393	-75.7843247	
Broadkill River	01484272	1484272	Broadkill River near Milton, DE		38.791	-75.2507778	
Brodhead Creek	01440400	1440400	Brodhead Creek near Analomink, PA	65.9	41.0848148	-75.2146251	
Brodhead Creek	PKBH7S	13			41.07343	-75.21811	use for summer 2020 only
Brodhead Creek	PKPC3S	15			41.07016	-75.22453	use for summer 2020 only
Brodhead Creek	PKFH1S	14			41.106106	-75.300068	use 2020 only
Cohansey River	KCLR1S	7			39.47422	-75.2308	
Cohansey River	KCFB1S	6			39.42468	-75.2314	
Crosswicks Creek	01464290	1464290	Crosswicks Ck at Hockamik Rd near Cookstown NJ	23.5	40.0361111	-74.5361111	
Crosswicks Creek	01464500	1464500	Crosswicks Creek at Extonville NJ	82.0	40.1372222	-74.6	
Lehigh River	01447500	1447500	Lehigh River at Stoddartsville, PA	91.7	41.1303626	-75.625467	
Lehigh River	01447720	1447720	Tobyhanna Creek near Blakeslee, PA	118.0	41.0848082	-75.6054666	
Lehigh River	01447800	1447800	Lehigh R bl Francis E Walter Res nr White Haven PA	290.0	41.1048062	-75.7321362	
Lehigh River	01449360	1449360	Pohopoco Creek at Kresgeville, PA	49.9	40.8975919	-75.5024077	
Lehigh River	01449800	1449800	Pohopoco Cr bl Beltzville Dam nr Parryville, PA	96.4	40.8456476	-75.6457437	
Lehigh River	01451380	1451380	Little Lehigh Creek near Trexlertown, PA	21.3	40.5312076	-75.6004652	
Lehigh River	01451400	1451400	Spring Creek at Trexlertown, PA	23.7	40.5340833	-75.6014722	

Table 3 cont'd. Description of gages used to calculate metrics and assess habitat suitability for American Shad, Alewife, and Blueback Herring.

priority tributary	gageIDfull	GageID	gage location	watershed area (mi^2)	latitude	longitude	Notes
Lehigh River	01451500	1451500	Little Lehigh Creek near Allentown, PA	80.8	40.5823197	-75.4829609	
Lehigh River	01451630	1451630	Cedar Creek at Mouth near Allentown, PA	14.5	40.5875	-75.4968056	
Lehigh River	01451650	1451650	Little Lehigh Creek at Tenth St. Br. at Allentown	98.2	40.5964864	-75.4740717	
Lehigh River	01451800	1451800	Jordan Creek near Schnecksville, PA	53.0	40.6617622	-75.626854	
Lehigh River	01454700	1454700	Lehigh River at Glendon, PA	1359.0	40.6692656	-75.2362881	
Lehigh River	ULLL2S	21			40.53963	-75.53192	large periods of time without data
Lehigh River	ULBC1S	18			40.83499	-75.51639	some periods of time without data
Lehigh River	ULBC2S	0			40.837165	-75.506634	some small periods without data
Lehigh River	ULHC2S	19			40.85175	-75.54234	
Lehigh River	ULHC3S	20			40.86914	-75.5452	some periods without data
Lehigh River	ULAQ1S	17			40.86361	-75.33749	
Musconetcong River	NHML13S	9			40.62995	-75.13804	
Musconetcong River	NHML14S	10			40.65198	-75.09165	
Musconetcong River	NHPB1S	11			40.68262	-75.03326	
Musconetcong River	NHML11S	8			40.70455	-74.98831	
Musconetcong River	NJDEP_AN0065		Lubbers Run; Rt 607		40.96425	-74.6745	not used for metric calculations
Musconetcong River	NJDEP_01455700		At River Rd.		40.9	-74.73090	not used for metric calculations
Musconetcong River	NJDEP_Rt604		At Rt 604		40.91269	-74.76650	not used for metric calculations
Neshaminy Creek	01465500	1465500	Neshaminy Creek near Langhorne, PA	210.0	40.1739982	-74.9568342	
Oldmans Creek	NJDEP_01477470		Rt. 45		39.684641	-75.293204	not used for metric calculations
Pequest River	Pequest_NJDFW_BFF	23			40.83168	-74.96331	
Rancocas Creek	01467024	1467024	Rancocas Creek at Bridgeboro, NJ	343.0	40.0291667	-74.9316667	tidal
Rancocas Creek NB	01466900	1466900	Greenwood Branch at New Lisbon, NJ	77.9	39.9561111	-74.6277778	
Rancocas Creek NB	01467000	1467000	NB Rancocas Creek at Pemberton, NJ	118.0	39.97	-74.6844444	

Table 3 cont'd. Description of gages used to calculate metrics and assess habitat suitability for American Shad, Alewife, and Blueback Herring.

priority tributary	gageIDfull	GageID	gage location	watershed area (mi^2)	latitude	longitude	Notes
Rancocas Creek NB	01467005	1467005	NB Rancocas C at Iron Works Park at Mount Holly, NJ	140.0	39.9930556	-74.7813889	
Rancocas Creek SB	01465850	1465850	South Branch Rancocas Creek at Vincentown, NJ	64.5	39.94	-74.7630556	
Rancocas Creek SB	01465880	1465880	Southwest Branch Rancocas Creek at Medford, NJ	47.2	39.8952778	-74.8236111	
Rancocas Creek SB	01466500	1466500	McDonalds Branch in Byrne State Forest, NJ	2.4	39.885	-74.5052778	
Rancocas Creek SB	NJDEP_01465850		at Vincetown, NJ	64.5	39.94	-74.7630556	not used for metric calculations
Rancocas Creek SB	0146587310	146587310	Haynes C at Tuckerton Rd at Lake Pine, NJ	14.9	39.8677222	-74.84175	
Red Clay	01480000	1480000	Red Clay Creek at Wooddale, DE	47.0	39.7628056	-75.6365	Temp format: min, max, mean
Salem River	KCCR1S	5			39.648	-75.32426	
Salem River	NJDEP_01482580		Rt. 130		39.6818569	-75.4914711	not used for metric calculations
Salem River	NJDEP_01482503		Salem River at Chestnut Run		39.64661	-75.32750	not used for metric calculations
Salem River	NJDEP_01482537		At Rt. 646		39.660873	-75.40927	not used for metric calculations
Schuylkill River	01470779	1470779	Tulpehocken Creek near Bernville, PA	70.4	40.4134258	-76.1716128	
Schuylkill River	01470960	1470960	Tulpehocken Cr at Blue Marsh Damsite near Reading, PA	175.0	40.3706482	-76.0252159	
Schuylkill River	01471875	1471875	Manatawny Creek near Spangsville, PA	56.9	40.339538	-75.7421359	
Schuylkill River	01472157	1472157	French Creek near Phoenixville, PA	59.1	40.1514906	-75.601305	
Schuylkill River	01473000	1473000	Perkiomen Creek at Graterford, PA	279.0	40.2295473	-75.451567	
Schuylkill River	01473169	1473169	Valley Creek at PA Turnpike Br near Valley Forge	20.8	40.0792737	-75.4607481	
Schuylkill River	01473500	1473500	Schuylkill River at Norristown, PA	1760.0	40.1112193	-75.3468502	
Schuylkill River	01474500	1474500	Schuylkill River at Philadelphia, PA	1893.0	39.9678905	-75.1885123	
White Clay Creek	01478120	1478120	East Branch White Clay Creek at Avondale, PA	11.3	39.8284429	-75.780773	
White Clay Creek	01478220	1478220	West Branch White Clay Creek near Chesterville, PA	9.9	39.7656662	-75.7960492	
White Clay Creek	01478245	1478245	White Clay Creek near Strickersville, PA	59.2	39.7475	-75.7708333	
White Clay Creek	01478650	1478650	White Clay Creek at Newark, DE	69.0	39.6892222	-75.74875	

Appendix

Appendix 1. Percentage of time the water temperature was within the metric range at gages on the Schuylkill River. See table 2 for a description of metrics and table 3 for gage information. Gages on larger watersheds 1472157 (Appendix 1), 1473000, 1473500, and 1474500 (Appendix 2) were weighted more heavily when assessing suitability.

Metric	Year											
	2018	2019	2020	2018	2019	2020	2019	2020	2017	2018	2019	2020
	Gage											
	1470779			1470960			1471875		1472157			
ALSAPSpawnTempOpt	65.6	73.2	58.0	63.0	77.4	53.2	69.4	56.9	69.7	68.7	76.9	56.8
ALSAPSpawnTempTol	95.8	99.4	99.5	89.5	100.0	100.0	97.6	97.1	97.3	92.1	98.3	97.5
ALSAPEggSprTempTol	95.8	99.4	99.5	89.5	100.0	100.0	97.6	97.1	98.0	92.1	98.3	98.2
ALSAPLarvSprTempOpt	54.5	61.7	51.1	53.7	67.7	44.1	58.7	51.4	62.9	64.9	69.0	51.8
ALSAPLarvSprTempTol	84.4	95.4	90.8	76.3	92.3	97.1	94.1	84.2	95.3	82.3	95.2	87.0
ALSAPJuvSumTempOpt	100.0	100.0	100.0	100.0	100.0	97.7	99.8	95.6	92.5	97.2	93.0	83.7
ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
ALPSESpawnTempTol	99.2	99.9	100.0	99.7	100.0	100.0	99.0	99.0	99.2	96.4	99.3	99.8
ALPSESpawnTempOpt	70.2	81.9	57.5	65.6	75.3	55.7	75.7	43.2	58.6	60.4	67.0	42.1
ALPSEEggTempTol	81.8	94.3	85.9	73.3	90.5	94.8	92.8	79.3	94.0	80.3	94.2	82.0
ALPSEEggTempOpt	20.8	23.8	32.7	31.5	40.4	32.8	29.8	27.0	22.9	38.3	37.7	24.6
ALPSEPosLarvTempTol	65.6	73.2	58.0	63.0	77.4	53.2	69.4	56.9	73.4	68.8	77.7	58.8
ALPSEPosLarvTempOpt	0.9	0.6	8.0	0.1	5.8	10.7	4.7	19.9	23.9	14.0	18.5	22.5
ALPSEProLarvTempTol	95.8	99.4	99.5	89.5	100.0	100.0	97.6	97.1	98.0	92.1	98.3	98.2
ALPSEProLarvTempOpt	54.5	61.7	51.1	53.7	67.7	44.1	58.7	50.5	60.3	64.6	68.2	50.2
ALPSEJuvSumTempOpt	82.6	79.9	53.4	34.0	7.0	18.3	46.6	26.2	32.9	29.0	28.8	17.1
ALPSEJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	100.0	99.9	97.7
ALAESSpawnTempTol	70.9	82.3	64.6	65.6	79.9	65.5	62.4		82.5	73.6	84.5	64.5
ALAESSpawnTempOpt	0.9	0.6	8.0	0.1	5.8	10.7	19.9		22.2	13.9	18.1	21.7
ALAESEggTempTol	34.3	27.5	42.7	37.5	23.0	48.2	42.6		26.6	27.9	22.4	41.5
ALAESLarvTempTol	70.9	82.3	64.6	65.6	79.9	65.5	62.4		82.7	73.6	84.5	64.6
ALAESJuvSumTempOpt	15.8	21.5	42.5	67.5	93.0	82.6	54.6	69.0	67.1	72.6	71.4	78.2
ALAESJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6

Appendix 2. Percentage of time the water temperature was within the metric range at gages on the Schuylkill River. See table 2 for a description of metrics and table 3 for gage information. Gages on larger watersheds 1472157 (Appendix 1), 1473000, 1473500, and 1474500 (Appendix 2) were weighted more heavily when assessing suitability.

Stage	Metric	1473000 2019	1473000 2020	1473169 2019	1473169 2020	1473500 2012	1473500 2013	1473500 2014	1473500 2015	1473500 2016	1473500 2017	1473500 2018	1473500 2019	1473500 2020	1474500 2019	1474500 2020
adult	ALSAPSpawnTempOpt	79.3	50.5	63.1	52.7	72.6	70.2	62.5	59.1	51.6	73.3	67.9	81.4	51.0	81.1	47.2
adult	ALSAPSpawnTempTol	96.9	93.9	99.0	98.5	93.9	93.9	98.0	88.6	83.4	91.7	97.4	99.8	94.0	99.6	90.6
egg	ALSAPEggSprTempTol	98.8	99.2	99.0	98.5	100.0	100.0	99.4	98.4	99.6	98.4	97.6	100.0	100.0	100.0	100.0
larval	ALSAPLarvSprTempOpt	73.1	48.3	48.8	42.4	69.3	68.7	57.7	58.5	46.4	65.6	62.5	76.3	44.7	76.4	41.1
larval	ALSAPLarvSprTempTol	95.9	91.6	94.9	88.6	100.0	95.1	92.2	95.0	96.8	94.5	85.0	98.2	98.8	98.9	99.3
juvenile	ALSAPJuvSumTempOpt	59.6	54.7	100.0	100.0	35.9	69.0	58.3	45.1	21.3	76.6	78.1	51.0	48.8	47.1	45.8
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempTol	99.3	98.7	99.6	100.0	97.8	99.7	100.0	97.7	98.2	99.0	100.0	100.0	99.7	100.0	99.7
adult	ALPSESpawnTempOpt	51.1	33.1	75.6	59.9	49.2	53.1	43.3	29.9	45.0	56.1	41.8	50.6	31.4	49.8	34.2
egg	ALPSEEggTempTol	94.1	83.6	93.4	82.5	95.5	90.9	89.4	86.9	84.2	91.2	81.5	96.1	90.1	96.4	89.5
egg	ALPSEEggTempOpt	28.7	17.7	16.4	21.2	34.8	33.5	23.9	21.6	14.7	31.4	32.7	28.3	14.2	27.5	12.7
larval	ALPSEPosLarvTempTol	83.6	61.8	63.1	52.7	80.3	84.4	70.2	78.9	75.6	86.6	72.6	84.6	63.9	84.7	61.6
larval	ALPSEPosLarvTempOpt	35.6	32.4	1.5	2.0	37.0	30.9	33.8	44.7	24.0	26.8	37.1	39.1	33.3	39.6	26.0
larval	ALPSEProLarvTempTol	98.8	99.2	99.0	98.5	100.0	100.0	99.4	98.4	99.6	98.4	97.6	100.0	100.0	100.0	100.0
larval	ALPSEProLarvTempOpt	70.4	42.4	48.8	42.4	65.4	65.3	54.6	50.6	39.7	61.0	60.2	74.5	41.9	75.2	37.4
juvenile	ALPSEJuvSumTempOpt	7.4	12.5	85.5	73.0	8.9	12.1	7.5	1.7	3.0	12.1	15.2	0.1	10.2	0.0	9.4
juvenile	ALPSEJuvSumTempTol	93.8	88.3	100.0	100.0	75.9	91.8	97.1	92.0	70.7	98.6	96.1	96.6	83.7	94.4	80.8
adult	ALAESSpawnTempTol	86.8	67.6	77.0	61.5	86.9	88.0	78.1	77.5	78.2	86.9	77.4	88.9	67.3	88.8	65.9
adult	ALAESSpawnTempOpt	34.3	28.2	1.5	2.0	34.8	24.7	29.3	37.7	17.8	21.6	34.1	37.1	27.5	37.3	22.9
egg	ALAESEggTempTol	16.3	37.5	38.1	48.5	18.9	15.8	30.3	19.6	23.9	13.1	28.0	16.3	36.3	15.6	39.3
larval	ALAESLarvTempTol	87.7	69.1	77.0	61.5	88.9	89.8	78.1	81.8	84.1	88.2	77.4	88.9	69.8	88.8	69.4
juvenile	ALAESJuvSumTempOpt	92.4	82.8	13.6	22.8	88.6	85.6	93.5	99.0	91.2	88.5	85.6	99.9	86.9	99.9	88.9
juvenile	ALAESJuvSumTempTol	100.0	99.9	100.0	100.0	100.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 3. Percentage of time dissolved oxygen (DO) was within a metric range at the Schuylkill River USGS gage 1473500. See table 2 for a description of metrics and table 3 for gage information.

Stage	Metric	Year								
		2012	2013	2014	2015	2016	2017	2018	2019	2020
adult	ALSAPSpawnDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
egg/larval	ALSAPEggLarvDO	100.0	99.1	100.0	100.0	99.3	100.0	100.0	100.0	100.0
juvenile	ALSAPJuvSumDO	97.3	100.0	100.0	100.0	97.7	100.0	99.8	100.0	99.2
juvenile	ALPSEJuvSumDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult/egg/larval	ALPSESpawnEggLarvDO	100.0	99.1	100.0	100.0	99.3	100.0	100.0	100.0	100.0
juvenile	ALAESJuvSumDO	99.9	100.0	100.0	100.0	99.8	100.0	100.0	100.0	100.0
adult/egg/larval	ALAESSpawnEggLarvDO	100.0	99.1	100.0	100.0	99.3	100.0	100.0	100.0	100.0

Appendix 4. Percentage of time pH was within a metric range at the Schuylkill River USGS gage 1473500. See table 2 for a description of metrics and table 3 for gage information.

		Year								
Stage	Metric	2012	2013	2014	2015	2016	2017	2018	2019	2020
egg	ALSAPEggpHTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
egg	ALSAPEggpHAveTol	83.2	88.3	100.0	88.2	85.1	100.0	88.1	98.9	97.2
larval	ALSAPLarvpHTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
larval	ALSAPLarvpHAveTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
egg/larval	ALPSEEggLarvpHOpt	83.2	88.3	100.0	88.2	85.1	100.0	88.1	98.9	97.2
adult	ALPSESpawnpHTol	21.4	41.5	9.9	21.4	4.0	14.2	25.8	21.9	7.3
egg	ALAESEggpHOpt	75.2	83.0	94.5	77.0	73.0	99.3	80.1	91.2	90.5
egg	ALAESEggpHSuit	83.2	88.3	100.0	88.2	85.1	100.0	88.1	98.9	97.2
larval	ALAESLarvpHOpt	75.2	83.0	94.5	77.0	73.0	99.3	80.1	91.2	90.5
larval	ALAESLarvpHSuit	83.2	88.3	100.0	88.2	85.1	100.0	88.1	98.9	97.2
adult	ALAESSpawnpHSuit	75.2	83.0	94.5	77.0	73.0	99.3	80.1	91.2	90.5
adult	ALAESSpawnpHOpt	75.2	83.0	94.5	77.0	73.0	99.3	80.1	91.2	90.5

Appendix 5. Percentage of time the water temperature was within the metric range at gages on the Brandywine Creek. See table 2 for a description of metrics and table 3 for gage information. Gages on larger watersheds (1481000 and 1481500, Appendix 6) were weighted more heavily when assessing suitability.

Stage	Metric	Gage 2		Gage 3			Gage 4				Gage 12	Gage 16				Gage 22					
	Year	2019	2020	2016	2017	2020	2017	2018	2019	2020	2020	2017	2018	2019	2020	2015	2016	2017	2018	2019	2020
adult	ALSAPSpawnTempOpt	48.8		80.3	33.3	56.3	62.9	52.3	58.2			66.7	70.9	81.3	60.0	72.0	56.7	60.7	67.5	63.5	56.6
adult	ALSAPSpawnTempTol	94.8		100.0	86.8	95.7	93.1	95.5	96.8			87.7	93.7	98.4	98.1	99.0	96.4	97.5	94.5	98.1	97.6
egg	ALSAPEggSprTempTol	94.8		100.0	86.8	95.7	93.1	95.5	96.8			87.7	93.7	98.4	98.3	99.0	96.4	97.5	94.5	98.1	97.6
larval	ALSAPLarvSprTempOpt	44.8		64.4	26.3	49.6	55.6	34.1	48.7			61.3	67.6	76.2	54.6	64.5	49.5	50.9	59.1	46.0	47.9
larval	ALSAPLarvSprTempTol	82.7		100.0	66.7	84.6	80.0	86.4	85.7			86.1	84.4	95.4	89.7	94.7	90.9	93.5	84.7	92.5	86.2
juvenile	ALSAPJuvSumTempOpt	99.9	100.0		99.5	96.5		100.0	100.0	95.8	99.7	95.3	88.9	86.4	83.6	99.9	99.6	100.0	100.0	100.0	100.0
juvenile	ALSAPJuvSumTempTol	100.0	100.0		100.0	100.0		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempTol	98.4		100.0	91.4	98.3	96.3	96.9	99.0			88.6	96.4	99.1	99.7	99.8	97.8	99.3	97.3	98.8	99.3
adult	ALPSESpawnTempOpt	41.5		83.3	36.1	48.4	60.3	66.9	52.0			49.8	50.8	58.1	40.1	63.3	57.0	63.4	69.4	76.1	56.9
egg	ALPSEEggTempTol	77.3		100.0	61.7	80.3	77.2	83.6	81.2			85.6	82.5	94.7	85.4	92.5	87.6	91.4	82.3	91.1	81.8
egg	ALPSEEggTempOpt	36.9		18.9	13.5	27.6	27.5	10.2	25.9			23.0	41.3	35.9	24.1	33.9	31.3	27.9	26.8	15.3	26.6
larval	ALPSEPosLarvTempTol	48.8		80.3	33.3	56.3	62.9	52.3	58.2			68.5	71.2	82.6	61.7	72.7	56.7	60.7	67.5	63.5	56.6
larval	ALPSEPosLarvTempOpt	14.2		7.3	4.3	14.8	8.4	0.0	13.3			29.0	24.9	30.2	27.2	15.8	7.8	8.5	3.3	0.2	6.5
larval	ALPSEProLarvTempTol	94.8		100.0	86.8	95.7	93.1	95.5	96.8			87.7	93.7	98.4	98.3	99.0	96.4	97.5	94.5	98.1	97.6
larval	ALPSEProLarvTempOpt	44.8		64.4	26.3	49.3	55.6	34.1	48.7			58.6	66.8	74.8	52.6	63.8	49.5	50.9	59.1	46.0	47.9
juvenile	ALPSEJuvSumTempOpt	68.9	36.0		68.1	26.9		21.6	100.0	18.3	69.0	27.0	11.4	21.7	7.7	60.9	48.7	69.3	65.1	71.6	49.4
juvenile	ALPSEJuvSumTempTol	100.0	100.0		100.0	100.0		100.0	100.0	100.0	99.7	100.0	100.0	99.3	99.9	100.0	100.0	100.0	100.0	100.0	100.0
adult	ALAESSpawnTempTol	55.0		90.2	40.2	62.8	68.1	66.9	64.5			78.2	74.5	87.5	66.8	78.6	64.6	71.2	72.3	76.4	62.9
adult	ALAESSpawnTempOpt	14.2		7.3	4.3	14.8	8.4	0.0	13.3			28.5	24.8	29.6	26.5	15.4	7.8	8.5	3.3	0.2	6.5
egg	ALAESEggTempTol	50.0		21.2	58.9	42.5	34.3	46.7	41.8			20.6	25.6	17.0	38.4	28.0	42.0	39.7	30.5	37.8	43.5
larval	ALAESLarvTempTol	55.0		90.2	40.2	62.8	68.1	66.9	64.5			78.2	74.5	87.5	66.9	78.6	64.6	71.2	72.3	76.4	62.9
juvenile	ALAESJuvSumTempOpt	31.1	60.2		32.3	66.8		79.9	0.0	83.1	22.4	74.0	89.0	79.2	89.2	36.9	51.7	28.8	37.1	27.4	46.1
juvenile	ALAESJuvSumTempTol	100.0	100.0		100.0	99.4		100.0	100.0	100.0	98.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6

Appendix 6. Percentage of time the water temperature was within the metric range at gages on the Brandywine Creek. See table 2 for a description of metrics and table 3 for gage information. Gages on larger watersheds (1481000 and 1481500, Appendix 6) were weighted more heavily when assessing suitability.

Stage	Metric	Year: 2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		Gage: 1481000										1481500									
adult	ALSAPSpawnTempOpt	67.2	72.6	68.5	81.2	66.1	69.3	63.4	76.4	71.5	83.7	62.6	67.8	66.0	80.5	67.1	66.8	59.2	74.6	71.4	83.7
adult	ALSAPSpawnTempTol	98.3	97.6	98.2	98.5	99.8	98.0	98.5	99.1	97.6	99.0	93.2	95.8	94.8	98.2	99.8	95.3	98.7	98.0	97.5	99.6
egg	ALSAPEggSprTempTol	100.0	97.6	100.0	98.5	99.8	98.7	98.5	99.2	97.6	99.0	100.0	97.3	100.0	98.5	99.8	98.7	98.7	99.3	97.9	99.6
larval	ALSAPLarvSprTempOpt	60.2	68.3	66.9	73.5	60.1	66.7	57.6	69.2	67.5	76.7	57.8	67.9	65.0	74.9	62.5	64.1	57.0	68.3	66.9	78.3
larval	ALSAPLarvSprTempTol	100.0	94.1	99.4	94.7	92.7	94.4	93.1	96.1	85.4	96.1	100.0	94.8	99.8	94.3	94.8	94.2	94.8	96.6	87.3	96.7
juvenile	ALSAPJuvSumTempOpt	72.4	73.9	71.5	92.7	98.0	84.1	62.6	86.1	87.4	89.6	58.4	63.4	53.6	88.7	91.4	70.3	46.3	76.1	75.6	77.0
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempTol	100.0	98.8	100.0	99.6	100.0	99.3	99.3	100.0	100.0	100.0	100.0	98.7	100.0	99.7	100.0	99.2	99.4	100.0	100.0	100.0
adult	ALPSESpawnTempOpt	48.2	43.8	46.4	63.3	54.2	41.9	43.8	61.2	50.7	62.3	48.5	39.3	43.9	57.7	53.1	38.2	40.6	58.9	43.6	56.4
egg	ALPSEEggTempTol	98.8	90.7	97.5	93.8	89.6	92.3	92.0	95.3	83.4	95.2	96.7	92.1	96.5	93.6	91.6	92.0	93.0	95.2	83.5	95.6
egg	ALPSEEggTempOpt	24.5	24.2	34.4	32.1	30.5	29.0	12.8	24.2	40.7	37.7	23.6	22.4	32.2	34.2	29.4	28.5	10.4	26.5	38.4	34.7
larval	ALPSEPosLarvTempTol	75.3	74.5	74.9	82.1	66.1	76.4	67.5	81.7	72.3	83.7	78.4	75.6	76.9	83.8	68.4	77.1	68.9	85.0	73.8	85.2
larval	ALPSEPosLarvTempOpt	35.3	34.8	32.6	25.9	20.6	38.6	33.7	28.7	27.7	26.9	34.0	38.3	35.4	32.1	25.9	40.5	37.9	30.9	34.7	34.3
larval	ALPSEProLarvTempTol	100.0	97.6	100.0	98.5	99.8	98.7	98.5	99.2	97.6	99.0	100.0	97.3	100.0	98.5	99.8	98.7	98.7	99.3	97.9	99.6
larval	ALPSEProLarvTempOpt	54.7	64.8	63.3	71.9	59.8	60.9	52.4	64.7	66.2	76.0	49.8	60.5	59.8	72.7	60.4	58.9	46.9	62.4	64.5	76.7
juvenile	ALPSEJuvSumTempOpt	16.1	18.6	31.9	30.4	22.5	14.0	6.6	18.4	17.7	15.9	7.0	16.4	15.9	25.1	18.7	11.2	6.1	14.6	14.4	7.7
juvenile	ALPSEJuvSumTempTol	98.2	94.8	98.2	100.0	100.0	100.0	95.7	98.8	100.0	99.8	94.3	91.8	94.0	99.0	100.0	99.8	90.0	96.5	98.8	98.8
adult	ALAESSpawnTempTol	84.7	78.0	79.8	88.4	73.9	80.7	77.3	89.2	76.4	88.0	87.9	78.8	82.8	88.8	78.1	81.4	78.3	90.4	77.0	89.5
adult	ALAESSpawnTempOpt	30.8	33.9	29.8	25.6	20.6	35.0	32.4	25.7	27.3	26.9	28.7	35.5	32.0	30.1	25.6	35.9	33.7	25.0	33.4	33.5
egg	ALAESEggTempTol	25.6	25.0	25.5	18.1	34.5	23.2	32.6	19.2	28.2	17.1	22.7	23.3	23.5	16.5	32.3	22.5	31.3	15.7	26.6	15.3
larval	ALAESLarvTempTol	84.8	78.0	80.0	88.4	73.9	80.7	77.3	89.2	76.4	88.0	88.7	78.8	83.6	88.8	78.1	81.5	78.3	90.4	77.0	89.5
juvenile	ALAESJuvSumTempOpt	84.9	81.5	68.2	68.8	78.0	86.6	93.6	82.3	83.4	85.5	94.0	82.0	84.7	76.1	81.4	89.3	93.3	85.8	86.8	93.1
juvenile	ALAESJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 7. Percentage of time dissolved oxygen (DO) was within a metric range at Brandywine Creek USGS gages 1481000 and 1481500. See table 2 for a description of metrics and table 3 for gage information.

Gage	Stage	Metric	Year									
			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1481000	adult	ALSAPSpawnDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481000	egg/larval	ALSAPEggLarvDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481000	juvenile	ALSAPJuvSumDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481000	juvenile	ALPSEJuvSumDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481000	adult/egg/larval	ALPSESpawnEggLarvDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481000	juvenile	ALAESJuvSumDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481000	adult/egg/larval	ALAESSpawnEggLarvDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481500	adult	ALSAPSpawnDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481500	egg/larval	ALSAPEggLarvDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481500	juvenile	ALSAPJuvSumDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481500	juvenile	ALPSEJuvSumDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481500	adult/egg/larval	ALPSESpawnEggLarvDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481500	juvenile	ALAESJuvSumDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481500	adult/egg/larval	ALAESSpawnEggLarvDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 8. Percentage of time pH was within a metric range at Brandywine Creek USGS gages 1481000 and 1481500. See table 2 for a description of metrics and table 3 for gage information.

Gage	Stage	Metric	Year									
			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1481000	egg	ALSAPEggpHTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481000	egg	ALSAPEggpHAveTol	99.9	96.2	99.7	89.4	100.0	95.3	91.3	96.0	88.7	99.7
1481000	larval	ALSAPLarvpHTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1481000	larval	ALSAPLarvpHAveTol	100.0	100.0	100.0	100.0	99.9	100.0	100.0	100.0	100.0	100.0
1481000	egg/larval	ALPSEEggLarvpHOpt	99.9	96.2	99.7	89.4	100.0	95.3	91.3	96.0	88.7	99.7
1481000	adult	ALPSESpawnpHTol	21.5	0.7	5.4	23.6	24.0	19.1	0.0	2.3	9.2	4.1
1481000	egg	ALAESEggpHOpt	92.5	86.2	85.9	83.3	98.8	80.2	77.5	82.1	77.0	94.8
1481000	egg	ALAESEggpHSuit	99.9	96.2	99.7	89.4	100.0	95.3	91.3	96.0	88.7	99.7
1481000	larval	ALAESLarvpHOpt	92.5	86.2	85.9	83.3	98.8	80.2	77.5	82.1	77.0	94.8
1481000	larval	ALAESLarvpHSuit	99.9	96.2	99.7	89.4	100.0	95.3	91.3	96.0	88.7	99.7
1481000	adult	ALAESSpawnpHSuit	92.5	86.2	85.9	83.3	98.8	80.2	77.5	82.1	77.0	94.8
1481000	adult	ALAESSpawnpHOpt	92.5	86.2	85.9	83.3	98.8	80.2	77.5	82.1	77.0	94.8
1481500	egg	ALSAPEggpHTol	100	100	100	100	100	100	100	100	100	100
1481500	egg	ALSAPEggpHAveTol	99.8	93.1	94.6	89.5	100.0	90.8	87.5	95.3	85.7	94.8
1481500	larval	ALSAPLarvpHTol	100	100	100	100	100	100	100	100	100	100
1481500	larval	ALSAPLarvpHAveTol	100	100	100	100	100	100	100	100	100	100
1481500	egg/larval	ALPSEEggLarvpHOpt	99.8	93.1	94.6	89.5	100.0	90.8	87.5	95.3	85.7	94.8
1481500	adult	ALPSESpawnpHTol	1.7	0.0	0.4	1.6	4.0	0.0	0.0	0.6	0.8	1.7
1481500	egg	ALAESEggpHOpt	74.5	75.9	74.0	74.7	88.4	64.4	70.2	69.7	64.9	86.5
1481500	egg	ALAESEggpHSuit	99.8	93.1	94.6	89.5	100.0	90.8	87.5	95.3	85.7	94.8
1481500	larval	ALAESLarvpHOpt	74.5	75.9	74.0	74.7	88.4	64.4	70.2	69.7	64.9	86.5
1481500	larval	ALAESLarvpHSuit	99.8	93.1	94.6	89.5	100.0	90.8	87.5	95.3	85.7	94.8
1481500	adult	ALAESSpawnpHSuit	74.5	75.9	74.0	74.7	88.4	64.4	70.2	69.7	64.9	86.5
1481500	adult	ALAESSpawnpHOpt	74.5	75.9	74.0	74.7	88.4	64.4	70.2	69.7	64.9	86.5

Appendix 9. Percentage of time the water temperature at White Clay Creek gages were within the metric range. See table 2 for a description of metrics and table 3 for gage information. Gages on larger watersheds (1478245 and 1478650, Appendix 9) were weighted more heavily when assessing suitability.

		Year				
		2020	2020	2020	2020	2019
		Gage				
Stage	Metric	1478120	1478220	1478245	1478650	
adult	ALSAPSpawnTempOpt	59.7	58.4	60.8	70.5	82.6
adult	ALSAPSpawnTempTol	98.0	96.8	98.2	99.5	98.6
egg	ALSAPEggSprTempTol	98.0	96.8	98.2	100.0	98.6
larval	ALSAPLarvSprTempOpt	52.6	53.6	55.3	70.1	76.5
larval	ALSAPLarvSprTempTol	88.3	86.0	89.1	97.3	95.7
juvenile	ALSAPJuvSumTempOpt	98.5	87.7	89.3	73.2	85.3
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempTol	99.7	98.8	99.7	100.0	99.6
adult	ALPSESpawnTempOpt	51.9	43.0	42.9	25.3	65.1
egg	ALPSEEggTempTol	83.2	81.8	84.3	95.4	95.1
egg	ALPSEEggTempOpt	30.9	24.2	26.0	22.9	37.3
larval	ALPSEPosLarvTempTol	59.7	60.0	61.6	77.9	83.0
larval	ALPSEPosLarvTempOpt	14.5	23.1	25.2	56.7	23.8
larval	ALPSEProLarvTempTol	98.0	96.8	98.2	100.0	98.6
larval	ALPSEProLarvTempOpt	52.6	51.5	53.7	64.0	75.4
juvenile	ALPSEJuvSumTempOpt	31.1	19.5	19.7	14.8	15.7
juvenile	ALPSEJuvSumTempTol	100.0	99.8	100.0	98.0	99.3
adult	ALAESSpawnTempTol	65.7	65.5	67.2	81.8	88.0
adult	ALAESSpawnTempOpt	14.5	22.4	24.9	52.9	23.8
egg	ALAESEggTempTol	40.8	39.4	38.7	22.5	17.4
larval	ALAESLarvTempTol	65.7	65.5	67.2	81.8	88.0
juvenile	ALAESJuvSumTempOpt	64.1	76.3	75.5	81.8	85.2
juvenile	ALAESJuvSumTempTol	100.0	100.0	99.9	100.0	100.0

Appendix 10. Percentage of time the water temperature at the Red Clay Creek gage 1480000 was within the metric range. See table 2 for a description of metrics and table 3 for gage information.

Stage	Metric Name	Year	
		2019	2020
adult	ALSAPSpawnTempOpt	83.5	60.4
adult	ALSAPSpawnTempTol	100.0	100.0
egg	ALSAPEggSprTempTol	100.0	100.0
larval	ALSAPLarvSprTempOpt	80.2	58.2
larval	ALSAPLarvSprTempTol	96.7	96.7
juvenile	ALSAPJuvSumTempOpt	92.4	81.5
juvenile	ALSAPJuvSumTempTol	100.0	100.0
adult	ALPSESpawnTempOpt	64.8	100.0
adult	ALPSESpawnTempTol	40.7	100.0
egg	ALPSEEggTempOpt	41.8	24.2
egg	ALPSEEggTempTol	96.7	89.0
larval	ALPSEPosLarvTempOpt	28.6	29.7
larval	ALPSEPosLarvTempTol	83.5	60.4
larval	ALPSEProLarvTempOpt	80.2	56.0
larval	ALPSEProLarvTempTol	100.0	100.0
juvenile	ALPSEJuvSumTempOpt	15.2	13.0
juvenile	ALPSEJuvSumTempTol	100.0	100.0
adult	ALAESSpawnTempOpt	28.6	29.7
adult	ALAESSpawnTempTol	91.2	70.3
egg	ALAESEggTempTol	16.5	39.6
larval	ALAESLarvTempTol	91.2	70.3
juvenile	ALAESJuvSumTempOpt	85.9	82.6
juvenile	ALAESJuvSumTempTol	100.0	100.0

Appendix 11. Percentage of time the water temperature was within the metric range at gages on the Lehigh River. See table 2 for a description of metrics and table 3 for gage information. Gages on larger watersheds (1449800 see Appendix 12; for gages 1451500, 1451650, and 1454700 see Appendix 13) were weighted more heavily when assessing suitability.

Stage	Metric	Gage 17				Gage 18				Gage 19				Gage 20		
	Year	2017	2018	2019	2020	2017	2018	2019	2020	2017	2018	2019	2020	2018	2019	2020
adult	ALSAPSpawnTempOpt	45.1	47.8	41.7		53.2	52.0	49.5		44.9	55.3	69.9		54.6	43.0	72.6
adult	ALSAPSpawnTempTol	85.5	95.6	90.7		77.9	95.2	94.6		82.6	92.4	97.6		91.6	97.4	98.3
egg	ALSAPEggSprTempTol	85.5	95.6	90.7		77.9	95.2	94.6		82.6	92.4	97.6		91.6	97.4	98.3
larval	ALSAPLarvSprTempOpt	31.1	34.1	34.5		44.2	41.5	45.2		35.8	46.3	61.9		43.7	29.1	63.6
larval	ALSAPLarvSprTempTol	76.0	89.3	72.0		71.9	89.4	75.6		73.9	88.6	89.9		84.0	92.0	91.2
juvenile	ALSAPJuvSumTempOpt	100.0	100.0	100.0	98.8	100.0	81.5	100.0	99.1	100.0	99.9	99.2	98.8	100.0	100.0	99.2
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	81.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempTol		90.8	97.8	96.2		85.2	97.6	98.0		87.8	93.8	98.7	95.2	98.6	99.3
adult	ALPSESpawnTempOpt		55.4	60.0	47.2		51.3	59.2	39.2		48.5	62.5	63.5	61.4	54.3	68.9
egg	ALPSEEggTempTol		73.1	85.8	67.2		70.5	84.8	70.5		71.1	85.8	87.9	81.4	85.4	89.1
egg	ALPSEEggTempOpt		9.5	9.8	13.9		21.0	13.5	26.0		14.7	18.1	32.9	16.6	9.0	36.0
larval	ALPSEPosLarvTempTol		45.1	47.8	41.7		53.2	52.0	49.5		44.9	55.3	69.9	54.6	43.0	72.6
larval	ALPSEPosLarvTempOpt		0.5	0.6	1.7		7.3	1.6	14.6		4.9	2.2	14.2	3.0	0.0	11.5
larval	ALPSEProLarvTempTol		85.5	95.6	90.7		77.9	95.2	94.6		82.6	92.4	97.6	91.6	97.4	98.3
larval	ALPSEProLarvTempOpt		31.1	34.1	34.5		44.2	41.5	45.0		35.8	46.3	61.9	43.7	29.1	63.6
juvenile	ALPSEJuvSumTempOpt	72.8	85.9	78.0	72.5	67.3	58.7	44.0	44.2	63.5	77.2	59.5	63.2	82.9	68.8	61.6
juvenile	ALPSEJuvSumTempTol	100.0	100.0	100.0	98.8	100.0	81.7	100.0	99.7	100.0	100.0	100.0	98.8	100.0	100.0	99.2
adult	ALAESSpawnTempTol		55.9	60.6	48.7		58.3	60.7	53.3		53.3	64.6	77.3	64.2	54.3	79.9
adult	ALAESSpawnTempOpt		0.5	0.6	1.7		7.3	1.6	14.6		4.9	2.2	14.2	3.0	0.0	11.5
egg	ALAESEggTempTol		47.0	51.8	55.4		33.3	46.9	48.9		43.8	39.5	29.4	41.8	57.4	27.6
larval	ALAESLarvTempTol		55.9	60.6	48.7		58.3	60.7	53.3		53.3	64.6	77.3	64.2	54.3	79.9
juvenile	ALAESJuvSumTempOpt	0.0	7.2	12.6	14.6	1.5	21.4	59.1	49.1	2.9	15.2	37.4	25.8	14.2	15.9	29.4
juvenile	ALAESJuvSumTempTol	100.0	100.0	99.9	97.7	100.0	81.7	100.0	99.0	100.0	100.0	99.9	98.1	100.0	100.0	98.5

Appendix 12. Percentage of time the water temperature was within the metric range at gages on the Lehigh River. See table 2 for a description of metrics and table 3 for gage information. on larger watersheds (1449800 see Appendix 12; 1451500, 1451650, and 1454700 see Appendix 13) were weighted more heavily when assessing suitability.

Stage	Metric	1447500 2018	1447500 2019	1447500 2020	1447720 2018	1447720 2019	1447720 2020	1447800 2018	1447800 2019	1447800 2020	1449360 2018	1449360 2019	1449360 2020	1449800 2018	1449800 2019	1449800 2020
adult	ALSAPSpawnTempOpt	55.3	53.6	48.8	61.7	53.0	48.5	49.7	38.5	31.7	45.1	39.9	42.9	24.2	33.3	33.6
adult	ALSAPSpawnTempTol	78.2	92.0	80.8	77.7	92.3	82.9	69.1	84.4	79.9	81.7	93.9	89.5	74.5	87.2	90.1
egg	ALSAPEggSprTempTol	78.2	92.0	80.8	77.7	92.3	82.9	69.1	84.4	79.9	81.7	93.9	89.5	74.5	87.2	90.1
larval	ALSAPLarvSprTempOpt	47.1	46.3	45.1	54.6	46.7	45.3	45.3	35.7	26.1	31.0	22.6	36.5	5.7	14.8	19.8
larval	ALSAPLarvSprTempTol	73.5	82.3	64.6	73.2	85.3	64.2	63.8	82.7	60.3	76.3	85.3	69.9	58.3	77.2	65.1
juvenile	ALSAPJuvSumTempOpt	97.0	97.6	91.0	97.7	98.8	98.9	100.0	100.0	99.8	100.0	100.0	99.5	100.0	100.0	99.5
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempTol	79.7	94.4	89.6	79.1	93.9	93.7	72.0	85.7	99.8	87.2	96.5	96.0	77.4	90.1	99.5
adult	ALPSESpawnTempOpt	52.7	57.7	39.2	49.9	57.5	36.9	52.9	48.1	33.9	56.4	53.4	49.0	39.0	48.8	42.6
egg	ALPSEEggTempTol	70.5	77.9	61.0	69.0	82.1	59.2	58.5	79.2	48.6	73.1	80.9	64.6	52.7	70.7	58.6
egg	ALPSEEggTempOpt	23.2	21.9	27.3	31.0	27.1	29.0	31.1	30.4	21.1	9.2	3.2	18.1	0.0	0.0	0.4
larval	ALPSEPosLarvTempTol	55.7	53.6	48.8	62.2	53.0	48.5	49.7	38.5	31.7	45.1	39.9	42.9	24.2	33.3	33.6
larval	ALPSEPosLarvTempOpt	9.3	4.3	13.2	16.0	4.2	14.6	0.0	0.0	1.5	0.6	0.0	1.4	0.0	0.0	0.0
larval	ALPSEProLarvTempTol	78.2	92.0	80.8	77.7	92.3	82.9	69.1	84.4	79.9	81.7	93.9	89.5	74.5	87.2	90.1
larval	ALPSEProLarvTempOpt	46.7	46.3	45.0	53.9	46.7	45.3	45.3	35.7	26.1	31.0	22.6	36.5	5.7	14.8	19.8
juvenile	ALPSEJuvSumTempOpt	47.5	43.6	31.2	27.7	45.5	30.6	33.0	33.1	24.2	82.2	79.8	63.2	90.2	51.1	62.9
juvenile	ALPSEJuvSumTempTol	99.8	100.0	98.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.5	100.0	100.0	99.5
adult	ALAESSpawnTempTol	61.6	61.7	51.9	65.1	61.4	50.8	52.9	48.1	34.9	56.8	53.4	50.1	39.0	48.8	42.6
adult	ALAESSpawnTempOpt	9.1	4.3	13.2	15.9	4.2	14.6	0.0	0.0	1.5	0.6	0.0	1.4	0.0	0.0	0.0
egg	ALAESEggTempTol	24.8	41.7	41.1	17.8	41.7	45.4	22.7	47.4	68.2	43.5	58.2	53.8	54.9	58.1	67.0
larval	ALAESLarvTempTol	61.6	61.7	51.9	65.1	61.4	50.8	52.9	48.1	34.9	56.8	53.4	50.1	39.0	48.8	42.6
juvenile	ALAESJuvSumTempOpt	48.0	51.8	61.6	73.2	51.6	62.6	68.3	69.0	77.8	8.0	15.4	26.1	5.3	0.0	0.0
juvenile	ALAESJuvSumTempTol	100.0	99.9	98.0	100.0	100.0	99.3	100.0	100.0	100.0	100.0	100.0	98.3	99.9	100.0	98.6

Appendix 13. Percentage of time the water temperature was within the metric range at gages on the Lehigh River. See table 2 for a description of metrics and table 3 for gage information. Gages on larger watersheds (1449800 see Appendix 12; 1451500, 1451650, and 1454700 Appendix 13) were weighted more heavily when assessing suitability.

Stage	Metric	2020	2020	2020	2020	2020	2020	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	Gage	1451380	1451400	1451500	1451630	1451650	1451800	1454700										
adult	ALSAPSpawnTempOpt	52.6	31.5	54.5	63.2	57.8	50.1		67.5	73.8	75.5	56.2	68.7	63.9	65.4	62.3	58.0	51.7
adult	ALSAPSpawnTempTol	97.5	100.0	100.0	99.7	100.0	91.1		96.3	100.0	96.5	92.8	94.5	97.9	97.7	86.0	98.2	99.7
egg	ALSAPEggSprTempTol	97.5	100.0	100.0	99.7	100.0	93.3		96.3	100.0	96.5	92.8	94.5	97.9	97.7	86.0	98.2	99.7
larval	ALSAPLarvSprTempOpt	44.2	21.3	44.3	55.8	48.1	47.2		56.3	68.0	69.0	51.8	65.0	59.3	58.7	54.5	50.2	50.2
larval	ALSAPLarvSprTempTol	85.7	90.4	92.1	94.0	93.6	80.1		84.0	100.0	93.6	83.6	84.3	90.5	90.1	79.0	92.2	79.8
juvenile	ALSAPJuvSumTempOpt	99.2	99.6	100.0	99.8	100.0	86.2	96.3	92.2	90.0	93.0	100.0	99.5	74.9	98.2	96.1	98.9	88.0
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempTol	99.4	100.0	100.0	100.0	100.0	96.4		99.4	100.0	99.3	98.4	97.0	99.5	99.1	93.0	100.0	100.0
adult	ALPSESpawnTempOpt	53.7	46.1	60.4	60.0	61.3	33.8		53.5	59.4	56.1	47.5	41.1	40.0	55.9	50.0	67.5	32.1
egg	ALPSEEggTempTol	80.4	84.4	86.6	90.2	88.1	74.5		81.8	99.5	92.1	81.2	82.9	89.4	89.5	77.4	90.6	74.7
egg	ALPSEEggTempOpt	20.3	7.7	21.8	32.5	27.6	21.1		30.9	36.2	27.8	28.3	36.4	17.8	21.4	27.8	33.2	26.9
larval	ALPSEPosLarvTempTol	52.6	31.5	54.5	63.2	57.8	55.7		67.5	73.8	75.5	56.2	68.9	64.9	65.4	62.3	58.0	51.7
larval	ALPSEPosLarvTempOpt	8.4	0.2	3.0	11.8	4.4	25.4		21.7	18.3	27.1	16.7	32.5	34.4	21.0	16.4	5.3	25.3
larval	ALPSEProLarvTempTol	97.5	100.0	100.0	99.7	100.0	93.3		96.3	100.0	96.5	92.8	94.5	97.9	97.7	86.0	98.2	99.7
larval	ALPSEProLarvTempOpt	44.1	21.3	44.3	55.8	48.1	44.0		56.3	67.8	68.8	51.8	64.0	56.2	58.7	54.3	50.2	49.0
juvenile	ALPSEJuvSumTempOpt	62.4	39.7	71.3	56.3	68.6	26.1	29.9	41.0	21.5	32.1	25.2	25.6	7.6	33.5	40.5	28.0	18.2
juvenile	ALPSEJuvSumTempTol	99.5	99.9	100.0	100.0	100.0	95.7	100.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult	ALAESSpawnTempTol	61.8	46.3	63.1	71.0	65.2	59.6		73.8	77.2	82.7	63.6	72.3	73.9	76.3	65.7	72.7	56.5
adult	ALAESSpawnTempOpt	8.4	0.2	3.0	11.8	4.4	23.1		21.7	18.3	27.1	16.7	32.5	34.2	21.0	16.4	5.3	25.3
egg	ALAESEggTempTol	47.9	69.6	46.7	37.4	43.3	41.3		32.8	26.5	24.5	42.4	28.5	35.6	35.1	31.4	43.3	48.5
larval	ALAESLarvTempTol	61.8	46.3	63.1	71.0	65.2	60.3		73.8	77.2	82.7	63.6	72.3	73.9	76.3	65.7	72.7	56.5
juvenile	ALAESJuvSumTempOpt	26.3	5.4	16.9	37.9	21.3	67.7	71.3	58.6	78.1	68.9	75.5	75.5	92.6	68.1	61.5	73.6	80.7
juvenile	ALAESJuvSumTempTol	98.6	98.2	99.7	100.0	100.0	98.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 14. Percentage of time dissolved oxygen (DO) was within a metric range at the Lehigh River USGS gage 1454700. See table 2 for a description of metrics and table 3 for gage information.

Stage	Metric	Year									
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
adult	ALSAPSpawnDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
egg/larval	ALSAPEggLarvDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
juvenile	ALSAPJuvSumDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
juvenile	ALPSEJuvSumDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult/egg/larval	ALPSESpawnEggLarvDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
juvenile	ALAESJuvSumDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult/egg/larval	ALAESSpawnEggLarvDO	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 15. Percentage of time pH was within a metric range at the Lehigh River USGS gage 1454700. See table 2 for a description of metrics and table 3 for gage information.

		Year									
Stage	Metric	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
egg	ALSAPEggpHTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
egg	ALSAPEggpHAveTol	100.0	99.6	100.0	100.0	100.0	99.2	100.0	100.0	98.5	100.0
larval	ALSAPLarvpHTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
larval	ALSAPLarvpHAveTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
egg/larval	ALPSEEggLarvpHOpt	100.0	99.6	100.0	100.0	100.0	99.2	100.0	100.0	98.5	100.0
adult	ALPSESpawnpHTol	0.0	0.4	0.4	5.6	0.5	0.0	5.5	4.5	0.0	1.5
egg	ALAESEggpHOpt	99.6	86.4	100.0	100.0	99.9	92.3	100.0	94.9	93.6	97.4
egg	ALAESEggpHSuit	100.0	99.6	100.0	100.0	100.0	99.2	100.0	100.0	98.5	100.0
larval	ALAESLarvpHOpt	99.6	86.4	100.0	100.0	99.9	92.3	100.0	94.9	93.6	97.4
larval	ALAESLarvpHSuit	100.0	99.6	100.0	100.0	100.0	99.2	100.0	100.0	98.5	100.0
adult	ALAESSpawnpHSuit	99.6	86.4	100.0	100.0	99.9	92.3	100.0	94.9	93.6	97.4
adult	ALAESSpawnpHOpt	99.6	86.4	100.0	100.0	99.9	92.3	100.0	94.9	93.6	97.4

Appendix 16. Percentage of time water temperature was within a metric range at the Neshaminy Creek Langhorne USGS gage 01465500. See table 2 for a description of metrics and table 3 for gage information.

Stage	Metric	Year	
		2019	2020
adult	ALSAPSpawnTempOpt	82.4	51.0
adult	ALSAPSpawnTempTol	97.8	93.1
egg	ALSAPEggSprTempTol	99.6	100.0
larval	ALSAPLarvSprTempOpt	76.8	48.1
larval	ALSAPLarvSprTempTol	97.1	94.8
juvenile	ALSAPJuvSumTempOpt	76.5	67.2
juvenile	ALSAPJuvSumTempTol	100.0	100.0
adult	ALPSESpawnTempOpt	53.2	33.1
adult	ALPSESpawnTempTol	99.8	98.1
egg	ALPSEEggTempOpt	32.0	17.4
egg	ALPSEEggTempTol	94.9	85.7
larval	ALPSEPosLarvTempOpt	35.4	32.5
larval	ALPSEPosLarvTempTol	85.6	63.5
larval	ALPSEProLarvTempOpt	74.9	42.0
larval	ALPSEProLarvTempTol	99.6	100.0
juvenile	ALPSEJuvSumTempOpt	8.2	11.5
juvenile	ALPSEJuvSumTempTol	95.2	86.4
adult	ALAESSpawnTempOpt	34.5	28.0
adult	ALAESSpawnTempTol	88.9	68.1
egg	ALAESEggTempTol	14.9	35.6
larval	ALAESLarvTempTol	89.5	70.2
juvenile	ALAESJuvSumTempOpt	91.5	83.3
juvenile	ALAESJuvSumTempTol	100.0	100.0

Appendix 17. Percentage of time the water temperature at Crosswicks Creek gages were within the metric range in 2020. See table 2 for a description of metrics and table 3 for gage information. Gage 1464500 was weighted more heavily due to its larger watershed area; both gages had similar values for each metric.

Stage	Metric	Gage	
		1464290	1464500
adult	ALSAPSpawnTempOpt	60.2	60.5
adult	ALSAPSpawnTempTol	97.3	100.0
egg	ALSAPEggSprTempTol	100.0	100.0
larval	ALSAPLarvSprTempOpt	54.8	56.0
larval	ALSAPLarvSprTempTol	97.7	97.3
juvenile	ALSAPJuvSumTempOpt	58.8	76.5
juvenile	ALSAPJuvSumTempTol	100.0	100.0
adult	ALPSESpawnTempTol	99.8	100.0
adult	ALPSESpawnTempOpt	39.6	40.2
egg	ALPSEEggTempTol	93.9	93.5
egg	ALPSEEggTempOpt	19.7	21.8
larval	ALPSEPosLarvTempTol	68.5	62.3
larval	ALPSEPosLarvTempOpt	35.7	31.0
larval	ALPSEProLarvTempTol	100.0	100.0
larval	ALPSEProLarvTempOpt	48.5	53.6
juvenile	ALPSEJuvSumTempOpt	11.3	12.8
juvenile	ALPSEJuvSumTempTol	93.5	100.0
adult	ALAESSpawnTempTol	76.4	70.8
adult	ALAESSpawnTempOpt	32.3	30.1
egg	ALAESEggTempTol	32.1	38.5
larval	ALAESLarvTempTol	77.3	70.8
juvenile	ALAESJuvSumTempOpt	87.1	84.0
juvenile	ALAESJuvSumTempTol	100.0	100.0

Appendix 18. Percentage of time water temperature was within a metric range at the NJDEP Bureau of Freshwater Fisheries gage. See table 2 for a description of metrics and table 3 for gage information.

Stage	Metric	Year				
		2013	2014	2015	2016	2017
adult	ALSAPSpawnTempOpt	94.2	74.7	66.8	62.1	65.2
adult	ALSAPSpawnTempTol	100.0	97.6	95.0	94.9	98.0
egg	ALSAPEggSprTempTol	100.0	97.6	95.0	94.9	98.0
larval	ALSAPLarvSprTempOpt	88.9	69.8	60.3	53.6	54.0
larval	ALSAPLarvSprTempTol	100.0	92.2	88.6	89.6	93.9
juvenile	ALSAPJuvSumTempOpt	99.9	100.0	100.0	99.7	100.0
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempOpt	65.8	69.7	56.6	58.5	63.9
adult	ALPSESpawnTempTol	100.0	99.6	97.6	97.3	98.7
egg	ALPSEEggTempOpt	50.4	47.8	37.2	29.6	24.8
egg	ALPSEEggTempTol	100.0	89.9	85.1	88.4	92.8
larval	ALPSEPosLarvTempOpt	30.6	11.6	16.3	11.8	12.8
larval	ALPSEPosLarvTempTol	94.2	74.7	66.8	62.1	65.2
larval	ALPSEProLarvTempOpt	88.9	69.8	60.3	53.6	54.0
larval	ALPSEProLarvTempTol	100.0	97.6	95.0	94.9	98.0
juvenile	ALPSEJuvSumTempOpt	52.2	63.8	38.6	59.2	56.5
juvenile	ALPSEJuvSumTempTol	100.0	100.0	100.0	100.0	100.0
adult	ALAESSpawnTempOpt	30.6	11.6	16.3	11.8	12.8
adult	ALAESSpawnTempTol	96.4	81.3	72.9	70.3	76.7
egg	ALAESEggTempTol	5.8	24.9	30.7	35.2	33.5
larval	ALAESLarvTempTol	96.4	81.3	72.9	70.3	76.7
juvenile	ALAESJuvSumTempOpt	32.0	18.0	61.4	30.5	34.7
juvenile	ALAESJuvSumTempTol	100.0	100.0	100.0	100.0	100.0

Appendix 19. Percentage of time the water temperature was within the metric range at gages on the Musconetcong River. See table 2 for a description of metrics and table 3 for gage information. Temperature data was not available for all gages and years.

Stage	Metric	Year: 2020			2017	2018	2019
	Gage	8	9	10	11		
adult	ALSAPSpawnTempOpt		58.2			52.7	52.0
adult	ALSAPSpawnTempTol		99.8			89.0	97.3
egg	ALSAPEggSprTempTol		99.8			89.0	97.3
larval	ALSAPLarvSprTempOpt		53.9			39.2	36.2
larval	ALSAPLarvSprTempTol		90.0			80.4	92.3
juvenile	ALSAPJuvSumTempOpt	100.0	98.5	99.8	100.0	100.0	
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	
adult	ALPSESpawnTempTol		100.0			93.6	99.0
adult	ALPSESpawnTempOpt		44.5			62.8	66.3
egg	ALPSEEggTempTol		85.0			78.1	90.1
egg	ALPSEEggTempOpt		30.3			14.7	9.7
larval	ALPSEPosLarvTempTol		58.2			52.7	52.0
larval	ALPSEPosLarvTempOpt		20.2			1.4	0.2
larval	ALPSEProLarvTempTol		99.8			89.0	97.3
larval	ALPSEProLarvTempOpt		53.7			39.2	36.2
juvenile	ALPSEJuvSumTempOpt	5.4	29.1	37.6	75.0	82.9	
juvenile	ALPSEJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	
adult	ALAESSpawnTempTol		64.0			64.1	66.4
adult	ALAESSpawnTempOpt		20.2			1.4	0.2
egg	ALAESEggTempTol		42.3			42.4	48.8
larval	ALAESLarvTempTol		64.0			64.1	66.4
juvenile	ALAESJuvSumTempOpt	1.3	64.6	54.5	4.0	12.1	
juvenile	ALAESJuvSumTempTol	100.0	100.0	99.7	100.0	100.0	

Appendix 20. Percentage of time the water temperature was within the metric range at four gages on the Broadhead Creek in 2020. See table 2 for a description of metrics and table 3 for gage information.

Stage	Metric	Gage			
		1440400	13	14	15
adult	ALSAPSpawnTempOpt	45.4		41.3	
adult	ALSAPSpawnTempTol	85.1		86.7	
egg	ALSAPEggSprTempTol	85.1		86.7	
larval	ALSAPLarvSprTempOpt	39.4		36.2	
larval	ALSAPLarvSprTempTol	64.7		65.4	
juvenile	ALSAPJuvSumTempOpt	99.9	99.5	100.0	100.0
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0
adult	ALAESSpawnTempOpt	6.9		7.5	
adult	ALAESSpawnTempTol	49.7		45.8	
egg	ALAESEggTempTol	48.7		54.9	
larval	ALAESLarvTempTol	49.7		45.8	
juvenile	ALAESJuvSumTempOpt	46.4	51.4	45.9	40.3
juvenile	ALAESJuvSumTempTol	99.4	99.4	99.5	99.1
adult	ALPSESpawnTempOpt	43.2		38.6	
adult	ALPSESpawnTempTol	93.5		95.7	
egg	ALPSEEggTempOpt	23.4		19.4	
egg	ALPSEEggTempTol	61.0		60.1	
larval	ALPSEPosLarvTempOpt	6.9		7.5	
larval	ALPSEPosLarvTempTol	45.4		41.3	
larval	ALPSEProLarvTempOpt	39.4		36.2	
larval	ALPSEProLarvTempTol	85.1		86.7	
juvenile	ALPSEJuvSumTempOpt	46.4	41.7	48.4	50.8
juvenile	ALPSEJuvSumTempTol	100.0	100.0	100.0	100.0

Appendix 21. Percentage of time the water temperature was within the metric range at gages on the Rancocas Creek. See table 2 for a description of metrics and table 3 for gage information. Gages upstream of tidal influence and on larger watersheds (1465850 see Appendix 21; 1467000, 1467005 see Appendix 22) were weighted more heavily when assessing suitability.

Stage	Metric	Year 2020	2020	2012	2013	2014	2015	2016	2017	2018	2019	2020	2020
	Gage	1465850	1465880	1466500									146587310
adult	ALSAPSpawnTempOpt	54.3	54.7	38.4	37.7	42.3	36.0	13.1	37.8	45.6	47.6	26.0	51.6
adult	ALSAPSpawnTempTol	94.7	91.9	100.0	91.1	93.9	89.2	97.5	97.6	86.0	94.3	100.0	92.0
egg	ALSAPEggSprTempTol	100.0	100.0	100.0	91.1	93.9	89.2	97.5	97.6	86.0	94.3	100.0	100.0
larval	ALSAPLarvSprTempOpt	52.4	51.0	18.4	28.7	22.0	21.5	2.0	19.1	32.1	40.9	4.9	44.4
larval	ALSAPLarvSprTempTol	98.5	99.6	91.9	80.3	77.4	76.2	78.0	87.2	72.2	90.1	76.2	100.0
juvenile	ALSAPJuvSumTempOpt	42.6	35.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	27.5
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempTol	99.6	98.5	100.0	92.7	98.2	95.3	100.0	100.0	95.6	98.8	100.0	98.0
adult	ALPSESpawnTempOpt	37.3	41.7	52.5	41.9	56.9	55.9	35.2	52.5	53.2	63.8	37.2	51.5
egg	ALPSEEggTempTol	92.3	94.0	81.3	70.3	72.0	70.8	61.8	83.5	68.0	87.0	66.4	93.8
egg	ALPSEEggTempOpt	17.8	17.1	0.3	13.9	0.0	0.9	0.0	0.0	0.0	12.5	0.0	18.8
larval	ALPSEPosLarvTempTol	68.6	70.9	38.4	37.7	42.3	36.0	13.1	37.8	45.6	47.6	26.0	66.3
larval	ALPSEPosLarvTempOpt	33.9	32.5	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.5
larval	ALPSEProLarvTempTol	100.0	100.0	100.0	91.1	93.9	89.2	97.5	97.6	86.0	94.3	100.0	100.0
larval	ALPSEProLarvTempOpt	44.6	44.8	18.4	28.7	22.0	21.5	2.0	19.1	32.1	40.9	4.9	39.9
juvenile	ALPSEJuvSumTempOpt	11.5	9.1	88.6	56.2	83.0	97.7	89.4	85.6	99.0	83.1	83.3	8.4
juvenile	ALPSEJuvSumTempTol	88.6	80.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	68.7
adult	ALAESSpawnTempTol	73.6	78.1	52.5	46.4	56.9	55.9	35.2	52.5	53.2	63.8	37.2	75.6
adult	ALAESSpawnTempOpt	29.2	26.3	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4
egg	ALAESEggTempTol	31.8	28.6	63.0	55.8	57.5	61.8	89.6	64.9	50.2	51.5	75.9	33.1
larval	ALAESLarvTempTol	75.8	80.6	52.5	46.4	56.9	55.9	35.2	52.5	53.2	63.8	37.2	78.6
juvenile	ALAESJuvSumTempOpt	88.1	88.5	4.0	28.8	0.0	0.0	0.0	0.0	0.0	2.8	0.0	83.8
juvenile	ALAESJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8

Appendix 22. Percentage of time the water temperature was within the metric range at gages on the Rancocas Creek in 2020. See table 1 for a description of metrics and table 2 for gage information. Gages upstream of tidal influence and on larger watersheds (1465850 see Appendix 21; 1467000, 1467005 see Appendix 22) were weighted more heavily when assessing suitability.

Stage	Metric	1466900	1467000	1467005
adult	ALSAPSpawnTempOpt	60.0	61.0	60.1
adult	ALSAPSpawnTempTol	100.0	100.0	100.0
egg	ALSAPEggSprTempTol	100.0	100.0	100.0
larval	ALSAPLarvSprTempOpt	54.7	56.4	56.0
larval	ALSAPLarvSprTempTol	98.7	99.5	99.3
juvenile	ALSAPJuvSumTempOpt	94.7	72.2	69.5
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0
adult	ALPSESpawnTempTol	100.0	100.0	100.0
adult	ALPSESpawnTempOpt	42.1	39.9	39.6
egg	ALPSEEggTempTol	95.1	98.0	97.2
egg	ALPSEEggTempOpt	23.4	20.1	19.7
larval	ALPSEPosLarvTempTol	60.1	62.5	62.6
larval	ALPSEPosLarvTempOpt	27.6	33.8	32.8
larval	ALPSEProLarvTempTol	100.0	100.0	100.0
larval	ALPSEProLarvTempOpt	54.2	53.0	52.6
juvenile	ALPSEJuvSumTempOpt	14.4	13.3	15.5
juvenile	ALPSEJuvSumTempTol	100.0	100.0	99.3
adult	ALAESSpawnTempTol	69.0	72.9	71.9
adult	ALAESSpawnTempOpt	27.6	33.5	31.8
egg	ALAESEggTempTol	40.2	38.4	38.7
larval	ALAESLarvTempTol	69.0	72.9	71.9
juvenile	ALAESJuvSumTempOpt	81.3	85.3	83.6
juvenile	ALAESJuvSumTempTol	100.0	100.0	100.0

Appendix 23. Percentage of time the water temperature was within the metric range at gage 01467024 on the Rancocas Creek in 2020. See table 2 for a description of metrics and table 3 for gage information. Gages upstream of tidal influence and on larger watersheds (1465850 see Appendix 21; 1467000, 1467005 see Appendix 22) were weighted more heavily when assessing suitability.

Stage	Metric	Year
adult	ALSAPSpawnTempOpt	47.0
adult	ALSAPSpawnTempTol	94.1
egg	ALSAPEggSprTempTol	100.0
larval	ALSAPLarvSprTempOpt	44.5
larval	ALSAPLarvSprTempTol	99.3
juvenile	ALSAPJuvSumTempOpt	26.0
juvenile	ALSAPJuvSumTempTol	100.0
adult	ALPSESpawnTempTol	99.8
adult	ALPSESpawnTempOpt	30.9
egg	ALPSEEggTempTol	92.7
egg	ALPSEEggTempOpt	12.3
larval	ALPSEPosLarvTempTol	61.4
larval	ALPSEPosLarvTempOpt	32.6
larval	ALPSEProLarvTempTol	100.0
larval	ALPSEProLarvTempOpt	36.0
juvenile	ALPSEJuvSumTempOpt	3.9
juvenile	ALPSEJuvSumTempTol	79.8
adult	ALAESSpawnTempTol	67.6
adult	ALAESSpawnTempOpt	27.1
egg	ALAESEggTempTol	39.5
larval	ALAESLarvTempTol	69.3
juvenile	ALAESJuvSumTempOpt	95.7
juvenile	ALAESJuvSumTempTol	100.0

Appendix 24. Percentage of time the water temperature at the Salem River gage KCCR1S was within the metric range. See table 2 for a description of metrics and table 3 for gage information.

Stage	Metric Name	Year		
		2018	2019	2020
adult	ALSAPSpawnTempOpt	96.0	82.5	30.9
adult	ALSAPSpawnTempTol	99.3	99.2	99.9
egg	ALSAPEggSprTempTol	100.0	99.2	99.9
larval	ALSAPLarvSprTempOpt	98.2	78.4	19.0
larval	ALSAPLarvSprTempTol	100.0	96.4	90.7
juvenile	ALSAPJuvSumTempOpt	73.6	80.8	90.7
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0
adult	ALPSESpawnTempOpt	25.1	56.6	43.1
adult	ALPSESpawnTempTol	100.0	99.5	100.0
egg	ALPSEEggTempOpt	48.3	34.3	4.1
egg	ALPSEEggTempTol	100.0	95.4	83.3
larval	ALPSEPosLarvTempOpt	76.0	34.2	0.0
larval	ALPSEPosLarvTempTol	100.0	85.4	30.9
larval	ALPSEProLarvTempOpt	93.8	75.4	19.0
larval	ALPSEProLarvTempTol	100.0	99.2	99.9
juvenile	ALPSEJuvSumTempOpt	6.9	17.2	24.5
juvenile	ALPSEJuvSumTempTol	99.3	99.6	100.0
adult	ALAESSpawnTempOpt	74.9	32.9	0.0
adult	ALAESSpawnTempTol	100.0	90.3	43.1
egg	ALAESEggTempTol	0.0	14.7	70.1
larval	ALAESLarvTempTol	100.0	90.3	43.1
juvenile	ALAESJuvSumTempOpt	93.4	83.8	75.9
juvenile	ALAESJuvSumTempTol	100.0	100.0	100.0

Appendix 25. Percentage of time the water temperature at gages on the Cohansey River were within the metric range. See table 2 for a description of metrics and table 3 for gage information. Although gage 6 and 7 are on tributaries to the mainstem Cohansey River and have small watersheds areas, they should reflect the dominant land use and water quality in the region.

		Year					
		2018	2019	2020	2018	2019	2020
Stage	Metric	Gage					
		6			7		
adult	ALSAPSpawnTempOpt	90.8	85.4	68.7	100.0	78.3	56.9
adult	ALSAPSpawnTempTol	98.8	98.4	99.1	100.0	98.9	97.2
egg	ALSAPEggSprTempTol	100.0	100.0	100.0	100.0	98.9	97.2
larval	ALSAPLarvSprTempOpt	95.3	85.8	62.0	97.0	66.8	49.4
larval	ALSAPLarvSprTempTol	100.0	100.0	100.0	100.0	95.7	86.7
juvenile	ALSAPJuvSumTempOpt	60.6	52.4	47.6	100.0	100.0	100.0
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempTol	100.0	100.0	100.0	100.0	99.4	98.9
adult	ALPSESpawnTempOpt	11.6	46.1	50.7	96.6	81.7	51.1
egg	ALPSEEggTempTol	99.7	99.6	100.0	100.0	94.4	83.0
egg	ALPSEEggTempOpt	29.0	35.5	18.8	55.6	34.9	26.9
larval	ALPSEPosLarvTempTol	100.0	93.3	78.8	100.0	78.3	56.9
larval	ALPSEPosLarvTempOpt	88.2	46.9	39.0	4.4	4.4	13.1
larval	ALPSEProLarvTempTol	100.0	100.0	100.0	100.0	98.9	97.2
larval	ALPSEProLarvTempOpt	84.2	78.1	52.1	97.0	66.8	49.4
juvenile	ALPSEJuvSumTempOpt	1.7	1.9	7.9	37.1	56.0	24.1
juvenile	ALPSEJuvSumTempTol	100.0	97.7	99.7	100.0	100.0	100.0
adult	ALAESSpawnTempTol	99.9	94	90.3	100	85.6	63.6
adult	ALAESSpawnTempOpt	84.7	43.8	34.4	4.41	4.4	13.1
egg	ALAESEggTempTol	0	6.95	22.4	0.24	22.1	42.7
larval	ALAESLarvTempTol	100	94.1	90.3	100	85.6	63.6
juvenile	ALAESJuvSumTempOpt	98.5	98.4	92.2	64.9	44.2	72.8
juvenile	ALAESJuvSumTempTol	100	100	100	100	100	100

Appendix 26. Percentage of time the water temperature was within a metric range at the Broadkill USGS gage 01484272. See table 2 for a description of metrics and table 3 for gage information.

Stage	Metric	Year			
		2017	2018	2019	2020
adult	ALSAPSpawnTempOpt	73.7	63.0	69.3	60.1
adult	ALSAPSpawnTempTol	84.0	92.5	86.6	86.9
egg	ALSAPEggSprTempTol	100.0	100.0	100.0	100.0
larval	ALSAPLarvSprTempOpt	72.5	63.7	72.2	51.4
larval	ALSAPLarvSprTempTol	100.0	99.7	100.0	100.0
juvenile	ALSAPJuvSumTempOpt	46.3	25.3	30.7	24.3
juvenile	ALSAPJuvSumTempTol	100.0	100.0	100.0	100.0
adult	ALPSESpawnTempOpt	46.9	24.8	40.2	50.3
adult	ALPSESpawnTempTol	98.3	99.2	96.1	98.1
egg	ALPSEEggTempOpt	37.5	18.5	34.0	17.3
egg	ALPSEEggTempTol	89.7	94.6	92.1	92.2
larval	ALPSEPosLarvTempOpt	35.7	53.8	43.7	27.2
larval	ALPSEPosLarvTempTol	94.2	80.1	90.5	81.0
larval	ALPSEProLarvTempOpt	69.9	55.5	63.6	47.2
larval	ALPSEProLarvTempTol	100.0	100.0	100.0	100.0
juvenile	ALPSEJuvSumTempOpt	0.5	0.0	0.4	8.7
juvenile	ALPSEJuvSumTempTol	85.1	72.8	71.2	69.3
adult	ALAESSpawnTempOpt	31.9	48.3	36.6	20.8
adult	ALAESSpawnTempTol	89.9	82.7	89.8	84.6
egg	ALAESEggTempTol	5.4	19.8	6.4	18.9
larval	ALAESLarvTempTol	96.5	84.8	92.8	89.2
juvenile	ALAESJuvSumTempOpt	98.1	97.7	94.0	85.3
juvenile	ALAESJuvSumTempTol	100.0	100.0	99.0	100.0

Appendix 27. Percentage of time dissolved oxygen (DO) was within a metric range at the Broadkill River USGS gage 01484272. See table 2 for a description of metrics and table 3 for gage information.

Stage	Metric	Year			
		2017	2018	2019	2020
adult	ALSAPSpawnDO	90.7	84.7	100.0	89.3
egg/larva	ALSAPEggLarvDO	83.7	64.0	96.6	80.3
juvenile	ALSAPJuvSumDO	23.9	28.0	51.1	23.7
juvenile	ALPSEJuvSumDO	54.2	69.4	87.5	67.1
adult/egg/larval	ALPSESpawnEggLarvDO	83.7	64.0	96.6	80.3
juvenile	ALAESJuvSumDO	42.3	54.9	78.5	53.2
adult/egg/larval	ALAESSpawnEggLarvDO	83.7	64.0	96.6	80.3

Appendix 28. Percentage of time pH was within a metric range at the Broadkill River USGS gage 01484272. See table 2 for a description of metrics and table 3 for gage information.

Stage	Metric	Year			
		2017	2018	2019	2020
egg	ALSAPEggpHTol	100.0	100.0	100.0	100.0
egg	ALSAPEggpHAveTol	100.0	100.0	100.0	100.0
larval	ALSAPLarvpHTol	100.0	100.0	100.0	100.0
larval	ALSAPLarvpHAveTol	100.0	99.9	100.0	100.0
egg/larval	ALPSEEggLarvpHOpt	100.0	100.0	100.0	100.0
adult	ALPSESpawnpHTol	96.1	97.0	96.0	85.7
egg	ALAESEggpHOpt	100.0	100.0	100.0	99.4
egg	ALAESEggpHSuit	100.0	100.0	100.0	100.0
larval	ALAESLarvpHOpt	100.0	100.0	100.0	99.4
larval	ALAESLarvpHSuit	100.0	100.0	100.0	100.0
adult	ALAESSpawnpHSuit	100.0	100.0	100.0	99.4
adult	ALAESSpawnpHOpt	100.0	100.0	100.0	99.4