Environmental Documentation
Appendix F

Rahway River Basin (Fluvial), New Jersey
Flood Risk Management Findings Report

September 2025

F.1 USFWS Preliminary ESA Technical Review Letter
F.2 USFWS FWCA PAR
F.3 Species List

**New Jersey
Department of
Environmental Protection**

**U.S. Army Corps of Engineers
New York District**

United States Department of the Interior

FISH AND WILDLIFE SERVICE
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In Reply Refer To:
2023-00118408

September 28, 2023

Peter Weppler, Chief
Environmental Analysis Branch
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Dear Mr. Weppler:

This letter responds to your August 14, 2023 request to initiate Endangered Species Act of 1973 (87 Stat. 884, as amended; 16 U.S.C. 153I *et seq.*) (ESA) Section 7 Informal consultation for the U.S. Army Corps of Engineers (Corps) Rahway River Basin (Fluvial), New Jersey Flood Risk Management Feasibility Study (Study). The Study currently proposes to review four alternatives including: Alternative 1 – No Action; Alternative 2 – Upstream Detention; Alternative 3 – Combination Plan; and Alternative 4 – Nonstructural. The U.S. Fish and Wildlife Service (Service), New Jersey Ecological Services Field Office has reviewed the preliminary information provided and is submitting this letter as technical assistance to help guide the Corps as they further develop the Study. The guidance below is limited to the project information and areas displayed within the figures provided to the Service thus far. As additional project information is received, the Service will be able to better articulate our concerns and conservation recommendations for the ESA listed, proposed, and candidate species.

Comments within this letter are provided pursuant to only the ESA. The following comments do not preclude additional comments that will be provided on forthcoming phases of the project and that are pursuant to our other authorities (*e.g.*, the Fish and Wildlife Coordination Act [48 Stat. 401; 16 U.S.C. 661 *et seq.*], National Environmental Policy Act [83 Stat. 852, as amended; 42 U.S.C. 4321 *et seq.*]).

ENDANGERED SPECIES ACT SECTION 7 CONSULTATION

Please ensure that the Service's Information for Planning and Consultation (IPaC) tool (at: *https://ipac.ecosphere.fws.gov/*) is utilized to request/update an official species list. Additionally, once enough project information is available, please utilize the Service's Northeast Endangered Species Determination Key on the IPaC website to evaluate species effects further. The results of the determination key may direct you to consult with us in a standard Section 7 consultation, but they may also result in a completed consultation. The determination key also asks for information that the Service would likely request during a standard project consultation. The key was developed to streamline projects and will make obtaining project concurrence easier. Thus, answering the keys will save time for both of our agencies.

The Service will require adequate project information to officially review and provide our concerns and concurrence if the Corps initiates standard Section 7 consultation. A step-by-step process of what to include with project review requests can be found at: *https://www.fws.gov/office/new-jersey-ecological-services/new-jersey-field-office-project-review-guide*. The information received thus far is not adequate for the Corps to initiate ESA informal Section 7 consultation. As additional project information is received, the Service will be able to better articulate our concerns and recommend conservation recommendations for federally listed, proposed, and candidate species.

The Corps should ensure that the proposed Study alternatives conserve the species below to the maximum extent practicable. Any future Section 7 consultation should ensure that impacts (indirect and direct) to suitable habitat and species are identified/explained and that conservation measures are utilized as necessary to avoid adverse effects. The Service may request additional recommendations once the proposed Study areas and activities are further refined and once/if the Corps initiates Section 7 consultation.

Habitat and species surveys are included in the recommendations below. Please keep in mind that these surveys should be utilized to inform the appropriate species impact determinations for Section 7 consultation. The Service recommends reviewing the ESA interagency regulations at 50 Code of Federal Regulations (CFR) Part 402 for more information on required information and analyses. The 1998 United States Fish and Wildlife Service and National Oceanic Atmospheric Administration National Marine Fisheries Service Endangered Species Consultation Handbook is also useful to review (located at: *https://www.fws.gov/media/endangered-species-consultation-handbook*).

FEDERALLY LISTED, PROPOSED, AND CANDIDATE SPECIES

Bog turtle (*Glyptemys muhlenbergii*, threatened)

At approximately 4 inches long, the bog turtle is one of North America's smallest turtles. This species typically shows a bright yellow, orange, or red blotch on each side of the head. The nearly parallel sides of the carapace (upper shell) give bog turtles an oblong appearance when viewed from above. Bog turtles inhabit open, unpolluted emergent and scrub/shrub wetlands such as shallow spring-fed fens, sphagnum bogs, swamps, marshy meadows, and wet pastures. Bog turtles are also known to use forested wetlands during the active and inactive seasons. These habitats are characterized by soft, muddy (often "mucky") bottoms, interspersed wet and dry pockets, vegetation dominated by low grasses and sedges, and a low volume of standing or slow-moving water, which often forms a network of shallow pools and rivulets. Bog turtles prefer areas with ample sunlight, high evaporation rates, high humidity in the near-ground microclimate, and perennial saturation of portions of the ground. Indirect threats to bog turtles include habitat loss from wetland alteration, invasive species, and natural vegetation succession, whereas direct threats include illegal collection for the commercial pet trade and injury/mortality by motorized vehicles and equipment.

The Study alternatives appear to propose construction outside of the range of bog turtle. Actions that are outside of the range of bog turtle, or that will not impact suitable habitat, are anticipated to have no effect to this species. However, the Study Area boundaries currently include areas that are within the range of bog turtle habitat (refer to Enclosure A). If impacts to suitable bog turtle habitat are anticipated to occur within this range, ESA Section 7 consultation will likely be required to determine if species surveys, or other conservation measures are necessary. As mentioned within the official species list, for this specific action area, consultation is recommended only for activities involving significant changes to surface/ground water, including stormwater. Please ensure that the species list and action area are regularly updated to determine if any changes occur.

Indiana Bat (*Myotis sodalis*, endangered):

Indiana bats hibernate in caves and abandoned mine shafts from October through April. Between April and August, Indiana bats inhabit floodplain, riparian, and upland forests, roosting under loose tree bark during the day, and foraging for flying insects in and around the tree canopy at night. During these summer months, numerous females roost together in maternity colonies. From late August to mid-November, Indiana bats "swarm" in the vicinity of their hibernacula, mating and building up final fat reserves for hibernation. Protection of Indiana bats during all phases of their annual life cycle is essential to the conservation of the species. Threats to the Indiana bat include disease such as white-nose syndrome; disturbance or killing of hibernating and maternity colonies; vandalism and improper gating of hibernacula; fragmentation, degradation, and destruction of forested summer habitats; and exposure to pesticides and other environmental contaminants.

Most of the Study area appears to be within the range of Indiana bat potential summer habitat. Additionally, areas located northwest of the Baltusrol Golf Club in Springfield Township, New Jersey are within the outer range (2.5 to 5 mile buffer) of a known Indiana bat maternity capture site. As such, Indiana bat may be present within the action area from April 1 to September 30. The Study alternatives will likely include tree removal, which could destroy and/or degrade Indiana bat summer habitat. Additionally, structural changes (*i.e.*, new structures, expansion, demolition) where Indiana bat could be roosting, may also affect these species. As such, the Service recommends the conservation measures described within the "Indiana Bat, northern long-eared bat, and tricolored bat conservation measures" section below.

Northern long-eared bat (*Myotis septentrionalis*, endangered) and tricolored bat (*Perimyotis subflavus*, proposed endangered)

During the summer, the northern long-eared bat (NLEB) typically roosts singly or in colonies underneath bark, crevices, or hollows of both live and dead trees and/or snags (typically greater than or equal to 3 inches diameter at breast height (DBH)). The NLEB is opportunistic in selecting roosts, selecting varying roost tree species throughout its range. NLEBs are also known to roost in artificial structures such as buildings, bridges, barns, sheds, and under window eaves. During the winter, NLEBs predominately hibernate in caves and abandoned mine portals. NLEBs engage in swarming activities within 5 miles from a hibernaculum. Threats to the NLEB include disease, such as white-nose syndrome (*Pseudogymnoascus destructans*), improper closure at hibernacula, degradation and destruction of summer habitat, and exposure to pesticides or other environmental contaminants.

The tricolored bat (TCB) is a small insectivorous bat that typically overwinters in caves, abandoned mines and tunnels, and road-associated culverts (southern portion of the range). They spend the rest of the year in a wide variety of forested/wooded habitats where they roost and forage, including adjacent and interspersed non-forested habitats such as emergent wetlands and adjacent edges of agricultural fields, old fields, and pastures. This also includes forests and woodlots containing trees with potential roost substrate (*i.e.*, live and dead leaf clusters of live and recently deceased deciduous trees, Spanish moss (*Tillandsia usneoides*), and beard lichen (*Usnea trichodea*)), as well as linear features such as fencerows, riparian forests, and other wooded corridors. TCBs will roost in a variety of tree species, especially oaks (*Quercus spp*.), and often select roosts in tall, large diameter trees, but will roost in smaller diameter trees when potential roost substrate is present (*e.g.*, 4-inch [10-centimeter]; Leput 2004). They may also roost in human-made structures, such as bridges and culverts, and occasionally in barns or the underside of open-sided shelters (*e.g.*, porches, pavilions).

On September 14, 2022, the Service published a proposal in the FR to list the TCB as endangered under the ESA (*Federal Register* (FR) Vol. 87 (177): 56381-56393). A final determination to either list the TCB under the ESA or to withdraw the proposal is anticipated during Fiscal Year 2024. The Service determined this bat species faces extinction primarily due to the range-wide impacts of white-nose syndrome, a deadly fungal disease affecting cave dwelling bats across North America. Since TCB populations have been greatly reduced due to white-nose syndrome, surviving bat populations are now more vulnerable to other stressors such as human disturbance and habitat loss.

The TCB has begun appearing on Official Species Lists requested from the Service. Species proposed for listing are afforded limited protections under the ESA and only the “conference” provisions of ESA Section 7 apply to them. A conference is only required if the proposed action is likely to jeopardize the continued existence of a proposed species (as defined by implementing ESA regulations at 50 CFR Part 402). However, informal Service review may be requested for actions that may affect a proposed species. The Service encourages that project impacts are analyzed to ensure that effects to proposed species are reviewed if/when they are officially listed. This is also beneficial to the Corps since it will help to prevent potential future delays or complications for project construction. Therefore, the Service recommends that the effects of the proposed project on TCB and their habitat is analyzed and minimized.

The Study area is partially within the range of potential summer habitat for the NLEB and is likely within summer habitat for TCB as well. As such, the bats may be present within the action area from April 1 to September 30. The Study alternatives will likely include tree removal, which could destroy and/or degrade NLEB and TCB summer habitat. Additionally, proposed new, expansion, and/or demolition of structures where NLEB and TCB could be roosting, may also affect these species. As such, the Service recommends the conservation measures described within the "Indiana Bat, northern long-eared bat, and tricolored bat conservation measures" section below.

<u>Indiana Bat, northern long-eared bat, and tricolored bat conservation measures</u>

The Service recommends the following:

1. Avoid cutting or other means of knocking down, bringing down, or trimming of trees that are greater than or equal to 3 inches diameter at breast height (DBH). This is inclusive of the 3 inch DBH trees NLEBs may roost in, the 4 inch DBH trees TCB may roost in, and the 5 inch DBH trees Indiana bat may roost in; or

2. If cutting or other means of knocking down, bringing down, or trimming of trees is less than or equal to 10 acres: avoid those activities for trees that are greater than or equal to 3 inches DBH from April 1 to September 30; or

3. Commission a presence/absence survey (see information about surveys below). Additionally, the following would apply to the results of this survey:

    A. If the survey is negative, the entire time of year restriction may be able to be lifted (depending on acreage and locations of knocking down, bringing down, or trimming of trees).

    B. If the survey is positive, the time of year restriction would be strongly recommended to avoid adverse effects. Additionally, if the survey is positive, further coordination with the Service to develop appropriate conservation measures and avoid adverse effects would be recommended.

4. Avoid removal or modifications to bridges, culverts larger than 5 feet wide, and other structures that could potentially harm roosting bats from April 1 to September 30. Alternatively, the Corps may survey or visibly inspect these structures for bats before construction begins. Please see the structure surveys information below for more information on structure surveys/visible inspections.

Please be aware that the Service will request the measurement and locations of the tree areas proposed for knocking down, bringing down, or trimming during our ESA Section 7 consultation. If the Corps is proposing over 10 acres of this activity, further review by the Service of the locations will be required to determine if presence/absence surveys are needed to result in a not likely to adversely affect determination.

For presence/absence surveys:

Survey plans shall be submitted to this office for approval (attention: Michael Ciappi, michael_ciappi@fws.gov) prior to the field survey. The surveys shall follow the 2023 Range wide Indiana Bat and NLEB Survey Guidelines available at: *https://www.fws.gov/media/range-wide-indiana-bat-and-northern-long-eared-bat-survey-guidelines.* Please note that the survey season is from May 15 to August 15 and that the 2023 guidance also includes survey recommendations for TCB. Survey results are valid for five years. Additionally, a recognized and qualified bat surveyor must conduct the survey (see Enclosure B).

The project proponent may opt to conduct either an acoustic or mist netting presence absence survey (unless noted otherwise in the text above). Please note, if an acoustic survey confirms presence, a follow up mist netting survey would be requested to determine if maternity roosts are located within the project area. As part of the mist netting survey, captured reproductive female and juvenile bats should be tracked with radio telemetry back to maternity roosts.

For structure surveys:

The project may encounter delays if a bat colony is unexpectedly discovered on a structure proposed for construction. The Service recommends the use of a structure survey to inspect for evidence of bat occupancy. Surveys should be conducted or supervised by personnel that have received training on identifying suitable bat roosts in structures. Please refer to the following documents for additional guidance:

1. New Jersey Guidance on Surveying Transportation Structures for Bat Occupancy at: *https://www.fws.gov/media/new-jersey-guidance-surveying-transportation-structures-bat-occupancy.* The bats in transportation structures survey form can be found at: *https://www.fws.gov/media/new-jersey-bats-bridges-survey-form.*

2. An emergence survey is recommended if the structure survey was not able to be completed or found evidence of bat occupancy and additional data is needed to confirm the species of bat and number of individuals that are using a structure. Information on emergence surveys can be found in the guidance for conducting bat emergence surveys at structures in New Jersey form at: *https://www.fws.gov/media/guidance-conducting-bat-emergence-surveys-structures-new-jersey*. The bat emergence survey form can be found at: *https://www.fws.gov/media/bat-emergence-survey-form-new-jersey-structures*.

Other bat conservation measures may be recommended once specific information about project details and impacts is developed/ready for Service review.

<u>Monarch butterfly (*Danaus plexippus*, candidate)</u>

The monarch butterfly was added to the list of Federal candidate species in 2020. Candidate species are those that the Service has determined warrant listing under the ESA and await formal listing. Although these species receive no substantive or procedural protection under the ESA until formal listing, the Service encourages consideration of candidate species in project planning and opportunities that may aid in their conservation. A listing determination for this species is expected in Fiscal Year 2024. The Service recommends including the monarch butterfly in any future Biological Assessments and effects analyses, to help avoid or minimize project delays if the species is listed before or during project construction.

Adult monarch butterflies are large and conspicuous, with bright orange wings surrounded by a black border and covered with black veins. The black border has a double row of white spots, present on the upper side of the wings. Adult monarch butterflies are sexually dimorphic, with males having narrower wing venation and scent patches. Each spring, monarch butterflies disperse from overwintering grounds to areas across the United States, including New Jersey. During the breeding season, monarch butterflies lay eggs on their obligate milkweed host plant (primarily *Asclepias spp.*), and larvae emerge after 2 to 5 days. Larvae develop through five larval instars (intervals between molts) over a period of 9 to 18 days, feeding on milkweed and sequestering toxic chemicals (cardenolides) as a defense against predators. The larva then pupates into a chrysalis before emerging 6 to 14 days later as an adult butterfly. There are multiple generations of monarch butterflies produced during the breeding season, with most adult butterflies living approximately 2 to 5 weeks; overwintering adults enter reproductive diapause (suspended reproduction) and live 6 to 9 months.

Within the Study area, monarch butterflies may be present during migration and breeding from May 1 to September 30 (Monarch Joint Venture 2019). Monarch butterfly habitat requires suitable shelter from poor weather such as fallen logs and leaf litter; food from plants such as milkweed and other nectar plants to support them throughout the breeding season; and water within brief flying range (New Jersey Department of Environmental Protection 2017). Suitable breeding habitat requires all the same conditions but also their obligate milkweed host plant. In the fall, surviving monarch butterflies migrate from and through New Jersey to their respective overwintering sites which is generally in the mountains of central Mexico.

The Service recommends the following for monarch butterfly:

1. Avoid removing of or impacting suitable monarch habitat. If avoiding impacts to suitable monarch habitat is not possible, avoid impacts during times of year monarch's may be present from May 1 to September 30. Review the "Mowing and Management: Best Practices for Monarch's" handout at: *https://monarchjointventure.org/blog/revised-handout-mowing-and-management-best-practices-for-monarchs* to see if any other conservation measures are applicable to this project/can be implemented.

2. Review the conservation measures and descriptions included in Section VII of the "Monarch CCAA Application" that can be found at: *https://rightofway.erc.uic.edu/working-group-access/monarchccaatoolkit*. Although the Candidate Conservation Agreement for monarch butterfly is not applicable for this project, we recommend reviewing the application to help aid in the development of possible conservation measures.

3. Review the Services website at: *https://www.fws.gov/initiative/pollinators/monarchs* and the New Jersey Department of Environmental Protection's (NJDEP) (2017) Monarch Butterfly Conservation Guide for possible conservation measures to implement.

If future listing of the monarch butterfly occurs before or during project construction, the Service will likely recommend additional conservation measures.

SPECIES UNDER REVIEW FOR ENDANGERED SPECIES ACT LISTING

The little brown bat (*Myotis lucifugus*), wood turtle (*Glyptemys insculpta*) and spotted turtle (*Clemmys guttata*) are under review for listing per the ESA and may be present in the Study area. Species under review for listing do not receive any protections under the ESA, and the Service has not yet determined if listing for these species is warranted. If these species are proposed for or listed per the ESA before or during project construction, potential delays/additional consultations may occur. As such, the Corps may wish to include them in any future effects analyses, to help avoid or minimize project delays if they are listed before or during project construction.

Please be aware that the wood turtle is listed as threatened and that the little brown is listed as special concern by the State of New Jersey. As such, the NJDEP Endangered and Nongame Species Program will likely offer or require conservation measures for these species during their review of this Study as well. Since these species are not currently listed or proposed per the ESA, additional conservation measures may be recommended by the Service as more information is developed in the future. The National Listing workplan for Fiscal Years 2023-2027 can be found at: *https://www.fws.gov/project/national-listing-workplan* for more information on species listing timelines.

<u>Little brown bat</u>

The Service is reviewing the little brown bat to determine if the species warrants protections under the ESA, with a decision expected during Fiscal Year 2024. The range of this species possibly includes the project area. To conserve the little brown bat, the Service will likely recommend similar/the same conservation measures for NLEB and TCB. If a bat presence/absence survey is conducted (as explained within the "Indiana Bat, northern long-eared bat, and tricolored bat conservation measures" information above) the Service would also request any captured reproductive female/juvenile little brown bats are tracked to their maternity roost trees. Information about the little brown bat can be found on the Services website at: *https://www.fws.gov/species/little-brown-bat-myotis-lucifugus.*

<u>Wood Turtle and Spotted Turtle</u>

The Service is reviewing the wood turtle and spotted turtle to determine if they warrant protections under the ESA, with a decision expected during Fiscal Year 2024. Potential habitat for these species may be present within the action area. The Service recommends that the Corps review the action area to determine if there is suitable habitat present and if it is within the range of these species. The Service recommends the following:

1. For wood turtle: refer to "A guide to Habitat Management for Wood Turtles" document at *https://www.northeastturtles.org/wood-turtle.html.* The document provides a description of wood turtles and their habitat, as well as management guidelines/conservation measures if habitat is present. The Service recommends reviewing this document and any other applicable information to determine if suitable habitat is present and, if necessary, to develop conservation measures.

2. For spotted turtle: refer to the "Status Assessment and Conservation Plan for the Spotted Turtle in the Eastern United States" document at: *https://www.northeastturtles.org/spotted-turtle.html*. The document provides a description of spotted turtle and their habitat. The Service recommends reviewing this document and any other applicable information to determine if suitable habitat is present and, if necessary, to develop conservation measures.

The Service appreciates the opportunity to provide preliminary ESA technical review comments on the Corps' Rahway River Basin (Fluvial), New Jersey Flood Risk Management Feasibility Study (Study). We look forward to the opportunity to comment on documentation for further phases of the project. For further assistance or questions, please contact Michael Ciappi at michael_ciappi@fws.gov.

Sincerely,

ERIC SCHRADING
Digitally signed by ERIC SCHRADING
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Eric Schrading
Field Supervisor

Enclosures:

Enclosure A – Study Area Extent and Bog Turtle Range
Enclosure B– Recognized Qualified Indiana Bat/Northern Long-eared Bat Surveyors

cc:
Ross Conover, USFWS
Kimberly Rightler, Corps
Carissa Scarpa, Corps

REFERENCES:

Leput, D.W. 2004. Eastern red bat (Lasiurus borealis) and eastern pipistrelle (Pipistrellus subflavus) maternal roost selection: Implications for forest management. Master's Thesis Clemson University, Clemson, South Carolina.

Monarch Joint Venture. 2019. Mowing and Management: Best Practices for Monarchs. Available at: *https://monarchjointventure.org/blog/revised-handout-mowing-and-management-best-practices-for-monarchs.*

New Jersey Department of Environmental Protection. 2017. New Jersey Monarch Butterfly Conservation Guide. Available at: *https://www.nj.gov/dep/docs/monarch-guide.pdf.*

Enclosure A

Study Area Extent and Bog Turtle Range

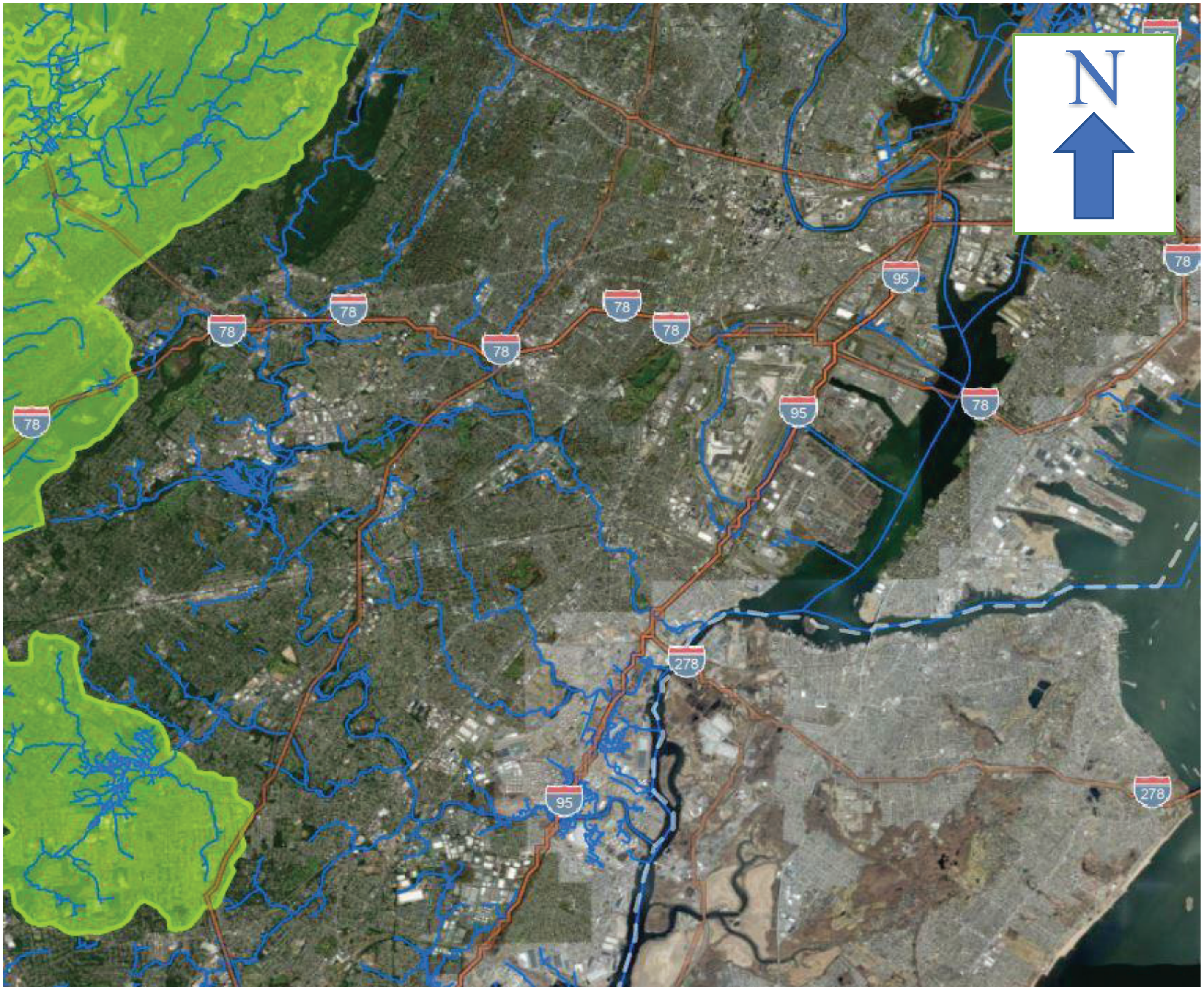

Figure 1. General Study Area Extent and Bog Turtle Range
The bog turtle range is in green, and the blue lines are watercourses.

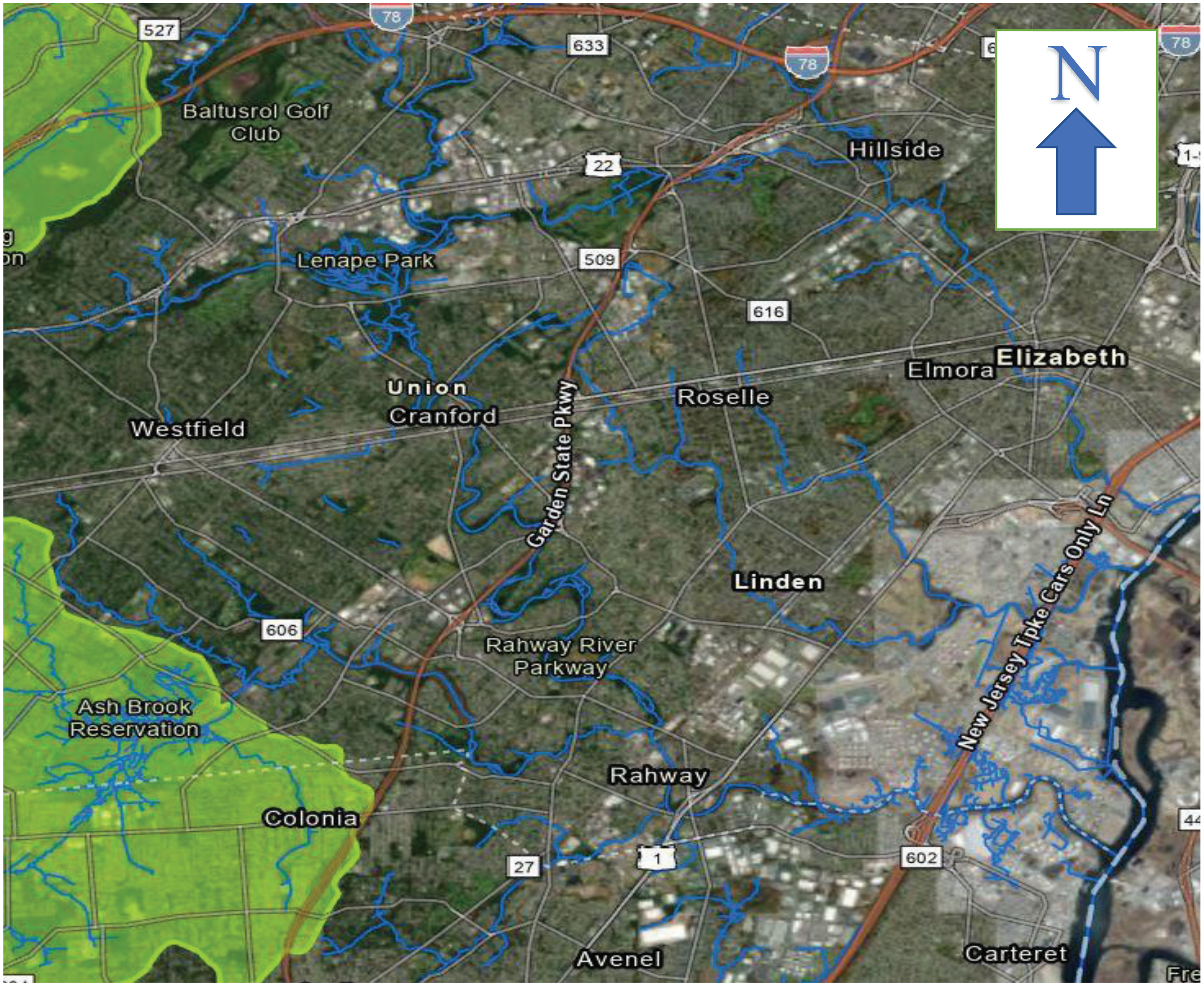

Figure 2. Southeastern Study Area Extent and Bog Turtle Range
The bog turtle range is in green, and the blue lines are watercourses.

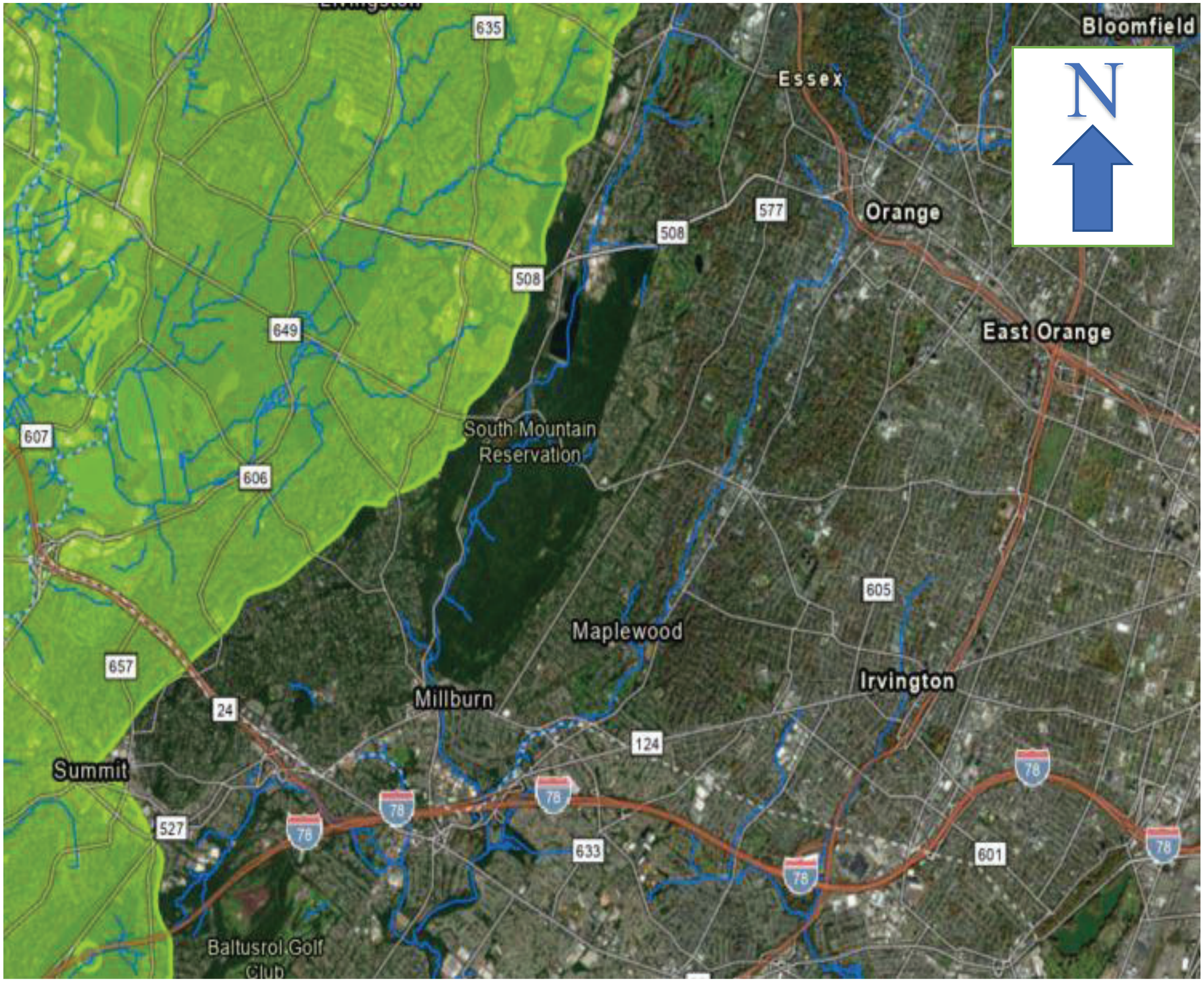

Figure 3. Northwestern Study Area Extent and Bog Turtle Range
The bog turtle range is in green, and the blue lines are watercourses.

Enclosure B

Recognized Qualified Indiana Bat/Northern Long-Eared Bat Surveyors

RECOGNIZED QUALIFIED INDIANA BAT/NORTHERN LONG-EARED BAT SURVEYORS

The following list includes individuals recognized by the U.S. Fish and Wildlife Service, New Jersey Field Office, and the New Jersey Department of Environmental Protection (NJDEP), Endangered and Nongame Species Program as qualified to conduct surveys for Indiana bats and northern long-eared bats. This list may not include all individuals qualified to survey for this species. This list will be updated periodically. Inclusion of names on this list does not constitute endorsement by the Service, the NJDEP, or any other U.S. Government agency or State agency.

Various techniques are used to sample and study bats in New Jersey (including hibernacula surveys, mist netting, acoustic detection, and radio-telemetry) and some surveyors on this list may not be qualified to conduct all techniques. Surveyors qualified to conduct only habitat assessments (Phase I) and acoustic surveys (Phase II) are marked with an asterisk (*) to differentiate them from surveyors qualified to conduct trapping efforts. A scientific collecting permit from the NJDEP is required to capture bats in New Jersey.

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FISH AND WILDLIFE COORDINATION ACT
PLANNING AID REPORT

Rahway River Basin (Fluvial)
New Jersey Flood Risk Management Feasibility Study

Prepared for:

U.S. Army Corps of Engineers
Planning Division
New York District
New York, New York

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EXECUTIVE SUMMARY

This Planning Aid Report (PAR) has been prepared at the request of the U.S. Army Corps of Engineers (USACE or Corps) in partial fulfillment of the Fish and Wildlife Coordination Act (48 Stat. 401; 16 U.S.C. 661 *et seq.*) (FWCA). This PAR provides the U.S. Fish and Wildlife Service's (Service) comments on the biological issues relevant to the Corp's *Rahway River Basin (Fluvial) New Jersey Flood Risk Management Feasibility Study* (hereafter referred to as the Study). The purpose of the FWCA is to ensure equal consideration of fish and wildlife conservation in the development of the Corps' Tentatively Selected Plan. This report is intended to provide technical assistance to the Corps during the early development of the proposed project. Eventually, the Service will submit a report as required under Section 2(b) of the FWCA that: (1) determines the magnitude of the direct, indirect, and cumulative impacts of the proposed projects on fish and wildlife resources; and (2) makes specific recommendations as to measures that should be taken to conserve those resources.

As currently developed, the proposed project area is within Essex and Union counties, New Jersey; includes the South Mountain Reservation in the northwest; and follows portions of the Rahway River southeast until it reaches its confluence with the Robinsons Branch watercourse in Rahway City. Additionally, the project area extends upstream Robinsons Branch until (approximately) it reaches the Milton Lake dam in Rahway City. The currently developed Study Area includes the boundary of multiple 14-digit Hydrologic Unit Code watersheds within Essex County, Middlesex County, and Union County, New Jersey. The Study Area that was analyzed includes the project alternatives and adjacent areas. Ecologically significant portions of the Study Area include fish and wildlife habitat within the South Mountain Reservation, along the Rahway River Parkway, and other areas mentioned throughout the PAR.

While a Tentatively Selected Plan by the Corps has not been chosen at this time, there are five alternatives that are currently under development. The alternatives include Alternative 1- no action; Alternative 2 – upstream detention; Alternative 3 – combination plan (basin wide); Alternative 4 – nonstructural plan; and Alternative 5 – Lenape Park detention basin and channel modifications. Together, these alternatives propose a new dam, modifications to an existing dam, new detention areas, roadway relocations, watercourse modifications, new levees, modifications to existing embankments/levees, new floodwalls, modifications to structures such as bridges, and non-structural measures. The project measures are still being developed and will likely update as planning progresses. As such, we will provide future coordination for subsequent planning, engineering, design, and construction phases to fulfill our agency's responsibilities under the FWCA. Consequently, the Service cannot render a FWCA 2(b) report at this time but submits this PAR as technical assistance to aid the Corps in addressing fish and wildlife resource opportunities, impacts, and mitigation. During our review, the Service has preliminarily identified several best management practices and mitigation planning recommendations that could potentially reduce impacts to fish and wildlife.

Finally, this report does not constitute consultation under Section 7 of the Endangered Species Act of 1973 (87 Stat. 884, as amended; 16 U.S.C. 1531 *et seq*.).

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I. INTRODUCTION

This Planning Aid Report (PAR) was prepared by the U.S. Fish and Wildlife Service (USFWS or Service) pursuant to the policies and guidance for the Fish and Wildlife Coordination Act of 1958 (FWCA; 48 Stat. 401; 16 U.S.C. 661 *et seq.)*. This PAR provides conservation and planning assistance to the U.S. Army Corps of Engineers' (USACE or Corps) *Rahway River Basin (Fluvial) New Jersey Flood Risk Management Feasibility Study* (Study). The PAR also includes comments pursuant to the Endangered Species Act (87 Stat. 884, as amended; 16 U.S.C. 1531 *et seq.*) (ESA), Migratory Bird Treaty Act of 1918 (40. Stat 755, as amended; 16 U.S.C. Section 703-712) (MBTA), and Bald and Golden Eagle Protection Act (54 Stat. 250, as amended, 16 U.S.C. 668a-d) (BGEPA).

The Service coordinates with the Corps on projects authorized under the Water Resource Development Act (110 Stat. 3658 *et seq*.; 33 U.S.C. 2201 *et seq*.) pursuant to the ESA, and the FWCA. Under the FWCA, the Corps and the Service coordinate at several steps during the Corps' project planning to conserve, protect, and enhance fish, wildlife, plants, and their habitats.

The Service plans to continue to review the Corps' Study, future Tentatively Selected Plan, and other alternatives as the planning process advances. We anticipate preparing a FWCA 2(b) Report after the Corps completes its initial preliminary and conceptual design phase. The FWCA 2(b) Report will constitute the report of the Secretary of the Interior as required by Section 2(b) of the FWCA, which establishes fish and wildlife conservation as a co-equal purpose or objective of federally funded or permitted water resource development projects. The FWCA allows for recommendations from the Service and state wildlife agencies to be integrated into the Corps' reports seeking authorization for the Federal action. Additionally, the FWCA grants the Corps the authority to include fish and wildlife conservation measures within these projects. The information provided herein is based on relevant literature; local, state, and Federal fish and wildlife reports and plans; and personal communications with knowledgeable biologists, planners, and other professionals. This PAR reflects our review of the Study alternatives that were preliminarily developed and are based on the current stage in the Corps' planning process.

II. PURPOSE, SCOPE, AND AUTHORITY

The purpose of the Corps' Study is to evaluate potential solutions to repetitive flooding problems within the Rahway River basin, specific to overbanking of the Rahway River and its tributaries during storm events. The scope of the Study is the upper fluvial reaches of the Rahway River Basin. This Study was previously analyzed and terminated by the Corps in 2019 due to the inability to find a feasible alternative. However, the Water Resources Development Act of 2020 nullified the termination and directed the Corps to restart the Study. As such, the Corps is currently revisiting previously analyzed alternatives and brainstorming new alternatives. Additionally, the New Jersey Department of Environmental Protection (NJDEP) is the non-federal sponsor of the Study.

This PAR is provided under authority of the FWCA. This Act established two important Federal policies, which are: (1) fish and wildlife resources are valuable to the nation, and (2) the development of water resources is potentially damaging to these resources. The FWCA mandates that "...wildlife conservation shall receive equal consideration and be coordinated with other factors of water resource development programs through effectual and harmonious planning, development, maintenance, and coordination of wildlife conservation and rehabilitation…"

To fully incorporate the conservation of fish and wildlife resources in the planning of water resources development projects, the FWCA mandates that Federal agencies consult with the Service and the state agency responsible for fish and wildlife resources in the Study Area. While this PAR is only submitted to the Corps, the future draft FWCA 2(b) report will also be provided to the NJDEP and National Oceanic and Atmospheric Administration – National Marine Fisheries Service (NOAA-NMFS) for their review and comments. At that time, comments from those agencies will then be incorporated into a final FWCA 2(b) Report.

Consultation during project planning is intended to allow state and Federal resource agencies to determine the potential adverse impacts on fish and wildlife resources and develop recommendations to avoid, minimize, or compensate for detrimental impacts. Therefore, this PAR will:

1. Describe the fish and wildlife resources in the Study Area, with a focus on Service identified priority at-risk and ESA listed, proposed, and candidate species.

2. Evaluate to the degree possible, due to the existing level of planning, the potential adverse impacts, both direct and indirect, on these resources from the proposed project.

3. To the degree possible due to the level of existing planning, develop recommendations to avoid, minimize, or compensate for any unavoidable, adverse environmental impacts.

4. Identify fish and wildlife resource concerns and enhancement opportunities.

5. Present an overall summary of findings and the preliminary position of the Service on the project.

The geographic scope of this report includes all areas that would be potentially impacted by the proposed project in the Study Area, and other areas within the broader Study Area where there are opportunities for fish and wildlife enhancement.

III. RELEVANT STUDIES PROJECTS, AND REPORTS

Over the years, the Service has been involved with reviewing multiple projects along the Rahway River. As mentioned, the Corps had previously analyzed and terminated the Study due to the inability to find a feasible alternative. The following is a list of Service reports relevant to the Study Area and alternatives:

1. FWCA Planning Aid Letter (PAL) for the Rahway River Flood Risk Management Feasibility Study: This PAL was prepared and submitted to the Corps on February 20, 2015. It was prepared for the previously terminated Study (USFWS 2015).

2. FWCA Final Section 2(b) Report for the Rahway River Basin Coastal Storm Risk Management Feasibility Study: This report was prepared for the tidal portions of the

Rahway River (USFWS 2018). However, the Study Area partially overlaps and is directly adjacent to the Study boundary being analyzed within this PAR. The Corps Chief's Report was approved on June 9, 2020 and the project has been authorized for construction.

IV. DESCRIPTION OF THE STUDY AND PROJECT AREA

As currently developed, the proposed project area is within Essex and Union counties, New Jersey, includes the South Mountain Reservation in the northwest, and follows portions of the Rahway River southeast until it reaches its confluence with the Robinsons Branch watercourse in Rahway City. Additionally, the project area extends upstream the Robinsons Branch until (approximately) it reaches the Milton Lake dam in Rahway City. The currently developed Study Area includes the boundary of multiple 14-digit Hydrologic Unit Code watersheds within Essex County, Middlesex County, and Union County, New Jersey. The Study Area includes the municipalities of Winfield Township, Summit City, Scotch Plains Township, Springfield Township, Rahway City, Plainfield City, Westfield, Kenilworth Borough, Garwood Borough, Clark Township, Linden City, Fanwood Borough, Cranford Township, Union Township, and Mountainside Borough in Union County; Edison Township, Woodbridge Township, and South Plainfield Borough in Middlesex County; and West Orange Township, Millburn Township, Maplewood Township, Newark City, South Orange Village Township, and the City of Orange Township in Essex County. The Service anticipates that the Study Area will likely change once the Corps progresses in their planning. Future FWCA documentation will utilize (if available) any updated Study Area developed by the Corps to analyze fish and wildlife within the area. Please refer to Figure 1 for an illustration of the currently developed Study Area.

The Study Area is mostly comprised of developed urban environments such as within Union Township. However, there is also the South Mountain Reservation, Rahway River Parkway, Ash Brook Reservation, and other open spaces explained in the Protected Open Spaces Section VII.A.1 below that have little to no development. Land use in the region includes residences, vacant disturbed lands, commercial properties, protected open spaces (parks, reservations, etc.), transportation, schools, government properties, industrial properties, and multiple country clubs and golf courses. The topography of Study Area is relatively flat except for the Watchung and South Mountain Reservation mountain ranges. Please refer to the Existing Fish and Wildlife Resources section below for a discussion of ecologically significant sites; fish and wildlife; and aquatic resources within the Study Area.

V. FISH AND WILDLIFE RESOURCE CONCERNS AND PLANNING OBJECTIVES

The purpose of the FWCA consultation is to ensure equal consideration of fish and wildlife resources in the planning of water resource development projects. The Service's emphasis for this Study is to advocate for alternatives that result in the least impacts to fish and wildlife, identify means and measures to mitigate the potential adverse impacts of the proposed project, and to make positive contributions to fish and wildlife resource problems and opportunities.

Rahway River Basin (Fluvial) Flood Risk Management Feasibility Study
Currently Developed Study Area for
Fish and Wildlife Coordination Act Planning Aid Report
Essex County, Middlesex County, and Union County, New Jersey

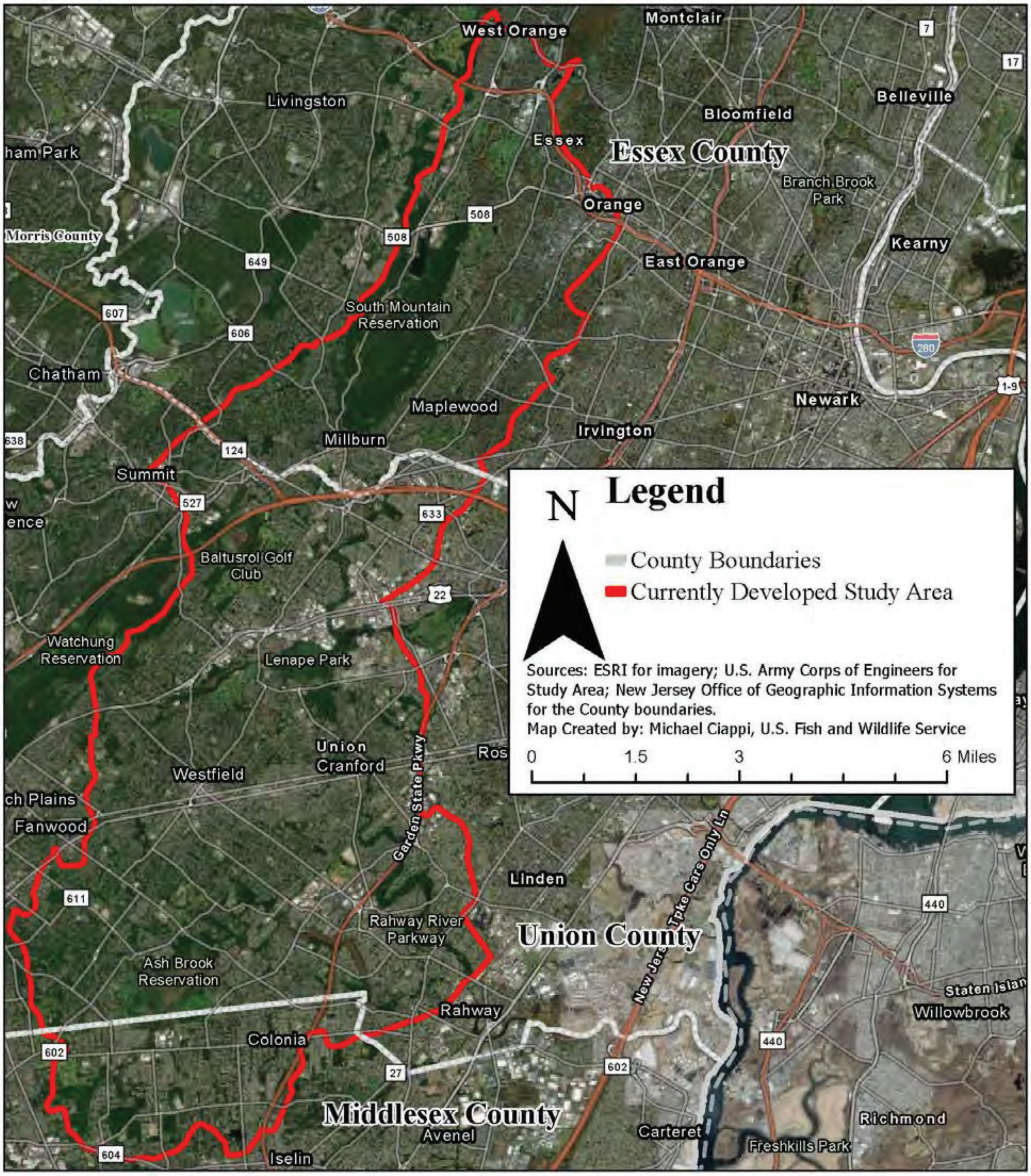

Figure 1. Currently Developed Study Area

A desired output of this FWCA coordination is to ensure the protection of healthy aquatic and terrestrial ecological communities. A summary of the Service's concerns and planning objectives along with a more detailed discussion are provided below.

A. FISH AND WILDLIFE RESOURCE CONCERNS

1. Habitat Loss and Degradation

The Study Area includes developed urban areas that represent degraded or lost terrestrial and aquatic ecosystems to accommodate extensive residential, commercial, and industrial development. Terrestrial ecosystems have been replaced with buildings, roads, and other impervious surfaces. The degradation of natural vegetative communities has fragmented fish and wildlife habitats, thus reducing feeding, breeding, and sheltering opportunities. The construction of dams along the Rahway River and other watercourses within the Study area has led to impediments for fish and other aquatic organism passage and possibly a reduction in water quality within the area. Additionally, developments adjacent to and within watercourses, such as the Rahway River, has resulted in loss of wetlands and riparian areas that are important for multiple species. Some natural areas, such as those within the South Mountain Reservation and Lenape Park (further explained in Section VII.A.1 below), remain high quality habitat for numerous species.

2. Invasive Species

Invasive species are likely problematic within the Study Area as they can negatively impact native species and ecosystems through competition and altered habitat, which can reduce biodiversity. Invasive species can also have other ecosystem effects such as alterations to energy, nutrient, and hydrological cycles; alterations to physical structure; and impacts on climate and atmospheric composition (Charles and Dukes 2007). Some invasive animal species that are likely to occur or have been documented in the Study Area include European starling (*Sturnus vulgaris*), red-eared slider (*Trachemys scripta elegans*), emerald ash borer (*Agrilus planipennis),* and spotted lanternfly (*Lycorma delicatula*) (iNaturalist Accessed 2024). Some invasive plant species that are likely to occur or have been documented in the Study Area include tree of heaven (*Ailanthus altissima*), Japanese stiltgrass (*Microstegium vimineum*), common reed (*Phragmites australis*), autumn olive (*Elaeagnus umbellata*), reed canary grass (*Phalaris arundinacea*), Japanese knotweed (*Reynoutria japonica*), Japanese honeysuckle (*Lonicera japonica*), multiflora rose (*Rosa multiflora*), and garlic mustard (*Alliaria petiolata*) (iNaturalist Accessed 2024).

3. Environmental Contaminants

The NJDEP prepares biennial integrated water quality reports that assess the health of the State's waters as required under Sections 303(d) and 305(b) of the Clean Water Act, the New Jersey Water Quality Planning Act, and the New Jersey Water Pollution Control Act (NJDEP 2022). The report analyzes whether waterbodies are meeting water quality standards by determining if they support a designated use. The report includes determinations as to whether water quality is "fully supportive" or "non supportive" of a designated use. There are also areas that have "insufficient data". The designated use is determined for large scale assessment units at subwatershed levels and individual water quality station monitoring locations as well. Within the Study Area there is data to determine if water quality contains characteristics that are generally supportive of aquatic life. While some individual water quality monitoring stations determined that waters within the Study Area were supportive of aquatic life, all the assessment units were non-supportive. The aquatic life monitoring focuses on determining if water quality has excessive nutrients and biological community impairments. Waters that are determined as non-supportive of aquatic life contain characteristics that are not likely to support healthy ecosystems. Water quality within the Study Area lacked support for the aquatic life designated use due to the biological data collected and dissolved oxygen and total phosphorus levels.

The NJDEP (2022) water quality report also included an analysis of whether water quality within assessment units is supportive of fish consumption. Fish tissues were monitored for metals including "legacy" pollutants such as polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), mercury, and chlordane. The Rahway River assessment unit located from Robinsons Bridge in Rahway City to Kenilworth Boulevard in Cranford Township was non supportive of fish consumption due to mercury levels. The remaining assessment units within the Study Area had insufficient data to determine fish consumption use.

Please note that the designated use determinations described above refer to characteristics of the watercourses that are non-supportive or supportive of those uses. As such, it does not mean that every aspect of the watercourses within the Study Area is non-supportive of aquatic life or that all fish there are unsafe for consumption. There are aspects of the watercourses within the Study Area that exhibit support for aquatic life and fish consumption. More information on water quality within the Study Area can be found within the report (NJDEP 2022), including an overview of designated uses within the fact sheet found within the "table of contents" section at: *https://dep.nj.gov/wms/bears/integrated-wq-assessment-report-2022/#introduction.*

The Study Area also has a history of industrial land uses and other development that may, or currently are, contributing to environmental contaminant concerns. Additionally, the NJDEP maintains records and maps of known contaminated sites throughout the state (NJDEP 2024). The mapping indicates 406 active contaminated sites present within the Study Area. These contaminated sites range from relatively simple to complex concerns and can have several sources of contamination.

B. PLANNING OBJECTIVES

The Service's recommended planning objectives aim to achieve long-term ecological integrity of native plant, fish, and wildlife habitats, and fully functioning restored ecosystems. Specific objectives for this FWCA report include:

1. To restore, enhance, and preserve aquatic resources to ensure the long-term conservation of fish and wildlife within the Study Area.

2. To restore, enhance, and preserve fish and wildlife resources and promote resiliency through measures such as natural and nature-based solutions and acquiring flood prone properties identified by the Corps.

3. To restore, enhance, and preserve areas that benefit fish and wildlife resources and their respective habitats, including for Service identified priority at-risk species; Birds of Conservation Concern; ESA listed, proposed, and candidate species; and other declining flora and fauna.

4. To restore native plant species to create better urban/suburban habitat resiliency and promote conservation of native bird and pollinator species.

5. To reduce invasive species populations in the Study Area, thereby promoting native species diversity and resiliency.

6. To improve water quality and environmental contaminants in the Study Area and create aquatic resources that are healthier for fish and wildlife species.

VI. EVALUATION METHODOLOGY

In this report, the Service provides a discussion of the Study alternatives and their impacts to fish and wildlife resources in the Study Area. Descriptions of existing natural resources are based on relevant literature; local, state, and Federal fish and wildlife reports and plans; and personal communications with knowledgeable biologists, planners, and other professionals. Certain aspects of our coordination, such as review of the project impacts on fish and wildlife resources, planning recommendations, and mitigation recommendations, will need additional coordination as the project planning proceeds since the Study is still in the early stages of development. This report aims to develop mitigation recommendations for the protection of fish and wildlife in accordance with the Service's Mitigation Policy (USFWS 2023c).

VII. EXISTING FISH AND WILDLIFE RESOURCES

A. ECOLOGICALLY SIGNIFICANT SITES WITHIN THE STUDY AREA

1. Protected Open Spaces

Multiple parks, open spaces, preserves, reservations, and conservation areas exist within the Study Area. While many of these sites are ecologically significant due to their contribution towards conservation of fish and wildlife habitat, the following are especially notable:

a. Ash Brook Reservation

The Ash Brook reservation is in Scotch Plains Township, Union County, New Jersey. The Reservation covers over 667 acres of land and provides fish and wildlife habitat consisting of forested areas, palustrine wetlands, non-tidal freshwater streams, riparian areas, and meadows (SNOFLO Accessed 2024). It also includes the Ashbrook swamp which is a part of the Service-identified Significant Habitats and Habitat Complexes of the New York Bight Watershed (described below). The Ashbrook Swamp includes the headwaters of the Robinson's Branch of the Rahway River, is forested, and is the largest remaining freshwater wetland in the Arthur Kill watershed (USFWS 1997). The area is surrounded by residential, commercial, and industrial development including several golf courses. Thus, the reservation provides important habitat for fish and wildlife that require undeveloped or less developed natural areas.

b. Lenape Park, Nomahegan Park, Echo Lake Park, and Rahway River Parkway

The Lenape Park, Nomahegan Park, Echo Lake Park and Rahway River Parkway are in the towns of Westfield, Cranford, Mountainside Borough, Springfield, Union, Kenilworth, Clark, and Rahway City within Union County, New Jersey. The parks and parkway are located adjacent to each other and are hydrologically connected by the Nomahegan Brook and Rahway River. Together, along with additional areas located north and south, the parks (except for the Echo Lake Park) form the Rahway River Parkway system (Friends of Rahway River Parkway Accessed 2024). The Nomahegan Brook flows east from Echo Lake Park, through Lenape Park, and into the Rahway River at Nomahegan Park. The Rahway River Parkway begins north of Lenape Park and continues south along the Rahway River corridor until it reaches Elizabeth Avenue in Rahway City, Union County, New Jersey. The parks and parkway provide fish and wildlife habitat primarily in the forms of upland forested areas; non-tidal freshwater streams and rivers; riparian areas; palustrine forests, scrub/shrub, and emergent wetlands; and meadows/herbaceous areas. The Rahway River Parkway consists of 950 acres of wooded land that is owned and maintained by Union County (Friends of Rahway River Parkway Accessed 2024). The parks and parkway are surrounded by residential, industrial, and commercial land uses. Thus, they provide important refuge and habitat for fish and wildlife that require undeveloped or less developed natural areas.

c. Clark (Middlesex) Reservoir

The Clark Reservoir is in Clark Township, Union County, New Jersey. The reservoir is formed by a dam of the Robinsons Branch, which is a tributary to the Rahway River. The reservoir provides important foraging habitat for migratory birds within the Service identified Arthur Kill Habitat Complex and it is a significant habitat of the New York Bight Watershed (described below) (USFWS 1997). The reservoir and portions of the surrounding upland areas are owned and maintained by Union County, New Jersey. The area contains habitat primarily in the forms of wetlands, non-tidal freshwater watercourses, riparian areas, and upland forested areas. The protected areas are surrounded by residential, commercial, and industrial land uses. Thus, it provides important habitat for fish and wildlife that require undeveloped or less developed natural areas.

d. South Mountain Reservation

The South Mountain Reservation is in West Orange Township, Millburn Township, and Maplewood Township within Essex County, New Jersey. The Study Area contains most of the reservation, except for the northwestern most boundaries. It is a 2,112-acre nature reserve that is located between the first and second ridges of the Watchung Mountains (Essex County Parks Accessed 2024). The West branch of the Rahway River flows southwest through the reservation and into multiple reservoirs and ponds (all artificially formed by dams) before it continues outside of the reservation. These consist of (upstream to downstream) the Orange Reservoir, Campbells Pond, and Diamonds Mill Pond. There are multiple ecologically important habitats present throughout the reservation. The reservation primarily provides habitat in the form of large swaths of deciduous forested uplands. However, other habitats throughout the reservation consist of non-tidal freshwater streams and ponded watercourses, riparian areas, palustrine wetlands, meadows, and herbaceous areas. Small waterfalls can also be found throughout the reservation as well. The areas surrounding the reservation are within more developed urban and suburban communities containing residential, industrial, commercial, and other land uses. Thus, it provides important habitat for fish and wildlife that require undeveloped or less developed natural areas.

e. Watchung Reservation

The Watchung Reservation is a 2,065 acre preserve owned by Union County, New Jersey and is in the municipalities of Summit, Scotch Plains, Springfield, Mountainside, and Berkeley Heights. The preserve consists of deciduous forests, lakes, wetlands, streams, springs, fields, and recreational areas (Somerset County 2006). However, the Study Area only includes the southeastern extent of the reservation located in Mountainside. Within this area, fish and wildlife habitat primarily consists of upland deciduous forests. There is mostly residential land use surrounding the reservation in this area. The reservation provides important habitat for fish and wildlife that require undeveloped or less developed natural areas.

2. Audubon Important Bird Areas

The Audubon Important Bird Area (IBA) program identifies, monitors, and protects habitats critical to the success of bird populations (Audubon Accessed 2024a). Portions of the Arthur Kill Complex and Tributaries IBA are within the Study Area. This includes portions located along the Rahway River corridor and in the Rahway River Parkway described above. Approximately 25 percent of all wading birds that breed in coastal New Jersey occur within the overall Arthur Kill Complex (Audubon Accessed 2024b). The freshwater wetlands and forests within the Study Area provide feeding and roosting habitat for waterbirds and migratory stopover habitat for many species of songbirds and raptors (Audubon Accessed 2024b). The Arthur Kill Complex is considered extremely important to birds as it provides some of the only remaining open spaces in this highly urbanized region (Audubon Accessed 2024b).

3. Service Identified Significant Habitats and Habitat Complexes of the New York Bight Watershed

The Service prepared an assessment (USFWS 1997) of Significant Habitats and Complexes of the New York Bight Watershed. The assessment focused on the identification and description of essential habitats for key marine, coastal, and terrestrial species inhabiting the New York Bight watershed to help guide informed and ecologically sound land use decisions and land protection efforts (USFWS 1997). The Arthur Kill Complex is the only complex present within the Study Area.

The Arthur Kill Complex encompasses a contiguous area on the northwest corner of Staten Island, the entire length of the Arthur Kill from its junction with Newark Bay south to the Outerbridge crossing bridge (Route 440), and several tributary corridors to the Arthur Kill in New Jersey (USFWS 1997). The Complex is of regional importance due to its remaining upland

and wetland open spaces that are located within a highly urbanized area, thus making these areas rare natural communities (USFWS 1997). Additionally, it is important for nesting and foraging herons, egrets, ibises, gulls, and waterfowl (USFWS 1997). Within the Study Area the Complex includes Ash Brook Swamp and Middlesex Reservoir, which are described in the Protected Open Spaces section above.

B. PLANTS

The Service did not receive funding to conduct any field surveys for plant species in the Study Area. Within the Study Area, the Ash Brook, Nomahegan Brook, Robinsons Branch, Rahway River, multiple reservoirs, and tributaries to them form riparian areas that support multiple plant species and connect/contribute to fish and wildlife habitat. Additionally, the ecologically significant sites within the Study Area mentioned above contain important plant communities for the fish and wildlife that utilize them. Plant communities play a major role towards contributing to fish and wildlife habitat refuge, foraging areas, and connectivity within the Study Area. Areas that have been extensively developed contain fewer and more degraded plant communities that provide reduced habitat quality as those undisturbed or maintained. Service identified plant communities present within the Study Area include, but are not limited to, the following:

Palustrine Wetlands

Palustrine wetland plant communities include those within "nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 parts per thousand" (Federal Geographic Data Committee 2013). These can be separated into areas of emergent, scrub shrub, and forested wetland plant communities that are likely found throughout the Study Area. Most of the Study area wetlands are influenced by non-tidal watercourses. However, small portions of the Rahway River and Robinsons Branch located at the eastern most extent of the Study Area are tidally influenced. The Robinsons Branch (tributary to the Rahway River) is tidally influenced until the Milton Lake Dam in Rahway City (USACE 2020). The Rahway River is tidally influenced up until at (approximately) the Jacksons Pond Dam located approximately at Valley Road in Clark Township (USACE 2020). Palustrine communities represent transitions between upland and aquatic ecosystems and contain a high diversity of wetland plants. Common plant species observed include common reed, cattails (*Typha spp.*), jewelweed (*Impatiens capensis*), sweet pepperbush (*Clethra alnifolia)*, rushes (*Juncus spp.),* sedges (*Carex spp*.), eastern skunk cabbage (*Symplocarpus foetidus*), spice bush (*Lindera benzoin*), silver maple (*Acer saccharinum*), red maple (*Acer rubrum*), and swamp white oak (*Quercus bicolor*) (iNaturalist Accessed 2024).

Upland Terrestrial

Multiple types of upland terrestrial plant communities occur throughout the Study Area. These include deciduous forests, meadows, and shrubland such as those within and in the vicinity of the protected open spaces mentioned above; riparian vegetation along watercourses; and anthropogenic environments such as those on residential properties, commercial properties, infrastructure features (such as biofiltration basins and stormwater drainage areas), and in parklands. Common plant species likely to be observed within and in the vicinity of protected open spaces and riparian areas include a variety of oak (*Quercus spp.*), maple (*Acer spp.)*, hickory (*Carya spp.*), American beech (*Fagus grandifolia*), tulip poplar (*Liriodendron tulipifera),* sweet gum (*Liquidambar styraciflua*), black gum (*Nyssa sylvatica*), American holly (*Ilex opaca*), eastern red cedar (*Juniperus virginiana*), maple-leaf viburnum (*Viburnum acerifolium*), arrowwood (*Viburnum dentatum*), witch hazel (*Hamamelis virginiana*), multiflora rose, fern species, milkweed (*Asclepias spp.*), grape (*Vitis spp.*), Japanese knotweed, Japanese honeysuckle, poison ivy (*Toxicodendron radicans*), and others (Arsenault 2009; iNaturalist Accessed 2024; South Mountain Conservancy Accessed 2024). Common plants likely to be observed in anthropogenic landscapes include some of those described but also callery pear (*Pyrus calleryana*), London plane tree (*Platanus x acerifolia*), ginkgo tree (*Ginkgo biloba*), cherry trees (*Prunus spp.*), eastern redbud (*Cercis canadensis*), and upland mowed vegetation (iNaturalist Accessed 2024).

C. AVIAN SPECIES

Native migratory birds are a Federal trust responsibility and are afforded protection under the MBTA. The MBTA implements four treaties that provide for international protection of migratory birds, which are a Federal trust resource. The MBTA prohibits taking, killing, possession, transportation, and importation of migratory birds, their eggs, parts, and nests, except when specifically authorized by the Service. Bald eagles are afforded additional legal protection under the BGEPA. Unlike the ESA, the MBTA does not currently have a regulation specific to the incidental take of migratory birds.

The Service did not receive funding to conduct any field surveys for avian species in the Study Area. Avian species occur throughout several ecosystems in the Study Area, including forests, herbaceous fields, urban environments, watercourses, and wetlands. For simplicity, the description of avian species that are likely to be found within the Study Area is divided into landbirds and waterbirds below.

Landbirds include tree-dwelling birds, perching birds or songbirds, raptors, and ground-feeding birds that spend most of their lives in terrestrial environments. They can be found feeding, breeding, and sheltering throughout the Study Area. Many of these species can be found nesting on or within (nest cavities) the trees of the Study Area. Some can be found nesting on the ground or within human-made structures (bridges, homes, buildings, etc.) as well. The Study Area contains breeding habitat (during the spring and summer months) for neotropical and short distance migratory species such as the wood thrush (*Hylocichla mustelina*) that breed within temperate areas and migrate to tropical or warmer areas for the winter. Forested areas, such as the South Mountain Reservation and Lenape Park, contain many species of breeding songbirds during the spring and summer seasons. In general, species may be migrating over and temporarily stopping within the Study Area to refuel or rest from April to mid-June (spring migration) and September to November (fall migration). Other species, such as wild turkeys (*Meleagris gallopavo*), northern cardinals (*Cardinalis cardinalis*), and American crows (*Corvus brachyrhynchos*) can be found year-round within the Study Area. Many birds such as woodpeckers, warblers, swallows, tyrant flycatchers, and vireos can be found feeding on food sources such as insects, seeds, berries, nuts, nectar, and fruit within the Study Area. Others such as diurnal raptors and owls can be found hunting and eating small mammals, snakes, fish, other birds, and other small animals. Sibley (2013) and eBird (Accessed 2024) were utilized to identify the following list of landbirds that may be present within the Study Area:

- Chickadees, nuthatches, and similar species such as the black-capped chickadee (*Poecile atricapilla*), brown creeper (*Certhia americana*), red-breasted nuthatch (*Sitta canadensis*), tufted titmouse (*Baeolophus bicolor*), and white-breasted nuthatch (*Sitta carolinensis*);
- Diurnal Raptors such as the American kestrel (*Falco sparverius*), bald eagle (*Haliaeetus leucocephalus*), black vulture (*Coragyps atratus*), Cooper's hawk (*Accipiter cooperii*), northern harrier (*Circus cyaneus*), merlin (*Falco columbarius*), osprey (*Pandion haliaetus*), peregrine falcon (*Falco peregrinus*), red-shouldered hawk (*Buteo lineatus*), red-tailed hawk (*Buteo jamaicensis*), and turkey vulture (*Cathartes aura*);
- Kinglets and gnatcatchers such as the blue-gray gnatcatcher (*Polioptila caerulea*), golden-crowned kinglet (*Regulus satrapa*), and ruby-crowned kinglet (*Regulus calendula*);
- Owls such as the barred owl (*Strix varia*), barn owl (*Tyto alba*), eastern screech-owl (*Otus asio*), and great-horned owl (*Bubo virginianus*);
- Nightjars such as the common nighthawk (*Chordeiles minor*)*;*
- Mimids such as the brown thrasher (*Toxostoma rufum*), gray catbird (*Dumetella carolinensis*), and northern mockingbird (*Mimus polyglottos*);
- Pigeons and doves such as the rock dove (*Columba livia*) and mourning dove (*Zenaida macroura*);
- Sparrows, finches and similar species such as the American goldfinch (*Spinus tristis*), American tree sparrow (*Spizelloides arborea*), chipping sparrow (*Spizella passerina*), dark-eyed junco (*Junco hyemalis*), eastern towhee (*Pipilo erythrophthalmus*), field sparrow (*Spizella pusilla*), fox sparrow (*Passerella iliaca*), house finch (*Haemorhous mexicanus*), house sparrow (*Passer domesticus*), Lincoln's sparrow (*Melospiza lincolnii*), pine siskin (*Spinus pinus*), purple finch (*Haemorhous purpureus*), savannah sparrow (*Passerculus sandwichensis*), song sparrow (*Melospiza melodia*), swamp sparrow (*Melospiza georgiana*), and white-throated sparrow (*Zonotrichia albicollis*);
- Swallows such as the bank swallow (*Riparia riparia*), barn swallow (*Hirundo rustica*), cliff swallow (*Petrochelidon pyrrhonota*), purple martin (*Progne subis*), and tree swallow (*Tachycineta bicolor*);
- Tanagers, cardinals, and similar species such as the indigo bunting (*Passerina cyanea*), rose-breasted grosbeak (*Pheucticus ludovicianus*), scarlet tanager (*Piranga olivacea*), and northern cardinal;
- Thrushes such as the American robin (*Turdus migratorius*), eastern bluebird (*Sialia sialis*), gray-cheeked thrush (*Catharus minimus*), hermit thrush (*Catharus guttatus*), Swainson's Thrush (*Catharus ustulatus*), veery (*Catharus fuscescens*), and wood thrush;
- Tyrant flycatchers such as the alder flycatcher (*Empidonax alnorum*), eastern kingbird (*Tyrannus tyrannus*), eastern phoebe (*Sayornis phoebe*), eastern wood-pewee (*Contopus virens*), great-crested flycatcher (*Myiarchus crinitus*), least flycatcher (*Empidonax minimus*), yellow-bellied flycatcher (*Empidonax flaviventris*), and willow flycatcher (*Empidonax traillii*);

- Vireos such as the blue-headed vireo (*Vireo solitarius*), Philadelphia vireo (*Vireo philadelphicus*), red-eyed vireo (*Vireo olivaceus*), yellow-throated vireo (*Vireo flavifrons*), warbling vireo (*Vireo gilvus*), and white-eyed vireo (*Vireo griseus*);
- Woodpeckers such as the downy woodpecker (*Picoides pubescens*), hairy woodpecker (*Picoides villosus*), northern flicker (*Colaptes auratus*), pileated woodpecker (*Dryocopus pileatus*), red-bellied woodpecker (*Melanerpes carolinus),* red-headed woodpecker (*Melanerpes erythrocephalus*), and yellow-bellied sapsucker (*Sphyrapicus varius*);
- Wood-warblers such as the American redstart (*Setophaga ruticilla*), bay-breasted warbler (*Setophaga castanea*), black-and-white warbler (*Mniotilta varia*), blackburnian warbler (*Setophaga fusca*), Canada warbler (*Cardellina canadensis*), common yellowthroat (*Geothlypis trichas*), northern parula (*Setophaga americana*), Nashville warbler (*Leiothlypis ruficapilla*), blue-winged warbler (*Vermivora cyanoptera*), black-throated blue warbler (*Setophaga caerulescens*), black-throated green warbler (*Setophaga virens*), blackpoll warbler (*Setophaga striata*), cape may warbler (*Setophaga tigrina*), cerulean warbler (*Setophaga cerulea*), chestnut-sided warbler (*Setophaga pensylvanica*), hooded warbler (*Setophaga citrina*), Kentucky warbler (*Geothlypis formosa*), magnolia warbler (*Setophaga magnolia*), mourning warbler (*Geothlypis philadelphia*), northern waterthrush (*Parkesia noveboracensis*), ovenbird (*Seiurus aurocapilla*), palm warbler (*Setophaga palmarum*), pine warbler (*Setophaga pinus*), prairie warbler (*Setophaga discolor*), prothonotary warbler (*Protonotaria citrea*), Tennessee warbler (*Leiothlypis peregrina*), yellow warbler (*Setophaga petechia*), yellow-rumped warbler (*Setophaga coronata*), Wilson's warbler (*Cardellina pusilla*), and worm-eating warbler (*Helmitheros vermivorum*);
- Wrens such as the Carolina wren (*Thryothorus ludovicianus*), house wren (*Troglodytes aedon*), marsh wren (*Cistothorus palustris*), and winter wren (*Troglodytes hiemalis*);
- Others such as the American coot (*Fulica americana*), American crow, Baltimore oriole (*Icterus galbula*), black-billed cuckoo (*Coccyzus erythropthalmus*), blue jay (*Cyanocitta cristata*), bobolink (*Dolichonyx oryzivorus*), brown-headed cowbird (*Molothrus ater*), cedar waxwing (*Bombycilla cedrorum*), chimney swift (*Chaetura pelagica*), common grackle (*Quiscalus quiscula*), common raven (*Corvus corax*), European starling, killdeer (*Charadrius vociferus*), red-winged blackbird (*Agelaius phoeniceus*), ruby-throated hummingbird (*Archilochus colubris*), rusty blackbird (*Euphagus carolinus*), and wild turkey.

Waterbirds are those that swim and live in or near water and other aquatic environments for most of their lives. They are highly dependent on watercourses for their survival and can be found feeding, breeding, and sheltering in or near aquatic environments. Species such as geese, ducks (exception of the wood duck (*Aix sponsa*)), and common loon (*Gavia immer*) may be found nesting on the ground near water or in slightly elevated areas to avoid flooding. Wading birds, shorebirds, and gulls are likely to nest in colonies that are located outside of the Study Area. Some species such as the American black duck (*Anas rubripes*) and great blue heron (*Ardea herodia*s) may be found year-round in the Study Area while others such as the snowy egret (*Egretta thula*) and lesser yellowlegs (*Tringa flavipes*) are likely to be found during the spring and summer months. Ducks and geese feed on grasses, insects, invertebrates, aquatic plants, and human foods. Wading birds, shorebirds, gulls, and others feed on fish, insects, small mammals, amphibians, reptiles, other birds, and human foods. Sibley (2013) and eBird (Accessed 2024) were utilized to identify the following list of waterbird species that may be present within the Study Area:

- Wading birds such as the American bittern (*Botaurus lentiginosus*), black-crowned night heron (*Nycticorax nycticorax*), cattle egret (*Bubulcus ibis*), great blue heron, great egret (*Ardea alba*), glossy ibis (*Plegadis falcinellus*), green heron (*Butorides virescens*), little blue heron (*Egretta caerulea*), snowy egret, and yellow-crowned night heron (*Nyctanassa violacea*);
- Ducks such as the American black duck, American wigeon (*Mareca americana*), bufflehead (*Bucephala albeola*), common merganser (*Mergus merganser*), gadwall (*Mareca strepera*), hooded merganser (*Lophodytes cucullatus*), mallard (*Anas platyhynchos*), northern pintail (*Anas acuta*), northern shoveler (*Spatula clypeata*), redhead (*Aythya americana*), ruddy duck (*Oxyura jamaicensis*), and wood duck;
- Geese such as the brant (*Branta bernicla*), Canada goose (*Branta canadensis*), and snow goose (*Anser caerulescens)*;
- Gulls such as the ring-billed gull (*Larus delawarensis*), herring gull (*Larus argentatus*), and great black-backed gull (*Larus marinus*);
- Shorebirds such as the American woodcock (*Scolopax minor*), greater yellowlegs (*Tringa melanoleuca*), least sandpiper (*Calidris minutilla*), lesser yellowlegs, pectoral sandpiper (*Calidris melanotos*), semipalmated sandpiper (*Calidris pusilla*), solitary sandpiper (*Tringa solitaria*), spotted sandpiper (*Actitis macularius*), and Wilson's snipe (*Gallinago delicata*);
- Others such as the belted kingfisher (*Ceryle alcyon*), common loon, double-crested cormorant (*Phalacrocorax auritus*), horned grebe (*Podiceps auritus*), and pied-billed grebe (*Podilymbus podiceps*);

Multiple avian species that may exist in the Study Area are Service identified Birds of Conservation Concern or Service identified priority at-risk species. Birds of Conservation Concern are species that, without additional conservation action, are likely to become candidates for listing under the ESA (USFWS 2021). A list of Birds of Conservation Concern that may be found within the Study Area is included within the Official Species List that the Service provided to the Corps on August 17, 2023 (see Appendix A). Service identified priority at-risk species are those that are not currently protected under the ESA but are declining and are "at-risk" of becoming candidates for listing. Relevant at-risk avian species include wood thrush and cerulean warbler, which both depend on forested ecosystems and are most likely present within or surrounding the protected open spaces listed in VII.A.1 above (eBird Accessed 2024; NJDEP 2023a). Additionally, the Rahway River (up to Nomahegan Park), Robinsons Branch, and the area around Clark Reservoir likely serve as foraging habitat for bald eagles, which are protected by the BGEPA (NJDEP 2023a).

In addition to the Service identified Birds of Conservation Concern and at-risk species listed above, there are multiple New Jersey State listed threatened and endangered species that may be in the Study Area as well. This includes the State endangered (breeding populations only) American bittern, bald eagle, northern harrier, peregrine falcon, red-shouldered hawk; State threatened American kestrel, barred owl, red-headed woodpecker, non-breeding populations only of bald eagle, and breeding populations only of black-crowned night heron, bobolink, cattle egret, osprey, Savannah sparrow, and yellow-crowned night heron (Sibley 2013; NJDEP 2023a; eBird Accessed 2024; NJDEP accessed 2024a;). NJDEP (2023a) landscape data for the piedmont region identified nest siting's for red-shouldered hawk; non-breeding sightings for barred owl and red-shouldered hawk; breeding sightings for the barred owl, brown thrasher, veery, and wood thrush; and foraging habitat for bald eagle, black crowned-night heron, cattle egret, glossy ibis, great blue heron, little blue heron, and snowy egret.

The most sensitive times of year for avian species within the Study Area are when they are establishing breeding territories, mating, building nests, laying eggs, hatching chicks, and raising fledged young to independence. Portions of the Study Area provide valuable habitat for these life-history needs. Generally, this sensitive time of year is March 15 to September 15. However, for certain species such as the barred owl, this may start as early as March 1 (NJDEP 2011).

D. AMPHIBIANS AND REPTILES

The Service did not receive funding to undertake any field surveys for amphibians and reptiles in the Study Area. Amphibians and reptiles that can be found in the Study Area include salamanders, toads, frogs, turtles, lizards, and snakes. The breeding season varies per species but is generally from March 1 to October 31 (NJDEP 2011; NJDEP Accessed 2024b).

Salamanders may be observed in woodlands, wetlands, and ditches throughout the Study Area. They utilize their smooth, moist, semipermeable skin for a portion of their breathing and many live in or rely on lakes, ponds and vernal pools, streams, and rivers. On land, salamanders are frequently found under rocks, logs, crevices, and sometimes within small animal burrows (NJDEP Accessed 2024b). Salamanders that may be present within the Study Area include four-toed salamander (*Hemidactylium scutatum*), Jefferson salamander (*Ambystoma jeffersonianum*), long-tailed salamander (*Eurycea longicauda longicauda*), marbled salamander (*Ambystoma opacum*), northern dusky salamander (*Desmognathus fuscus fuscus*), northern red salamander (*Pseudotriton ruber ruber*), northern slimy salamander (*Plethodon glutinosus*), northern spring salamander (*Gyrinophilus porphyriticus porphyriticus*), northern two-lined salamander (*Eurycea bislineata*), red-backed salamander (*Plethodon cinereus*), red-spotted newt (*Notophthalmus viridescens viridescens*), and spotted salamander (*Ambystoma maculatum*) (NJDEP Accessed 2024b). These species are most likely to be found within the protected open spaces described in Section VII.A.1. above such as the South Mountain Reservation, Ash Brook Reservation, Watchung Reservation, and Rahway River Parkway. Vernal pools that serve as breeding sites may also be located within the Study Area. Forested wetlands that represent habitat to these species are located within the protected open spaces mentioned and along the watercourses of the Study Area. Additionally, some of these species may be located along other less developed portions of the watercourse corridors and riparian areas throughout the Study Area.

Toads and frogs may be observed in woodlands, ponds and vernal pools, lakes, streams, ditches, and wetlands throughout the Study Area. Toads and frogs that may be present within the Study Area include the American toad (*Anaxyrus americanus*), bullfrog (*Rana catesbeiana*), Fowler's toad (*Bufo woodhousii fowleri*), green frog (*Rana clamitans melanota*), New Jersey chorus frog (*Pseudacris triseriata kalmi*), northern cricket frog (*Acris crepitans crepitans*), northern gray treefrog (*Hyla versicolor*), northern spring peeper (*Pseudacris crucifer crucifer*), pickerel frog

(*Rana palustris*), southern leopard frog (*Rana utricularia*), and wood frog (*Rana sylvatica*) (NJDEP Accessed 2024b).

Turtles may occur in wetlands, streams, ponds, lakes, rivers, woodlands, and ditches throughout the Study Area. Turtles that may be present within the Study Area include the bog turtle (*Glyptemys muhlenbergii*), common musk turtle (*Sternotherus odoratus*), common snapping turtle (*Chelydra serpentina serpentina*), eastern box turtle (*Terrapene carolina carolina*), eastern mud turtle (*Kinosternon subrubrum*), eastern painted turtle (*Chrysemys picta picta*), red-eared slider (*Trachemys scripta elegans & T. s. scripta*), spotted turtle (*Clemmys guttata*), and wood turtle (*Clemmys insculpta*) (NJDEP Accessed 2024b).

Native lizards and snakes may occur in woodlands, trees, rock crevices, rocky hillsides, fields, riverbanks, and wetlands throughout the Study Area. These include the black rat snake (*Elaphe obsoleta obsoleta*), eastern garter snake (*Thamnophis sirtalis sirtalis*), eastern milk snake (*Lampropeltis triangulum triangulum*), eastern ribbon snake (*Thamnophis sauritus sauritus*), eastern worm snake (*Carphophis amoenu amoenus*), five-lined skink (*Eumeces fasciatus*), northern black racer (*Coluber constrictor constrictor*), northern brown snake (*Storeria dekayi dekayi*), northern redbelly snake (S*toreria occipitomaculata occipitomaculata*), northern ringneck snake (*Diadophis punctatus edwardsii*), and northern water snake (*Nerodia sipedon sipedon*) (NJDEP Accessed 2024b).

The bog turtle is federally threatened per the ESA and State listed as endangered (NJDEP Accessed 2024a). Also, the spotted turtle and wood turtle are Service priority at-risk species and are under review for listing per the ESA. In addition, the bog turtle is a State endangered species, and the long-tailed salamander and wood turtle are State threatened species (NJDEP Accessed 2024a). NJDEP (2023a) landscape data for the piedmont region identified occupied habitat for the following species:

- eastern box turtle at the western extent of the Study Area, just south of the Morris Turnpike in Summit City;
- long-tailed salamander at the Watchung Reservation;
- spotted turtle at the Ash Brook Reservation; and
- wood turtle at the Ash Brook Reservation and Watchung Reservation.

Additional information about bog turtles, wood turtles, and spotted turtles are included in the at-risk, threatened, and endangered species section below.

E. MAMMALS

The Service did not receive funding to conduct field surveys for mammalian species in the Study Area. Only terrestrial mammals can be found in the Study Area.

Terrestrial mammals are commonly observed throughout all the environments within the Study Area. They inhabit a wide range of ecosystems and habitat types from the more developed/urban areas to those that are more naturally occurring, such as the forested areas of the South Mountain Reservation. Mammals within the Study Area are a variety of diurnal, crepuscular, and nocturnal species that are herbivores, omnivores, and carnivores. They can be found burrowing underground, in open fields; roosting within the trees; flying or gliding in the skies; swimming and foraging in the waters; and feeding on the plants and animals throughout the Study Area. Undeveloped areas that contain forested and other vegetated environments, riparian areas, wetlands, and watercourses such as at the protected open spaces described in Section VII.A.1. above are likely to contain the greatest diversity of mammals within the Study Area.

Large terrestrial mammals that may be present within the projects Study Area include black bear (*Ursus americanus*), eastern coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), red fox (*Vulpes vulpes*), and white-tailed deer (*Odocoileus virginianus*) (NJDEP Accessed 2024c; iNaturalist Accessed 2024). Small terrestrial mammals that may be present within the Study Area include, but are not limited to, eastern cottontail rabbit (*Sylvilagus floridanus*), eastern chipmunk (*Tamias striatus*), eastern gray squirrel (*Sciurus carolinensis*), groundhog (*Marmota monax*), masked shrew (*Sorex cinereus*), meadow vole (*Microtus pennsylvanicus*), muskrat (*Ondatra zibethicus*), opossum (*Didelphis virginiana*), short-tailed shrew (*Blarina brevicauda*), southern flying squirrel (*Glaucomys volans*), striped skunk (*Mephitis mephitis*), raccoon (*Procyon lotor*), and white-footed mouse (*Peromyscus leucopus*) (NJDEP Accessed 2024c; iNaturalist Accessed 2024). Introduced nuisance mammal species likely include the feral cat (*Felis catus*), house mouse (*Mus musculus*), and Norway rat (*Rattus norvegicus*).

Flying terrestrial mammals that may be present within the Study Area include several bat species such as the Indiana bat (*Myotis sodalis*), northern long-eared bat (*Myotis septentrionalis*), tricolored bat (*Perimyotis subflavus*), little brown bat (*Myotis lucifugus*), silver-haired bat (*Lasionycteris noctivagans*), big brown bat (*Eptesicus fuscus*), red bat (*Lasiurus borealis*), eastern small-footed bat (*Myotis leibii*), and hoary bat (*Lasiurus cinereus*) (Braun and Grace 2008; NJDEP Accessed 2024c). Outside of their hibernacula, bats are primarily active in the Study Area from spring to early fall. During the fall, they migrate to hibernate in areas such as caves and abandoned mines for the winter. However, the hoary bat, red bat, and silver haired bats migrate south in the fall to overwinter. Bats feed on insects and can be found foraging in areas such as floodplains, wetlands, over watercourses, riparian areas, open fields, and forests. They may roost within the leaf litter, underneath bark, and other crevices of trees during the day. Also, bats have been known to roost in other tight crevices such as cracks in rocks and on artificial human made structures such as bridges, buildings, barns, sheds, and under window eaves.

The Indiana bat and northern long-eared bat are federally listed as endangered pursuant to the ESA. The tricolored bat is proposed endangered, and the little brown bat is under review for listing pursuant to the ESA. In addition, the Indiana bat and northern long-eared bat are listed as State endangered species (NJDEP Accessed 2024a). Additional information about northern long-eared bat and Indiana bat are included in the at-risk, threatened, and endangered species section below.

F. INVERTEBRATES

The Service did not receive funding to conduct any field surveys for invertebrate species in the Study Area. Invertebrates that can be found within the Study Area include insects, spiders, crayfish, snails, slugs, earthworms, and nematodes. Invertebrates are crucial to healthy, well-functioning ecosystems, benefiting other wildlife and humans as well. A brief description of invertebrates and their habitat that may be found within the Study Area is presented below.

The Study Area includes many different types of insects such as butterflies, bees, dragonflies, flies, and beetles. Insects serve multiple crucial ecological purposes within the Study Area such as pollinating plants, being consumed by and providing food sources (or being the sole source of food) to other animals higher up in the food chain, and decomposing wastes. Undeveloped areas that include vegetation, riparian areas, wetlands, and watercourses such as at the protected open spaces described in Section VII.A.1. above are likely to contain the highest diversity of insects within the Study Area. Butterflies and bees can be found feeding on nectar producing plants and pollen in open meadows or fields. If the appropriate plants are present, such as milkweed (*Asclepias spp.*) or bee balm (*Monarda species*), species may be attracted to more developed areas such as the lawns of residential properties as well. Dragonflies can be found near watercourses within the Study Area, where they lay eggs and develop until they emerge from the water, molt, and form wings to fly. Dragonflies will feed on other insects within the Study Area. Flies can be found throughout all portions of the Study Area. They are important for decomposing wastes and feeding on organic decaying matter. Flies, can also be found feeding on other species, such as the mosquito does, which feed on the blood of other animals. Beetles can be found throughout the Study Area as well and may be found feeding on sources such as other insects or plant matter. Insects that may be observed within the Study Area include (but is not limited to) butterflies and bees such as the monarch butterfly (*Danaus plexippus*), eastern tiger swallowtail (*Papilio glaucus*), Peck's skipper (*Polites peckius*), carpenter bees, honeybees, and bumble bees; flies and dragonflies such as mosquitos, common whitetail (*Plathemis lydia*), and blue dasher (*Pachydiplax longipennis*); and beetles such as Asian lady beetle (*Harmonia axyridis*) and click beetles (family *Elateridae*) (iNaturalist Accessed 2024). The monarch butterfly is currently a candidate for listing under the ESA.

Other species such as spiders, crayfish, snails, slugs, earthworms, and nematodes also have habitats throughout the Study Area. Crayfish may be found in the Study Area but are most likely to be observed on watercourse bottoms in the upstream extents of the Rahway River, such as within the South Mountain Reservation. Crayfish feed on food sources such as worms, fish, and other animals. Spiders, snails, slugs, earthworms, and nematodes can be found in multiple areas such as on trees and other plants, in human made structures, and in the soils. Benefits that some of these species provide include improving/maintaining soil quality and health; providing food to other species higher up in the food chain; and decomposing organic matter from plants and other animals.

G. FISH

The Service did not receive funding to conduct any field surveys for fish in the Study Area. Fish that inhabit freshwater environments may be found in the watercourses throughout the Study Area.

Watercourses that contain fish in the Study Area include the Rahway River and the multiple tributaries that connect to it. Additionally, there are ponds, lakes, and reservoirs within the Study Area that also contain fish. Refer to Section I regarding aquatic resources and the map of watercourses in Figure 2 below for additional information about the watercourses. The Rahway

River flows east into and is tidally influenced by the Arthur Kill. Fish that utilize the Arthur Kill in this area may also travel into the tidal Rahway River. However, as previously mentioned, most of the Study Area is influenced by non-tidal watercourses. Within the Study Area, only a small portion of Rahway River and Robinsons Branch (tributary to the Rahway River) is tidally influenced. Two dams mark the approximate point of tidal influence along the Rahway River and Robinsons Branch. For the Rahway River, this includes the Jacksons Pond Dam located approximately at Valley Road in Clark Township (USACE 2020). For Robinsons Branch, this includes the Milton Lake Dam located in Rahway City (USACE 2020). Along the non-tidal portions of the Rahway River, there are multiple dams within South Mountain Reservation and other areas that form ponds and reservoirs. The dams mentioned, along with others in the Study Area, are likely an impediment to fish passage.

Fish feed on several resources that are within the Study Area such as other fish, insects, snails, mollusks, algae, plants, detritus, worms, frogs, and crayfish (NJDEP Accessed 2024d). Fish may also be found spawning and sheltering within the Study Area. They provide a major food source to other animals higher up in the food chain and are important indicators of water quality. NJDEP survey data from 2005 to 2014 of the tidal portions of the Rahway River and Robinsons Branch found the following species: American eel (*Anguilla rostrata*), banded killifish (*Fundulus diaphanus*), black crappie (*Pomoxis nigromaculatus*), blacknose dace (*Rhinichthys atratulus*), bluegill (*Lepomis macrochirus*), brown bullhead (*Ameiurus nebulosus*), golden shiner (*Notemigonus crysoleucas*), green sunfish (*Lepomis cyanellus*), hybrid green sunfish x pumpkinseed (*Lepomis cxg*), largemouth bass (*Micropterus salmoides*), pumpkinseed (*Lepomis gibbosus*), redbreast sunfish (*Lepomis auritus*), spottail shiner (*Notropis hudsonius*), striped bass (*Morone saxatilis*), tessellated darter (*Etheostoma olmstedi*), and white sucker (*Catostomus commersoni*) (NJDEP 2005a; NJDEP 2009a; NJDEP 2010a; NJDEP 2014a; NJDEP 2014b). NJDEP survey data from 2005 to 2019 of the non-tidal portions of the Rahway River, Pumpkin Patch Brook, and Nomahegan Brook found the following species: American eel (*Anguilla rostrata*), banded killifish (*Fundulus diaphanus*), black crappie (*Pomoxis nigromaculatus*), blacknose dace (*Rhinichthys atratulus*), bluegill (*Lepomis macrochirus*), brown bullhead (*Ameiurus nebulosus*), common shiner (*Luxilus cornutus*), creek chub (*Semotilus atromaculatus*), eastern mudminnow (*Umbra pygmaea*), fathead minnow (*Pimephales promelas*), goldfish (*Carassius auratus*), golden shiner (*Notemigonus crysoleucas*), green sunfish (*Lepomis cyanellus*), largemouth bass (*Micropterus salmoides*), mummichog (*Fundulus heteroclitus*), pumpkinseed (*Lepomis gibbosus*), redbreast sunfish (*Lepomis auritus*), redfin pickerel (*Exox americanus americanus*), spottail shiner (*Notropis hudsonius*), striped bass (*Morone saxatilis*), tessellated darter (*Etheostoma olmstedi*), western mosquitofish (*Gambusia affinis*), white sucker (*Catostomus commersoni*), and yellow bullhead (*Ameiurus natalis*) (NJDEP 2005b; NJDEP 2010b; NJDEP 2013a; NJDEP 2013b; NJDEP 2014c; NJDEP 2014d; NJDEP 2014e; NJDEP 2016; NJDEP 2019a; NJDEP 2019b). The lower echo park pond in Mountainside Borough is also trout stocked by the NJDEP fish and wildlife in the Fall (NJDEP Accessed 2024e). The same or similar species are anticipated to be found in the other watercourses throughout the Study Area as well.

The American eel is a catadromous fish (migrates from freshwater to spawn in the sea), which uses different habitats throughout its life stages. Eels spawn in the Sargasso Sea where the eggs hatch into larvae and are transported on the currents towards the coast of the United States. As they drift, the larvae mature into glass eels which are 5 to 8 cm long and transparent. Glass eels swim into estuaries and mature into elvers which are greater than 10 cm in length and begin to develop pigmentation. Elvers migrate into brackish waters and continue to develop while some migrate into streams, lakes, ponds, and rivers. It may take the eels another 3 to 40 years to reach maturation before they head back to the Sargasso Sea to spawn and die (USFWS Accessed 2024a). As mentioned above, American eels are present within the Study Area and have been found in the areas upstream of dams within the Rahway River and its tributaries. As such, they are likely climbing the dams to migrate upstream.

Essential Fish Habitat

Essential fish habitat (EFH) is described by the NOAA-NMFS as the following:

"*Essential fish habitat, also known as EFH, is like real estate for fish. It includes all types of aquatic habitat and, in practice, specifies where a certain fish species lives and reproduces. Marine fish could not survive without these prime locations. Congress established the EFH mandate in 1996 to improve the nation's main fisheries law—the Magnuson-Stevens Fishery Conservation and Management Act—highlighting the importance of healthy habitat for commercial and recreational fisheries.*

Essential fish habitat covers federally managed fish and invertebrates, but it does not apply to strictly freshwater species. Species not covered by EFH, such as lake trout, might be managed by a state or local authority" (NOAA-NMFS Accessed 2024b)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) requires federal agencies to consult with the NOAA-NMFS on any action or proposed action authorized, funded, or undertaken by such agency that may adversely affect EFH (NOAA-NMFS Accessed 2024c). If actions have the potential to adversely affect marine, estuarine, or anadromous species or their habitat, NOAA-NMFS makes recommendations on how to avoid, minimize, or compensate for those impacts. Please be aware that the information in this PAR does not satisfy any required EFH consultations with the NOAA-NMFS as required by the MSFCMA.

The NOAA-NMFS has developed a Mapper that displays areas of EFH, habitat areas of concern, and EFH areas protected from fishing (NOAA-NMFS Accessed 2024a). The mapper was utilized and generated a report that indicated that the Study Area may contain EFH for the following species: Atlantic butterfish (*Peprilus triacanthus*), Atlantic herring (*Clupea harengus*), bluefish (*Pomatomus saltatrix*), clearnose skate (*Raja eglanteria*), little skate (*Leucoraja erinacea*), longfin inshore squid (*Doryteuthis pealeii*), red hake (*Urophycis chuss*), summer flounder (*Paralichthys dentatus*), windowplane flounder (*Scophthalmus aquosus*), winter flounder (*Pseudopleuronectes americanus*), and winter skate (*Leucoraja ocellata*). Additionally, the report explained that any submerged aquatic vegetation is a habitat area of particular concern for summer flounder that may be within the Study Area. However, after reviewing the Study Area, it appears unlikely that submerged aquatic vegetation is present. Please refer to Appendix A for a copy of the EFH mapper Report and further details.

H. AT-RISK, THREATENED, AND ENDANGERED SPECIES

1. Federally Listed, Proposed, and Candidate Species

Pursuant to Section 7 of the ESA, the Corps is required to make a determination as to whether the proposed project "may affect" listed species and, if so, seek concurrence from the Service. The Corps accessed the Service's Information, Planning and Conservation System (IPaC) (*https://ipac.ecosphere.fws.gov/*) to obtain information on listed species that should be incorporated into the effects determination process when consulting with the Service. The Service's New Jersey Field Office project review guide (located at: *https://www.fws.gov/office/new-jersey-ecological-services/new-jersey-field-office-project-review-guide)* has guidance about what information to submit for ESA consultation.

Below is a brief discussion of the federally listed, proposed, and candidate species under the jurisdiction of the Service that may occur in the Study Area. Their status has been previously noted in this report, but more detailed information is provided below.

<u>Bog turtle</u>

The bog turtle was federally listed as a threatened species on November 4, 1997. At only about 4 inches long, the bog turtle is one of North America's smallest turtles. This species typically shows a bright yellow, orange, or red blotch on each side of the head. The nearly parallel sides of the upper shell (carapace) give bog turtles an oblong appearance when viewed from above. These small, semi-aquatic turtles consume a varied diet including insects, snails, worms, seeds, and carrion (USFWS 2001).

Bog turtles usually occur in small, discrete populations, generally occupying open-canopy, herbaceous sedge meadows and fens bordered by wooded areas. These wetlands are a mosaic of micro-habitats that include dry pockets, saturated areas, and areas that are periodically flooded. Bog turtles depend upon this diversity of micro-habitats for foraging, nesting, basking, hibernating, and sheltering. Unfragmented riparian systems that are sufficiently dynamic to allow the natural creation of open habitat are needed to compensate for ecological succession. Beaver, deer, and cattle (*Bos taurus*) may be instrumental in maintaining the open-canopy wetlands essential for this species' survival (USFWS 2001).

Bog turtles inhabit open, unpolluted emergent and scrub/shrub wetlands such as shallow spring-fed fens, sphagnum bogs, swamps, marshy meadows, and wet pastures. Bog turtles also use forested wetlands during the active and inactive seasons. These habitats are characterized by soft, muddy (often "mucky") bottoms, interspersed wet and dry pockets, vegetation dominated by low grasses and sedges, and a low volume of standing or slow-moving water, which often forms a network of shallow pools and rivulets. Bog turtles prefer areas with ample sunlight, high evaporation rates, high humidity in the near-ground microclimate, and perennial saturation of portions of the ground (USFWS 2001).

The greatest threats to the bog turtle are the loss, degradation, and fragmentation of its habitat from wetland alteration, development, pollution, invasive species, and natural vegetational succession. Bog turtles can also be killed or injured by heavy construction equipment.

Additionally, the species is also threatened by collection for illegal wildlife trade (USFWS 2001).

The majority of the Study Area appears outside of the range of bog turtle. Actions that are outside of the range of bog turtle, or that will not impact suitable habitat, are anticipated to have no effect to this species. However, portions of the Study Area including and southwest of the Ash Brook Reservation are within the range of bog turtle habitat. As mentioned within the official species list (see Appendix A), for this specific action area, consultation is recommended only for activities involving significant changes to surface/ground water, including stormwater. Please ensure that the species list and action area are regularly updated to determine if any changes occur.

<u>Indiana Bat</u>

The Indiana bat was federally listed in 1967 and classified as an endangered species in 1973. The Indiana bat is a small, brown mammal about 1.5 to 2 inches long. This species closely resembles the little brown bat, from which it can be distinguished by small differences in fur coloration and the structure of the feet. As with all eastern U.S. bat species, Indiana bats feed almost exclusively on insects (USFWS 2007).

From April to September, Indiana bats inhabit their summer habitats. Suitable summer habitat consists of a wide variety of forested ecosystems where they roost, forage, and travel and may also include some adjacent and interspersed non-forested areas such as emergent wetlands and adjacent edges of agricultural fields, old fields and pastures. This includes forests and woodlots containing potential roosts (*i.e.*, live trees and/or snags greater than or equal to 5 inches diameter at breast height (DBH) that have exfoliating bark, cracks, crevices, and/or hollows), as well as linear features such as fencerows, riparian forests, and other wooded corridors. These wooded areas may be dense or loose aggregates of trees with variable amounts of canopy closure. Individual trees may be considered suitable habitat when they exhibit the characteristics of a potential roost tree and are located within 1,000 feet of other forested/wooded habitat. Indiana bats have also been observed roosting in human-made structures, such as bridges (USFWS 2023a).

During the summer months, numerous female bats roost together in maternity colonies. Maternity colonies use multiple roosts in both living and dead trees. Female Indiana bats raise a single offspring each year. Adult males usually roost in trees near maternity roosts, but some males remain near the hibernaculum and use caves and mines during the summer (USFWS 2007).

Each fall from late August through mid-November, Indiana bats migrate from their summer habitats to congregate in the vicinity of their hibernation sites, which include caves and abandoned mine shafts. During this time, the bats “swarm” in the vicinity of their hibernacula, mating and accumulating final fat reserves for hibernation. The bats then hibernate from late October to April, the precise timing is dependent on climatic conditions. After emerging from hibernation, Indiana bats forage in the vicinity of the hibernation site before migrating to summer habitats. Studies indicate that Indiana bats typically forage within 10 miles of hibernacula before and after hibernation (USFWS 2007).

Most of the Study area appears to be within the range of Indiana bat potential summer habitat (see range information at USFWS Accessed 2024c). Additionally, areas located northwest of the Baltusrol Golf Club in Springfield Township, New Jersey are within the outer range (2.5 to 5 mile buffer) of a known Indiana bat maternity capture site. As such, Indiana bats may be present within the action area from April 1 to September 30.

Threats to Indiana bats include disturbance or killing of hibernating and maternity colonies; vandalism and improper closure of hibernacula; fragmentation, degradation, and destruction of summer habitats; and use of pesticides and other environmental contaminants. Additionally, white-nose syndrome due to the fungus *Pseudogymnoascus destructans* is a major threat to the Indiana bat and many other bat species (USFWS 2007).

<u>Monarch butterfly</u>

The monarch butterfly was added to the list of Federal candidate species in 2020. Candidate species are those that the Service has determined warrant listing under the ESA and await formal listing. Although these species receive no substantive or procedural protection under the ESA until formal listing, the Service encourages consideration of candidate species in project planning and opportunities that may aid in their conservation. A listing determination for this species is expected in Fiscal Year 2024.

Adult monarch butterflies are large and conspicuous, with bright orange wings surrounded by a black border and covered with black veins. The black border has a double row of white spots, present on the upper side of the wings. Adult monarch butterflies are sexually dimorphic, with males having narrower wing venation and scent patches. Each spring, monarch butterflies disperse from overwintering grounds to areas across the United States, including New Jersey. During the breeding season, monarch butterflies lay eggs on their obligate milkweed host plant (primarily *Asclepias spp.*), and larvae emerge after 2 to 5 days. Larvae develop through five larval instars (intervals between molts) over a period of 9 to 18 days, feeding on milkweed and sequestering toxic chemicals (cardenolides) as a defense against predators. The larva then pupates into a chrysalis before emerging 6 to 14 days later as an adult butterfly. There are multiple generations of monarch butterflies produced during the breeding season, with most adult butterflies living approximately 2 to 5 weeks; overwintering adults enter reproductive diapause (suspended reproduction) and live 6 to 9 months.

Within the Study area, monarch butterflies may be present during migration and breeding from May 1 to September 30 (Monarch Joint Venture 2019). Monarch butterfly habitat requires suitable shelter from poor weather such as fallen logs and leaf litter; food from plants such as milkweed and other nectar plants to support them throughout the breeding season; and water within brief flying range (NJDEP 2017). Suitable breeding habitat requires all the same conditions but also their obligate milkweed host plant. In the fall, surviving monarch butterflies migrate from and through New Jersey to their respective overwintering sites which is generally in the mountains of central Mexico.

Northern long-eared bat

The northern long-eared bat was federally listed as endangered (previously listed as threatened) in March 2023. The northern long-eared bat is a medium-sized bat weighing approximately five to eight grams with females slightly larger than males. It is distinguished from other *Myotis* species by its long ears.

Northern long-eared bats utilize summer habitats from April to September. Suitable summer habitat consists of a wide variety of forested ecosystems where they roost, forage, and travel and may also include some adjacent and interspersed non-forested areas such as emergent wetlands and adjacent edges of agricultural fields, old fields, and pastures. This includes forests and woodlots containing potential roosts (*i.e.*, live trees and/or snags greater than or equal to 3 inches DBH that have exfoliating bark, cracks, crevices, and/or cavities), as well as linear features such as fencerows, riparian forests, and other wooded corridors. These wooded areas may be dense or loose aggregates of trees with variable amounts of canopy closure. Individual trees may be considered suitable habitat when they exhibit characteristics of suitable roost trees and are within 1,000 feet of other forested areas. The bats have also been observed roosting in human-made structures, such as buildings, barns, bridges, and bat houses; therefore, these structures should also be considered potential summer habitat (USFWS 2023a).

Northern long-eared bats congregate in the vicinity of their hibernacula (caves and abandoned mine portals) in August or September and enter hibernation from October to November. The bats engage in swarming activities within 5 miles of their hibernaculum. In April, the bats emerge from hibernation and migrate to summer habitat. Migratory movements are short compared to the Indiana bat, with movement typically between 35 and 55 miles (USFWS 2022).

Threats to the northern long-eared bat include disturbance or killing of hibernating and maternity colonies; vandalism and improper closure of hibernacula; fragmentation, degradation, and destruction of forested summer habitats; and use of pesticides and other environmental contaminants. White-nose syndrome (*Pseudogymnoascus destructans*) is also a major threat to this and other bat species (USFWS 2022). The Study area is partially within the range of potential summer habitat for the northern long-eared bat (see range information at USFWS Accessed 2024b). As such, the bats may be present from April 1 to September 30.

Tricolored bat

On September 14, 2022, the Service published a proposal in the FR to list the tricolored bat as endangered under the ESA (*Federal Register* (FR) Vol. 87 (177): 56381-56393). A final determination to either list the tricolored bat under the ESA or to withdraw the proposal is anticipated during Fiscal Year 2024.

The tricolored bat is a small insectivorous bat that typically overwinters in caves, abandoned mines and tunnels, and road-associated culverts (southern portion of the range). They spend the rest of the year in a wide variety of forested areas where they roost and forage, including adjacent and interspersed non-forested areas such as emergent wetlands and adjacent edges of agricultural fields, old fields, and pastures. This also includes forests and woodlots containing trees with potential roost substrate (*i.e.*, live and dead leaf clusters of live and recently deceased deciduous trees, Spanish moss (*Tillandsia usneoides*), and beard lichen (*Usnea trichodea*)), as well as linear features such as fencerows, riparian forests, and other wooded corridors. tricolored bats will roost in a variety of tree species, especially oaks, and often select roosts in tall, large diameter trees, but will roost in smaller diameter trees when potential roost substrate is present (*e.g.*, 4-inch [10-centimeter]; Leput 2004). They may also roost in human-made structures, such as bridges and culverts, and occasionally in barns or the underside of open-sided shelters (*e.g.*, porches, pavilions) (USFWS 2023a). The Study Area is likely entirely within the range of tricolored bat potential habitat.

The Service determined this bat species faces extinction primarily due to the range-wide impacts of white-nose syndrome, a deadly fungal disease affecting cave dwelling bats across North America. Since tricolored bat populations have been greatly reduced due to white-nose syndrome, surviving bat populations are now more vulnerable to other stressors such as human disturbance and habitat loss.

2. Service Priority At-risk Species

The following species are Service identified priority at-risk species. As mentioned above, Service identified priority at-risk species are those are declining and are “at-risk” of becoming candidates for ESA listing. They are not federally listed, proposed or candidate species per the ESA. As such, the ESA does not currently offer them any protections.

Cerulean Warbler

The cerulean warbler is a small bird that has sky blue plumage streaked with patches of white and black. Cerulean warblers may be found breeding in the spring and summer months within New Jersey and prefer using the canopies of mature, structurally diverse deciduous forests. After breeding, the birds migrate to their wintering grounds in the Andes mountains of South America. Large tracts of its habitat are disappearing in its breeding range, though areas of the Appalachian region remain a stronghold for the species. Additionally, large swaths of its wintering grounds are also under heavy development pressure. Multiple observations of cerulean warbler have been identified within and in the vicinity of the Study Area during the spring, including at South Mountain Reservation (eBird Accessed 2024). The mature forests within the South Mountain Reservation and other protected open spaces described in Section VII.A.1. above appear most likely to contain suitable habitat for this species (USFWS Accessed 2024e; eBird Accessed 2024).

Historically ranging throughout most of the eastern United States, the cerulean warbler has experienced some of the most dramatic population declines of any bird species in recent decades, averaging 3 percent losses every year from 1966 to 2005, according to breeding bird survey data. Declines are attributed to habitat loss, degradation, and fragmentation within its breeding and wintering grounds and along its migration route (USFWS Accessed 2024e).

Spotted Turtle

Spotted turtles are small (3.4 to 4.5 inches long), aquatic turtles with a smooth black shell containing yellow polka dot spots. They also have orange or yellow coloration on the head, neck, and forelegs. This species occurs in wetlands throughout the east coast and in the Great Lakes region of the United States. Favored habitats include shallow aquatic areas, often with abundant vegetation. Wetlands that are important for this species includes areas such as marshes or swamps that are covered often intermittently with shallow water or have soil saturated with moisture. Individuals, in particular males, will wander some distance from wetlands, especially during the spring. Spotted turtles mostly eat other animals, including worms and frogs, but will also eat aquatic vegetation. During winter months, spotted turtles will dive down to muddy wetland bottoms and drastically slow their metabolism, allowing them to survive without food and very little oxygen. Courtship and mating occur in early spring, with males pursuing females in an underwater courtship display. Nesting occurs in May and June in open, sunny locations with moist and well-drained soils. Females typically lay one clutch of eggs, that emerge in August or September. Females may lay a second clutch a few days after the first (USFWS Accessed 2024f).

The range of this species likely includes the Study Area. As previously mentioned, NJDEP (2023a) landscape data for the piedmont region identified occupied habitat for spotted turtle at the Ash Brook Reservation. Threats to spotted turtles include the loss, alteration, and fragmentation of wetlands. Climate change has the potential to impact the hydrology of the wetlands the species depends upon over time. Poaching and collection for the foreign and domestic pet trade also pose a threat for spotted turtle populations (USFWS Accessed 2024f).

The Service is reviewing spotted turtle to determine if the species warrants protections under the ESA, with a decision expected during Fiscal Year 2024.

Wood Turtle

The Northeast Wood Turtle Working Group (2017) explains that wood turtle are medium sized turtles with females typically averaging about 6.7 to 7.9 inches in shell length, and males up to 11 percent larger. They are omnivorous with a diet of slugs, worms, tadpoles, insects, algae, wild fruits, leaves, grass, moss, and carrion (Connecticut Department of Energy and Environmental Protection Accessed 2024). The Northeast Wood Turtle Working group (2017) also explains that wood turtle habitat requirements include both aquatic and terrestrial ecosystems. Their populations are almost always associated with slow-moving sections of clear, cold, woodland streams, especially those with sand, gravel, or rock substrates. They overwinter in streams and are generally active from late March to late October. Wood turtles also mate in streams and nest on land from mid-May to late July. They require well-drained, elevated, and exposed areas of sand and or/gravel for nesting. During late spring to fall, they spend much of their time in floodplain and upland areas, including forested and non-forested ecosystems. They generally occupy a mosaic of ecosystems including mature forests and early successional cover types. Edge habitats provide an important role to help wood turtles balance thermoregulation and food requirements. Major threats to wood turtles include roads, habitat loss and fragmentation, dams, severe floods, streambank stabilization, and other human induced threats (Northeast Wood Turtle Working Group 2017).

The range of this species likely includes the Study area. As previously mentioned, NJDEP (2023a) landscape data for the piedmont region identified occupied habitat for wood turtle within the Study Area at the Ash Brook Reservation and Watchung Reservation. As such, wood turtles are likely present.

The Service is reviewing wood turtle to determine if the species warrants protections under the ESA, with a decision expected during Fiscal Year 2024.

Wood Thrush

The wood thrush is a Service identified priority at-risk species. It is not a federally listed, proposed or candidate species per the ESA. As such, the ESA does not currently offer it any protections. It is widespread across most of the eastern United States and into southern Canada. The wood thrush inhabits forested areas, particularly those dominated by deciduous trees. This species is most likely to occur in multiple areas of a forested ecosystem such as underbrush or forest floors and has reddish-brown back feathers with a white and brown speckled underside. The wood thrush breeds throughout New Jersey during the spring and summer months. It migrates to wintering grounds in the lowlands of Mexico and Central America after breeding (USFWS Accessed 2024d). As previously mentioned, NJDEP (2023a) landscape data for the piedmont region identified breeding sightings of wood thrush within the Study Area. The forested portions of the Study Area, especially within and in the vicinity of Lenape Park, Rahway River Parkway, and Ash Brook Reservation are the most likely to contain habitat for this species.

The wood thrush is threatened by habitat loss, degradation, and fragmentation not only in its breeding grounds, but also in its wintering grounds and along its migration route. The species is undergoing sharp declines in population and is likely to experience range contractions because of habitat loss and climate change (USFWS Accessed 2024d).

I. AQUATIC RESOURCES

1. Watercourses

As mentioned above, watercourses within the Study Area provide important habitats for fish, amphibians, birds, invertebrates, and the other wildlife that may be present. The quality of and access to these watercourses is crucial to maintaining the overall health of fish and wildlife within the Study Area. Watercourses within the Study Area were identified below through usage of the NJDEP's (2023b) surface water quality classification geographic information systems (GIS) data. Only the rivers, streams, and tributaries to them were identified. The Study Area also includes multiple ponds, lakes, and reservoirs. All watercourses were identified as freshwater. Additionally, except for the Rahway River, they all flow entirely within the Study Area.

1. Rahway River: This includes the East Branch of the Rahway River and unnamed tributaries leading to the Rahway River. The Rahway River is the main watercourse present throughout most of the Study Area. The headwaters begin within the northern portion of the Study Area. It then flows southeast, outside of the Study Area, and eventually into the Arthur Kill.

2. Robinsons Branch and its unnamed tributaries: This watercourse flows east from the Ash Brook Reservation and into the Rahway River.

3. Ash Brook and its unnamed tributaries: This watercourse flows south from (approximately) Kramer Manor Park in Scotch Plains Township, into the Ash Brook Reservation, and eventually into Robinsons Branch.

4. Nomahegan Brook and its unnamed tributaries: This watercourse flows east from (approximately) Chipmunk Hill Road in Mountainside Borough, through Echo Lake Park and Lenape Park, and eventually empties into the Rahway River.

5. Pumpkin Patch Brook and its unnamed tributaries: This watercourse flows north from New Dover Road in Woodbridge Township and into Robinsons Branch.

6. Turtle Brook: This watercourse flows west from the Essex County Country Club in West Orange Township and into the Rahway River.

7. Van Winkle Brook: This watercourse flows south from (approximately) Millburn High School in Millburn Township and into an unnamed tributary of the Rahway River.

8. Winding Brook and its unnamed tributaries: This watercourse flows southeast from (approximately) Brookside Park in Scotch Plain Township and into Robinsons Branch.

A map of the watercourses within the Study Area is provided in Figure 2 below.

2. Wetlands

As mentioned above, palustrine wetland communities that provide valuable habitat for fish and wildlife are present within the Study Area. Wetlands are known to filter our chemicals, pollutants, and sediments that clog and contaminate watercourses; provide natural flood control by soaking up stormwater runoff; and provide hydrological input of stored flood waters to streams during droughts (NJDEP Accessed 2024f). The ecosystem services that wetlands provide are crucial to ensuring healthy habitats for fish and wildlife, not only within the wetlands themselves but for other habitats such as within the watercourses they benefit. Service mapped wetlands from National Wetland Inventory data (USFWS 2023b) were utilized to identify wetlands within the Study Area. The Study Area includes large swaths of wetlands. Notable areas include (but is not limited to) the large swaths of palustrine forested and scrub shrub wetlands at Ash Brook Reservation, Lenape Park, and Nomahegan Park. Please refer to Figure 2 for a visual representation of the Service (USFWS 2023b) mapped wetlands within the Study Area.

3. Riparian Areas

Although definitions vary, riparian areas can generally be described as rivers, streams, creeks, and other waterbodies and the adjacent land areas that influence one another. Riparian areas are an ecotone where aquatic and terrestrial ecosystems converge. These areas tend to support diverse plant species and provide valuable habitat for several aquatic and terrestrial animal species including migratory birds (Gregory et al. 1991; Naiman et al. 1993; Pennington et al. 2008; Pennington et al. 2010). In addition to providing wildlife habitat, riparian areas also reduce adverse effects to water quality by removing sediments, nutrients, and pollutants from storm water runoff; moderating storm water flows; dispersing aquatic organisms and plant propagules; floodwater storage; and connecting adjacent natural areas (Naiman and Decamps 1997; Naiman et al. 1993; NJDEP Accessed 2024g). The health and integrity of vegetated streamside riparian areas are essential to supporting the health and integrity of watercourses within the Study Area. Many of the riparian areas within the Study Area have been degraded and continue to be threatened due to alterations such as human development, channel straightening, bank stabilization and hardening, increased sediment inputs, dams, and invasive species.

VIII. FUTURE WITHOUT PROJECT CONDITIONS

This report assumes that several projects and conservation efforts are likely to continue or be undertaken within the Study Area, even if this project is not implemented. This includes projects such as new property developments (homes, commercial properties, etc.) and transportation construction. Conservation efforts may occur on private lands and on public lands such as at the South Mountain Reservation and the several other protected open spaces listed in VII.A.1 above. These projects and conservation efforts may be completed by municipalities, counties, State and Federal agencies, and not for profit organizations. Other projects such as the Corps' Rahway River Basin Coastal Storm Risk Management are also planned within the area (USACE 2020). Additionally, programs such as the NJDEP's Blue Acres program and Natural Climate Solutions Grant program may acquire and restore natural areas for flood storage and enhance New Jersey's natural carbon sinks such as forests, urban parks, woodlands, and street trees (NJDEP Accessed 2024h and 2024i).

Without the proposed project, the effects of climate change, erosional events, and future storms are likely to continue. Human infrastructure such as buildings, transportation facilities, and others may directly be threatened by these events due to flooding and other storm induced damages. Natural areas such as wetlands, riparian areas, and forests may be inundated more frequently, having potentially deleterious effects. Additionally, invasive species may continue to spread within the area without conservation action. Some species that depend on these natural areas for habitat, such as migratory birds and pollinators may, or continue to, experience population declines due to loss of or degradation of habitat. However, protected areas such as those mentioned within VII.A.1 above will likely continue to provide high quality habitat for predominantly native species.

The carrying capacity of the existing fish and wildlife habitats withing the Study Area is not anticipated to increase in terms of area. However, restoration initiatives such as controlling invasive species; enhancing, preserving, or creating aquatic resources; and creating or enhancing upland habitat may provide some modest increases in habitat availability or quality. Avian

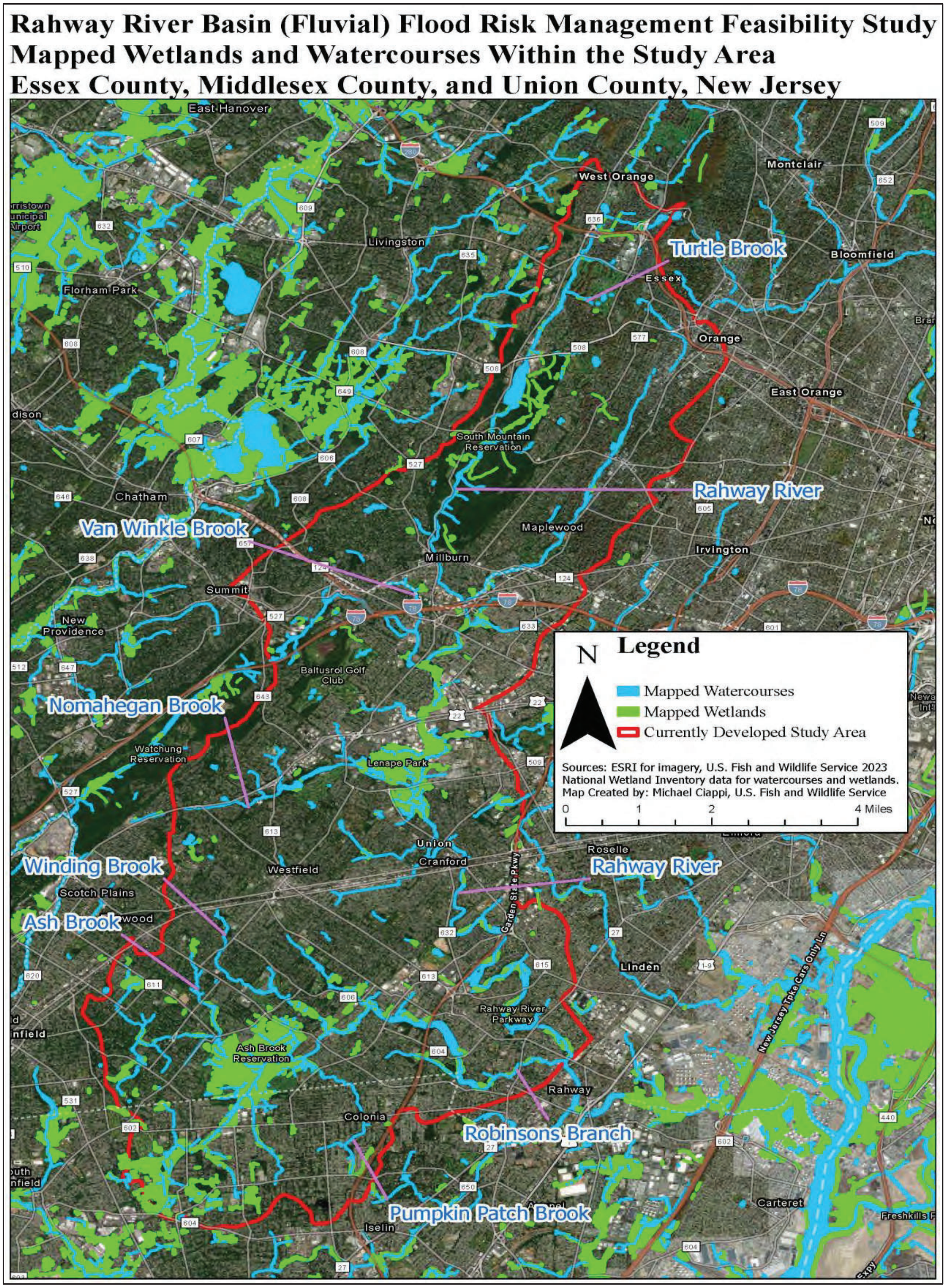

Figure 2. Mapped Wetlands and Watercourses Within the Study Area

abundance and diversity will likely continue to reflect trends typically seen throughout the Study Area. As noted previously, several species of conservation concern rely on the habitats present within the Study Area. Their conservation will be dependent on efforts to protect, conserve, and restore that habitat.

IX. PROJECT DESCRIPTION

As currently developed, no Tentatively Selected Plan or preferred alternative has been developed by the Corps for the proposed project. However, multiple alternatives are in development and are being considered. The goal of the alternatives is to address flood risk along the Rahway River Basin. Details will likely change as more information is known and developed by the Corps. Additionally, more in depth project descriptions will be provided in the future as planning progresses. The alternatives developed thus far include:

A. ALTERNATIVE 1 – NO ACTION

This alternative would involve no action by the Corps. It is included in the Corps' analysis to serve as a baseline for future without project conditions and is required by the National Environmental Policy Act (NEPA).

B. ALTERNATIVE 2 – UPSTREAM DETENTION

As currently developed, this alternative proposes a new dam within the South Mountain Reservation. The proposed dam would be located at the northern most extent of Campbells Pond, where the Rahway River flows into it. It is anticipated to be approximately 70 feet high and 810 feet long. The dam is anticipated to impound water and form dry detention in areas upstream where that does not currently occur. The new dam and detention areas may also involve the relocation of a portion of the adjacent Brookside Drive further to the West. This would require relocation and creation of a new road through undisturbed forested portions of the South Mountain Reservation. Additionally, the dam would require a minimum 50-foot woody vegetation free zone from its toe of slope. This alternative may also result in undetermined modifications to the Rahway River, the Campbell Pond, and Diamond Mill Pond within the South Mountain Reservation.

C. ALTERNATIVE 3 – COMBINATION PLAN (BASIN WIDE)

As currently developed, this alternative proposes 88,500 linear feet of channel modifications along the East Branch of the Rahway River, Rahway River, and Robinsons Branch. This may include deepening watercourse bottom depths and constructing retaining walls along the watercourse boundary. Levees, floodwalls, and modifications to structures such as bridges may also be included. Additionally, property buyouts and potential localized flood storage within those areas may be proposed. This alternative also includes flood storage within natural areas.

The potential channel modifications are in three locations (all approximately described). The first is located along the Rahway River from the Southern boundary of the South Mountain Reservation to Route 22. This location also includes a portion of the East Branch of the Rahway

River from Route 78 to the southwestern boundary of the Maplewood Country Club in Maplewood Township. The second is located along the Rahway River from Springfield Avenue to Lincoln Avenue East within Cranford Township. The third location is along the Robinsons Branch from the Milton Lake Dam to where it meets the Rahway River.

D. ALTERNATIVE 4 – NONSTRUCTURAL PLAN

As currently developed, this alternative proposes to utilize non-structural measures to protect structures within the area from being impacted by floods. These measures may be proposed within multiple municipalities throughout the Rahway River Basin. This may include measures such as floodproofing, elevation changes, and relocating or acquiring properties.

E. ALTERNATIVE 5 – LENAPE PARK DETENTION BASIN AND CHANNEL MODIFICATIONS

As currently developed, this alternative proposes modifications to the Rahway River and Lenape Park Detention Basin within Cranford Township. Channel modifications to the Rahway River include deepening watercourse bottom depths and constructing retaining walls along the watercourse boundary. Channel modifications and work is proposed (approximately) from the North Avenue Bridge to the Lenape Park Dam and includes portions of the Rahway River that flows through Nomahegan Park.

Other potential project features include modifying and replacing portions of the existing Lenape Dam. The dam's spillway is proposed for replacement, will be raised by 6 feet, and widened by 100 feet. The auxiliary spillway is also proposed to be widened to 400 feet. The dam's orifice is proposed to be widened to 40 feet and lowered by 0.5 feet. Additionally, modifications to 10,000 feet of the dam's embankments/levees are proposed by raising them 6 feet. Floodwalls will also be added to the existing embankments/levees at the northern area of Lenape Park near Fadem Road in Springfield Township.

Alternatives 2, 3, possibly 4, and 5 will likely include permanent and temporary impacts to wetlands, watercourses, riparian areas, and forested or other vegetated areas. Please refer to Appendix B for maps and descriptions of the alternatives. The maps are preliminary, and work is likely to change or be modified as more information is developed. The maps and descriptions were extracted from an Alternatives presentation that the Corps provided to Cranford Township (Cranford Township Accessed 2024) and from information provided to the Service during previous presentations and meetings.

X. DESCRIPTION OF PROJECT IMPACTS ON FISH AND WILDLIFE RESOURCES

The NEPA documentation and project details are still early in development from the Corps. This lack of information makes it difficult to assess the full effects to fish and wildlife resources that will result from the proposed project. As such, the following discussion of impacts associated with the Study alternatives is based on the potential effects from Service knowledge of the Study Area and other outside or internal information/reports. The analysis below discusses the measures currently proposed within the Alternatives in the project description above and the impacts they may have to fish and wildlife in the Study area.

A. ACTIVE CONSTRUCTION IMPACTS

Active construction impacts are those that would be required during the installation, application or creation of the measures within the alternatives proposed. This will include impacts caused by construction noises that are louder than existing baseline conditions; lighting; and temporary or permanent effects to areas such as trees or other vegetation, wetlands, riparian areas, and watercourses. Construction noises may frighten wildlife, causing them to displace from adjacent suitable habitats into areas of reduced suitability. Lighting may attract species such as birds to construction areas, where they may be injured or waste energy reserves. The lighting may also delay or prevent emergence from bat roosts, resulting in reduced foraging during the peak time just after dusk (Bat Conservation Trust Accessed 2024). Clearing of trees and other vegetation due to access requirements will likely result in the loss of those habitats for birds, invertebrates, mammals, reptiles, amphibians, and other species that rely upon those areas.

Construction within watercourses, wetlands, riparian areas, and adjacent areas will likely result in increased erosion and sedimentation. This may affect the species present within those environments such as turtles and fish that may be harmed or buried/killed by the additional sedimentation input and turbid conditions. Additionally, watercourse bottoms may contain contaminated materials that may be resuspended during construction. This can expose species in the water column to potentially adverse levels of environmental contaminants that can spread throughout the food chain. Sedimentation will cause greater adverse effects to fish and wildlife habitat if proper soil erosion and sediment controls are not utilized/maintained during construction.

B. NEW DAM AND DETENTION AREA WITHIN SOUTH MOUNTAIN RESERVATION

The proposed new dam and detention areas as part of Alternative 2 are anticipated to have adverse effects to fish and wildlife. The new dam and detention area would inundate areas located upstream of the dam with water from the Rahway River during storm events. Additionally, the dam and detention areas may impound water upstream and create permanent disturbances to adjacent habitats. The proposed dam will fragment the Rahway River from areas located upstream and create impediments for aquatic organism passage. The dam, detention areas, and any impoundment of waters will likely reduce aquatic biodiversity, alter habitat, disrupt the natural movement of water and sediment, and alter water quality (Minnesota Department of Natural Resources 2013).

The proposed work will alter habitat within the South Mountain Reservation. Riparian, wetland, and upland terrestrial habitats (*e.g.,* forests) located adjacent to the Rahway River and upstream of the new dam may be permanently transformed if the dam results in impoundments of water or if the detention areas require their removal. The detention areas may transform these habitats into maintained grassed areas for floodwater storage that offer little to no ecological benefits. If water is impounded, it would transform these habitats into areas that resemble lakes/ponds. The areas upstream of the new dam may also be flooded more frequently during storm events. The plants within those areas may not be adapted to that type/frequency of hydrologic input and may not be able to survive those conditions. Additionally, any erosion caused by flooding of those areas may further degrade that habitat. As such, the proposed dam and detention basin may result in the loss of adjacent terrestrial ecosystems that species such as amphibians, reptiles, birds, mammals, and invertebrates currently utilize for breeding, feeding, and sheltering. Service priority at-risk, threatened, and endangered species such as bats and birds will lose habitat if they are present within those areas. The detention area may be able to continue to provide some beneficial impacts to fish and wildlife if it also results in the creation of natural areas. For example, if the Corps plans to incorporate/plant native vegetation with the detention basin for species such as pollinators, that could benefit multiple species. However, if the detention basins are designed to simply store storm water and not also provide habitat, they will likely offer no benefits.

New dams create an impediment for fishes since they will not be able to, or may have increased difficulty traveling upstream and downstream from those areas, thereby affecting spawning and migration. However, within the South Mountain Reservation, there are two existing dams downstream (with the closest approximately 0.2 mile away) and two existing dams upstream (with the closet 1.4 miles away) of this location, creating multiple ponds and reservoirs. There appears to be nine other dams located further downstream from South Mountain Reservation and along the Rahway River, all within the Study Area. The dams do not appear to have fish passage installations currently installed (Weston Solutions, Inc 2009). However, an investigation of whether existing fish passage installations currently exist at these dams is needed. Many of the other watercourses throughout the Study Area are also dammed. As such, fish passage within the South Mountain Reservation and the Study Area is already impeded. While the new dam would cause an additional impediment to fish passage and exacerbate the issue, its effects would likely result in minor adverse impacts to fish since the watercourses are already so extensively dammed.

The new dam will likely reduce the water quality of the Rahway River due to the expected loss of adjacent areas (*e.g.*, wetlands, riparian areas, upland vegetation) that filter out sediments and nutrients before they enter the watercourse, which will likely impact all species that utilize the Rahway River located downstream. The dam may also reduce watercourse velocities upstream and permanently impact the benthic habitats that fish and wildlife depend upon by allowing more sediment to settle. Areas located downstream of the dam may receive less water, resulting in the permanent reduction of the elevation of the watercourse and loss of stream habitat for fish and wildlife. Wetlands and riparian areas located downstream that depend on flooding from the watercourse at higher elevations may be lost as well since they will no longer be receiving that fluvial input.

C. RELOCATION OF BROOKSIDE DRIVE AT SOUTH MOUNTAIN RESERVATION

The proposed relocation of Brookside Drive as part of Alternative 2 would shift it westward within the South Mountain Reservation. Large portions of this area are currently undeveloped upland forests. The new road would cause multiple impacts to fish and wildlife within the area. This includes, but is not limited to, permanent loss and modification to upland forests and vegetated areas that they utilize; fragmentation of wildlife habitat by creation of a new road; and addition of new roadway induced noises, lighting, pollution, and stormwater drainage where they do not currently occur. Additionally, the new road will remove forested and herbaceous areas that filter sediment and pollutants before they flow into the Rahway River during storm events.

This work is proposed within one of the more sensitive and high-quality habitats throughout the Study Area. The permanent destruction of and modification to fish and wildlife habitat and additional new disturbances will adversely impact the species that utilize this area. This may include Service priority at-risk, threatened, and endangered species as outlined in the Existing Fish and wildlife Resources section above. For example, mammals such as bats will lose summer roosting and foraging habitat. Birds that may breed or forage within these areas will also be impacted due to the permanent loss of and disturbance to habitat. Reptiles such as turtles and snakes may lose suitable habitat through deforestation. The new road will result in the loss of forested and herbaceous areas that likely filter pollutants and sediments from stormwater before they flow into the Rahway River. This will add to the degradation of water quality within the Rahway River and impact aquatic species such as fish. The proposed work may result in the incidental killing of species if conservation measures are not implemented during construction. For example, if tree clearing is conducted during times of the year when birds are nesting/when flightless chicks are present.

The road relocation will likely result in the incidental killing of species attempting to cross it so that they can access habitats on the other side. Vehicle induced issues such as exhausts; humans disposing trash or other pollution from them; contaminants (*e.g.*, leaking oil or other fluids); and debris, lack of maintenance, and accidents will all impact species as well. The road relocation will be within an area that is currently protected open space that functions as refuge for wildlife. New roadway induced pollution and disturbances will result in the degradation of the adjacent wildlife habitat.

D. WATERCOURSE MODIFICATIONS

Alternatives 2, 3, and 5 propose watercourse modifications. The proposed watercourse modifications have not yet been fully described the Corps. As currently developed, Alternative 2 has identified that the modifications will occur along the Rahway River, Campbell Pond, and Diamond Mill Pond within the South Mountain Reservation. Alternatives 3 and 5 currently propose modifications that will include deepening the bottom depths of the Rahway River, East Branch of the Rahway River, and Robinsons Branch and constructing retaining walls along the watercourse boundaries.

The deepening of the watercourses/channels proposed as part of Alternatives 3 and 5 may have adverse impacts to fish and wildlife that depend on the Rahway River and adjacent habitats. Deepening the watercourses can change the stability of them by impacting stream flows, rates of bank and channel erosion, and sediment transport (West Virginia Flood Protection Task Force 2004). These changes can cause permanent impacts to aquatic ecosystems and the species that depend upon them. For example, if watercourse flow rates increase, it can cause additional erosion to adjacent habitats and possible degrade/destroy riparian areas or wetlands. The fish and wildlife that depend on those areas for breeding, feeding, and sheltering will be adversely impacted by those changes. Additionally, spawning and benthic habitat for fish may be removed if watercourse bottoms are eroded or flow rates increase. The potential increase in sedimentation

from the proposed modifications after construction may also permanently change watercourse morphology and alter existing fish and wildlife habitat over time.
The retaining walls proposed within Alternatives 3 and 5 will likely disconnect habitats located landward from the watercourses. This may result in the fragmentation of riparian areas/floodplains, wetlands, and access from other terrestrial habitats. These fragmentations can cause the degradation/destruction of the habitats that depend upon watercourses for their existence. For example, riverine wetlands need to be regularly flooded to sustain their hydrophytic plant, hydric soil, and hydrologic conditions. The construction of a retaining wall in front of one of these wetlands will disconnect it from the watercourse, which is a major source of its hydrology, and degrade/destroy the wetland. The fish and wildlife that depend upon these lost/degraded habitats for breeding, feeding, and sheltering will be adversely affected. Additionally, the retaining walls can result in the loss of shallow in-water habitats that fish depend upon. The retaining walls will also straighten watercourse segments, potentially resulting in increased velocities (U.S. Forest Service 2002). This may result in additional losses to the wetlands, riparian areas, and adjacent terrestrial ecosystems. Water quality issues will also be exacerbated by retaining walls due to the loss of wetlands and other areas that filter sediments and pollutants before they enter watercourses. Additionally, water temperatures will increase if adjacent shade vegetation is removed, thereby impacting the fish and other aquatic organisms that depend upon cooler water temperatures.

Large swaths of the watercourse/channel modifications are proposed within the protected open spaces mentioned in Section VII.A.1 above. This includes the South Mountain Reservation, Nomahegan Park, Lenape Park and other areas along the Rahway River Parkway. Permanent impacts to ecosystems within these areas will adversely impact the species that depend upon them for important feeding, breeding, and sheltering habitat. Additionally, these protected open spaces offer some of the most sensitive habitats within the Study Area for fish and wildlife since there are minimal locations for them to take refuge within an already urbanized area.

For the watercourse/channel modifications that have not been determined yet, multiple impacts to fish and wildlife may occur. Channel modification may permanently impact the watercourses and adjacent floodplain areas including the riparian areas and wetlands that are within them. Depending on what is proposed, this may adversely affect the fish and wildlife that utilize those areas. Fish species such as the American eel and others mentioned in the Existing Fish and Wildlife Resources section above may be present within the area. Channel modifications may reduce water quality or increase velocities and sedimentation inputs that will affect habitats. Additionally, modifications that create impediments to aquatic organism passage and restrict access to habitat will adversely affect the species traveling through the area. Removal of vegetation for possible erosion control measures such as riprap, may result in additional loss of fish and wildlife habitat. Vegetated streambank areas also serve to remove harmful nutrients and sedimentation before they enter watercourses and flows downstream. If applied, natural and nature-based channel modifications (*e.g.*, increasing natural sources of floodplain storage, restoring vegetated streambanks, etc.) are less likely to have adverse effects to fish and wildlife.

If measures such as dredging are used to increase water storage, this can cause increased turbidity downstream that may permanently affect the fish and wildlife that use the bottom as habitat. Of particular concern is the amphibians, reptiles, invertebrates, and fish that utilize those areas. If they are present within the watercourse at the time of dredging, they may be injured or killed by the proposed work. Additionally, birds that utilize those areas as foraging habitat will likely have to relocate to find other food sources during dredging. Fish and wildlife habitat located downstream may also be affected if the dredging results in increased watercourse velocities.

E. LEVEES, FLOODWALLS, AND MODIFICATIONS TO STRUCTURES SUCH AS BRIDGES

Levees and floodwalls are intended to restrict water to the stream channel and as such, they disconnect it from its floodplain. This can reduce nutrient and sediment transport to the floodplain, cut off wetlands from riverine inputs of water and nutrients, and reduce the recharge of aquifers. Levee and floodwall construction removes riparian vegetation, thereby eliminating fish and wildlife habitat and riverine shading. Levees tend to have a larger footprint than floodwalls and may, therefore, contribute to greater habitat loss than a vertical floodwall structure. Although levees may be more aesthetically pleasing than floodwalls, they provide little habitat value since vegetation is generally maintained as a mowed grass cover. The construction of levees and floodwalls may remove habitat, including vegetation within upland areas, riparian areas, tributaries, swales, and wetlands. Additionally, levees impact floodplain functions which may also cause adverse changes to the physical features of watercourses that fish rely upon (Knox et al. 2022).

While levees and floodwalls may provide protection to adjacent lands and structures, they may also contribute to flooding and erosion in areas upstream and downstream of their construction. The levees/floodwalls may force the Rahway River, or other watercourses where they are proposed, into a narrow channel during storms, which may raise water levels upstream. When compared to a natural/vegetated stream bank, water is subject to less friction as it flows through a leveed or floodwall section, which may cause gains in velocity and contribute to flooding and erosion downstream. The increase in water levels upstream and flooding/erosion downstream are likely to cause additional impacts to fish and wildlife habitat.

The floodwalls and levees are currently proposed as part of Alternative 3. It is undetermined at this time where they will be located. However, if they are proposed or require construction within fish and wildlife habitats such as upland vegetation, riparian areas, and wetlands they may cause adverse impacts. The construction of these structures may result in the permanent loss of these areas that could impact the feeding, breeding, and sheltering behaviors of fish and wildlife. For example, birds likely utilize the trees and vegetation within those areas for nesting. Mammals such as the northern long-eared bat and Indiana bat may be roosting in the trees for summer habitat. Pollinators, such as the monarch butterfly, may also be impacted if construction permanently removes nectar producing plants and host breeding plants that the species rely upon. If levees and floodwalls create increased flooding or erosion upstream and downstream of where they are proposed, species in those areas will likely also be impacted.

Modifications to bridges or other structures has the possibility of adversely impacting fish and wildlife. Bats and birds may utilize the structures for roosting or nesting during the spring and summer. Depending on the time of year and what type of construction is proposed, roosting bats, and nesting migratory birds may be impacted by the proposed work. If any in-water work is proposed, the construction may permanently destroy or modify that habitat and impact aquatic organisms. Additionally, any modifications that result in the fill of wetlands, riparian areas, upland vegetated terrestrial areas, or other habitats also has the potential to adversely impact fish and wildlife that depend upon them. Through the usage of time year restrictions, soil erosion and sediment controls, and other conservation measures, these impacts can be reduced. Additionally, structure modifications have the potential to benefit aquatic organisms if it removes current impediments to watercourse passage.

F. MODIFICATIONS TO THE LENAPE PARK DAM AND EMBANKMENTS/LEVEES

Alternative 6 proposes modifications to the Lenape Park Dam and its embankments/levees. Additionally, floodwalls will be added to the existing embankments/levees at the northern area of Lenape Park near Fadem Road in Springfield Township. As mentioned above, dams, levees, and floodwalls can have adverse impacts to fish and wildlife. As such, the existing dams and embankments/levees are likely already having adverse impacts to fish and wildlife within the area. If the modifications and floodwalls include new impacts to upland vegetated areas, wetlands, riparian areas, and watercourses, potentially new adverse impacts to fish and wildlife may occur. It is unclear if the current dam offers passage to fish and other aquatic organisms. If not, the construction may offer beneficial effects to those organisms if passage is included in the construction. From desktop review, it appears that the current embankment/levees proposed for modification are mostly unvegetated and have recreational paths or roads located on top. If the new construction includes planting/habitat creation plans along the levees/embankments that could benefit species such as pollinators, birds, and other wildlife, beneficial effects to them may occur. If the proposed work modifies the existing dam and embankments/levees without providing beneficial features for fish and wildlife, then it will likely continue to adversely impact them.

G. NON-STRUCTURAL MEASURES AND PROPERTY BUYOUTS FOR FLOOD STORAGE (INCLUDING WITHIN NATURAL AREAS)

Alternative 4 proposes non-structural measures such as floodproofing, elevation raising and relocation of properties, and acquiring properties for flood storage. The proposed floodproofing and elevation raising of properties is anticipated to have minimal impacts to fish and wildlife habitat since these are likely all in previously developed areas. The relocation and acquisition of properties for flood storage may be beneficial to fish and wildlife if it also results in the restoration/creation of natural areas. For example, if the Corps plans to provide vegetation that is habitat for pollinators or to restore wetlands, this work could benefit multiple species. However, if the relocation and acquisition of properties for flood storage are designed to simply store storm water, and not also provide habitat to fish and wildlife, the benefits will be minimal. Additionally, if species such as bats or birds are roosting or nesting within buildings or other structures at the time of construction, they may be adversely affected.

Alternative 3 proposes flood storage within undetermined natural areas. Depending on the scope, flood storage within existing natural areas may have adverse effects to fish and wildlife. Flood storage within natural areas may alter hydrology to habitats fish and wildlife rely upon that are not adapted for that amount of water. For example, if flood storage is proposed within upland forested areas, the plants there are likely not adapted to being flooded for extended periods of time and may die. Additionally, if the flooding creates temporary ponded areas for long enough periods of time, this may degrade/destroy other habitats such as wetlands and riparian areas that require drier periods of time as well. The fish and wildlife that depend upon these habitats for breeding, feeding, and sheltering will be impacted if those habitats are flooded for extended periods of the year or are degraded/destroyed.

H. CUMULATIVE IMPACTS

Future NEPA documentation should describe how additional loss of natural areas such as forests, wetlands, watercourses, and riparian areas will further exacerbate an already impacted Study Area. The NEPA documentation should reference that these areas, as well as their corresponding ecological functions and values (including flood protection), continue to be lost in New Jersey due to development and the on-going effects of climate change. The Corps' cumulative analysis of impacts and corresponding compensatory mitigation, if any, should also be consistent with Executive Order (EO) 11988 (Floodplain Management) and EO 11990 (Protection of Wetlands).

XI. SERVICE PLANNING AND MITIGATION RECOMMENDATIONS

The NEPA documentation and project details are still early in development from the Corps. As such, the following planning and mitigation recommendations for the associated Study alternatives is based on Service knowledge of the Study Area and other outside or internal information/reports.

A. PLANNING RECOMMENDATIONS

1. Further identification of fish and wildlife presence and habitat impacts

We recommend that the Corps obtain basic biological data in parts of the Study Area that lack this information to aid the development of appropriate conservation measures and mitigation plans for affected/disturbed fish and wildlife habitat. While the Existing Fish and Wildlife Resources description that the Service provided above explains species and habitats that may be present within the Study Area, the Corps should evaluate these resources in more detail. In particular, the Service recommends habitat evaluations to determine if suitable habitats for the priority at-risk, threatened, and endangered species identified in VII.H. above are definitively present. If habitat for those species is present and are unable to be avoided by the proposed project, we would recommend surveys to definitively determine if those species are present and the best ways to avoid adversely affecting them. Habitat evaluations and surveys should occur before construction begins to ensure that the project will not adversely affect species. Future discussions during ESA Section 7 consultation will be necessary to discuss federally listed species requirements. If species surveys will be conducted, additional coordination with the New Jersey Fish and Wildlife will be required for species that are State listed. Additionally, aquatic resource delineations should be incorporated into future NEPA and Study documentation to determine more accurately the extent of impacts to those habitats.

The Corps should plan to evaluate how potential watercourse elevation changes, increases to erosion, changes to watercourse velocities, changes to sediment transport, and other effects of the measures proposed will impact fish and wildlife habitat. In particular, the proposed work including existing or new embankments/levees, floodwalls, dams, detention areas, flood storage within natural areas, watercourse channel modifications, and bridge or structure modifications may create these impacts. Please be cognizant that areas such as wetlands, riparian areas, upland vegetated areas, and watercourses may be lost or degraded due to these changes. Additionally, all project related impacts to riparian areas, wetlands, watercourses, forested and other vegetated areas should be clearly identified and explained in future NEPA and Study documentation. The fish and wildlife that currently inhabit or may utilize those areas should be explained so that it is clear what effects will occur.

2. Natural and Nature-Based Features

The Service discourages the selection of hard engineered solutions such as floodwalls, levees, dams, road relocations, and retaining walls within watercourses unless they are accompanied by significant ecological gains for the Study Area. The Service strongly recommends that the Corps expend considerable effort on nonstructural measures and natural and nature-based features that provide an ecological benefit and promote long-term sustainability of fish and wildlife populations and their habitats. Potential losses and modifications to natural areas such as wetlands, riparian areas, forests and other vegetation, and watercourses associated with some of the alternatives would be of considerable concern and should be avoided to the maximum extent practicable. Overall, the Corps should strive to ensure avoidance of adverse effects to the environment and to meet NEPA's goal of protecting and enhancing the quality of the human environment. Additionally, as much as possible, the Corps should minimize possible impacts to aquatic resources to avoid conflicts with existing EOs 11988 and 11990 relating to the protection of floodplains and wetlands.

The Service recommends that the Corps work closely with potentially affected stakeholders and pursue alternatives that improve fish and wildlife habitats described in the Existing Fish and Wildlife Resources section above. Improvements to and creation of fish and wildlife resources can lead to additional flood storage and storm attenuation in the Study Area. Watershed restoration methods can also reduce flood flows and be environmentally restorative. It is understood that these measures alone may not resolve issues related to flooding of human infrastructure, but we recommend that they be fully evaluated. The Service recommends that the Corps considers the following features during project planning:

- Re-forestation or re-vegetation of previously disturbed areas and planting of trees in urban areas;
- Transition to permeable paving of existing impervious areas;
- Usage of rain gardens, bioswales, and green roofs;
- Where possible/effective retain, enhance, or restore riparian areas, wetlands, watercourses, forests, and other vegetated areas;
- Restore natural stream channel morphology and reconnect stream to floodplains;
- Create woody material and engineered log jams for hydraulic resistance;
- Enhance roadside ditch designs and maintenance;

- Incorporate plantings that are favorable to pollinators and other wildlife.

3. Retreats and Buyouts

The Service recommends that the Corps further analyzes the usage of a State or Federal retreat and buyout program. This could consist of an expansion to the Corps' non-structural Alternative 4 that is currently being considered. Non-water dependent alternatives that may be economically viable and meet the purpose of the Study could include a retreat program for businesses and residences that suffer repeatable flood losses. Properties eligible for a retreat program could be purchased, relocated outside the floodplain, or be raised above a certain storm height elevation. Non-structural alternatives (*e.g.*, flood-proofing or financial buyouts) undertaken by NJDEP's Green and Blue Acres Acquisition Programs demonstrate the efficacy of these alternatives and, therefore, should rank high in the Corps' future Tentatively Selected Plan process.

Not only would adverse impacts from hard infrastructure such as the dam and floodwalls be avoided under a strategic retreat plan, but some of the areas currently at-risk to flooding and storms could be returned to their previous natural state (such as restoring to wetlands), providing added economic and ecological benefits. Once properties are purchased and the corresponding houses or infrastructure removed, the lands can be returned to natural conditions, which may also provide further resilience within the area to future storms. Another added benefit of a buyout and retreat/relocation alternative is the potential for the restored property to become valuable habitat for Service priority at-risk, threatened, and endangered species. For properties that are vacated, the Service prefers the use of upland areas for the construction of berms or levees over any additional losses to the aquatic and riparian environment.

The implementation of a retreat program should be carefully coordinated with representatives of the U.S. Department of Housing and Urban Development, the Federal Emergency Management Agency, and respective state and local agencies, as each of these agencies manage programs to acquire or relocate flood prone properties and businesses.

B. MITIGATION RECOMMENDATIONS

The preliminary recommendations provided herein for the protection of fish and wildlife resources are in accordance with the Service's Mitigation Policy (USFWS 2023c). Given that the Study is still early in planning, these are likely to change or be modified within future FWCA documentation. The Mitigation Policy provides Service personnel with guidance in making recommendations to protect or conserve fish and wildlife resources. The policy helps ensure consistent and effective Service recommendations, while allowing agencies and developers to anticipate Service recommendations and plan early for mitigation needs. The intent of the policy is to conserve, protect, and enhance fish, wildlife, plants, and their habitats, and uses thereof, for future generations.

The Service applies a general policy and set of principles when utilizing the mitigation policy for reviewing projects. The Service has a responsibility to ensure that impacts to fish, wildlife, plants, and their habitats are considered when actions are planned, and that those impacts are mitigated so that these resources may provide a continuing benefit to the American people. The principles below guide Service recommended or required mitigation. Please refer to the Service's mitigation policy for more information.

- Utilizing a mitigation hierarchy by first considering avoidance, then minimization, and then compensatory mitigation.
- Seeking avoidance of all high-value habitats.
- To achieve no net loss by ensuring that the status of the affected resources is undiminished relative to pre-impact conditions. Mitigation that meets the no net loss goal should fully offset the impacts of the action to the affected resources, including consideration for temporal losses, risk, and uncertainty. This includes a focus on important, scarce, or sensitive resources, as informed by established conservation objectives and strategies.
- When possible, utilizing a landscape approach to inform mitigation.
- Ensure consistent and transparent mitigation.
- Utilizing science-based mitigation.
- Recommending or requiring that mitigation measures are durable.
- Recommending effective compensatory mitigation.
- Ensuring that all appropriate mitigation measures have a clear connection (*i.e.*, nexus) with the anticipated effects of the action and be commensurate (*i.e.*, proportional) with the scale and nature of those effects.
- Applying equivalent standards to all compensatory mitigation mechanisms to ensure consistent implementation and effectiveness.

1. Avian Species

a. The proposed project includes installations that will likely introduce new lighting into areas where birds may be present. As such, the Service recommends that the Corps uses (as applicable) lighting that reduces adverse effects to migratory birds at night. For more information, please refer to Appendix C – Beneficial Practices to Reduce the Potential Impact of Lighting on Migratory Birds.

b. Numerous birds breed within the Study Area and many of these species have experienced population declines in recent decades. The most sensitive times of year for avian species within the Study Area are when they are establishing breeding territories, mating, building nests, laying eggs, hatching chicks, and rearing fledglings to independence. The Service recommends identifying project areas that have the potential to contain nests, eggs, and flightless migratory birds. If those areas are planned to be removed or altered, we recommend incorporating time of year restrictions to avoid direct mortality or other effects to species resulting from construction activities. Generally, this sensitive time of year is from March 15 to September 15. However, for certain species such as the barred owl, this may start as early as March 1 (NJDEP 2011). If the time of year restriction cannot be implemented, we recommend conducting field surveys no more than 5 days before project activities begin to locate any nests with eggs and/or highly vulnerable chicks with limited mobility. This recommendation will also ensure that the Corps is complying with the MBTA which prohibits (without prior authorization by the Service) the wounding, killing, trapping, capturing, or collecting of migratory birds and their nests or eggs. Additionally, regardless of time of year, if native migratory birds are present at the time of the proposed work, the Service recommends providing an opportunity for those birds to leave the area before work occurs. Please be cognizant that birds and their nests may be on/within human made structures (*e.g.*, buildings and bridges) as well.

c. For the conservation of cerulean warbler and wood thrush habitat, as possible, retain tree and vegetation species of high value to birds such as white oak, red oak (*Quercus rubra*), chestnut oak (*Quercus prinus*), hickories (*Carya spp.*), sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), American hophornbeam (*Ostrya virginiana*), spicebush (*Lindera benzoin*), dogwood (*Cornus spp.*), and other native fruit-bearing plants (Wood et al. 2013; Lambert et al. 2017).

d. The Rahway River (up to Nomahegan Park), Robinsons Branch, and the area around Clark Reservoir likely serve as foraging habitat for bald eagles (NJDEP 2023a). The Service does not currently have data documenting nesting within 660 feet of the proposed impact areas. However, if bald eagles are observed nesting within 660 feet of the proposed impact areas, the Service recommends using the Northeast Bald Eagle Project Screening Form to determine if avoidance measures should be utilized or if further review by the Service is required. The form is available at: *https://www.fws.gov/sites/default/files/documents/northeast-bald-eagle-project-screening-form-2021-12-01.pdf.* Please review the Service's Eagle Management Program website (at: *https://www.fws.gov/program/eagle-management)* for additional information and appropriate contacts for questions or concerns. Bald eagles are protected by the BGEPA and impacts from the proposed project may require the Corps to apply for a permit from the Service.

   Please ensure that any required consultation with the NJDEP Endangered and Nongame Species Program is also included to ensure compliance with the New Jersey Endangered Species Conservation Act of 1973. Information about bald eagles in New Jersey can be found at: *https://dep.nj.gov/wp-content/uploads/njfw/baldeagle.pdf.*

2. Wood Turtle and Spotted Turtle

If suitable habitat or presence of these species are confirmed within the project area:

a. Wood Turtles: Please refer to "A Guide to Habitat Management for Wood Turtles" document at *https://www.northeastturtles.org/wood-turtle.html.* The document provides a description of wood turtles and their habitat, as well as management guidelines/conservation measures if habitat is present. The Service recommends reviewing this document and any other applicable information to determine if suitable habitat is present and, if necessary, to develop conservation measures.

b. Spotted Turtles: Please refer to the "Status Assessment and Conservation Plan for the Spotted Turtle in the Eastern United States" document at: *https://www.northeastturtles.org/spotted-turtle.html*. The document provides a description of spotted turtle and their habitat. The Service recommends reviewing this this document and any other applicable information to determine if suitable habitat is present and, if necessary, to develop conservation measures.

3. Bats

a. Whenever possible, avoid cutting or other means of knocking down, bringing down, or trimming of trees that are greater than or equal to 3 inches diameter at breast height from April 1 to September 30.

b. Avoid removal or modifications to bridges and culverts larger than 5 feet wide, buildings that bats may be roosting within, and other structures that could potentially harm roosting bats from April 1 to September 30. Alternatively, the Corps may conduct emergence surveys or visibly inspect these structures for bats before construction begins.

c. To avoid potential impacts from lights, ensure that any new permanent lighting that is proposed within or adjacent to forested bat habitat utilizes only downward-facing, full cut-off lens lights. Additionally, during construction, avoid temporary lighting being directed at surrounding forested/roosting habitats.

4. Monarch Butterfly

a. Identify suitable monarch butterfly habitat (as described in the Existing Fish and Wildlife Resources section above) that may be affected by the proposed project. If avoiding impacts to suitable habitat is not possible, avoid impacts during times of year monarch's may be present from May 1 to September 30. Review the "Mowing and Management: Best Practices for Monarch's" handout at: *https://monarchjointventure.org/blog/revised-handout-mowing-and-management-best-practices-for-monarchs* to see if any other conservation measures are applicable to this project/can be implemented.

b. Reviewing the conservation measures and descriptions included in Section VII of the "Monarch CCAA Application" that can be found at: *https://rightofway.erc.uic.edu/working-group-access/monarchccaatoolkit.* Although the Candidate Conservation Agreement for monarch butterfly is not applicable for this project, we recommend reviewing the application to help aid in the development of possible conservation measures.

c. Reviewing the Services website at: *https://www.fws.gov/initiative/pollinators/monarchs* and the NJDEP's (2017) Monarch Butterfly Conservation Guide for possible conservation measures to implement.

5. Fish

a. If modifications to existing or new dams, culverts, road-stream crossings, or other possible impediments to fish passage are selected for construction, please ensure that they are designed for aquatic organism passage. Ensure to the maximum extent practicable that passage of these species is conserved and not further degraded within the Study Area. This should include the usage of nature-like fishways which are artificial instream structures that (longitudinally) span stream barriers. Nature-like fishways are constructed of boulders, cobble, and other natural materials to create diverse physical structures and hydraulic conditions that dissipate energy and provide efficient passage to multiple species, including migratory and resident fish assemblages. For the new dam that the Corps included in the Study alternatives, this may include the construction of a rock ramp leading to the dam. Rock ramps are a sloped watercourse that link two pools of different elevations (*e.g.*, headwater and tailwater of dam) that is constructed in the existing channel and spans the width of the watercourse. This will likely help to alleviate adverse effects caused by the impediments to fish passage that the new dam will create. New culverts or other impediments to aquatic organism passage can also be designed for hydraulic passage or to provide a continuous streambed that approximates the natural streambed up to the bank full flows (USFWS 2019).

Please ensure that nature-like fishway passages or other methods are designed for target species specific to the area. For example, if a rock ramp is too steep of a slope or not designed for the target fish species within that area, they may not be able to use it or will not be able to use it as effectively. Designs may have to include pools, large boulders, or other features that provide adequate resting areas (USFWS 2019). Additionally, when possible, water control structures and alignments should be designed to avoid the need for aquatic organisms to pass through multiple structures (*i.e.*, structures behind structures) to access an area.

The Service recommends that the Corps refers to and utilizes the Service's 2019 Northeast Region Fish Passage Engineering Design Criteria (located within Appendix D) while designing this project. The Service's design criteria provides in-depth information, options, and typical details that will be helpful for conserving fish passage within the area. The criteria also refer to the Federal Interagency Nature-like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes (Turek et al. 2016) which provides other helpful information.

Please ensure that fish passage designs are coordinated with the Service, NJDEP, NOAA-NMFS (as applicable), and any other applicable conservation organizations.

b. Avoid in-water work during sensitive times of year to protect fish species. Enforcing riparian area buffers will also help to ensure their conservation. Please coordinate with the NJDEP to develop these time of year restrictions and buffer areas per applicable permitting conditions. Additionally, please ensure that EFH and any other necessary coordination with NOAA-NMFS occurs to ensure that time of year restrictions and other conservation measures are implemented.

6. Multiple Or All Species

a. Where possible/as necessary, construct buffers to prevent noise and disturbance in areas where at-risk, threatened, and endangered species are or may be present. Additionally, utilize plans that include measures for temporarily stopping construction when it is likely to disturb areas that contain habitats and occur during sensitive times of year for those species, such as during breeding seasons. For example, the potential relocation of Brookside Drive as part of Alternative 2 will require construction within portions of the South Mountain Reservation, which is bat habitat. If nighttime noises are generated, this may disturb those species. As such, reducing those noises to the extent practicable is recommended.

b. To ensure the protection of resources such as wetlands and watercourses from erosion and sedimentation generated during construction, ensure that erosion and sediment control measures are utilized (and plans developed) as necessary.

c. If necessary, the Corps should provide scour protection to ensure that fish and wildlife habitat is not further diminished within watercourses downstream, upstream or within the proposed construction areas. As applicable, the Service recommends the utilization of nature-based solutions such as revegetating stream banks.

d. Develop compensatory mitigation plans for fish and wildlife habitat that will be permanently impacted or lost due to the proposed project. An emphasis should be placed for migratory birds, Service priority at-risk, and ESA listed, proposed or candidate species. For example, this may include restoring forested or aquatic ecosystems to enhance habitat for migratory birds, turtles, pollinators, and fish species. At a minimum, the Service would request a 1:1 ratio for replacement of habitats that are not already protected by other laws/regulations (*e.g.*, wetlands/waters protected by the Clean Water Act and NJDEP's Freshwater Wetlands Protection Act and Flood Hazard Area Control Act). We recommend these habitat losses are replaced to provide equal or better functions to wildlife than they are currently serving. Potential mitigation options could include the expansion of property for, or restoration of the protected open spaces mentioned in Section VII.A.1 with the goal of ensuring that there has been no net loss of the ecologically significant habitats there.

e. Develop a long-term monitoring and management plan to evaluate fish and wildlife impacts related to the proposed project. Conduct a before-and-after analysis approach to understand the impacts that structures and proposed measures (such as a new dam, watercourse/channel deepening, flood storage in natural areas) will have to the environment/natural processes and to the fish and wildlife that depend upon them. Any unanticipated impacts to fish and wildlife resources that occur after construction is completed, and that are a result of the structures, should be mitigated. For example, if unanticipated impacts to wetlands, riparian areas, watercourses, forests, and other vegetation occur due to the proposed work, and adversely impact the fish and wildlife that depend upon them, the Corps should determine the extent of those impacts and provide appropriate mitigatory measures in coordination with the Service and NJDEP.

f. For Native and Invasive Plants:

   1) As possible, avoid impacts to any native trees, shrubs, and aquatic resource vegetation. The areas of temporary and permanent impacts to forested and vegetated areas should be identified and the impacts to the species within those areas should be described. A replanting plan should be developed to provide reforestation or afforestation to mitigate these impacts. Among other benefits, forested and vegetated areas provide habitat and refuge for a multitude of species that are considered Federal

trust resources by the Service. This includes habitat for birds, bats, and other species such as pollinators whose populations have been declining and impacting ecosystems.

2) Minimize impacts by reseeding all disturbed areas at the completion of construction with native forbs and grasses. Minimize the impact of removal and/or trimming of any trees and shrubs by having these activities supervised and/or completed by a certified arborist.

3) Remove invasive species to create healthy stream buffers that increase absorption rates and reduce effects of flood waters. Additionally, include a plan to prevent the colonization or recolonization of invasive species over the life of the project. Measures should address the proper revegetation of disturbed habitat and the cleaning and inspection of construction equipment and machinery to aid in invasive species control. The next phase of feasibility planning should incorporate this effort and identify areas for invasive species management, monitoring, and maintenance.

g. If the Corps plans to restore and/or create fish and wildlife habitat:

1) Provide investigations to ensure that there are no environmental contaminants present. The restorations will likely attract fish and wildlife to those areas. If environmental contaminants are identified, they should be removed before restoration/creation efforts begin to minimize exposure and harm of fish and wildlife.

2) As applicable, provide educational and recreational resources to engage the public about project conservation efforts. Public outreach opportunities are important for educating recreational users about conservation efforts of species of concern to the Service.

h. If proposed to be completed, environmental contaminants testing results should be forwarded to the Service for review. If sediments exhibit contaminant concentrations above New Jersey ecological screening criteria (NJDEP 2009b), provide measures to ensure that it is properly removed from the environment. Additionally, ensure that contaminated materials are not remobilized during construction through usage of erosion and sediment controls and appropriate construction techniques/equipment to protect fish and wildlife.

i. Implement the following to ensure that the relocation or modification to Brookside Drive proposed in Alternative 2 avoids and minimizes adverse effects to fish and wildlife:

1) The Corps should consider the usage of wildlife crossings to avoid the incidental killing and harm that will likely occur when species attempt to cross the new road to access habitats on either side. The NJDEP's Fish and Wildlife Connecting Habitat Across New Jersey program provides valuable guidance information regarding roadway passage systems that the Corps should review. This includes example schematics and recommendations for specific species. This information can be found at: *https://dep.nj.gov/njfw/conservation/tools-of-chanj/.*

2) Further review and avoidance of lighting that may be harmful for species. Examples of this includes what is recommended for bats and avian species above.

3) Provide funding for the removal of and to ensure that pollution from vehicles is not diminishing adjacent roadside habitats.

j. Ensure compliance for all mitigation requirements as required by the Clean Water Act, New Jersey State laws, and other environmental laws. This satiates requirements for impacts to aquatic (*i.e.,* wetlands, watercourses) and other (*e.g.,* forests, riparian areas) environmental resources. Aquatic resource mitigation should be developed consistent with the Clean Water Act Section 404(b)(1) Guidelines. Additionally, the Service recommends that any mitigation plans developed incorporates nature-based strategies that could mitigate for the loss of habitat or potentially aid in habitat restoration, especially to migratory birds, Service priority at-risk species, and ESA listed, proposed, and candidate species. Once developed, the Service requests an opportunity to review the mitigation plans and provide any recommendations or comments.

7. Enhancement Opportunities

There are numerous fish and wildlife resource opportunities that the Corps could undertake to enhance natural resource conservation within the Study Area. We recommend that the Corps evaluate alternatives that conserve and protect natural areas while also maintaining and improving their biological diversity. We also recommend that the Corps establish long term protective measures that protect fish and wildlife resources such as establishing conservation easements and incorporating education and outreach activities to inform the public about the potentially impacted ecosystems.

a. As habitats in the Study Area have been lost and modified due to human development, we recommend that the Corps coordinate with the Service to identify and evaluate areas that could enhance habitat and address localized impacts of flooding. Overall, we recommend that the Corps create fish and wildlife habitat as mitigation where appropriate throughout the Study Area and incorporate adequate monitoring and maintenance of these fish and wildlife habitats to ensure they remain of high quality. Suggested focus areas could include restoring wetlands, riparian areas, watercourses, and forested or vegetated portions of the Study Area. Enhancement of these areas may also improve water quality within the watercourses in the Study Area and ensure that further fish and wildlife habitat is not diminished.

b. For activities that result in the alteration to the Rahway River or other watercourses in the Study Area, provide enhancements that benefit aquatic organism habitat. This may include designing meandering channels; incorporating pool/riffle/run flow sequences that provide multiple habitats and encourage colonization by diverse populations of aquatic organisms; and extracting any gravel/cobble components from excavated river channel materials and replacing them into the channel after removing finer sediments. Additionally, stabilizing existing streambanks from existing erosion and sediment issues;

reconnecting them to historic or existing floodplains that improve ecological function; and reestablishing native riparian and wetland plant communities can also be beneficial.

c. For the existing and proposed levees/embankments and detention areas, implement habitat creation plans into their designs that benefit and enhance habitat for species such as pollinators, birds, and other wildlife. This may include the usage of a planting plan. For example, there are multiple herbaceous species that may be utilized to create pollinator habitats. You can refer to a list of potential pollinator plant species to plant at the following Rutgers Gardens website: *https://rutgersgardens.rutgers.edu/gardens/pollinator-garden/#:~:text=Bee%20Balm%20(Monarda%20species).*

d. Whenever practicable, remove or modify existing impediments to aquatic organism passage along watercourses within the Study Area. This may include measures such as replacing existing culverts with better designed structures suitable for passage (or restoring to natural conditions), removing existing dams, improving passage at existing road-stream crossings, and providing programs or funding for improving passage. Please refer to the information about designing for aquatic organism passage within the fish section above for additional information. The Southeast Aquatic Resources Partnership, with support by the Service, created the National Aquatic Barrier Inventory and Prioritization Tool (Southeast Aquatic Resources Partnership Accessed 2024). While the tool is still being developed for usage within New Jersey, it provides access to download GIS data of dams and road-related barriers that can be helpful for identifying where to focus these efforts.

   If construction to the Lenape Park Dam is chosen to be incorporated into the tentatively selected plan and it has existing aquatic organism passage features installed, evaluate its adequacy. If it is providing inadequate passage for species, provide updates to or replace it so that it is better designed and will be more effective in the future.

8. Threatened and Endangered Species Recommendations

Section 7(a)(2) of the ESA, requires all Federal agencies, in consultation with the Secretary of the Interior, to ensure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any listed species. In consultation with the Service, the Corps must utilize its authority to further the purposes of the ESA in the conservation and recovery of listed species and the ecosystems on which they depend. The Service will require adequate project information to officially review and provide our concerns/concurrence related to the ESA Section 7 consultation. A step-by-step process of what to include with project review requests for consultation with the New Jersey Field Office can be found at: *https://www.fws.gov/office/new-jersey-ecological-services/new-jersey-field-office-project-review-guide.* Additionally, please review the ESA interagency regulations at 50 Code of Federal Regulations Part 402 for more information on required information and analyses. The Service also provided ESA technical assistance on September 28, 2023 to help guide the Corps as they further develop the Study.

Please be aware that Section 7(a)(1) of the ESA also directs Federal agencies to utilize their authorities to further the purposes of the Act by carrying out conservation programs for the benefit of endangered and threatened species. We recommend that the Corps coordinate with the Service on conservation measures to advance threatened and endangered species recovery efforts, minimize or avoid adverse effects of a proposed action on listed species, and develop biological information. Whenever possible, the Corps should adopt a strategy of incorporating the habitat needs of ESA listed species in the design of any Study alternative considered.

Along with the ESA listed species described in the Existing Fish and Wildlife Resources section above, there are multiple other species that are either proposed, candidates, or are under review for listing. These include the proposed tricolored bat, candidate for listing monarch butterfly, and species under review little brown bat, wood turtle, and spotted turtle. Species proposed for listing, are afforded limited protections under the ESA and the "conference" provisions of Section 7 apply to them. While consultation under Section 7 of the ESA is required when a proposed action "may affect" a listed species, a conference is only required if the proposed action is likely to jeopardize the continued existence of a proposed species. Candidate species and species under review for listing receive no substantive or procedural protection under the ESA until formal listing. Decisions for listing of these species are anticipated to occur during fiscal year 2024. If species are proposed for or listed per the ESA before construction begins, potential delays/additional consultations may occur. As such, the Service recommends including them in any future effects analyses to help avoid or minimize project delays if they are listed before or during project construction.

The Service will continue to coordinate with the Corps during their Section 7 ESA consultation process for this project. Future recommendations for endangered and threatened species under the jurisdiction of the Service will be described during that time.

XII. SERVICE CONCLUSIONS

Section 2(b) of the FWCA requires that the final report of the Secretary of the Interior: 1) determine the magnitude of the impacts of the proposed project on fish and wildlife resources; and 2) make specific recommendations as to measures that should be taken to conserve those resources. The Service has reviewed and provided the fish and wildlife resources that may exist within the Study Area. The Corps is still early in the planning of their Study alternatives and determination of associated impacts to fish and wildlife. Once plans are further developed, we will likely have additional comments and input into the potential impacts and benefits that the proposed project will have on fish and wildlife resources, additional opportunities to advance fish and wildlife conservation, and mitigation recommendations. The Service has made some planning recommendations at this time to help guide the Corps in identifying fish and wildlife enhancement opportunities and approaches to mitigation. The Service plans to continue the review of the Corps' Study, future NEPA documentation, and other alternatives as the planning process advances.

We anticipate preparing a FWCA 2(b) Report once Study plans and impacts are further developed. The Service is not likely to support structural measures in a future FWCA 2(b) report without ample evidence and data from the Corps explaining that there are no other alternatives available that are less harmful to fish and wildlife resources. Additionally, we will be reviewing future documentation to ensure that the Service planning and mitigation recommendations described above were considered and, as possible, incorporated into the project. Disregard of these recommendations will likely result in the Service not supporting this project in future FWCA 2(b) reports. The future FWCA 2(b) Report will constitute the report of the Secretary of the Interior as required by Section 2(b) of the FWCA, which establishes fish and wildlife conservation as a co-equal purpose or objective of federally funded or permitted water resource development projects.

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Appendix A

Species and Habitat Lists

Includes:

- U.S. Fish and Wildlife Service August 17, 2023 Official Species List
- National Oceanic and Atmospheric Administration – National Marine Fisheries Service December 22, 2023 Essential Fish Habitat Mapper Report

United States Department of the Interior

FISH AND WILDLIFE SERVICE
New Jersey Ecological Services Field Office
4 E. Jimmie Leeds Road, Suite 4
Galloway, NJ 08205
Phone: (609) 646-9310

In Reply Refer To: August 17, 2023
Project Code: 2023-0118408
Project Name: Rahway River Basin Flood Risk Management Feasibility Study

Subject: List of threatened and endangered species that may occur in your proposed project location or may be affected by your proposed project

To Whom It May Concern:

The enclosed species list identifies threatened, endangered, proposed and candidate species, as well as proposed and final designated critical habitat, that may occur within the boundary of your proposed project and/or may be affected by your proposed project. The species list fulfills the requirements of the U.S. Fish and Wildlife Service (Service) under section 7(c) of the Endangered Species Act (Act) of 1973, as amended (16 U.S.C. 1531 *et seq.*).

If the enclosed list indicates that any listed species may be present in your action area, please visit the New Jersey Field Office consultation web page as the next step in evaluating potential project impacts: http://www.fws.gov/northeast/njfieldoffice/Endangered/consultation.html

On the New Jersey Field Office consultation web page you will find:

- habitat descriptions, survey protocols, and recommended best management practices for listed species;
- recommended procedures for submitting information to this office; and
- links to other Federal and State agencies, the Section 7 Consultation Handbook, the Service's wind energy guidelines, communication tower recommendations, the National Bald Eagle Management Guidelines, and other resources and recommendations for protecting wildlife resources.

The enclosed list may change as new information about listed species becomes available. As per Federal regulations at 50 CFR 402.12(e), the enclosed list is only valid for 90 days. Please return to the IPaC website at regular intervals during project planning and implementation to obtain an updated species list. When using IPaC, be careful about drawing the boundary of your Project Location. Remember that your action area under the ESA is not limited to just the footprint of the project. The action area also includes all areas that may be indirectly affected through impacts such as noise, visual disturbance, erosion, sedimentation, hydrologic change, chemical exposure, reduced availability or access to food resources, barriers to movement, increased human intrusions or access, and all areas affected by reasonably foreseeable future that would not occur without ("but for") the project that is currently being proposed.

Additionally, please note that on March 23, 2022, the Service published a proposal to reclassify the northern long-eared bat (NLEB) as endangered under the Endangered Species Act. The U.S. District Court for the District of Columbia has ordered the Service to complete a new final listing determination for the NLEB by November 2022 (Case 1:15-cv-00477, March 1, 2021). The bat, currently listed as threatened, faces extinction due to the range-wide impacts of white-nose syndrome (WNS), a deadly fungal disease affecting cave-dwelling bats across the continent. The proposed reclassification, if finalized, would remove the current 4(d) rule for the NLEB, as these rules may be applied only to threatened species. Depending on the type of effects a project has on NLEB, the change in the species' status may trigger the need to re-initiate consultation for any actions that are not completed and for which the Federal action agency retains discretion once the new listing determination becomes effective (anticipated to occur by December 30, 2022). If your project may result in incidental take of NLEB after the new listing goes into effect this will first need to addressed in an updated consultation that includes an Incidental Take Statement. If your project may require re-initiation of consultation, please contact our office for additional guidance.

We appreciate your concern for threatened and endangered species. The Service encourages Federal and non-Federal project proponents to consider listed, proposed, and candidate species early in the planning process. Feel free to contact this office if you would like more information or assistance evaluating potential project impacts to federally listed species or other wildlife resources. Please include the Consultation Tracking Number in the header of this letter with any correspondence about your project.

Attachment(s):

- Official Species List
- USFWS National Wildlife Refuges and Fish Hatcheries
- Migratory Birds
- Wetlands

OFFICIAL SPECIES LIST

This list is provided pursuant to Section 7 of the Endangered Species Act, and fulfills the requirement for Federal agencies to "request of the Secretary of the Interior information whether any species which is listed or proposed to be listed may be present in the area of a proposed action".

This species list is provided by:

New Jersey Ecological Services Field Office
4 E. Jimmie Leeds Road, Suite 4
Galloway, NJ 08205
(609) 646-9310

PROJECT SUMMARY

Project Code: 2023-0118408
Project Name: Rahway River Basin Flood Risk Management Feasibility Study
Project Type: Flooding
Project Description: Feasibility study to evaluate measures to manage fluvial flood risk associated with the Rahway River and its tributaries. Municipalities in study area boundary include Maplewood, Millburn, Cranford and Rahway. The Tentatively Selected Plan is anticipated to be identified in April 2024.
Project Location:

The approximate location of the project can be viewed in Google Maps: https://www.google.com/maps/@40.68948855,-74.29726604864038,14z

Counties: Essex , Middlesex , and Union counties, New Jersey

ENDANGERED SPECIES ACT SPECIES

There is a total of 5 threatened, endangered, or candidate species on this species list.

Species on this list should be considered in an effects analysis for your project and could include species that exist in another geographic area. For example, certain fish may appear on the species list because a project could affect downstream species. Note that 1 of these species should be considered only under certain conditions.

IPaC does not display listed species or critical habitats under the sole jurisdiction of NOAA Fisheries[1], as USFWS does not have the authority to speak on behalf of NOAA and the Department of Commerce.

See the "Critical habitats" section below for those critical habitats that lie wholly or partially within your project area under this office's jurisdiction. Please contact the designated FWS office if you have questions.

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1. NOAA Fisheries, also known as the National Marine Fisheries Service (NMFS), is an office of the National Oceanic and Atmospheric Administration within the Department of Commerce.

MAMMALS

NAME	STATUS
Indiana Bat *Myotis sodalis* There is **final** critical habitat for this species. Your location does not overlap the critical habitat. Species profile: https://ecos.fws.gov/ecp/species/5949	Endangered
Northern Long-eared Bat *Myotis septentrionalis* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/9045	Endangered
Tricolored Bat *Perimyotis subflavus* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/10515	Proposed Endangered

REPTILES

NAME	STATUS
Bog Turtle *Glyptemys muhlenbergii* Population: Wherever found, except GA, NC, SC, TN, VA No critical habitat has been designated for this species. This species only needs to be considered under the following conditions: ▪ Activity is in a supporting watershed for known/suspected bog turtle habitat. Consultation recommended only for activities involving significant changes to surface/ground water, including stormwater. See details on FWS NJFO website. Species profile: https://ecos.fws.gov/ecp/species/6962	Threatened

INSECTS

NAME	STATUS
Monarch Butterfly *Danaus plexippus* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/9743	Candidate

CRITICAL HABITATS

THERE ARE NO CRITICAL HABITATS WITHIN YOUR PROJECT AREA UNDER THIS OFFICE'S JURISDICTION.

YOU ARE STILL REQUIRED TO DETERMINE IF YOUR PROJECT(S) MAY HAVE EFFECTS ON ALL ABOVE LISTED SPECIES.

USFWS NATIONAL WILDLIFE REFUGE LANDS AND FISH HATCHERIES

Any activity proposed on lands managed by the National Wildlife Refuge system must undergo a 'Compatibility Determination' conducted by the Refuge. Please contact the individual Refuges to discuss any questions or concerns.

THERE ARE NO REFUGE LANDS OR FISH HATCHERIES WITHIN YOUR PROJECT AREA.

MIGRATORY BIRDS

Certain birds are protected under the Migratory Bird Treaty Act[1] and the Bald and Golden Eagle Protection Act[2].

Any person or organization who plans or conducts activities that may result in impacts to migratory birds, eagles, and their habitats should follow appropriate regulations and consider implementing appropriate conservation measures, as described below.

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1. The Migratory Birds Treaty Act of 1918.
2. The Bald and Golden Eagle Protection Act of 1940.
3. 50 C.F.R. Sec. 10.12 and 16 U.S.C. Sec. 668(a)

The birds listed below are birds of particular concern either because they occur on the USFWS Birds of Conservation Concern (BCC) list or warrant special attention in your project location. To learn more about the levels of concern for birds on your list and how this list is generated, see the FAQ below. This is not a list of every bird you may find in this location, nor a guarantee that every bird on this list will be found in your project area. To see exact locations of where birders and the general public have sighted birds in and around your project area, visit the E-bird data mapping tool (Tip: enter your location, desired date range and a species on your list). For projects that occur off the Atlantic Coast, additional maps and models detailing the relative occurrence and abundance of bird species on your list are available. Links to additional information about Atlantic Coast birds, and other important information about your migratory bird list, including how to properly interpret and use your migratory bird report, can be found below.

For guidance on when to schedule activities or implement avoidance and minimization measures to reduce impacts to migratory birds on your list, click on the PROBABILITY OF PRESENCE SUMMARY at the top of your list to see when these birds are most likely to be present and breeding in your project area.

NAME	BREEDING SEASON
Bald Eagle *Haliaeetus leucocephalus* This is not a Bird of Conservation Concern (BCC) in this area, but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities.	Breeds Sep 1 to Jul 31
Black-billed Cuckoo *Coccyzus erythropthalmus* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/9399	Breeds May 15 to Oct 10
Cerulean Warbler *Dendroica cerulea* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/2974	Breeds Apr 28 to Jul 20
Chimney Swift *Chaetura pelagica* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.	Breeds Mar 15 to Aug 25
Eastern Whip-poor-will *Antrostomus vociferus* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.	Breeds May 1 to Aug 20
Golden Eagle *Aquila chrysaetos* This is not a Bird of Conservation Concern (BCC) in this area, but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities. https://ecos.fws.gov/ecp/species/1680	Breeds elsewhere
Kentucky Warbler *Oporornis formosus* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.	Breeds Apr 20 to Aug 20
Prairie Warbler *Dendroica discolor* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.	Breeds May 1 to Jul 31
Prothonotary Warbler *Protonotaria citrea* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.	Breeds Apr 1 to Jul 31

NAME	BREEDING SEASON
Red-headed Woodpecker *Melanerpes erythrocephalus* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.	Breeds May 10 to Sep 10
Rusty Blackbird *Euphagus carolinus* This is a Bird of Conservation Concern (BCC) only in particular Bird Conservation Regions (BCRs) in the continental USA	Breeds elsewhere
Wood Thrush *Hylocichla mustelina* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska.	Breeds May 10 to Aug 31

PROBABILITY OF PRESENCE SUMMARY

The graphs below provide our best understanding of when birds of concern are most likely to be present in your project area. This information can be used to tailor and schedule your project activities to avoid or minimize impacts to birds. Please make sure you read and understand the FAQ "Proper Interpretation and Use of Your Migratory Bird Report" before using or attempting to interpret this report.

Probability of Presence (■)

Each green bar represents the bird's relative probability of presence in the 10km grid cell(s) your project overlaps during a particular week of the year. (A year is represented as 12 4-week months.) A taller bar indicates a higher probability of species presence. The survey effort (see below) can be used to establish a level of confidence in the presence score. One can have higher confidence in the presence score if the corresponding survey effort is also high.

How is the probability of presence score calculated? The calculation is done in three steps:

1. The probability of presence for each week is calculated as the number of survey events in the week where the species was detected divided by the total number of survey events for that week. For example, if in week 12 there were 20 survey events and the Spotted Towhee was found in 5 of them, the probability of presence of the Spotted Towhee in week 12 is 0.25.
2. To properly present the pattern of presence across the year, the relative probability of presence is calculated. This is the probability of presence divided by the maximum probability of presence across all weeks. For example, imagine the probability of presence in week 20 for the Spotted Towhee is 0.05, and that the probability of presence at week 12 (0.25) is the maximum of any week of the year. The relative probability of presence on week 12 is 0.25/0.25 = 1; at week 20 it is 0.05/0.25 = 0.2.
3. The relative probability of presence calculated in the previous step undergoes a statistical conversion so that all possible values fall between 0 and 10, inclusive. This is the probability of presence score.

Breeding Season (■)

Yellow bars denote a very liberal estimate of the time-frame inside which the bird breeds across its entire range. If there are no yellow bars shown for a bird, it does not breed in your project area.

Survey Effort (|)
Vertical black lines superimposed on probability of presence bars indicate the number of surveys performed for that species in the 10km grid cell(s) your project area overlaps. The number of surveys is expressed as a range, for example, 33 to 64 surveys.

No Data (–)
A week is marked as having no data if there were no survey events for that week.

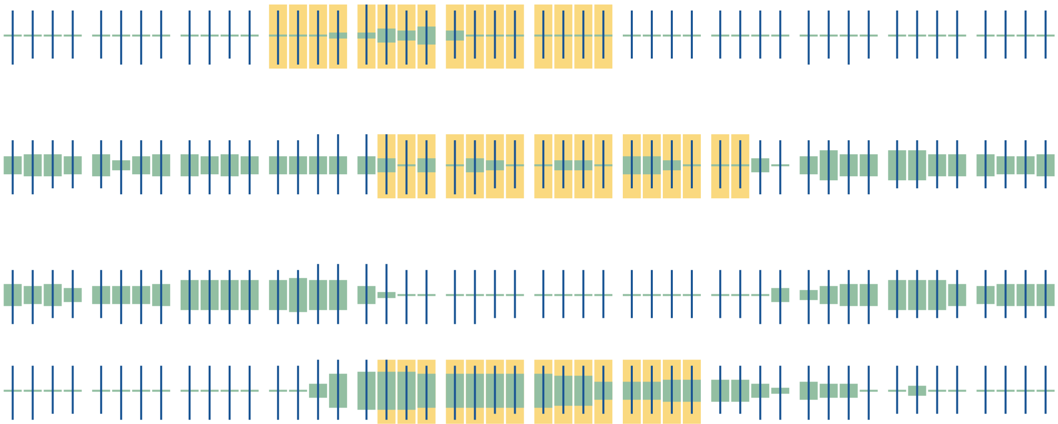
Survey Timeframe
Surveys from only the last 10 years are used in order to ensure delivery of currently relevant information. The exception to this is areas off the Atlantic coast, where bird returns are based on all years of available data, since data in these areas is currently much more sparse.

Prothonotary Warbler
BCC Rangewide (CON)

Red-headed Woodpecker
BCC Rangewide (CON)

Rusty Blackbird
BCC - BCR

Wood Thrush
BCC Rangewide (CON)



Additional information can be found using the following links:

- Birds of Conservation Concern https://www.fws.gov/program/migratory-birds/species
- Measures for avoiding and minimizing impacts to birds https://www.fws.gov/library/collections/avoiding-and-minimizing-incidental-take-migratory-birds
- Nationwide conservation measures for birds https://www.fws.gov/sites/default/files/documents/nationwide-standard-conservation-measures.pdf

MIGRATORY BIRDS FAQ

Tell me more about conservation measures I can implement to avoid or minimize impacts to migratory birds.

Nationwide Conservation Measures describes measures that can help avoid and minimize impacts to all birds at any location year round. Implementation of these measures is particularly important when birds are most likely to occur in the project area. When birds may be breeding in the area, identifying the locations of any active nests and avoiding their destruction is a very helpful impact minimization measure. To see when birds are most likely to occur and be breeding in your project area, view the Probability of Presence Summary. Additional measures or permits may be advisable depending on the type of activity you are conducting and the type of infrastructure or bird species present on your project site.

What does IPaC use to generate the list of migratory birds that potentially occur in my specified location?

The Migratory Bird Resource List is comprised of USFWS Birds of Conservation Concern (BCC) and other species that may warrant special attention in your project location.

The migratory bird list generated for your project is derived from data provided by the Avian Knowledge Network (AKN). The AKN data is based on a growing collection of survey, banding, and citizen science datasets and is queried and filtered to return a list of those birds reported as occurring in the 10km grid cell(s) which your project intersects, and that have been identified as warranting special attention because they are a BCC species in that area, an eagle (Eagle Act requirements may apply), or a species that has a particular vulnerability to offshore activities or development.

Again, the Migratory Bird Resource list includes only a subset of birds that may occur in your project area. It is not representative of all birds that may occur in your project area. To get a list of all birds potentially present in your project area, please visit the Rapid Avian Information Locator (RAIL) Tool.

What does IPaC use to generate the probability of presence graphs for the migratory birds potentially occurring in my specified location?
The probability of presence graphs associated with your migratory bird list are based on data provided by the Avian Knowledge Network (AKN). This data is derived from a growing collection of survey, banding, and citizen science datasets.

Probability of presence data is continuously being updated as new and better information becomes available. To learn more about how the probability of presence graphs are produced and how to interpret them, go the Probability of Presence Summary and then click on the "Tell me about these graphs" link.

How do I know if a bird is breeding, wintering or migrating in my area?
To see what part of a particular bird's range your project area falls within (i.e. breeding, wintering, migrating or year-round), you may query your location using the RAIL Tool and look at the range maps provided for birds in your area at the bottom of the profiles provided for each bird in your results. If a bird on your migratory bird species list has a breeding season associated with it, if that bird does occur in your project area, there may be nests present at some point within the timeframe specified. If "Breeds elsewhere" is indicated, then the bird likely does not breed in your project area.

What are the levels of concern for migratory birds?
Migratory birds delivered through IPaC fall into the following distinct categories of concern:

1. "BCC Rangewide" birds are Birds of Conservation Concern (BCC) that are of concern throughout their range anywhere within the USA (including Hawaii, the Pacific Islands, Puerto Rico, and the Virgin Islands);
2. "BCC - BCR" birds are BCCs that are of concern only in particular Bird Conservation Regions (BCRs) in the continental USA; and
3. "Non-BCC - Vulnerable" birds are not BCC species in your project area, but appear on your list either because of the Eagle Act requirements (for eagles) or (for non-eagles) potential susceptibilities in offshore areas from certain types of development or activities (e.g. offshore energy development or longline fishing).

Although it is important to try to avoid and minimize impacts to all birds, efforts should be made, in particular, to avoid and minimize impacts to the birds on this list, especially eagles and BCC species of rangewide concern. For more information on conservation measures you can implement to help avoid and minimize migratory bird impacts and requirements for eagles, please see the FAQs for these topics.

Details about birds that are potentially affected by offshore projects

For additional details about the relative occurrence and abundance of both individual bird species and groups of bird species within your project area off the Atlantic Coast, please visit the Northeast Ocean Data Portal. The Portal also offers data and information about other taxa besides birds that may be helpful to you in your project review. Alternately, you may download the bird model results files underlying the portal maps through the NOAA NCCOS Integrative Statistical Modeling and Predictive Mapping of Marine Bird Distributions and Abundance on the Atlantic Outer Continental Shelf project webpage.

Bird tracking data can also provide additional details about occurrence and habitat use throughout the year, including migration. Models relying on survey data may not include this information. For additional information on marine bird tracking data, see the Diving Bird Study and the nanotag studies or contact Caleb Spiegel or Pam Loring.

What if I have eagles on my list?
If your project has the potential to disturb or kill eagles, you may need to obtain a permit to avoid violating the Eagle Act should such impacts occur.

Proper Interpretation and Use of Your Migratory Bird Report
The migratory bird list generated is not a list of all birds in your project area, only a subset of birds of priority concern. To learn more about how your list is generated, and see options for identifying what other birds may be in your project area, please see the FAQ "What does IPaC use to generate the migratory birds potentially occurring in my specified location". Please be aware this report provides the "probability of presence" of birds within the 10 km grid cell(s) that overlap your project; not your exact project footprint. On the graphs provided, please also look carefully at the survey effort (indicated by the black vertical bar) and for the existence of the "no data" indicator (a red horizontal bar). A high survey effort is the key component. If the survey effort is high, then the probability of presence score can be viewed as more dependable. In contrast, a low survey effort bar or no data bar means a lack of data and, therefore, a lack of certainty about presence of the species. This list is not perfect; it is simply a starting point for identifying what birds of concern have the potential to be in your project area, when they might be there, and if they might be breeding (which means nests might be present). The list helps you know what to look for to confirm presence, and helps guide you in knowing when to implement conservation measures to avoid or minimize potential impacts from your project activities, should presence be confirmed. To learn more about conservation measures, visit the FAQ "Tell me about conservation measures I can implement to avoid or minimize impacts to migratory birds" at the bottom of your migratory bird trust resources page.

WETLANDS

Impacts to NWI wetlands and other aquatic habitats may be subject to regulation under Section 404 of the Clean Water Act, or other State/Federal statutes.

For more information please contact the Regulatory Program of the local U.S. Army Corps of Engineers District.

Please note that the NWI data being shown may be out of date. We are currently working to update our NWI data set. We recommend you verify these results with a site visit to determine the actual extent of wetlands on site.

Due to your project's size, the list below may be incomplete, or the acreages reported may be inaccurate. For a full list, please contact the local U.S. Fish and Wildlife office or visit https://www.fws.gov/wetlands/data/mapper.HTML

RIVERINE

- R1UBV
- R4SBC
- R2UBF
- R4SBCx
- R5UBH
- R5UBFx
- R2UBHx
- R2UBH

FRESHWATER FORESTED/SHRUB WETLAND

- PFO1Ch
- PFO1E
- PFO1R
- PFO1D
- PFO1/SS1A
- PFO1/EM1A
- PFO1Cd
- PFO1C
- PFO1A
- PSS1D
- PFO1B
- PFO1Ed
- PFO1/SS1Ch
- PSS1E
- PFO1/SS1Cd
- PFO1/4C

FRESHWATER POND

- PUBH
- PUBHh
- PUBHx

FRESHWATER EMERGENT WETLAND

- PEM1C
- PEM1F
- PEM1Ad
- PEM1Ed
- PEM1A
- PEM1E
- PEM1Cd

LAKE

- L1UBHh

IPAC USER CONTACT INFORMATION

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EFH Mapper Report

EFH Data Notice

Essential Fish Habitat (EFH) is defined by textual descriptions contained in the fishery management plans developed by the regional fishery management councils. In most cases mapping data can not fully represent the complexity of the habitats that make up EFH. This report should be used for general interest queries only and should not be interpreted as a definitive evaluation of EFH at this location. A location-specific evaluation of EFH for any official purposes must be performed by a regional expert. Please refer to the following links for the appropriate regional resources.

Greater Atlantic Regional Office
Atlantic Highly Migratory Species Management Division

Query Results

Degrees, Minutes, Seconds: Latitude = 40º 36' 8" N, Longitude = 75º 43' 39" W
Decimal Degrees: Latitude = 40.602, Longitude = -74.272

The query location intersects with spatial data representing EFH and/or HAPCs for the following species/management units.

*** W A R N I N G ***

Please note under "Life Stage(s) Found at Location" the category "ALL" indicates that all life stages of that species share the same map and are designated at the queried location.

EFH

Link	Data Caveats	Species/Management Unit	Lifestage(s) Found at Location	Management Council	FMP
		Atlantic Butterfish	Larvae	Mid-Atlantic	Atlantic Mackerel, Squid,& Butterfish Amendment 11
		Atlantic Herring	Adult, Juvenile, Larvae	New England	Amendment 3 to the Atlantic Herring FMP
		Bluefish	Adult, Juvenile	Mid-Atlantic	Bluefish
		Clearnose Skate	Adult, Juvenile	New England	Amendment 2 to the Northeast Skate Complex FMP
		Little Skate	Adult, Juvenile	New England	Amendment 2 to the Northeast Skate Complex FMP
		Longfin Inshore Squid	Eggs	Mid-Atlantic	Atlantic Mackerel, Squid,& Butterfish Amendment 11

Link	Data Caveats	Species/Management Unit	Lifestage(s) Found at Location	Management Council	FMP
		Red Hake	Adult, Eggs/Larvae/Juvenile	New England	Amendment 14 to the Northeast Multispecies FMP
		Summer Flounder	Adult, Juvenile, Larvae	Mid-Atlantic	Summer Flounder, Scup, Black Sea Bass
		Windowpane Flounder	Adult, Eggs, Juvenile, Larvae	New England	Amendment 14 to the Northeast Multispecies FMP
		Winter Flounder	Eggs, Juvenile, Larvae/Adult	New England	Amendment 14 to the Northeast Multispecies FMP
		Winter Skate	Adult, Juvenile	New England	Amendment 2 to the Northeast Skate Complex FMP

Pacific Salmon EFH

No Pacific Salmon Essential Fish Habitat (EFH) were identified at the report location.

Atlantic Salmon

No Atlantic Salmon were identified at the report location.

HAPCs

Link	Data Caveats	HAPC Name	Management Council
		Summer Flounder SAV	Mid-Atlantic Fishery Management Council

EFH Areas Protected from Fishing

No EFH Areas Protected from Fishing (EFHA) were identified at the report location.

Spatial data does not currently exist for all the managed species in this area. The following is a list of species or management units for which there is no spatial data. ****For links to all EFH text descriptions see the complete data inventory: open data inventory -->**
All EFH species have been mapped for the Greater Atlantic region, **Atlantic Highly Migratory Species EFH**, Bigeye Sand Tiger Shark, Bigeye Sixgill Shark, Caribbean Sharpnose Shark, Galapagos Shark, Narrowtooth Shark, Sevengill Shark, Sixgill Shark, Smooth Hammerhead Shark, Smalltail Shark

Appendix B

Maps and Descriptions of Alternatives 1, 2, 3, 4, and 5

RAHWAY RIVER BASIN, NEW JERSEY – ALTERNATIVES

The array of alternatives is formulated from the FRM measures. All retained measures are considered in the initial array of alternatives.

Alternative	Alternative Description
Alternative 1	No Action
Alternative 2	Upstream Detention
Alternative 3	Combination plan – targeted channelization, along with buyouts and potential localized storage from bought out areas, and targeted levees and floodwalls
Alternative 4	Nonstructural Plan consisting of acquisition, relocation, elevation, and floodproofing
Alternative 5	Lenape Park Detention Basin & Channel Modifications

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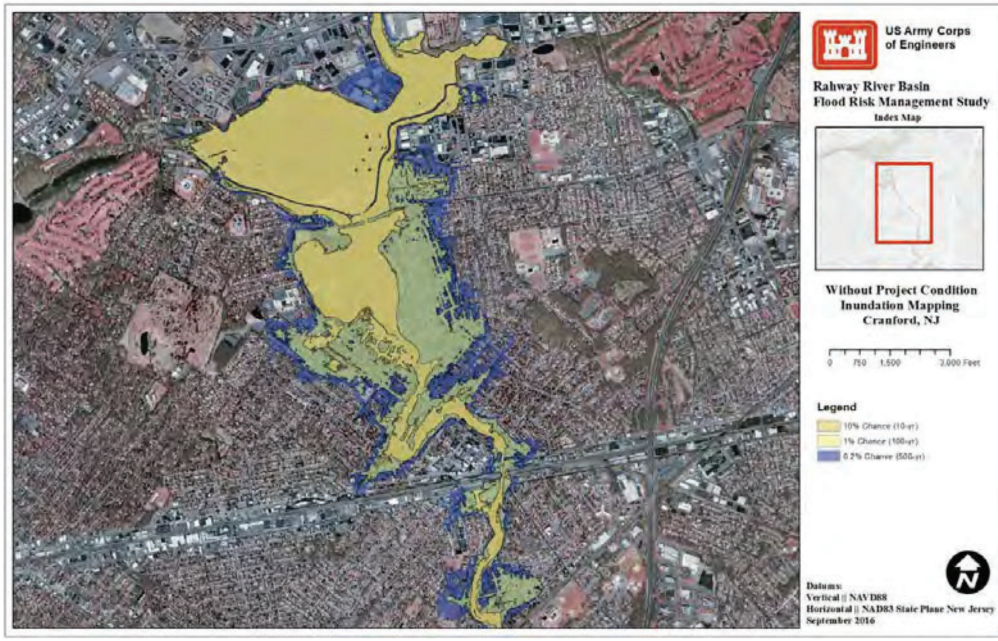
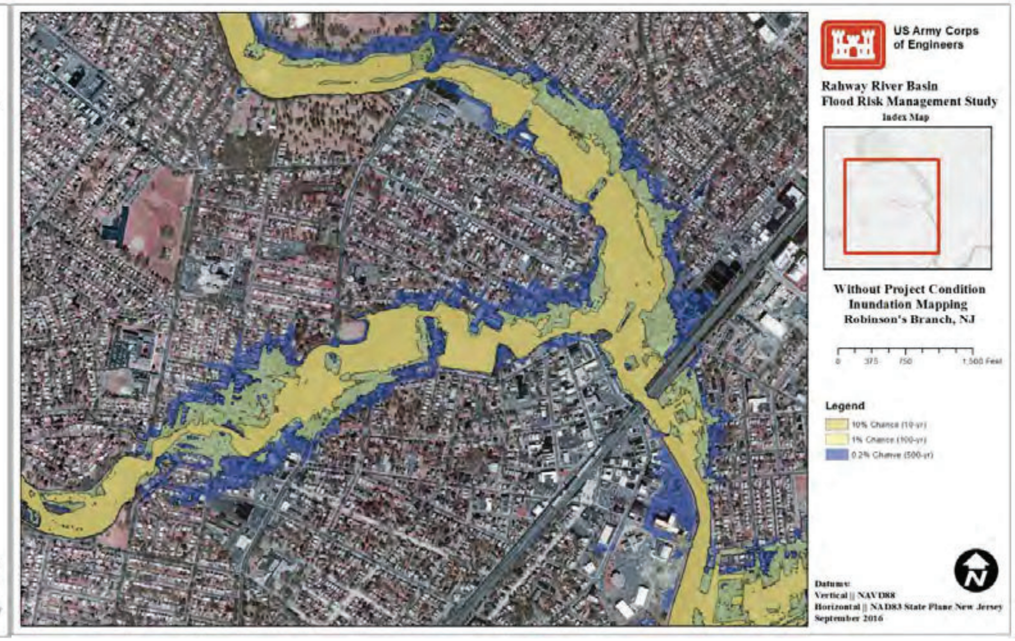
ALTERNATIVE 1 – NO ACTION



Cranford/Upstream



Robinson's Branch

No Action plan provides baseline against which the project benefits are measured. Structure inventory will be updated for future without project damages.

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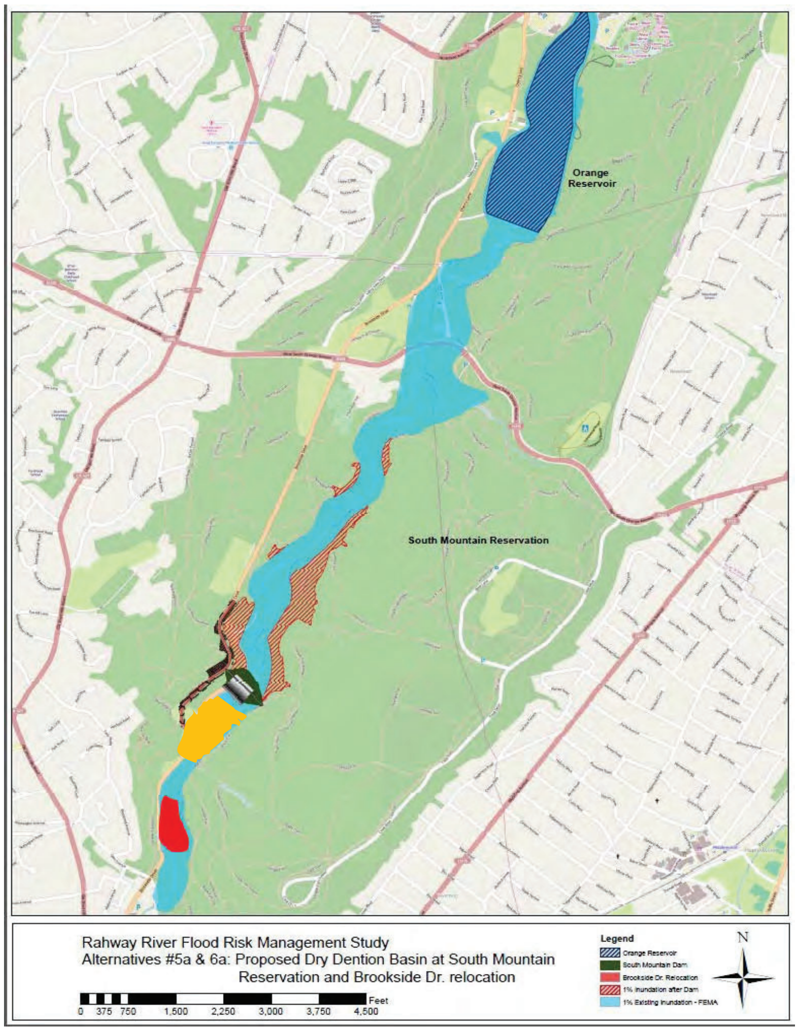
ALTERNATIVE 2 – UPSTREAM DETENTION



Upstream Detention Basin:

- **South Mountain Dry Detention standalone**
- South Mountain Dry Detention with channel improvement
- Modification to existing small ponds (Campbell and Diamond Mill) with channel improvement

Legend

- Orange Reservoir
- 1% inundation after dam
- 1% Existing Inundation - FEMA
- Campbells Pond
- Diamond Mill Pond

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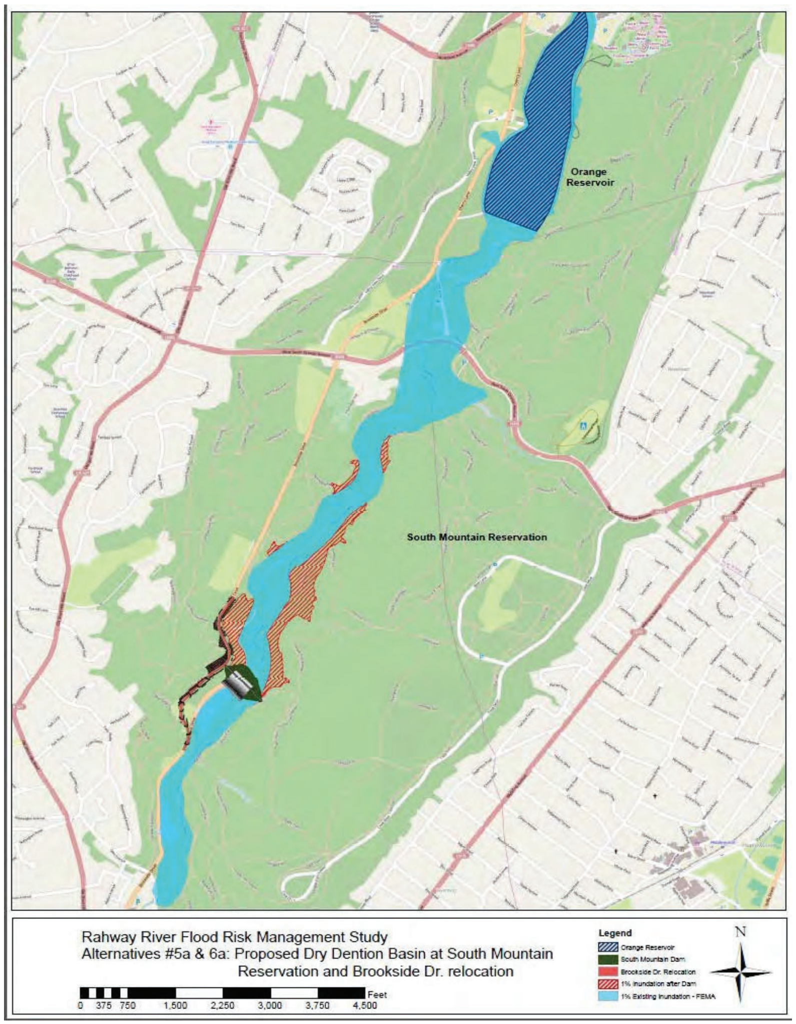
ALTERNATIVE 2 – UPSTREAM DRY DETENTION BASIN



Project Features:

- South Mountain Reservation Dry Detention Basin standalone similar to the plan developed in 2016 Draft Feasibility Report:
  - Approx 70 ft high and 810 ft long; BCR was 1.1
  - Situated above Campbells Pond
  - Potential Relocation of a portion of Brookside Drive

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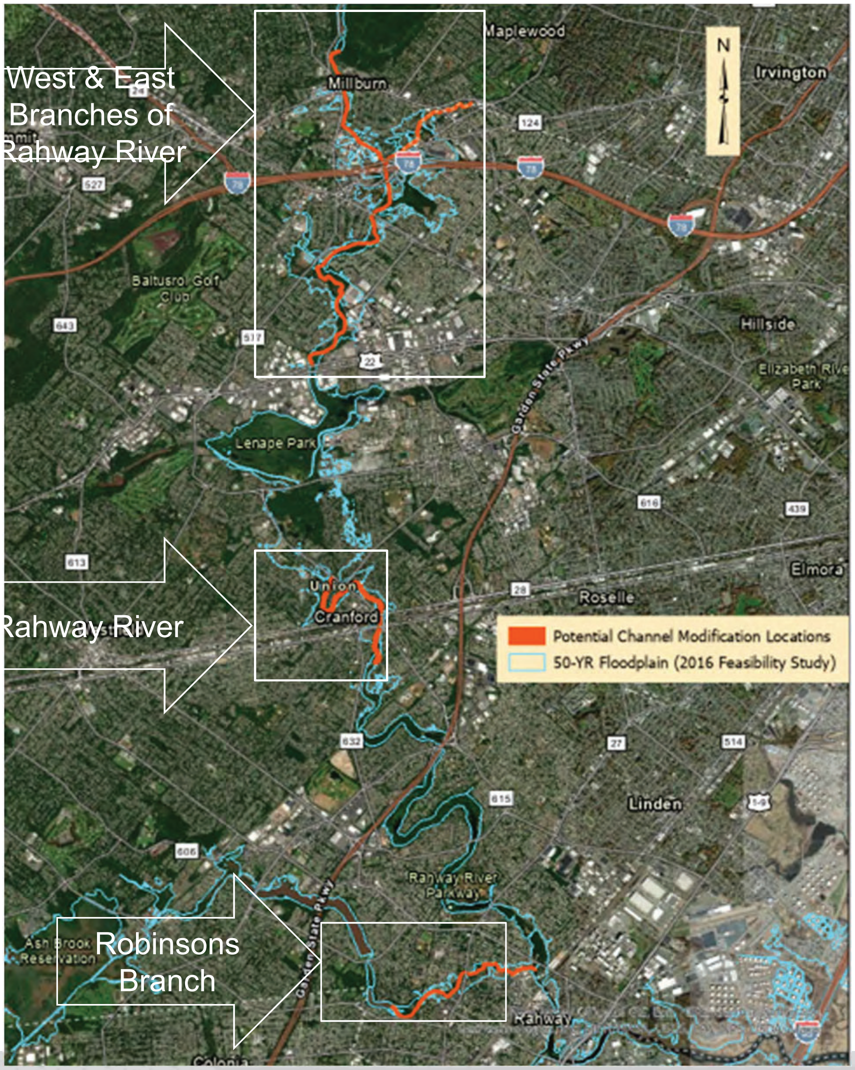
ALTERNATIVE 3 – COMBINATION PLAN



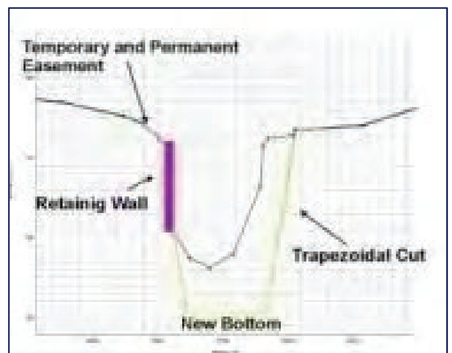
Potential Project Features *Note: Still under development

- Channel Modifications- 88,500 LF
  - East Branch Rahway River
  - Rahway River
  - Robinson's Branch
- Storage in natural areas

Legend

Potential Channel Modification Locations

50 yr Floodplain



Typical Section

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ALTERNATIVE 4 – NONSTRUCTURAL PLAN

Nonstructural Potential Aggregation Method

Characteristic	Grouping	Explanation
Hydraulic	Left/Right Bank	Indicates where the channel is
	Source of Flooding	Indicates where the water comes from
	Frequency of Flooding	Damage loss is proportional to flooding frequency
	Physics of Flooding (depths)	Damage loss is proportional to depth of water
Structure	First Floor Elevation	Damage loss is negatively related to elevation height
	Land use, Structure type	Structures of similar type would likely be damaged in comparable ways
Community	Political Jurisdictions	Incorporates socio-economic differences across census tracts

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ALTERNATIVE 4 – NONSTRUCTURAL

Benefits and costs estimations update with inflation cost adjustment from 2016 to 2023

Nonstructural Alternatives	Number of Structures	Annual Benefits	Annual Cost	Net Benefits	BCR
Low 10-yr floodplain (Robinson's Branch)	21	$ 2,008,500	$ 562,973	$ 1,445,527	3.6
High 100-yr floodplain (Robinson's Branch)	224	$ 3,055,400	$ 2,125,042	$ 930,358	1.4
Low 10-yr floodplain (Cranford Upstream)	66	$1,466,900	$ 1,226,998	$ 239,902	1.2
High 100-yr floodplain (Cranford Upstream)	726	$ 3,374,100	$ 9,695,288	$(6,321,188)	0.3

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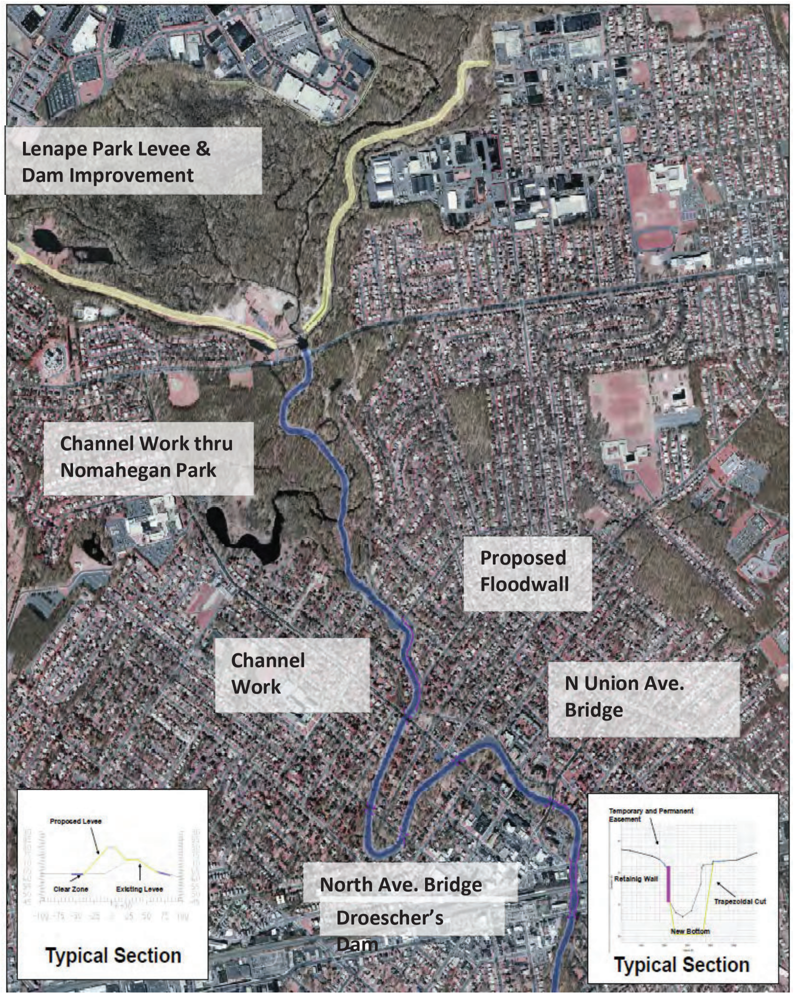
ALTERNATIVE 5: LENAPE PARK



Channel modification at the Rahway River in Cranford Township, and modification to Lenape Park Detention Basin

Potential Project Features (2016 Report):

- Replacing the existing Lenape Dam spillway structure and raising by 6 ft.
- Widening the spillway by 100 ft.
- Widening the orifice to 40 ft. and lowering by 0.5 ft.
- Modifying 10,000 ft. dam embankments by raising 6 ft.
- Widening the auxiliary spillway to 400 ft.
- Adding 6 ft. of floodwalls to the existing embankments in the northern area of Lenape Park near Fadem Rd. at Springfield Township.

0.6 BCR in the 2016 Draft Report

*NFS requested this alternative to be reevaluated

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Appendix C

Beneficial Practices to Reduce the Potential Impact of Lighting on Migratory Birds

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Migratory Bird Program
https://www.fws.gov/program/migratory-birds

May 12, 2023

Subject: Beneficial practices to reduce the potential impact of lighting on migratory birds

To Whom It May Concern:

The enclosed document identifies beneficial practices to reduce the potential adverse effects of artificial light at night on migratory birds. The U.S. Fish and Wildlife Service (Service) is the Federal agency delegated with the primary responsibility for managing migratory birds. Our authority derives from the Migratory Bird Treaty Act of 1918, as amended (MBTA; 16 U.S.C. 703 et seq.), which implements treaties with Canada, Mexico, Japan, and the Russian Federation. Migratory bird in 50 CFR 10.12 means "any bird, whatever its origin and whether or not raised in captivity, which belongs to a species listed in 50 CFR 10.13, or which is a mutation or a hybrid of any such species, including any part, nest, or egg of any such bird, or any product, whether or not manufactured, which consists, or is composed in whole or part, of any such bird or any part, nest, or egg thereof." The list of protected birds is maintained in regulation at 50 CFR 10.13 and includes over 1,000 species.

The Service interprets MBTA to prohibit incidental take of migratory birds and will enforce the statute accordingly (see https://www.fws.gov/policy-library/do225). Incidental take means the taking or killing of migratory birds that results from, but is not the purpose of, an activity. The Service recognizes that a wide range of activities may result in incidental take of migratory birds. Pursuing enforcement for all these activities would not be an effective or judicious use of our law enforcement resources. For that reason, the Service will focus our enforcement efforts on specific types of activities that both foreseeably cause incidental take and where the proponent fails to implement known beneficial practices to avoid or minimize incidental take. Our intention through this policy is to apply a transparent and consistent approach to managing and prioritizing our enforcement of incidental take, taking into account the case law applicable in a given jurisdiction and the facts and circumstances of each case.

a. The following types of conduct are not a priority for enforcement:
   (1) A member of the general public conducting otherwise legal activities that incidentally take migratory birds;
   (2) A Federal agency conducting activities in accordance with a signed memorandum of understanding with the Service developed under Executive Order 13186 for the conservation of migratory birds; or
   (3) A public- or private-sector entity conducting activities in accordance with applicable beneficial practices for avoiding and minimizing incidental take.

b. The Service prioritizes the following types of conduct for enforcement:
   (1) Incidental take that is the result of an otherwise illegal activity; or
   (2) Incidental take that:
      (i) results from activities by a public- or private-sector entity that are otherwise legal;
      (ii) is foreseeable; and
      (iii) occurs where known general or activity-specific beneficial practices were not implemented.

To better protect migratory bird populations and provide more certainty for the regulated public, the Service seeks to address human-caused mortality by providing information on beneficial practices to avoid and minimize the incidental injury and killing of migratory birds. Beneficial practice means an action implemented to avoid or minimize the incidental take of migratory birds. We also refer to beneficial practices as best management practices, conservation measures, best practices, mitigation measures, etc.

Artificial light at night can attract and disorient migratory birds, leading to exhaustion and collisions with humanmade structures such as buildings and communications towers. Under certain circumstances (*e.g.*, low cloud ceiling, precipitation, high migration passage rate), artificial light at night may contribute to mass mortality of nocturnally migrating birds. This risk may be significantly reduced or eliminated through informed design and operation of artificial lighting. Effective interventions include modifying lighting's angle/direction, timing, and color/wavelength. Please use the attached Service-provided beneficial practices as your guide for reducing risk of incidental take from lighting.

Attachment:
Incidental Take Beneficial Practices: Lighting

PROTECT OUR NIGHT SKIES

Using Bird-Conscious Lighting

Why We Should Protect Our Night Skies

The night sky is a resource that all people and wildlife, including birds, share. The cycle of day and night is important for the natural rhythms of all living things, promoting natural behavior, health, and well-being. For example, a dark sky is important for billions of birds to properly navigate their nighttime migrations. Artificial lighting at night (lighting), meaning light from sources created by people, may be helpful for security and increasing visibility when it is used well, to the extent it is needed, and when it illuminates only what is intended. However, lighting can attract large numbers of night-migrating birds from as far as 5 kilometers away. Birds can become entrapped in these areas of bright lights, circling endlessly, depleting energy stores needed for migration, and colliding with buildings and infrastructure. This phenomenon can be exaggerated on nights with low-cloud ceilings or foggy weather, when birds tend to migrate at lower altitudes and light reflecting on clouds is disorienting. Multiple mass-mortality events involving hundreds of birds have been documented associated with lighting at substations and other towers, buildings, and construction sites on foggy nights during migration.

Bird-conscious lighting is using lighting only where and when it is necessary and illuminating only the intended area. When lighting is necessary, the direction of the light, how long the light is on, the color of the light, and restricting light to the minimum required for safety can all help reduce lighting's negative effects. Below are voluntary approaches to reduce lighting, and we recommend special attention to reduce lighting on foggy nights at substations and other towers, buildings, and construction sites.

Spotlight on Practical and Easy Solutions

Use this step-by-step guide to adopt bird-conscious lighting and make our skies safer for birds.

Turn It Off

- If the lighting is not needed, consider turning it off permanently or see "Timing" below.
- Birds are at greater risk from lighting during spring and fall migration on cloudy nights. Consider if lighting can be temporarily turned off on cloudy nights April-May and August-October.
- If birds become entrapped in an area of bright light that cannot be turned off permanently, turning lights off for 15 to 20 minutes can allow birds to escape the disorienting light and return to normal behavior. If you are unsure whether birds are or will be entrapped, plan regular breaks in the lighting or implement timers (see below) to allow an opportunity for birds to escape.

Migrating birds become disoriented by lights and drawn into brightly lit areas where they can easily collide with structures, injuring or killing them.

To the left, you see an example of a shielded light, using amber light, which is less impactful to birds.

U.S. FISH & WILDLIFE SERVICE
DEPARTMENT OF THE INTERIOR

Turning Lights Off
Always In Fashion!

Timing

- Limit lighting to necessary times only.
- Use timers, dimmers, or motion sensors to turn lights on and off automatically and as needed.

Illuminate paths as close to the ground as possible with shielded amber or red lights.

Direction

- Turn off lights that face up into the sky or lights that illuminate the surrounding landscape.
- Avoid upward light scatter by shielding, selecting, or positioning lights where light is not emitted above the horizontal plane.
- Keep lighting as low to ground as possible, only illuminating necessary structures.

Color and Brightness

- Use amber, or "warmer", light that is less harmful for most species.
    - Warmer colors have longer wavelengths ($\geq$560 nm) and lower correlated color temperatures (CCT $\leq$ 3000 Kelvin degrees)
- Avoid using blue, white, or "cooler", light that is least favorable for birds and other wildlife.
    - Cooler colors have short wavelengths (<560 nm) and higher correlated color temperatures (CCT >3000 Kelvin degrees)
- Keep light as dim as possible or is necessary.

Benefits Of Bird-Conscious Lighting

- Immediately effective
- Saves money through less infrastructure and lower energy consumption
- Increases visibility of night skies
- Helps preserve natural cycles important to the health of people, birds, and other wildlife

Additional Resources To Help You Preserve The Night Sky

- Learn when seasonal lighting restrictions can be most helpful to migrating birds: https://birdcast.info/
- More information about requirements to light tall structures is here: https://www.faa.gov/faq/what-are-requirements-aircraft-warning-lights-tall-structures, and Communication Tower lighting recommendations are here: https://www.fws.gov/sites/default/files/documents/usfws-communication-tower-guidance.pdf
- Illuminating Engineering Society. 2020. Lighting Practice: Environmental Considerations for Outdoor Lighting, An American National Standard. Illuminating Engineering Society, 120 Wall Street, New York, New York 10005.
- Guide for parking lot lighting: ParkingLotLightingGuide.pdf (rpi.edu)
- States with laws to reduce light pollution: https://www.ncsl.org/environment-and-natural-resources/states-shut-out-light-pollution
- Night sky friendly products (*these products can be considered bird-conscious when the voluntary approaches described above are used*): https://www.darksky.org/our-work/lighting/lighting-for-industry/fsa/fsa-products/

Questions? Please contact your local Ecological Services Field Office or Regional Migratory Birds office for more information.

Using timers to turn lights off in office buildings is an effective and easy solution to keeping our night skies dark.

HOW TO IMPROVE YOUR LIGHTS

1. To adopt bird-conscious lighting, first evaluate individual or groups of lights wherever they occur, for example: buildings, parking lots, roadways, walkways, nighttime projects and construction, towers, and any supporting infrastructure. Evaluate lights for whether they are required, useful, or aesthetic. If you are in the design phase of the project, consider the questions below for outdoor and indoor lighting; if your project is already constructed, visit lit areas at nighttime and include visible indoor lighting in the evaluation. Below is an example data sheet for conducting an evaluation.

Location	Interior or Exterior	# of lights	Required or Useful (Y or N)	Aesthetic (Y or N)	Illuminating more than intended area (Y or N)	Steady burning (Y or N)	Color	Direction

2. Review the results of the evaluation using the if/then table below, create an action plan, and then implement the action plan.

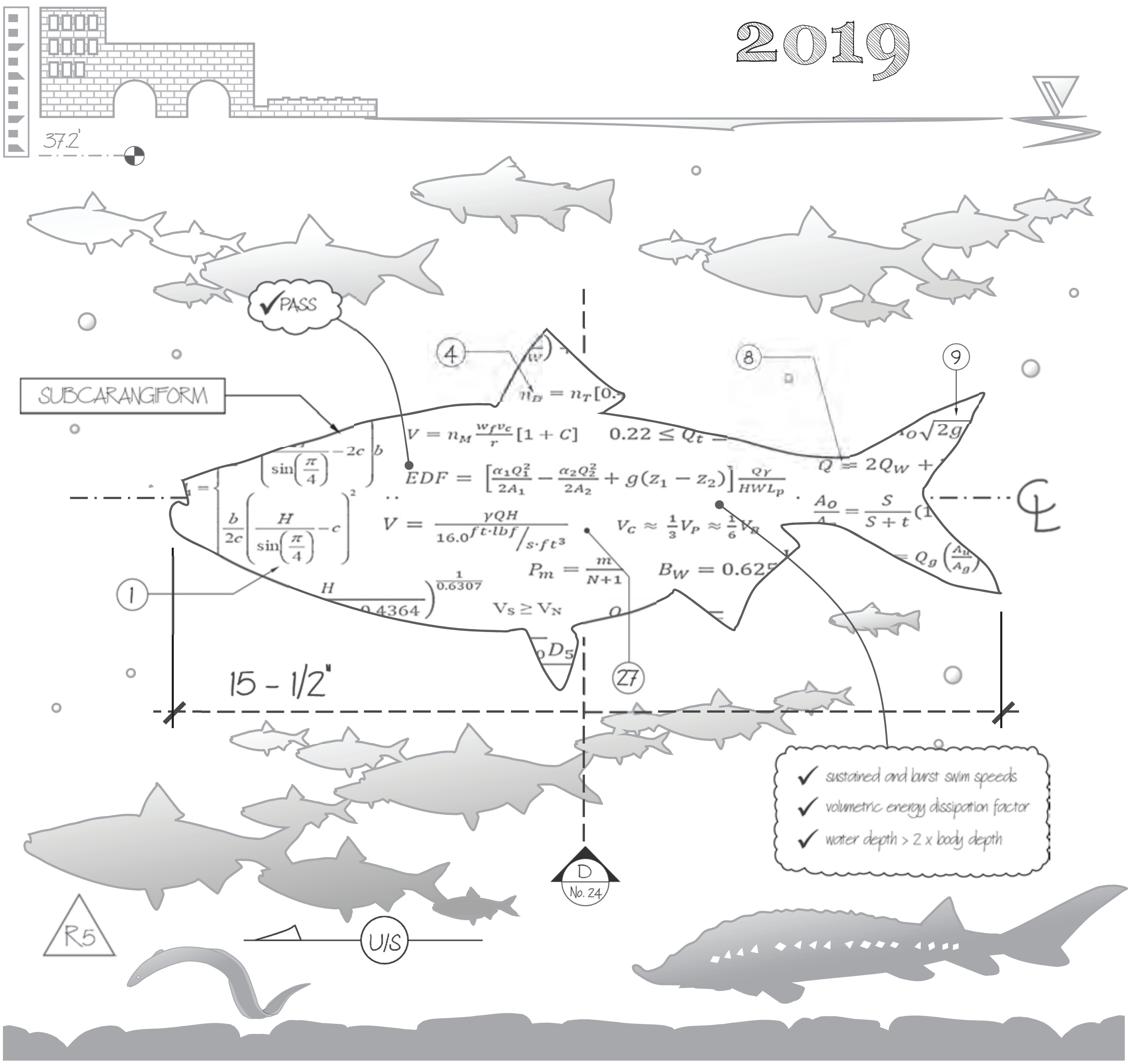
If:	and:	then you should:
lighting is not required, useful, or aesthetic		turn the lighting off
lighting is required or useful	illuminating more than the intended area	physically adjust, shield, or lower exterior lighting and block interior lighting with blinds to only illuminate desired areas or switch to lower intensity or dimmer lighting
lighting is required or useful	steady-burning	use timers, dimmers, or motion sensors to turn lighting on/off as needed and turn lights off during spring and fall migration
lighting is required or useful	a 'colder' color (e.g., blue or white)	switch to warmer amber lighting (wavelength > 560 nm, color temperature < 3000 K)
lighting is required or useful	pointing upward (i.e., uplighting)	turn the lighting off during spring and fall migration or if this is not feasible, turn it off intermittently and during bad weather/low cloud ceiling
lighting is not required or useful but is aesthetic		discuss with the people using the lighting whether it can be turned off when not in use or made unnecessary by shifting activity from night to day

Appendix D

U.S. Fish and Wildlife Service Northeast Region 2019 Fish Passage Engineering Design Criteria

FISH PASSAGE ENGINEERING DESIGN CRITERIA

2019



U.S. Fish and Wildlife Service Northeast Region June 2019

Fish and Aquatic Conservation, Fish Passage Engineering
Ecological Services, Conservation Planning Assistance

United States Fish and Wildlife Service
Region 5

FISH PASSAGE ENGINEERING DESIGN CRITERIA

June 2019

This manual replaces all previous editions of
the Fish Passage Engineering Design Criteria
issued by the U.S. Fish and Wildlife Service Region 5

Suggested citation:

USFWS (U.S. Fish and Wildlife Service). 2019. Fish Passage Engineering Design Criteria. USFWS, Northeast Region R5, Hadley, Massachusetts.

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1 Scope of this Document

1.1 Role of the USFWS Region 5 Fish Passage Engineering

The U.S. Fish and Wildlife Service (Service) Region 5 (R5) Fish Passage Engineering (Engineering) team provides technical and engineering assistance to the Fish and Aquatic Conservation program, Service biologists, and other federal, state, tribal, and non-governmental partners working to improve passage for migratory fish and other aquatic organisms. For hydroelectric projects under the jurisdiction of the Federal Energy Regulatory Commission (FERC), Engineering coordinates and consults with R5 Ecological Services' Conservation Planning Assistance program.

1.2 Purpose of This Document

Anthropogenic activities in rivers may introduce undue hazards to many aquatic organisms and contribute to overall habitat fragmentation. Fragmentation may negatively alter the structure and diversity of both diadromous and resident fish populations. These adverse impacts can be mitigated through dam removal, and a variety of technical and nature-like fish passage and protection technologies. Fish passage and protection (hereafter simply "fish passage") requires the integration of numerous scientific and engineering disciplines including fish behavior, ichthyomechanics, hydraulics, hydrology, geomorphology, and hydropower. This document is intended to: 1) establish Engineering's "baseline" design criteria for fishways, dam removals, road crossings and other fish passage related technologies; 2) serve as a resource for training in these disciplines; and 3) support the implementation of the Service's statutory authorities related to the conservation and protection of aquatic resources (e.g., Section 18 of the Federal Power Act, Endangered Species Act, Fish and Wildlife Coordination Act, and the Anadromous Fish Conservation Act).

1.3 Limitation of Criteria and Consultation

The efficacy of any fish passage structure, device, facility, operation, or measure is highly dependent on local hydrology, target species and life stage, dam orientation, turbine operation, and myriad other site-specific considerations. The information provided herein should be regarded as generic guidance for the design, operation, and maintenance of fishways throughout the northeastern U.S. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Fish and Wildlife Service. The criteria described in this document are not universally applicable and should not replace site-specific recommendations, limitations, or protocols. This document provides generic guidance only and is not intended as an alternative to active consultation with Engineering. Application of these criteria in the absence of consultation does not imply approval by Engineering or the U.S. Fish and Wildlife Service.

1.4 Acknowledgements

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2 Fishway Implementation and Performance

2.1 Definition of a Fishway

A fishway is the combination of elements (structures, facilities, devices, project operations, and measures) necessary to ensure the safe, timely, and effective movement of fish past a barrier. Examples include, but are not limited to, volitional fish ladders, fish lifts, bypasses, guidance devices, zones of passage, operational flows, and unit shutdowns.

The terms "fishway," "fish pass," or "fish passageway" (and similarly "eelway," "eel pass," or "eel passageway") are interchangeable. However, Engineering recommends use of the terms "fishway" or "eelway" as they are consistent with 16 U.S.C. § 811 (1994), which reads:

> *"That the items which may constitute a 'fishway' under section 18 for the safe and timely upstream and downstream passage of fish shall be limited to physical structures, facilities, or devices necessary to maintain all life stages of such fish, and project operations and measures related to such structures, facilities, or devices which are necessary to ensure the effectiveness of such structures, facilities, or devices for such fish."*

The term "fish passage" (or "eel passage") refers to the act, process, or science of moving fish (or eels) over a stream barrier (e.g., dam).

2.2 Zone of Passage

The zone of passage (ZOP) refers to the contiguous area of sufficient lateral, longitudinal, and vertical extent in which adequate hydraulic and environmental conditions are maintained to provide a route of passage through a stream reach influenced by a dam (or stream barrier).

2.3 Safe, Timely, and Effective

The elements of a fishway are designed and implemented to provide safe, timely, and effective fish passage. These three key species-specific passage characteristics are defined below:

- *Safe Passage:* The movement of fish through the ZOP that does not result in unacceptable stress, incremental injury, or death of the fish (e.g., by turbine entrainment, impingement, and increased predation). If movement past a barrier results in delayed mortality or a physical condition that impairs subsequent migratory behavior, growth, or reproduction, it should not be considered safe passage.

- *Timely Passage:* The movement of fish through the ZOP that proceeds without materially significant delay or impact to essential behavior patterns or life history requirements.
- *Effective Passage:* The successful movement of target species through the ZOP resulting from a favorable alignment of structural design, project operations, and environmental conditions during one or more key periods. Effectiveness includes both qualitative assessments (e.g., integrity of wooden weir boards, timing of the hopper cycle) and quantitative measurements. The term "efficiency" (and its hyponyms passage efficiency and attraction efficiency) is reserved for the quantitative elements of effectiveness.
    - *Efficiency:* A quantitative measure of the proportion of the population motivated to pass a barrier (i.e., motivated population) that successfully moves through the entire ZOP; typically expressed as the product of attraction and passage efficiencies.
    - *Attraction Efficiency:* A measure of the proportion of the (motivated) population that is successfully attracted to the fishway; typically measured as a percentage of the motivated population that locates and enters the fishway.
    - *Passage Efficiency:* A measure of the proportion of fish entering the fishway that also successfully pass through the fishway; successful passage through the fishway is typically measured at the fishway exit; also referred to as "internal fishway efficiency."

2.4 Performance Standards

A performance standard establishes a measurable level of success needed to ensure safe, timely, and effective passage for fish migrating through (or within) the ZOP. These three characteristics may be evaluated quantitatively through a site-specific framework agreed upon by the Service and the dam and/or facility owner, although the specific standard may take many forms. For example, a performance standard established for upstream-migrating adult American shad may include a passage efficiency of 85%, an attraction efficiency of 90%, and a maximum migration delay of 4 days.

Other, more stringent performance standards that emphasize short and long-term survivability may apply. For example, the following performance standards have been established by NOAA (2012) for the passage of Atlantic salmon in the Gulf of Maine; the Distinct Population Segment of Atlantic salmon are protected under the Endangered Species Act and these standards have been codified in project-specific species protection plans and biological opinions:

- *Example Atlantic Salmon Downstream Passage Performance Standard*: The downstream migrant successfully locates and uses the downstream fish passage system within 24 hours of encountering the project dam or fishway. In addition, the downstream migrant does not exhibit any trauma, loss of equilibrium, or descaling greater than 20% of the body surface (Black Bear Hydro Partners, 2012).
- *Example Atlantic Salmon Upstream Passage Performance Standard*: The upstream migrant enters the project tailrace (defined as 200 meters downstream of the lowermost water discharge structure), locates the fishway entrance, and passes within 48 hours. In addition, the upstream migrant does not exhibit any trauma, loss of equilibrium, or descaling greater than 20% of the body surface (Black Bear Hydro Partners, 2012).

Generally, the performance standard is informed by state and federal agency biologists with expertise in the life history requirements of the region's fish populations. Factors to consider include the impact of each barrier within the watershed and the minimum number of fish required to sustain a population's long-term health and achieve identified management plan objectives and goals. In waterways where multiple barriers have a cumulative impact upon migratory fish, a "cumulative efficiency" performance standard may apply (i.e., the proportion of the stock that has successfully passed through the composite zone of passage spanning multiple barriers).

2.5 Project Phases

In general, the life of a fishway can be partitioned into distinct stages or phases. The phases in this sequence are listed, along with Engineering's typical support activities, in Table 1. While this sequence is followed in most fish passage projects, certain activities in Table 1 may only be appropriate for work performed in a regulatory environment.

Table 1: Typical fishway project phases and related activities

Phase	Activities
Fisheries Management	identify target species; stream barrier assessment; fishway facility/device needs; FERC re-licensing support; study plan development and review
Planning	fishway capacity and sizing; hydrologic/hydraulic analyses; determination of fishway design flows and operating range; alternatives analyses; conceptual designs; cost estimates; establishment of appropriate fish passage criteria
Design	preliminary (i.e., 30%) design review and input; final (i.e., 90%) design review and input; liaison with owner/consultant on design issues
Construction	construction review and inspection; photo documentation and survey; quality control (QC); post-construction engineering evaluation; commissioning; review/author fishway operation and maintenance (O&M) plan
Biological Evaluation	following commissioning, coordinate with biologists on the development and implementation of studies (e.g. telemetry, video) to determine if fishway is safe, timely and effective; assist in development of solutions/strategies to address performance issues
Operation	development of a data collection protocol; annual fishway inspection; support FERC compliance activities; troubleshoot known fishway performance issues; evaluation of fishway compliance with criteria; revision of O&M plan; general engineering and technical support

2.6 Trial Operation, Evaluation, and Commissioning of a New Fishway

A newly constructed (or significantly modified) fishway should undergo a period of testing and trial operation to verify proper functioning of the facilities. This trial operation, or “shakedown period,” focuses on final adaptations to the facility that optimize hydraulic conditions for fish passage. Ordinarily, the shakedown:

- is carried out during the first passage season, but may extend beyond the initial season if time is required to resolve serious design, construction or operational issues;

- focuses on verifying that all major elements of the fishway (e.g., gates, pumps, screens, lifts) function according to the approved design and specifications;
- provides an opportunity to verify that the fishway meets the requirements stipulated in any Section 18 prescription, water quality certificate, biological opinion, settlement agreement or FERC order (e.g., a specific quantity of attraction flow);
- is used to establish the protocols for the initial fishway operations and maintenance (O&M) plan;
- necessitates, where appropriate, consultation with Service biologists and engineers, federal and state resource agencies, signatories to relevant agreements, and/or parties with statutory authority.

In a regulatory environment, completion of the trial operation period often ends in a formal commissioning of the fishway, whereupon the Service may certify that the facilities were built as prescribed (or intended).

Shakedown assesses whether the fishway was constructed to, and capable of operating in accordance with, the approved design. However, conformity with design is not a guarantee of performance. Roscoe and Hinch (2010) noted that despite the presence of increasingly sophisticated fishways, many do not allow target and non-target fish to pass. Since fishways do not always perform as intended there is a need to monitor and evaluate fishways after construction, and if necessary modify them (Roscoe and Hinch, 2010, Odeh 1999). Indeed, biological evaluation (which follows shakedown) is typically necessary to determine if the fishway is safe, timely and effective. Evaluation may take many forms including video observation, sample collection, hydro-acoustics, telemetry, or passive integrated transponder (PIT) studies. The evaluation periods often lasts 1 to 3 years. Information gleaned from these studies may be used to verify the efficacy of the new fish passage facilities or, if applicable, determine whether or not a formal performance standard has been met. Failure to meet performance expectation(s) may necessitate structural or operational changes, followed by additional evaluation.

2.7 Fishway Operations and Maintenance Plan

An operations and maintenance (O&M) plan is a best-management practice that formally establishes the protocols and procedures necessary to keep a fishway in proper working order. An O&M plan may contain:

- Schedules for routine maintenance, pre-season testing, and the procedures for routine fishway operations, including seasonal and daily periods of operation;
- Standard operating procedures for counting fish;
- Plans for post-season maintenance, protection, and, where applicable, winterizing the fishways;
- Details on how the fishway, spillway, powerhouse and other project components shall be operated, inspected, and maintained during the migration season to provide for adequate fish passage conditions, including, as appropriate:
  - pre-season preparation and testing;
  - sequence of turbine start-up and operation under various flow regimes to enhance fishway operation and effectiveness;
  - surface and underwater debris management at the fishway entrance, guidance channels, the fishway exit, attraction water intakes, and other water supply points;
  - water surface elevations at the fishway entrance and exit, and attraction water flow rate/range.

Engineering recommends that dam owners develop an O&M plan at least three months prior to the commissioning of the fishway and submit it to the Service and other stakeholders for review. The owner should update the O&M plan annually to reflect any changes in fishway operation and maintenance planned for the year. For any FERC jurisdictional fishway, any modifications to the O&M plan by the licensee should require approval by the Service and, if necessary, FERC prior to implementation.

2.8 Fishway Inspections

For a FERC jurisdictional fishway, annual inspections by Engineering are recommended. While daily operation, inspection, and routine maintenance of a FERC project’s fishway are the responsibility of the owner and licensee, annual inspections by Service staff allow for documentation of changing site conditions, updated assessment of component design life, and verification of operational settings. Fishway inspections are a critical element of long-term successful passage at any site. In the absence of pre-existing, site-specific, robust inspection protocols, Engineering recommends the implementation of procedures described in Appendix B, “Fishway Inspection Guidelines” by Towler et al. (2013).

2.9 Data Collection and Reporting

As a complement to the annual inspection, Engineering recommends collection of hydraulic conditions in the fishway (e.g., river flows, unit operations, head differential at the fishway entrance, velocities, water temperature, dissolved oxygen levels, tailwater (TW) and headwater (HW) elevations) during the migration season throughout the entirety of the project life. Data collection should be collected at short time intervals (e.g., hourly) via automated systems such as programmable logic controllers. Daily data should be collected manually at projects where automated data collection is not feasible. The hydraulic data collection can help to identify conditions that are: 1) not conducive to passage that may result from improper operations, changing site conditions, malfunctioning of a fishway component, and/or some other unforeseen circumstance; and 2) advantageous to passage that may be useful in updating fishway criteria and informing future designs.

2.10 Vertical Geodetic Datums

In various scientific, engineering, architectural, and legal documents, reference is made to one or more different elevation datums. Accuracy of elevation data is critical to the design, construction and operation of fishways; nevertheless, the following missteps are surprisingly common and should be avoided: 1) the misapplication of an unofficial datum; 2) a conflation of NAVD 88 with NGVD 29; and 3) the incorrect assumption of a datum.

The so-called USGS datum and the term “MSL” are frequently misapplied. The USGS datum was never an official datum, but a term that collectively referred to the (now obsolete) vertical datum of National Geodetic Vertical Datum of 1929 (NGVD 29) and the horizontal datum of North American Datum of 1927 (NAD 27). MSL refers to "mean sea level" and is a periodically updated tidal datum that should not be confused with a vertical geodetic datum. Continued use of the USGS and MSL datums may contribute to significant measurement, reporting, and construction errors.

In 1991, the U.S. Geodetic Survey NGVD 29 was discontinued and replaced with the NAVD 88. Use of the NAVD 88 datum has been adopted by NOAA, FEMA, and is the basis for the USGS's primary elevation data product: the National Elevation Dataset or NED. In the conterminous U.S., the difference between NGVD 29 and NAVD 88 ranges between -40 cm to +150 cm, or 1.3 ft. to 4.9 ft. (Zilkoski et al., 1992). Based on a reference point in Great Lakes-St. Lawrence River system, the datum shift is most pronounced in the high elevation areas of the western U.S. Nevertheless, the discrepancy is still significant along the Atlantic seaboard. In coastal New England for example, at 42.090933, -71.264355 in Norfolk County, Massachusetts, NAVD 88 and NGVD 29 measurements differ by nearly 10 inches. Uncorrected datum shifts of even this magnitude can lead to serious errors in conservation work. Considering the frequency with which pre-adjustment documents and drawings (i.e., pre 1991) are used with new ones, the opportunities for datum shift errors are lamentably numerous.

Elevations are commonly reported with no reference to any datum. Incorrectly assuming an elevation with a specific datum (e.g., NAVD 88, NGVD 29) may result in errors of several inches or feet. Indeed, the elevation may not be linked to an official geodetic datum at all. The magnitude of the error could be much greater if an official datum is assumed when the measurement was simply anchored to a local reference point (e.g., dam crest, abutment or other monument). Such errors in a fishway design (if uncorrected) can starve a ladder or lift of water making it non-functional; errors in dam removal projects may inadvertently expose a water line or perch a culvert; errors in FERC license articles or filings could lead to incorrect project operations resulting in dry bypasses during spawning seasons.

Engineering recommends the following practices:

1. For documents produced before 1991, one can generally assume elevations labelled "USGS datum" are actually NGVD 29.
2. After 1991 and especially prior to the advent of GPS-enabled surveying equipment, NAVD 88 and NGVD 29 were both in common use. Given the informal (and often misunderstood) nature of the USGS datum, any elevation reported in that benchmark should be regarded with

uncertainty. If accuracy of the elevation is critical (i.e., used to construct or define operational ranges), a re-survey or verification of a local elevation monument may be necessary.

3. For existing documents, put no confidence in any reference to MSL or elevations with no reported datums; it may refer to NAVD 88 or NGVD 29 or a tidal datum or even a local datum. Confirm with the source material if possible. If the datum cannot be confirmed and accuracy is critical (i.e., elevation will be used to construct or define operational ranges), a re-survey may be necessary.
4. When generating new documents (e.g. plans or study reports), note the datum with the elevation (e.g., invert of culvert is 50 ft. NAVD88) or if there are numerous elevations in the document include a single note indicating that "all elevations in this document are referenced to NAVD 88."
5. On all future work, avoid using the MSL or USGS datums.
6. An elevation in NGVD 29 can be vertically shifted to NAVD 88 using a variety of tools. NOAA's National Geodetic Survey provides a convenient online conversion tool: https://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl

2.11 Drawing Standards

Engineering recommends use of standards that are consistent with FERC exhibit drawing requirements described in the Code of Federal Regulations, 18 CFR §4.39 "Specifications for maps and drawings." Emphasis should be placed on the legibility and scale of drawings, excerpted here:

- 18 CFR §4.39 (c): Drawings depicting details of project structures must have a scale in full-sized prints no smaller than (1) one inch equals 50 feet for plans, elevations, and profiles; and (2) one inch equals 10 feet for sections.
- 18 CFR §4.39 (d): Each map or drawing must be drawn and lettered to be legible when it is reduced to a print that is 11 inches on its shorter side.

3 Populations

By necessity, the flow through a fishway is only a fraction of the total river flow. Consequently, the design engineer of a fishway must estimate the maximum number of fish that can safely, timely, and effectively pass through the fishway (the biological capacity) versus the total passage goal (the design population) in a given time duration. Each component of the fishway should be designed such that the biological capacity is equal to or greater than the design population within a specified time interval. Typically, the design population is developed by the state, Service or other federal agency biologists, or other local experts.

3.1 Estimating Design Populations

The design population is often estimated as the product of the amount of estimated upstream habitat area (e.g., 10,000 acres) the regional carrying capacity of fish per unit habitat area (e.g., 100 American shad per acre). In other instances, the design population can be an estimate of the number of fish required to support a restoration target or a fisheries management goal. Four examples from the Northeast U.S.A. are provided below:

- *Connecticut Department of Energy & Environmental Protection (CT DEEP):* The CT DEEP uses the common species specific carrying capacity of the habitat to determine the design population for a fishway. The approach is based on the quantity of available upstream habitat and the amount of fish per acre which that habitat type can typically support to determine the design population for a fishway. For American shad, their estimates use a minimum of 50 fish per acre of riverine habitat and are based on the St. Pierre (1979) study. For Blueback Herring in large rivers, their estimate is 90 fish per acre and is based on data prior to 1986 at the Holyoke Dam in Massachusetts. For alewives in coastal streams, the estimate is 900 to 1,000 fish per acre of lake habitat, although data collected from 2012-2013 showed values as high as 5,036 and low as 324 alewives per acre (Pierre, 1979). More recently, the Connecticut River Atlantic Salmon Commission (CRASC) has proposed adult target levels of 82 fish per acre in the main stem. This standard, developed by cooperating agencies, has been incorporated into an updated draft of the CRASC Shad Management Plan.

- *U.S. Fish and Wildlife Service, Maine Department of Inland Fisheries and Wildlife (ME IFW), Maine Atlantic Sea Run Salmon Commission, Maine Department of Marine Resources (ME DMR):* These agencies jointly authored a management plan for the Saco River in Maine (McLaughlin et al., 1987). The plan, which estimates production and escapement based on habitat and fishway efficiencies, assumes a shad production of 2.3 adults per 100 square yards (111 adults per acre) of riverine habitat.
- *Maryland Department of Natural Resources (MDNR):* The MDNR also applied the work of St. Pierre (1979) in the development of a restoration target for the Susquehanna River. The target, or design population in this context, was determined using the area-density estimate of 48 American shad per acre in the free-flowing reaches of the river upstream of York Haven, Pennsylvania.
- *New Hampshire Fish and Game Department (NH Fish and Game):* The NH Fish and Game developed a sustainability plan in 2011 which established a restoration target of 350 river herring per acre of available spawning habitat in the state's smaller coastal river basins. This target was based on a percentage of the mean annual return of river herring in the prior 20 years.

4 Design Flows

Upstream fish passage design flows define the range of flow over which timely, safe, and effective passage can be achieved. As such, these design flows correlate to specific river flow conditions and do not generally represent the discharge through the fish passage devices themselves. Timely passage relates to seasonal hydrology; the spawning migrations of many East Coast diadromous fishes are typically linked to elevated flow events and water temperature (the latter, in turn, often being influenced by the former). Safe passage may become an issue under extreme flow conditions when low flows may strand migrants in disconnected pools or when high flows may force fish over emergency spillways under supercritical conditions impacting on chute blocks or natural ledge outcroppings. Effective passage can be compromised by high flows in numerous ways including the development of adverse hydraulic conditions in the fishway, the presence of competing flows over adjacent spillways, and generally impassible conditions which encourage fish to temporarily suspend their migration until river conditions improve. The relationship between hydrology, design flows, project discharge, and operating range is illustrated in Appendix A, Reference Plate 4-1 “Fishway Operating Range.”

4.1 Streamflow Data

Fish passage design flows for new or retrofitted projects are based on estimates of predicted (i.e., future) daily average streamflow conditions. Though influenced by upstream man-made barriers and driven by well-known seasonal trends, future daily streamflow cannot generally be predicted with certainty. Consequently, Engineering often applies the concept of stationarity by relying on trends demonstrated in historical hydrologic records to estimate future streamflow. In this context, a time series of historical streamflow data is assumed to have the same temporal distribution as future streamflow.

Contrary to the concept of stationarity, the frequency of storm events (i.e., high flow events) have been increasing within the Northeast (Collins, 2009). Engineering acknowledges that the use of calibrated hydrology and climate models may be the best approach to estimate future streamflow. However, these models are often nonexistent at a site, require extensive effort to create, and may still possess a high degree of uncertainty. Thus, in most cases site stationarity remains the basis for the development of design flows and flood flows as described in the following subsections.

4.1.1 Period of Record

The period of record (POR) is defined as the continuous record of historical streamflow data that is of sufficient length to adequately characterize daily and seasonal variations in flow.

- Where possible, the POR should include 30 years of data to demonstrate hydrologic stationarity for all flood flow events up to and including the 100-year flood. The U.S. Water Resources Council (1981) recommends the use of the log-Pearson Type III method for a flood flow frequency analysis.
- Based on climatic trends in the Northeast established by Collins (2009), Engineering recommends using post-1970 data only. Where older data is needed to establish design flows, watershed specific pre- and post-1970 data trends should be investigated before proceeding.
- Under certain circumstances, it is advisable to use a shorter POR (of no less than 10 years) even when 30 years of data are available. For example, a truncated POR should be used when recent construction or changes in operations upstream have significantly altered the temporal distributions of streamflow.

Calculation of the design flows requires a refinement to the POR based on the migration season of one or more target species, referred to as the migratory POR (MPOR). The MPOR is the truncated streamflow data set comprised of only the dates within the migration season of one or more target species. Although the spawning migrations of East Coast anadromous species typically correlate to elevated flow events and water temperature, the migration season tends to vary regionally throughout each species' geographical range, between adjacent watersheds, and even across years. This variation is locally influenced by environmental factors such as (Turek et al., 2016):

- Precipitation and other weather events and patterns;
- Freshwater, estuarine or oceanic conditions;
- River flows including the effects of storage impoundment releases or water withdrawals;

- In-stream turbidity, dissolved oxygen levels and water temperatures, and in particular short-term fluctuations in air and water temperatures;
- Time of day and in particular, ambient light conditions;
- The specific passage site location within a watershed.

In consideration, Engineering employs conservative estimates for a target species migration season. Typically, the migration season for a particular species in a particular location is provided to Engineering by Service or state biologists or other local experts. Generally, the fishway should be operational during the defined migration period.

4.1.2 Streamflow Data Sources

Historical streamflow data are used to establish fish passage design flows. As such, the data influence many of the design parameters (e.g., pool depth and length) that are linked to hydraulic conditions (e.g., water depth and velocity) fish will encounter within the ZOP. This hydrologic information can come from a variety of sources; however, any streamflow data used in the design of a FERC jurisdictional fishway should be reviewed and approved by Engineering.

In general, Engineering recommends the use of U.S. Geological Survey (USGS) streamflow gage data where possible. The USGS National Streamflow Information Program maintains the largest network of stream gages in the U.S. and provides access to a comprehensive online database of historical streamflow (http://water.usgs.gov/nsip/). While many USGS stream gages are located at existing dams (and fishway sites), most are not. Therefore a method of estimating flow at ungaged sites is required. The most common method to estimate streamflow at an ungaged site is linear proration by drainage area of a nearby gaged site in the watershed. The ungaged target site streamflow, Q_u, is calculated by:

$$Q_u = Q_g\left(\frac{A_u}{A_g}\right) \qquad \text{Eq. (1)}$$

where Q_g is the streamflow at the gaged reference site, A_g is the watershed area at the gaged site, and A_u is the watershed area at the ungaged target site. The reference gage should be of similar watershed size, land use, geology, and exposed to the same precipitation events as the target site.

If no adequate reference gages exist, other methods of estimating streamflow at an ungaged site may be available. These include, but are not limited to, regional regression equations and rainfall-runoff modeling (e.g., HEC-HMS), and more complex stochastic methods of generating synthetic hydrology. Engineering strongly recommends any method for developing streamflows at ungaged sites be both locally calibrated and of sufficient accuracy to capture the daily variation in flow.

4.2 Flow Duration Analysis

A flow duration analysis is a method commonly used by both states and federal agencies to estimate hydrologic extremes and fish passage design flows. A flow-duration curve (FDC) is a cumulative frequency curve that shows the percent of time a specified variable (e.g., daily average streamflow, 7-day average flow) was equaled or exceeded during a given period.

To develop a FDC, the independent variables (or observations) are arranged in descending order. The largest observation is ranked m = 1 and the smallest observation is ranked m = N, where N is the number of observations. These ranked observations are plotted on the y-axis against the plotting position, P_m, on the x-axis. P_m is considered an estimate of the exceedance probability of the associated ordered observation and is calculated by the Weibull plotting position formula:

$$P_m = \frac{m}{N+1} \quad \text{Eq. (2)}$$

4.3 Operating Range

The operating range over which safe, timely and effective passage can be achieved is bounded by the low and high design flows. In establishing these two design flows for specific fishways, site hydrologic data and the timing of local migrations are paramount. Engineering presumes that for flow rates outside of the operating range (e.g., during storm events), fish may either: 1) pass the barrier without the use of the fishway; or 2) not be actively migrating.

4.3.1 Low Design Flow

The low design flow (Q_L) defines the nominal lower limit of river flow that can achieve safe, timely, and effective fish passage. Engineering defines the design low flow as the mean daily average river flow that is equaled or exceeded 95% of the time during the MPOR for target species normally present in the river basin and at the fish passage site. The low design flow is interpolated from a FDC (defined in Section 4.2) where P_m equals 0.95. In other terms, the low design flow, Q_L can be defined as:

$$Q_L = Q_{95} \quad \text{Eq. (3)}$$

Competing demands for water under low design flows are particularly important. River flows should be apportioned to the fishway before generation, process water, irrigation or other consumptive use. On sites where the minimum environmental bypass flows are required, this requirement should be met, where possible, by the fishway discharge (i.e., attraction flow).

4.3.2 High Design Flow

The high design flow (Q_H) defines the nominal upper limit of river flow that can achieve safe, timely, and effective fish passage. Engineering defines the design high flow as the mean daily average river flow that is equaled or exceeded 5% of the time during the MPOR for target species normally present in the river basin and at the fish passage site. The high design flow is interpolated from a FDC (defined in Section 4.2) where P_m equals 0.05. In other terms, the high design flow, Q_H can be defined as:

$$Q_H = Q_5 \quad \text{Eq. (4)}$$

4.3.3 Constraints on Design Flows

Design flows (i.e., operating ranges) are based upon myriad site conditions and hydrologic analyses. Post-construction operating ranges are sometimes modified (through effectiveness studies and adaptive management) to ensure compliance with performance standards or fishery management goals. However, once prescriptions for specific projects are made and incorporated into license articles, they may not be changed without adequate justification and a written waiver from the Service. If a fishway operator perceives a need to revise the operational period and design flow range, documentation should be provided for Engineering and Service biologists to review.

4.3.4 Alternate Methods

Alternate methods, some of which are listed below, may be used to determine fishway design flows but should be reviewed by Engineering.

4.3.4.1 Three Day Delay Discharge Frequency Analysis

An alternate method to compute a fishway high design flow is through a three day delay flow duration analysis, proposed by Katopodis (1992). In this method, a flow duration analysis is performed using Q_{3d} (the largest daily average streamflow value that is equaled or exceeded three times in three consecutive days over the fish migration period during a particular year) as the independent variable. The high design flow is set equal to the Q_{3d} value which corresponds to an exceedance probability of 0.1 (or a 10-year return period). This return period is chosen assuming that a delay period of greater than three days is acceptable if occurring at a frequency of once every ten years (or more).

4.3.4.2 USGS Regression Analysis

The USGS has developed regional regression equations to estimate flow duration events based on watershed area, annual precipitation, and regional variables (Natural Resource Conservation Service (NRCS), 2007). The USGS StreamStats tool (http://water.usgs.gov/osw/streamstats/) offers a simple way to access some of these regression equations.

4.3.4.3 Mean Flow Indices

The mean flow indices method computes the high design flow based on a multiple (e.g., three to four) of annual or monthly average streamflow. In the case of using monthly average streamflow, the month in which the peak of the migration season occurs is normally selected. In most situations, the Service recommends against using this technique because it provides no estimate of frequency or duration of passable conditions.

4.3.4.4 Regional flow-duration curves for ungaged sites

Methods to create regional flow-duration curves for ungaged sites have been developed in New Hampshire (Dingman, 1978) and Massachusetts (Fennessey and Vogel, 1990).

4.4 Flood Flow Considerations

In consideration of significant flood flows event and their adverse impact on in-stream structures, major fishways should be designed:

- to prevent overtopping of the fishway under any event up to the 50 year flood;
- with adequate protections (e.g., flood wall) and contingencies (e.g., crane access) to ensure the fishway may be returned to service within one week following any event up to the 50 year flood;

- with sufficient integrity to ensure that major structural elements (e.g., entrance channels, concrete fishway pools, and other water-retaining structures) can withstand any event less than the dam's (or spillway's) design storm.

5 Hydraulic Design Considerations

Many anadromous species make tremendous journeys over the course of their lives. The freshwater portion of the "sea to source" path is an arduous one characterized by an energetically demanding migration upstream to reach spawning habitat, relying on stored energy reserves (Glebe and Leggett, 1981; Leonard and McCormick, 1999). For iteroparous fishes, their post-spawning return journey to the ocean is equally challenging and often initiated under the stress of greatly reduced energy reserves in less favorable environmental conditions (e.g., elevated water temperatures). These challenges are compounded by the presence of dams and hydropower projects which create impoundments, bypass natural river reaches via canals, and channel significant portions of the river flow through hydroelectric turbines including into pumped storage reservoirs. Technical fishways provide a corridor for migrants to pass stream barriers, but in doing so can create complex hydraulic conditions such as turbulence and plunging flow. The following subsections provide an overview of the key hydraulic concepts associated with a fishway and how fish biology informs hydraulic design. Each of these concepts must be evaluated over the full operating range of the fishway.

5.1 Depth

Providing sufficient depth allows fish to swim normally (i.e., fully submerged, including dorsal fin) and may alleviate any adverse behavioral reaction to shallow water. In general, Engineering recommends a depth of flow greater than or equal to two times the largest fish's body depth. This minimum water depth may occur during operation at low design flows, particularly in nature like fishways. Where the water depth varies over a passage structure (e.g. a weir), the depth of flow is measured from the fish's approach. Table 2 shows the recommended minimum entrance depths for technical fishways. Minimum entrance depth, also known as submergence, refers to the vertical distance between the invert of the fishway entrance floor to the tailwater (or downstream pool) surface elevation. These minimum depths incorporate factors such as fishway capacity and hydraulic design; thus, they generally override the body-depth-based criterion above. For fishways that employ vertical-lift or hinged overshot gates to achieve entrance velocities, these gates must maintain a minimum of two body depths at all times; however, for American shad, a submergence depth of 3.0 feet is recommended (see Appendix A, Reference Plate 6-3 "Fishway Entrance Gates"). Similarly, the minimum depth at an entrance gate, or submergence depth, is measured as the vertical distance between the gate lip or crest to the tailwater (or downstream pool) surface elevation. Different depth criteria may apply to other fishway components for similar reasons.

5.2 Width

In a natural environment, fish are accustomed to moving in an open river. Fishways, by necessity, concentrate flow and narrow openings accelerate velocity. These resulting conditions may exceed swimming ability, injure fish or elicit an avoidance response. These factors must be taken into consideration when designing a fishway. Table 2 below displays typical ranges of entrance widths and minimum entrance depths for several technical fishway types. Note that specific site conditions may warrant values outside of these ranges.

Table 2: Typical fishway entrance widths and minimum depths.

Fishway Type	Entrance Widths (ft)	Minimum Entrance Depth (ft)
Standard Denil	2 - 4	2
Model A/A40 Steeppass	1.17	1.08
Ice Harbor	4 - 10	4
Vertical Slot	4 - 10	4
Fish Lift	4 - 14	4

5.3 Velocity

By design, fishways create spatially and temporally variable water velocities (e.g., low speed in a quiescent pool and high speed over a weir crest). The desired range is dependent upon: 1) the swim speed abilities; and 2) the endurance of the target fish species (the duration in which the swim speed can be sustained), Δt (Larinier et al., 2002).

5.3.1 Swimming Performance Model

Species and site specific data and models are preferred in estimating the swimming abilities of fish. In the absence of such information, a three-tiered model, described below, is a suitable method for describing the swimming abilities (swim speed and endurance) of fish. However, the existing literature contains inconsistent usage of terms to describe each of the three swimming modes (Beamish, 1978; Bell, 1991; Katopodis, 1992). For the purposes of this manual, the swimming modes will be referred to as cruising, prolonged, and burst (Bell, 1991). Further details are below and can also be found on Appendix A, Reference Plate 5-1 "Swim Speed Categories."

- *Cruising speed, V_c*
  - The swim speed a fish can maintain for hours without causing any major physiological changes.
  - An aerobic muscle activity ("red" muscle tissue).
  - Influenced by temperature and oxygen; Bell (1991) suggests swim speeds reduced by 50% at extreme temperatures.
  - For fishway design, V_C should be used for transport flumes, holding pools, etc.
- *Prolonged speed, V_P*
  - The swim speed a fish can maintain for minutes; tires the fish.
  - An aerobic and anaerobic ("white" muscle tissue) muscle activity, in variable proportions.
  - Bain and Stevenson (1999) suggests speed can be maintained for 5-8 minutes; Beamish (1978) suggests 20 seconds to 200 minutes.
  - $4 \text{ BL/s} \leq V_P \leq 7 \text{ BL/s}$ (BL/s → body lengths per second).
  - For fishway design, V_P can be used in conjunction with the duration of the swim speed, Δt, to estimate travel distance, D, before fatigue.
- *Burst speed, V_B*
  - The swim speed a fish can maintain for seconds.
  - Species specific, with correlation among similar species (e.g., salmonids).
  - Primarily an anaerobic muscle activity.
  - Bell (1991) suggests speed can be maintained for 5-10 seconds; Bain and Stevenson (1999) 2-3 seconds; Beamish (1978) < 20 seconds.
  - Decreases at extreme water temperature (high or low).
  - Increases with length of fish; Speed used for predator avoidance or feeding; in fishways, use to ascend weir crests.
  - For fishway design, velocities should be kept below V_B for the weakest target species at all times.

Eq. (5) below relates each of the swim speeds:

$$V_C \approx \frac{1}{3} V_P \approx \frac{1}{6} V_B \qquad \text{Eq. (5)}$$

The following are examples of how the swimming performance is considered in the design of a fishway:

- 200 foot long roughened rock ramp nature like fishway might be designed to allow prolonged speed for an alewife, 3 feet per second (fps);
- A pool-and-weir ladder for alewife might be designed for the combination of burst speed (over weirs) followed by prolonged speed (in pools), 6 fps vs 1 fps.

5.3.2 Fatigue

A fishway must be designed such that no velocity barriers impede safe, timely, and effective passage. Water velocity becomes a barrier when: 1) the water velocity is greater than the burst speed of the fish; or 2) the fish fatigues prior to passing an area of high velocity. Engineering recommends the use of one or more of the following methods to estimate the level of fatigue a fish will incur during an attempt to pass the barrier:

- *Fatigue – Distance Model;* A concept based in the knowledge of the swimming performance model. For an example in its simplest form, the distance a fish can swim at a prolonged speed prior to fatigue, D, can be calculated by the following set of equations:
    - $V_g = V_w - V_P$, where V_g is the speed of the fish relative to the ground and V_w is the water velocity;
    - $D = V_g \Delta t$, given Δt for V_P is 5 minutes $\leq \Delta t \leq$ 8 minutes.

  A more sophisticated Fatigue – Distance approach was proposed by Castro-Santos (2004).
- *Work – Energy Model;* Utilizes fluid mechanics to estimate the virtual mass force, non-Archimedean buoyant force, and profile drag on fish in order to estimate the net propulsive power and net energy required by a fish to pass a fishway (Behlke, 1991).
- *Survival Analysis Model;* The survivorship function describes the proportion of fish successfully passing a velocity barrier of distance, D. The equation is a function of six species-specific variables including: shape and scale parameters, temperature, fork length, velocity coefficients, and a regression intercept (Haro et al., 2004).

5.4 Turbulence, Air Entrainment, and the Energy Dissipation Factor

Turbulence has been shown to influence both swimming behavior and performance of fish (Lupandin, 2005; Enders et al., 2003; Pavlov et al., 2000). A phenomenon common to the natural river environment, turbulence is often exacerbated by the dissipation of energy that is characteristic of dams and other anthropogenic in-stream structures. In many cases, the dissipation is the result of a rapid conversion of potential energy to kinetic energy (e.g., high velocity flow over a spillway impounding a quiescent reservoir). Fishways overcome these barriers by providing continuous hydraulic pathways over or around dams. Kinetic energy in these pathways must be dissipated to ensure flow velocities do not exceed the swimming ability of fish. Dissipation can be effected through increased roughness (form or surface) or through the momentum exchange that occurs when high speed jets discharge into larger quiescent pools. However, excessive power dissipation or energy dissipation rates can also lead to unwanted turbulence and air entrainment. Thus, the challenge is to design a fishway that simultaneously reduces flow velocities to speeds below maximum fish swimming speeds while maintaining acceptably low levels of turbulence (Towler et al., 2015). Engineering's preferred metric of turbulence in the design of fishways is the energy dissipation factor (EDF).

- The EDF is a measure of the volumetric power (or rate of energy) dissipation in a pool, chute or stream reach.
- The EDF is particularly useful because it correlates well to meso-scale turbulence (e.g., eddies the size of fish) and aeration.
- Eq. (6) expresses the potential energy loss (or dissipation) rate per unit length of fishway (Towler et al., 2015) and is the basis for the EDF:

$$loss_{1-2} = \gamma_w Q \frac{dh}{d\ell} \qquad \text{Eq. (6)}$$

where dh/dℓ is the effective hydraulic gradient, γ_w is the unit weight of water in pound per cubic feet (lbf/ft^3), Q is the flow rate in cubic feet per second (cfs), and $loss_{1-2}$ is the energy loss rate per unit length of fishway from cross section 1 (upstream) to cross section 2 (downstream).

Specific forms of the EDF equation and criteria values are discussed in Section 6.7. Criteria and threshold EDF values are presented on Appendix A, Reference Plate 5-2 "Power Dissipation Rates."

5.5 Streaming and Plunging Flow

In pool-type fish ladders, the hydraulic jet formed over the upstream control (e.g., weir, low flow notch) typically either plunges downwards into the pool (referred to as "plunging flow") or skims across the pool surface toward the downstream control (referred to as "streaming flow"). At lower flow rates, plunging flow conditions develop producing two counter-rotating hydraulics or rollers. These rollers are efficient at dissipating energy due to the rapid momentum transfer between the submerged jet and the surrounding water. At higher flow rates, streaming flow conditions develop creating a lesser forward hydraulic and a pronounced jet which skims across the pool surfaces and weir crests. These regimes have been shown to correlate with a dimensionless transitional flow term, Q_t:

$$Q_t = \frac{Q_w}{BSL^{3/2}\sqrt{g}} \qquad \text{Eq. (7)}$$

where Q_w is the flow over the weir in cfs, B is the width of the weir in ft, L is the length of the pool in ft, S is the arithmetic slope of the fishway, and g is the acceleration due to gravity.

The transition from plunging flow to streaming flow has been shown to occur in the range of $0.22 \leq Q_t \leq 0.31$ (Rajaratnam et al., 1988). As implied by the range, the transition from plunging to streaming flow is difficult to predict precisely. From a design standpoint, this transitional regime should be avoided because of its inherent instability (i.e., the flow regime may change between streaming and plunging when within this range). Furthermore, significant anadromous target species for the East Coast (e.g., American shad and alewife) have difficulty leaping over or ascending plunging flow nappes. For these reasons, Engineering recommends that pool-type fish ladders meet or exceed a transition discharge parameter of $Q_t = 0.31$ to ensure operation in the streaming flow regime. Figure 1 further illustrates plunging and streaming flow conditions in a pool-type fish ladder.

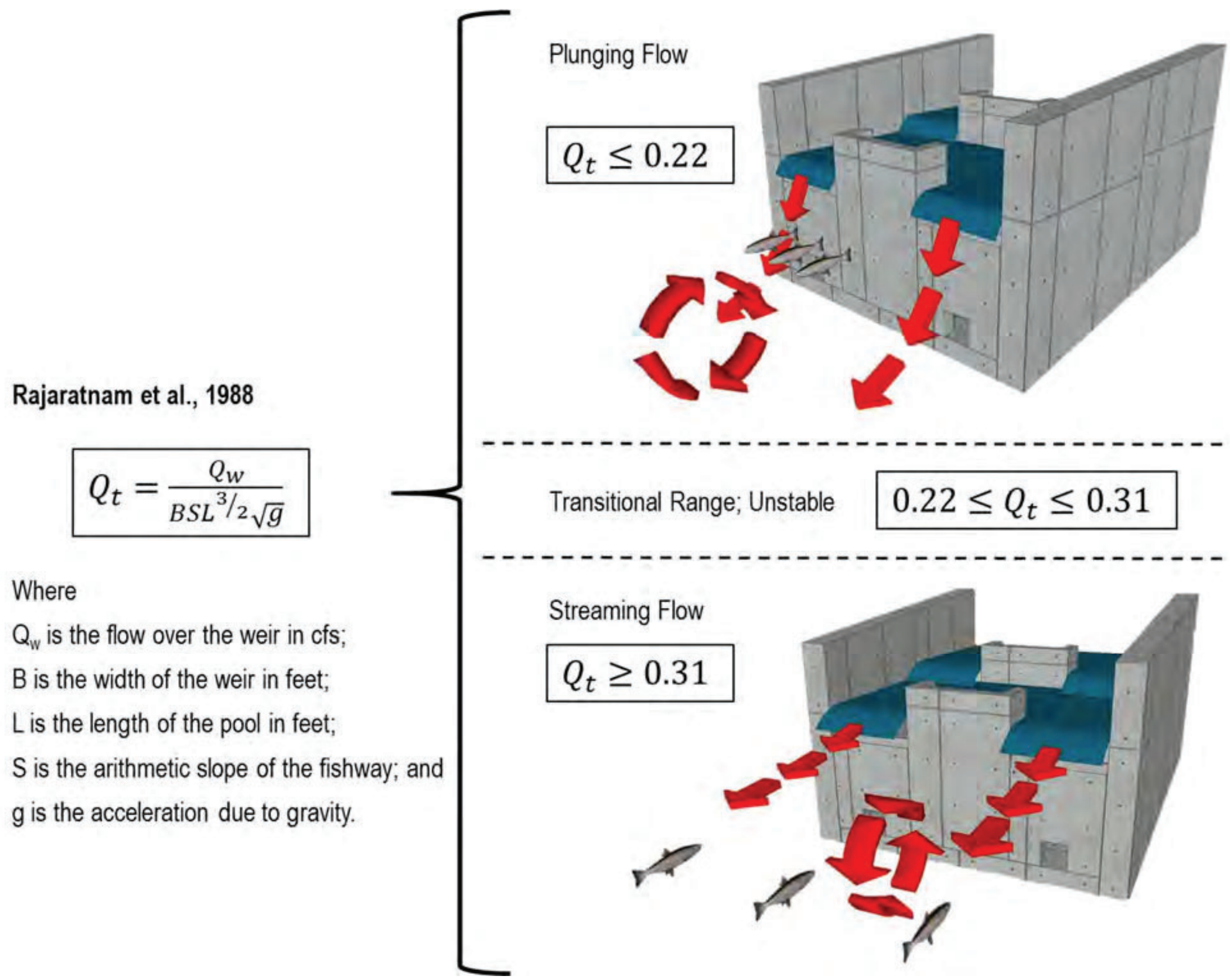


Figure 1: Plunging versus streaming flow conditions.

Plunging versus streaming flow conditions illustrated within an Ice Harbor fishway.

5.6 Water Temperature

Water temperature plays a significant role in regulating migratory fish behavior, performance, physiology, and survival. A sudden change in water temperature within the zone of passage at any fishway is an environmental condition of particular concern in fish passage (Caudill et al., 2013). Reservoirs or impoundments created by dams that are operated for hydroelectric storage or generation often experience thermal layering within their vertical water column. Thermal stratification upstream of dams is more pronounced in the following circumstances; greater dam height, longer mean water retention time in the impoundment, at lower seasonal flows (i.e., late summer and early fall), and with larger impoundment surface area and concomitant insolation.

At dam sites where the intakes for the turbine units in the powerhouse are at a lower elevation than the intake for the attraction water of the fishway, migratory fish may encounter relatively cool water in the dam tailrace, and then experience warmer water after entering the fishway. Temperature gradients (ΔT) within a fishway zone of passage could potentially become migration obstacles that slow fish passage and increase the rate of fallback. With regard to migratory fish, Caudill et al. (2013) demonstrated: 1) that there is a consistent association between temperature gradients larger than one degree Celsius ($\Delta T > 1.0°C$) and an increase in fish passage times (i.e., delay); and that 2) fish body temperatures increase with temperature gradients within the fishway.

Where feasible, supplemental or auxiliary water system intakes should be installed and oriented to avoid introducing adverse temperature gradients within the fishway.

5.7 Other Considerations

Fish size, physiological/spawning state, and environmental conditions are additional factors influencing fish movement, behavior (e.g., propensity to pass in schools or groups), passage efficiency, and ultimately passage restoration effectiveness as described in Appendix C, "Federal Interagency Nature-like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes" (Turek et al., 2016).

6 General Upstream Fish Passage

As described in Section 2.1, the term "fishway" has a comprehensive definition that encompasses many different technologies. Appendix A, Reference Plate 6-1 "Fishway Types," relates common fishway types and their broader categories. This section provides information related to many different upstream fishways.

6.1 Site Considerations

A myriad of site-specific factors must be considered prior to the design of a fishway. These include, but are not limited to, the following:

- Topography and bathymetry data;
- Details of existing barrier (plan view map, elevations, etc.);
- Project operational information (powerhouse capacity, period of operation, etc.);
- Project forebay and tailwater rating curves;
- River morphology trends;
- Soil conditions;
- Accessibility;
- Target and non-target species at the site that require passage;
- Predatory species at the site.

6.2 Zone of Passage for Upstream Migration

The ZOP (defined in Section 2.2), as it pertains to upstream migration, encompasses a far-field attraction zone, a near-field attraction zone, the fish passage facility, and the impoundment upstream of the barrier.

Numerous other conceptual models have been developed to describe the regions influenced by a hydroelectric project beyond the fishway entrance and exit. For example, Castro-Santos and Perry (2012) and Castro-Santos (2012) partition this area into three regions: an approach zone, an entry zone, and a passage zone; the former two regions describing areas downstream of the fish passage facility entrance, the latter zone referring to movement within the fishway (e.g., ladder, lift).

6.3 Fishway Attraction

6.3.1 Competing Flows

At typical hydroelectric facilities, river flows are passed over, through, and around various machines and water-control structures. The resulting flows are often complex and spatially separated. The flow fields created by these project elements (i.e., turbines, spillways, flood gates, and trash/log sluices), may attract (or dissuade) fish and thus, compete with the directional cues created by fishways. Figure 2 displays an example of the competing flows created by various project elements at a hydroelectric facility.

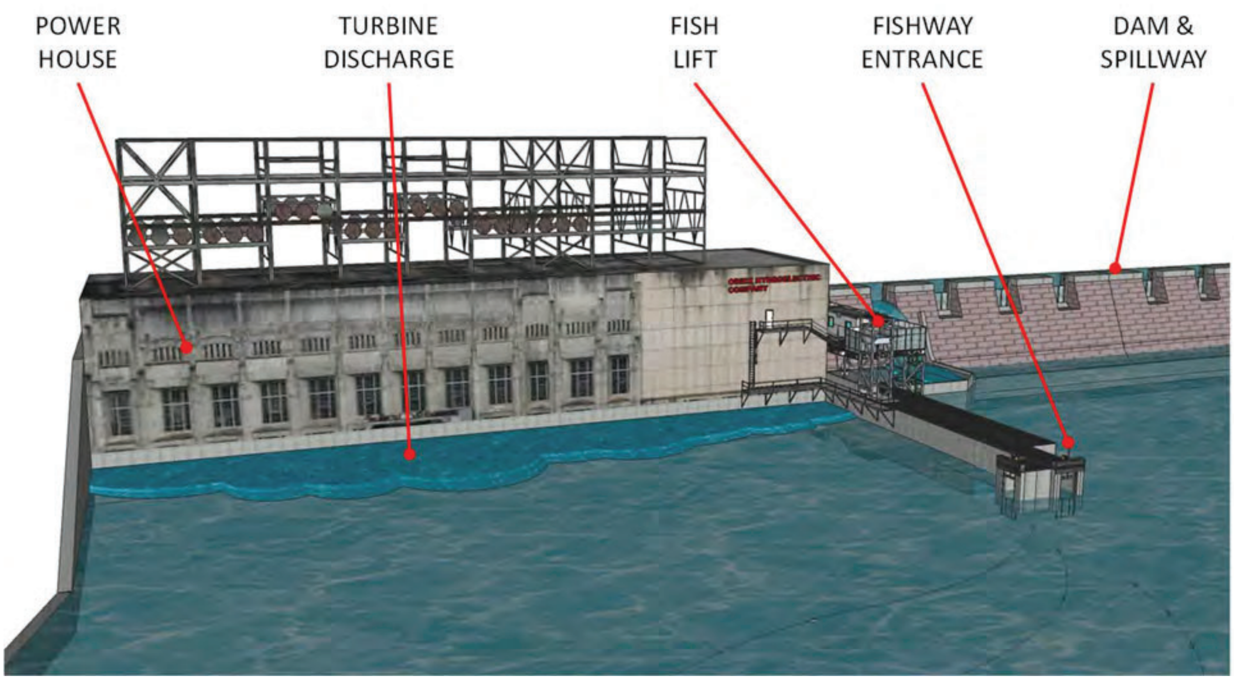


Figure 2: An example of competing flow fields at a hydroelectric facility.

In this illustration, the turbine discharge acts as the primary competing flow field to the attraction flow from the fishway entrances. The flood gates, when opened, act as another competing flow field.

6.3.2 Attraction Flow

Successful fishways must create hydraulic signals strong enough to attract fish to one or multiple entrances in the presence of competing flows (i.e., false attraction). Under most operating conditions, fishways do not directly discharge sufficient attraction flow. Therefore, to create adequate attraction flow, fishways must be supplemented by auxiliary water. The terms fishway "attraction water" or "attraction flow" refer to the combination of discharges from an operating fishway and associated auxiliary water systems (AWS).

In a survey of the literature, the following two approaches for determining adequate attraction flow were identified:

- *Statistical Hydrology:* This approach sets the attraction flow equal to a percentage of a hydrologic statistical measure (e.g., 5% of the mean annual river flow).
- *Percentage of Competing Flows:* This approach expresses attraction flow as a percentage of the sum of other competing flows. Recognizing that powerhouse discharge is typically the most dominant and predictable competing flow (especially at run-of-river projects), this method is often simplified to express attraction flow as a percentage of powerhouse hydraulic capacity.

In general, the higher the percentage of total river flow used for attraction into the fishway, the more effective the facilities will be in providing upstream passage (National Marine Fisheries Service (NMFS), 2011a). For non-hydropower sites, NMFS' Northwest Region recommends an attraction flow between 5% and 10% of the high design flow (see Section 4.3.2) for streams with mean annual flows greater than 1,000 cfs; for smaller streams, a larger percentage is recommended. For hydropower sites, Engineering expresses the attraction flow requirement as a fraction of the competing flows (e.g., turbine discharge). Specifically, Engineering recommends that fishways be designed for a minimum attraction flow per fishway equal to 5% of the total station hydraulic capacity or a flow rate of 50 cfs, whichever is greater. In addition, Engineering's preference is that the entirety of the attraction flow be discharged through, or at, the fishway entrance(s). While adjacent turbine units can often be sequenced to attract fish to the fishway entrance, the discharge from the turbine is not generally used to meet, in whole or in part, the Service's attraction flow requirement.

6.4 Entrance

The entrance for upstream passage is a structure through which: 1) fish access the fishway; and 2) attraction flow is discharged into the tailrace and/or surrounding river channel. A properly designed and operated entrance is critical to passage success. The entrance is typically equipped with a water control gate or submerged weir boards to develop the high velocity attraction jet.

The entrance transitions into an entrance channel, which may include a collection gallery. Figure 3 illustrates an example of an entrance gate and channel in the lower section of a fish lift.

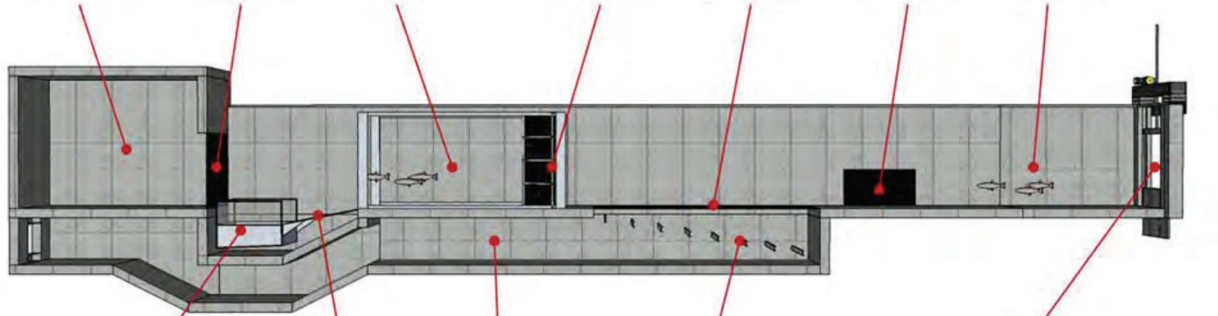


Figure 3: Cross-sectional view of the lower section of a fish lift.

A cross-sectional view of the lower section of a fish lift, including the entrance gate, entrance channel, AWS chamber, and hopper

6.4.1 <u>Location</u>

Fishway entrances should be located where migrating fish will quickly detect the entrance through the discharge of attraction flow. Observation of fish movement patterns downstream of the barrier can help to inform the ideal entrance location. Generally, the entrance should be located immediately downstream of the barrier and adjacent to the dominant source of far field attraction flow (e.g., powerhouse discharge, spillway). In some cases, excavation to create a deeper, slower, and less turbulent region at the fishway entrance and/or additional entrances is required. In other cases, locating the fishway entrance (or one of multiple entrances) downstream of, or laterally separated from, a highly turbulent area or other source of false attraction may be necessary. The combined discharge of the fishway and AWS should create an attraction jet that migrating fish will sense as they approach the entrance. In general, the design should minimize the impacts of competing flows (e.g., turbine boil, spill) on the direction, magnitude, and coherence of the attraction jet to ensure its hydraulic signal reaches as far downstream (from the entrance) as possible. Hydraulic modeling (i.e., physical models, computational fluid dynamics models) may be needed to identify optimal entrance locations at complex sites.

6.4.2 Orientation

The attraction jet discharged from the fishway entrance is directly influenced by both the orientation of the entrance structure and the competing flow fields (e.g., turbine discharge). Entrances adjacent to appreciable competing flows should be oriented parallel to the direction of the competing flow field to maximize the influence of the attraction jet's hydraulic cue downstream. Entrances without significant competing flow (e.g., water supply dams) should be oriented perpendicular to the dam to project the jet laterally across the length of the barrier. These are generalized cases; project-specific entrance orientation should be developed in consultation with Engineering. Hydraulic modeling (i.e., physical models, computational fluid dynamics models) may be needed to identify optimal entrance orientations at complex sites.

6.4.3 Entrance Width

Fishway entrance width is influenced largely by: 1) the attraction discharge flow rate; and 2) the behavioral tendencies (e.g., schooling or shoaling) of target species.

- At hydroelectric projects, fishway entrances should be 4.0 feet wide or greater; exceptions may include minor projects with small baffled chute fishways (i.e., 3-foot-wide Denil ladders, or steeppasses).
- Additional width (greater than 4 feet), may be required to ensure entrance jet velocity criteria are maintained (see Section 6.4.5).
- Where adjustable contractions at the entrance are necessary to accelerate flow, an automated gate is preferred, but manual gates or stop logs may be acceptable. Lateral contractions, such as a horizontal slide gate, may be used to accelerate the flow (and thus reduce width); however the opening width should be 1.5 feet or greater at all times.
- On Standard Denil ladders, permanent lateral contractions at the entrance to accelerate flow may be appropriate. To avoid adverse hydraulics, the entrance width should be greater than or equal to 62.5% (5/8) of the chute channel width. Additionally, the lateral contraction should be beveled or rounded to promote favorable hydraulics.

6.4.4 Entrance Depth

The depth of water at the entrance influences entry into baffled chute fishways. Denil entrances should always maintain a minimum of 2 feet of depth above the channel invert or vertical constriction (i.e., gate lip or weir boards). Model A and A40 steeppass ladders discharge very little flow and rarely include auxiliary water systems. Consequently, vertical constriction of the steeppass' limited depth is not recommended.

At large fishways, the entrance depth should be evaluated in terms of the submergence of the gate crest. The submergence depth is calculated as the vertical distance between the elevations of the tailwater and crest of the entrance gate or weir boards (Figure 4). In a laboratory setting, Mulligan et al. (2018) measured the fishway entry rates of American shad under different gate arrangements and hydraulic conditions. Results demonstrated that a submergence depth of 0.914 meters (3 feet) greatly increased entry rates.

- Engineering recommends that large fishways designed for American shad and other alosines maintain a submergence depth of 3 feet or greater.
- Where entrances are not controlled by a gate or restricted by a weir, an unrestricted entrance depth of 4 feet or greater is recommended.

6.4.5 Entrance Jet Velocity

The entrance jet, or attraction flow jet, refers to the locally accelerated velocity field (typically created by a gate or weir boards) and projected downstream of the entrance into the tailwater. For a fishway to be effective, the velocity of the jet and quantity of attraction flow must produce enough momentum to project into the tailwater to a point where fish are commonly present; this will create the opportunity for fish to detect the hydraulic cue created by the jet. Concurrently, the jet velocity must not be so high that it creates a velocity barrier to migrating fish.

The relationship between entrance gate settings and entrance velocity are based on specified channel geometry, width of the entrance gate, inclined angle of the gate measured from the horizontal axis (e.g., 90 degrees is a vertical lift gate), tailwater elevations, level of gate submergence, and attraction flow. Gate positions must be adjusted in response to varying tailwater elevations in order to maintain favorable fish passage conditions. For additional details, refer to Appendix A, Reference Plate 6-3 “Fishway Entrance Gates”.

For East Coast projects, Engineering recommends that the entrance jet velocity (measured at the entrance) be within a range of 4 to 6 fps at any site where river herring are present. If only the stronger swimming Atlantic salmon and American shad are present, then an entrance jet velocity of 6 to 8 fps is permissible. General recommendations from other sources are below:

- Larinier et al. (2002) states that "for most species, a speed of the order of 1 m/s (3.28 fps) would normally be the minimum…The optimal speed for salmonids and large migrants is of the order of 2 m/s to 2.4 m/s (6.56 fps to 7.87 fps)."
- Clay (1995) states that the entrance jet velocity for salmon should be a minimum of 4 fps. The author also states that it "is doubtful if 8 fps may be safely exceeded even for the strongest fish, and velocities approaching this value should be maintained for only a short distance at the entrance of the fishway."

6.4.6 Entrance Channels

The entrance channel is the section of the fishway that hydraulically connects the most downstream baffle/weir of a ladder or the crowder of a fish lift to the entrance gate/weir boards. Water enters the entrance channel through either the upstream ladder or the AWS diffusers and discharges into the tailrace or surrounding flow field through the fishway entrance. The location and size of AWS horizontal and vertical attraction flow diffusers will influence the entrance channel geometry. In ladders, vertical (wall) diffusers and horizontal (floor) diffusers are incorporated downstream of the last baffle or weir. In lifts, a portion of the AWS diffusers are incorporated upstream of the hopper; the remaining portion are built into the entrance channel downstream of the crowder.

- Velocities within the entrance channel should be within the range of 1.5 to 4 fps and be as close to a uniform velocity distribution as possible; however, the upper end of this range (i.e., 4 fps) is intended to accommodate the accumulation of flow discharged by internal wall and floor diffusers and should never occur within the holding pool.
- The entrance channel should be void of high turbulent and aeration zones.
- Generally, the entrance channel in large technical fishways should be designed for a depth of 6 feet below normal tailwater; though in operation, actual depth may be adjusted (via gate or weir boards) to meet the attraction flow and entrance velocity jet requirements.

6.4.7 Collection Galleries

A collection gallery is a type of manifold fishway entrance constructed on the downstream face of the powerhouse above the turbine outlets (i.e., draft tubes). The gallery provides multiple entrances to a common conveyance channel connected to the fishway (Clay, 1995; FAO/DVWK, 2002). Velocity within the collection gallery should be maintained between 1.5 fps to 4.0 fps.

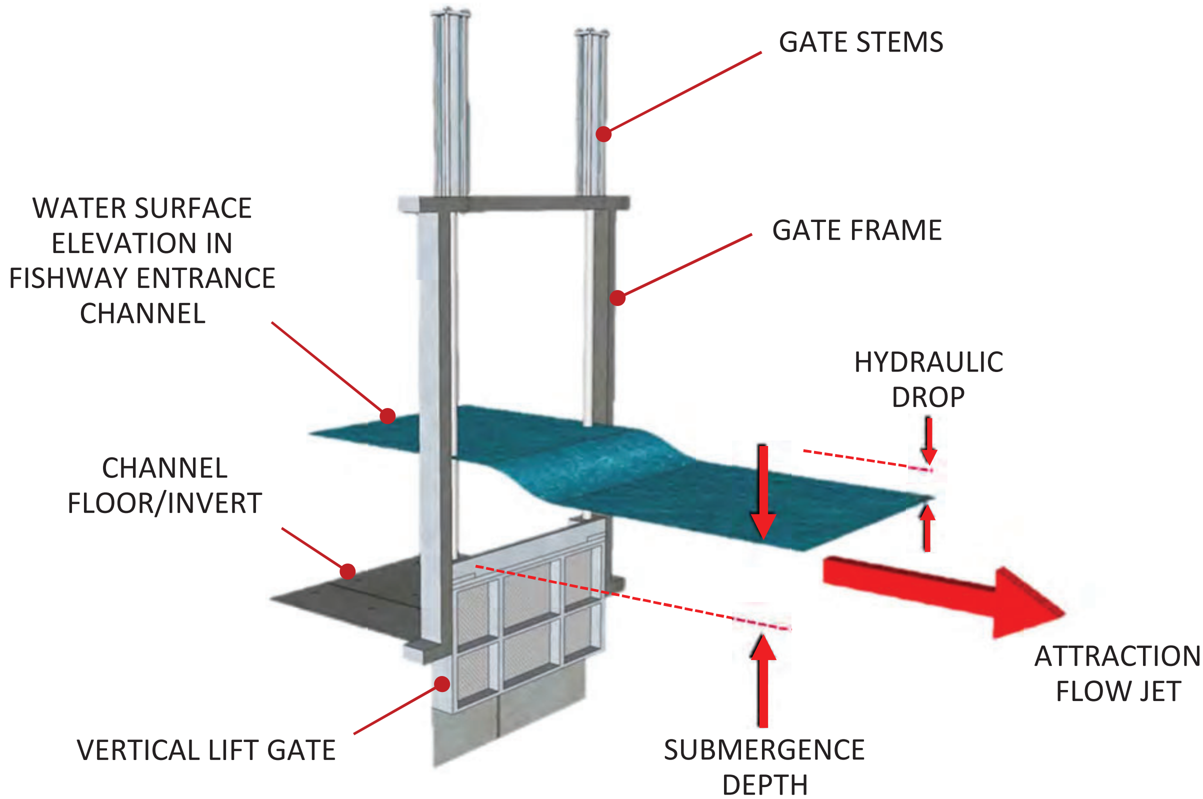


Figure 4: A typical entrance gate at a large technical fishway.

The hydraulic drop across the gate is a function of the inclined gate angle (here shown as vertical, e.g., 90 degrees), attraction flow rate, entrance channel geometry, gate width, and tailwater elevations.

6.4.8 <u>General Considerations</u>

- The hydraulic drop across the entrance (Figure 4) should not produce plunging flow (see Section 5.5).
- A fishway entrance located on or adjacent to a spillway should be protected by a non-overflow section; non-overflow sections can be created using flashboards.
- The non-overflow structure should be designed provide sufficient separation between the spillway and the entrance that ensures coherence of the attraction jet without creating a

quiescent area (between the flows) that would be prone to the formation of large scale eddies.

- Mulligan et al. (2018) have shown American shad prefer overshot gates to vertical lift gates (see Appendix A, Reference Plate 6-3 “Fishway Entrance Gates”).

6.5 Exit

The fishway exit for upstream passage is the structure through which: 1) fish exit the facility; 2) water enters the fishway; and in some cases, 3) water enters the AWS. The exit refers to both the actual exit immediately downstream of the exit trash rack and the exit channel immediately downstream of the actual exit and upstream of the ladder or lift. The fishway exit diminishes the effect of headwater fluctuations and creates adequate hydraulic conditions as the flow enters the downstream sections of the fishway (e.g., pool-and-weirs). Figure 5 displays an example of a fishway exit at a lift, including the exit flume, crowder for a counting facility, and exit trash rack.

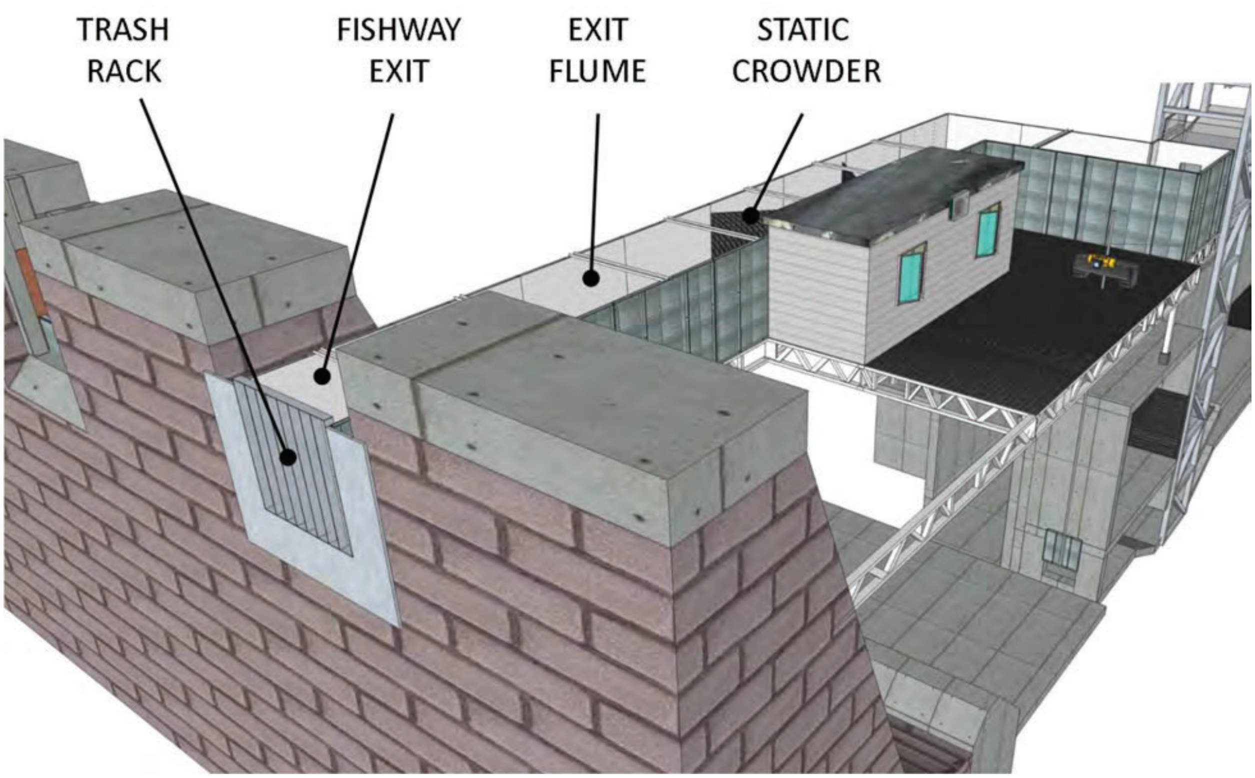


Figure 5: Example of a fish lift exit.

Example of a fish lift exit, including the exit trash rack and flume.

6.5.1 Location

The location of a fishway exit must consider: 1) possible exhaustion after swimming through a volitional fishway, 2) the risk for the fish to be overwhelmed by the surrounding flow field and either fall back downstream of the barrier or be entrained into the turbines; and 3) the potential for debris accumulation.

- Engineering recommends the fishway exit be placed along the bank of the river channel in a region where water velocities are less than or equal to 4 fps.

6.5.2 Orientation

The fishway exit should be oriented such that the flow entering the exit is at an angle of 0 (parallel) to 45 degrees from the main river flow surrounding the exit.

6.5.3 Depth of Flow

The depth of flow within the exit flume should be a minimum of 4.0 feet for any lift or large pool-type fishway. The depth of flow in any exit flume connected to a baffled chute ladder is determined by the minimum operating depth of the baffled chute. No fishway should operate with flow depth less than two fish body depths at all times and locations.

6.5.4 Velocity at Exit

Velocities within an exit section should be less than 1.5 fps so that fish can enter the forebay without undue difficulty or exertion.

6.5.5 Trash (Grizzly) Racks

Coarse trash racks should be installed immediately upstream of the fishway exit to stop large debris (e.g., trees) from entering the fishway. If large debris enters the fishway, it may partially block passage, result in unintended velocity barriers, or cause injury to fish.

- The bottom of the coarse trash rack should be set at the invert of the fishway exit.
- The rack should extend above the elevation corresponding to the high design flow or, if present, to the top of the working deck.
- The rack should be installed at a maximum slope of 1:5 Horizontal/Vertical (H:V) to enable cleaning.

- To avoid an adverse behavioral reaction from the fish, the exit trash rack should have a 12-inch (in.) minimum clear space between the vertical bars. Common designs use 3/8 in. thick, 3-4 in. wide flat stock for vertical bars.
- Horizontal structural support bars may impact fish movement and are not recommended. Where necessary, horizontal bars must be kept as distant as possible above the free surface. Increasing vertical bar thickness (or otherwise increasing section modulus) may reduce the need for horizontal supports.
- The gross velocity through a clean coarse trash rack, Eq. (8), should be less than 1.5 fps:

$$V_g = \frac{Q}{A_g} \qquad \text{Eq. (8)}$$

where Q is the flow through the exit in cfs, A_g is the trash rack gross area (the projected vertical surface area of the unobstructed opening) in square feet (ft^2), and V_g is the gross velocity in fps.

- On sites where debris loading is expected to be high, the fishway design should include debris booms, curtain walls, and an automated mechanical debris removal system.

6.5.6 Exit Gates

An exit gate is the water control mechanism used for dewatering a fishway during maintenance or off season. The design of an exit gate must ensure that it in no way adversely affects fish movement. Gate stems, bolts, and other potentially injurious protrusions should never be in the path of fish. An exit gate must be fully open during fish passage operations. Orifice conditions can locally accelerate the flow which may unnecessarily fatigue, confuse, or delay fish as they exit the ladder or lift. Creating an orifice condition to skim debris or throttle flow is not acceptable. If debris accumulation in the fishway is severe, a porous screen (e.g., perforated plate, grating, netting) may be used at the surface provided the water depth at the exit is 4 feet or more. The screen, presumably hung from the bottom of a vertical lift gate (or immediately upstream of it), should not be submerged more than 1 foot into the water column.

6.6 Fishway Capacity

In general, fishway capacity is a measure of the quantity of fish that the facility can successfully convey, upstream or downstream, in a given period. Timing and space constraints inherent in upstream passage are generally not critical in downstream passage design. Therefore, the criteria and methods presented in this section are limited to upstream technology.

6.6.1 Population and Loading

Migratory runs of anadromous fish on the East Coast tend to be of a highly compressed duration. A properly designed fishway will limit the effect of crowding and minimize delay caused by the barrier during these migratory runs. The quantity of fish that the fishway can safely, timely, and effectively convey over a barrier in a given time period is referred to as the fishway (or biological) capacity. Biological capacity of a fishway may be expressed as the number or pounds of fish per unit of time. Typical time periods include annual, daily, and hourly.

The annual biological capacity, n_T, is defined as the total annual count of fish designed to pass a barrier through the fishway. In the design of a new fishway, this value is set equal to the annual design population (refer to Section 3.0).

The peak day, n_D, is defined as the largest number of fish designed to pass during a 24-hour period. One approach to calculate the peak day is to use the following regression equation:

$$n_D = n_T[0.4193 - 0.026 \ln n_T] \qquad \text{Eq. (9)}$$

where n_T is the annual biological capacity of the fishway. Eq. (9) is based on a regression analysis of fish counts of American shad passing the Bonneville and The Dalles dams on the Columbia River during the periods 1938-1966 (Bonneville) and 1957-1966 (The Dalles) (Rizzo, 2008). Eq. (9) is valid over a range of n_T from 2,800 to 1,250,000.

The peak hour, n_H, is defined as the largest number of fish designed to pass in a 1-hour period during the peak day. For existing, well-performing facilities, n_H is estimated using historical count data. For new facilities, Engineering's approach is to develop fish count regression analyses on similar facilities, in similar locations, that pass the same target species (or a reasonable surrogate fish). In the absence of better data, the following relationship between peak day and peak hour may be used for screening-level estimates:

$$n_H = \beta n_D \qquad \text{Eq. (10)}$$

Where β is a coefficient ranging from 0.10 to 0.20.

In addition, it is convenient to define the average number of fish passed per minute during the peak hour:

$$n_M = n_H \left(\frac{1\,hr}{60\,m}\right) \qquad \text{Eq. (11)}$$

In a typical design process, these values are provided by, or developed in consultation with, the fisheries agency or project biologist.

6.6.2 Fish Lifts and Pool-Type Fishways Capacity Parameters

In order to convert the peak hour rate, n_H, into an expression of volume per unit time (required for fishway capacity calculations of pool-type fishways and fish lifts), the following parameters must first be estimated.

6.6.2.1 Design Adult Weight for Selected Species

For the purposes of the fishway capacity calculation, a design weight must be selected for the target species at a specified life stage. Engineering recommends the use of the following design weights, w_f, for prevalent adult anadromous fish species on the East Coast.

Table 3: Design adult weight for selected species, w_f.

Species	Design Adult Weight, w_f (lb)
American shad	4.0
Alewives	0.5
Blueback herring	0.5
Atlantic salmon	8.0

6.6.2.2 Non-Target Species Allowance

The fishway capacity calculation must also take into account allowances for non-usable space (e.g., sharp corners in a lift hopper) and for the presence of other species that may be in the fishway. Migratory fish runs in the same watershed rarely peak simultaneously; however, the peak day of one species may partially overlap with the start or end of another species run (e.g., alewife and blueback herring). As a consequence, one must assume some percentage of non-target species is in the fishway and increase volume accordingly.

Engineering employs a lumped coefficient, C, to represent the additional volume requirements of unusable space and non-target species. A reasonable range for C is 0.10 to 0.15 (10% to 15%);

0.15 is recommended. However, this is a site specific parameter. For example, very large migrations of non-target species may require the volume of a fishway component (e.g., lift hopper, lift holding pool, pool in a pool-type fishway) to be increased by as much as an order of magnitude or more.

6.6.2.3 Crowding Limit

It has been shown that fishway capacity is constrained by crowding within pools (Lander, 1959). To minimize this effect, a permissible level of crowding in each different fishway component (e.g., lift hopper, lift holding pool, pool in a pool-type fishway) must be selected. Engineering applies the following crowding limit, v_c, for the following fishway components:

- Ladder pools: $v_c = 0.50$ ft^3/lbf
- Lift holding pools: $v_c = 0.25$ ft^3/lbf
- Lift hopper: $v_c = 0.10$ ft^3/lbf

Note that the lift hopper crowding limit is only valid for lift cycle times equal to or less than 15 minutes. For cycle times greater than this, the crowing limit should be increased beyond 0.10 ft^3/lbf. Bell (1991) recommends a crowding limit of 0.13 ft^3/lbf for long hauls.

6.6.2.4 Pass Rate

The pass rate, r, for the fishway must also be estimated to calculate the fishway capacity of a pool-type fish ladder or fish lift. For pool-type fishways, the pass rate is the rate of ascent, a measure of how quickly fish of different species can traverse the fishway and is expressed in pools per minute (Table 4). This parameter reflects both behavioral characteristics and the swimming speed of the fish. Conceptually, the inverse of r can be regarded as a residence time.

Table 4: Rates of ascent for pool-type fishways

Source	Species	Rate of ascent, r (pools/min)
Bell (1991)	general	0.250 – 0.400
Clay (1995)	chinook salmon	0.200
Elling & Raymond (1956)	general	0.172 – 0.303
USFWS R5 Recommendation	Atlantic salmon	0.250
	American shad	0.250
	river herring	0.250

For fish lifts, the pass rate, r, is the design cycle time. The cycle time of a lift represents the time required to perform the steps outlined in Section 7.8. For all but the tallest of lifts, one may assume a cycle time of 15 minutes or less. Ultimately, the cycle time is a function of the mechanical design of the various lift elements. Prolonged time in the hopper induces stress in the fish and should be avoided.

6.6.3 Capacity of Fish Lifts and Pool-Type Fishways

To calculate the required volume for the pools, V, within a pool-type fishway, fish lift holding pools, and fish lift hoppers, Eq. (12) is used:

$$V = n_M \frac{w_f v_c}{r} [1 + C] \qquad \text{Eq. (12)}$$

For a pool-type fishway, this is required to be less than or equal to the volume of water held in the pool under normal operating conditions. For a lift holding pool, this is required to be less than or equal to the volume of water (used by fish) between the downstream edge of the hopper brail (or leading edge of the hopper) and the closed mechanical crowder. For a lift hopper, this is required to be less than or equal to the water-retaining volume of the bucket.

Other important considerations are below:

- The volume of a pool in a pool-type fishway must also consider the effects of hydraulic parameters such as the energy dissipation factor and streaming versus plunging flow;
- Biological capacity of the fish lift holding pool must be equal to or exceed the capacity of the hopper(s) for proper functioning.

6.6.4 Capacity of Baffled Chute Fishways

Based on research by Slatick (1975), Slatick and Basham (1985), Haro et al. (1999), and monitoring studies, the USFWS has estimated capacities of Standard Denil ladder fishways (described in Section 7.6) and Model A Steeppasses (described in Section 7.7). The values reported in Table 5 assume that there is no overlap in the timing of the migration run for each of the reported species. In the event of overlapping migrations, the capacity can be expressed in terms of an equivalent biomass using the design weights presented in Table 3.

Table 5: Fishway capacity for baffled chute fishways

Fishway Type	Species	Annual Biological Capacity, n_T
Standard 4 ft Wide Denil Ladder	adult American shad	25,000
	adult Atlantic salmon	12,000
	adult river herring	200,000
Model A Steeppass	adult river herring	50,000
	adult Atlantic salmon	3,125

6.7 Energy Dissipation in Upstream Fishways

The energy dissipation factor (EDF), introduced in Section 5.4, is a measure of the volumetric energy dissipation rate (or power dissipation) in a pool, chute or stream reach.

6.7.1 Sizing Step Pools

Eq. (6) in Section 5.4 expresses the potential energy loss (or dissipation) rate per unit length of fishway. The well-known EDF equation for fishway step pools, illustrated in Figure 6, is derived from Eq. (6) by: 1) dividing both sides by the mean cross-sectional area of the fishway pool; and 2) recognizing that the term $dh/d\ell$ is equivalent to the (hydraulic) drop per pool over the length of the pool.

$$EDF = \frac{\gamma QD}{\forall_P} \qquad \text{Eq. (13)}$$

where D is the hydraulic drop per pool in ft, $\forall_P$ is the volume of the pool in cubic feet (ft^3), γ is the unit weight of water in lbf/ft^3, and EDF is the energy dissipation factor in $ft\text{-}lbf/s\text{-}ft^3$.

Multiplying both sides of Eq. (13) by the pool volume and dividing both sides by the EDF results in Eq. (14), used for the sizing of fishway step pools:

$$\forall_P = \frac{\gamma Q D}{EDF} \qquad \text{Eq. (14)}$$

In Eq. (14), the EDF is considered a species-specific criterion. Section 6.7.3 provides Engineering's recommended values for selected anadromous fish species.

It is important to note that a proper aspect ratio and depth must be selected in the design of the step pool. Engineering should be consulted in the design process to ensure that the step pool acts as both an energy dissipation zone and a resting zone. Further details on the EDF can be found on Appendix A, Reference Plate 5-2, "Power Dissipation Rates."

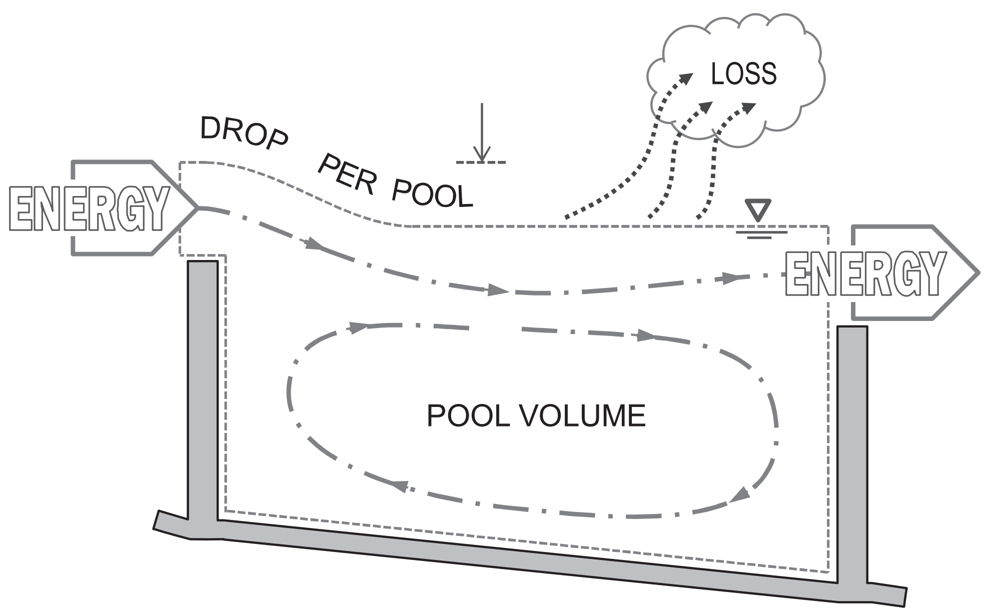


Figure 6: Sizing step pools in a ladder type fishway based on the EDF.

6.7.2 Sizing Denil Resting Pools

A transferable energy dissipation function, based on energy loss rate from a Standard Denil resting pool, was developed by Towler et al. (2015):

$$EDF = \left[\frac{\alpha_1 Q_1^2}{2A_1} - \frac{\alpha_2 Q_2^2}{2A_2} + g(z_1 - z_2)\right]\frac{Q\gamma}{HW\ p} \qquad \text{Eq. (15)}$$

where H is the mean water surface elevation in the resting pool in ft, W is the width of the Denil channel in ft, L_P is the length of the resting pool in ft, α is the Coriolis coefficient (also referred to as the kinetic energy correction coefficient), Q is the flow rate in cfs, A is the cross-sectional area in ft^2, g is the gravitational constant in ft/s^2, γ is the unit weight of water in lbf/ft^3, z is the elevation of the inlet and outlet sections, and EDF is the energy dissipation factor in $ft\text{-}lbf/s\text{-}ft^3$.

Shown in Figure 7, the upstream cross section 1 is located at the upstream interface between the sloped, baffled section and the horizontal pool and the downstream cross section 2 is located at a point close to the end of the resting pool where conditions are nearly uniform. At cross section 1, the area of flow is given by the following discontinuous function that accounts for the transition between the v-notched and vertical sections of the baffle:

$$A_1 = \begin{cases} \dfrac{bc}{2} + \left(\dfrac{H}{\sin\left(\dfrac{\pi}{4}\right)} - 2c \right) b & H > 2c\sin\left(\dfrac{\pi}{4}\right) \\ \dfrac{b}{2c}\left(\dfrac{H}{\sin\left(\dfrac{\pi}{4}\right)} - c \right)^2 & c\sin\left(\dfrac{\pi}{4}\right) < H \le 2c\sin\left(\dfrac{\pi}{4}\right) \end{cases} \qquad \text{Eq. (16)}$$

where b and c are the geometric scaling parameters for the Standard Denil baffle as shown in Figure 7. For Standard Denil designs, resting pools are generally prismatic, horizontal extensions of the sloped channel. Thus, the flow area at downstream cross section 2 in Figure 7 is simply the product of H and W. Translating the head above the baffle notch at cross section 1 to the common resting pool floor datum yields:

$$z_1 = H\sqrt{2}\cos\left(\frac{-\pi+4\,\mathrm{t}\quad^{-1}(S_0)}{4}\right) \qquad \text{Eq. (17)}$$

Towler et al. (2015) provides an in-depth analysis of the effect of α on the Eq. (15). When used in open channel flow calculations, Coriolis values typically range from α = 1 (uniform velocity distribution) to α = 2. Despite the large range, values above 1.15 rarely occur in regular channels (Henderson, 1966). However, Denil baffles generate more intense turbulence and irregular velocity distributions than ordinary open channel flows. To account for this uncertainty, Engineering recommends the proposed range of acceptable deviations be incorporated into the design equation. Substituting Eq. (17) into Eq. (15) and replacing α with a ± 5% error bound results in the following expression for EDF in Standard Denil resting pools:

$$EDF = \left[\frac{Q}{2}\left(\frac{1}{A_1} - \frac{1}{HW}\right) + gH\left(\sqrt{2}\cos\left(\frac{-\pi + 4\tan^{-1}(S_0)}{4}\right) - 1\right)\right]\frac{Q\gamma}{HWL_p} \pm 5\% \qquad \text{Eq. (18)}$$

Recognizing that HWL_P is equal to the volume of the pool, $\forall_P$, and dividing each side of Eq. (18) by the EDF and multiplying each side by $\forall_P$, the generalized equation to size Denil resting pools is developed:

$$\forall_P = \left[\frac{Q}{2}\left(\frac{1}{A_1} - \frac{1}{HW}\right) + gH\left(\sqrt{2}\cos\left(\frac{-\pi + 4\tan^{-1}(S_0)}{4}\right) - 1\right)\right]\frac{Q\gamma}{EDF} \pm 5\% \qquad \text{Eq. (19)}$$

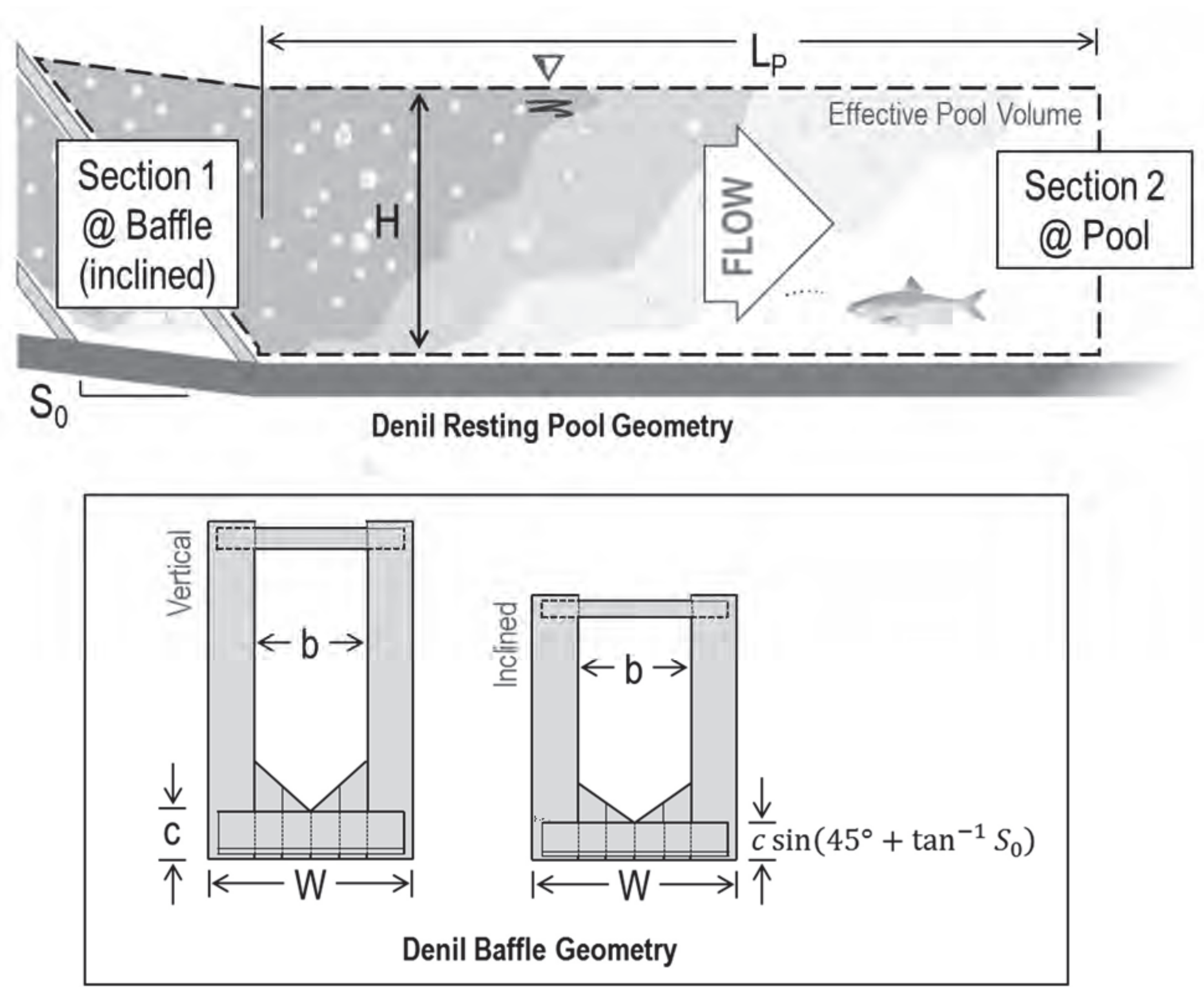


Figure 7: A cross-sectional view of a Denil fishway resting pool and baffle.

On the east coast of the U.S., Standard Denil fishways typically employ horizontal prismatic resting pools that are as wide as the sloped baffled section (e.g., 3 ft, 4 ft). From a design standpoint, the goal is to select a resting pool length adequate to reduce the EDF to a level acceptable for the target species. For clarity and application to these standard designs, regression equations were fit to Eq. (18) for both the 3-foot wide and 4-foot wide Standard Denil fishways at three common channel slopes. These equations, couched in the form of energy dissipation rate per unit area, take the form:

$$EDF \times L_P = K_1(H - h_v)^{K_2} \quad \text{Eq. (20)}$$

where H is the head above the channel invert in ft, h_v is vertical height of the baffle notch in ft, EDF–L_p is the energy dissipation rate per unit area in ft-lbf/s/ft^2 and the regression coefficients K_1 and K_2 depend on the width as shown in Table 6.

Additional details on the development of EDF for Denil resting pools can be found on Appendix A, Reference Plate 6-2 “Denil Resting Pool.”

Table 6: Standard Denil Fishway regression coefficients.

Regression coefficients for energy dissipation rate per unit area for 3-foot and 4-foot wide Standard Denil fishways at three common channel slopes (V:H).

Fishway	**Parameter**	**1:6**	**1:8**	**1:10**
3-foot Wide	h_v (ft)	0.6103	0.592	0.5805
	K_1	13.523855	9.728355	7.697128
	K_2	1.774059	1.802865	1.773244
4-foot Wide	h_v (ft)	0.8137	0.7894	0.774
	K_1	12.483282	9.166344	7.160788
	K_2	1.772447	1.779516	1.765067

6.7.3 Species Specific Criteria

Table 7 displays species specific EDF criteria. The rows in bold are the criteria adopted by Engineering.

Table 7: Species specific EDF criteria

Species	EDF (ft-lb/s-ft^3)	Source
Salmonids, juvenile	2.0	NMFS, 2011a
Non-salmonids	2.09	Armstrong et al., 2010
Trout	3.13	Armstrong et al., 2010
Salmonids, adult	3.13	NMFS, 2011a
American shad	**3.15**	**Engineering**
Atlantic salmon	**4.0**	**Engineering**
Salmonids	5.0	Maine DOT, 2008

6.8 Supplemental Attraction Water

Auxiliary water is defined as the portion of attraction flow (see Section 6.3.2) that is diverted into the fishway through the AWS prior to flowing out of the fishway entrance. An AWS typically consists of an intake screen, hydraulic control gate, and energy dissipating pools, baffles, and diffusers. Not only may the AWS be used to provide additional attraction flow through the fishway entrance, but it also may be used to add water depth at various locations through the fishway. Figure 3 in Section 6.4 displays an example of a gravity-fed AWS supplying flow to a fish lift. Attraction flow is routed through the exit flume via a conduit to the rear AWS chamber and lower AWS chamber. The flow enters the hopper through a rear diffuser and flow enters the entrance channel via wall and floor diffusers.

6.8.1 Free Surface (Gravity) AWS

A gravity-fed AWS is a conduit hydraulically connecting the headwater (or forebay) to the fishway entrance by converting significant potential energy into kinetic energy.

6.8.2 Pressurized AWS

A pressurized AWS is the most common type on the East Coast. The auxiliary water is transported from the forebay via a closed pipe. The type of valve used within the pipe must be able to minimize debris entry and any entrained air. Three common valve types are the butterfly, knife, and bladder valve. The bladder valve is the preferred option as it reduces both debris and air entering into the system. A bladder valve is made of an inflatable material; when closed, the bladder valve is filled with air and it effectively seals off the pipe from flow. The knife valve is effective at reducing air entrainment but can have problems closing when debris is present, unlike the bladder valve which has been shown to close even around debris. A butterfly valve should not be used as it is subject to problems with both air entrainment and debris.

6.8.3 Pump AWS

A pump-fed AWS converts mechanical energy into kinetic energy by pumping water from the tailrace to the fishway.

6.8.4 Intakes

Racks or screens at the flow entrance of an AWS are used to reduce the amount of debris and prevent fish from entering the system. Engineering recommends:

- Juvenile downstream migrants should not be entrained or impinged by the AWS intake screen (for a gravity-fed system). Screening or other protection measures are assessed by Engineering on a site-by-site basis.
- A clear space between the vertical flat bars of 3/8 inch or less is required; this criterion is based on the exclusion of adult river herring. Alternatively, punch pate with 3/8 inch diameter holes (or smaller) may be used. To minimize injury, punch plate should be oriented with the smooth side facing out.
- Flow velocities should be as close to uniform as possible as the water passes through the rack or screen.
- The gross maximum velocity through the fine trash rack should be less than 1.0 fps as calculated by Eq. (8).
- To facilitate cleaning, the trash rack should be installed at a horizontal to vertical slope of 1:5 or greater and the overall trash rack design should allow for personnel access and maintain clearance for manual or automated raking.
- Occlusion or blockage creates a hydrostatic and hydrodynamic load on a rack. This load manifests itself, in part, as a head differential across the intake and fine trash rack. The head differential across a rack should be minimal.
- AWS trash racks should be of sufficient structural integrity to minimize deformation.

6.8.5 Diffusers

Both wall and floor diffusers are commonly included in an AWS design. The diffusers provide a means to reduce excess energy and entrained air as the flow passes from the AWS conduit to directly within the flow path of the fishway. Wall diffusers consist of vertically-oriented grating of galvanized steel or aluminum, whereas floor diffusers consist of horizontally-oriented grating. The following are general recommendations by Engineering pertaining to AWS diffusers:

- Diffuser grating panels are typically constructed of 1”x3” or 1”x4” galvanized steel or aluminum grating. To minimize movement of small fish (e.g., alewife) through a diffuser panel, the grating should always be installed with the longer dimension (i.e., 3 in. or 4 in.) aligned to the horizontal plane. However, tighter spacing may be required depending upon the species present at the site.
- The screen size of the AWS intake must be less than or equal to the screen size of the diffuser screen to prevent fish from being trapped within the AWS.
- Vertical (wall) diffusers are preferred over horizontal (floor) diffusers due to the maintenance, de-watering, and performance issues associated with horizontal diffusers.
- AWS vertical (wall) diffuser velocities should be less than or equal to 0.5 fps; this criterion is based on Engineering’s observations that, above 0.5 fps, AWS discharge can attract and delay fish at the wall diffuser.
- Based on the poor performance of high-velocity floor diffusers installed throughout the region in years past, Engineering has adopted the National Marine Fisheries Service, Northwest Region horizontal (floor) diffuser velocity criterion of 0.5 fps (NMFS, 2011a).
- AWS diffusers installed upstream of a hopper in a fish lift may produce acceptable velocities as high as 1.5 fps.
- AWS diffuser velocity calculations should be based on Eq. (8).
- The velocity distribution exiting the diffuser should be as close to uniform as possible.
- Wall and floor diffusers should be submerged during normal operation of the fishway.
- Orientation of the grating should maximize the open area of the diffuser.
- All bar edges and surfaces exposed to fish should be rounded or smooth.
- Diffuser panels are susceptible to leaves and woody debris. Access for debris removal from each diffuser should be included within the design.
- AWS pits below diffusers must be clear of debris.

6.8.6 Turning Vanes

Turning vanes, illustrated in Figure 3 of Section 6.4, are designed to turn the flow in such a way that the flow field will quickly approximate a uniform velocity distribution in a desired direction. These vanes are typically located below horizontal diffusers and direct the flow up through the diffuser.

Historically, simple timber baffles have been used as "turning vanes". Timber baffles have a limited life span due to the high velocity and turbulence characteristic of AWS diffuser pits. Often failure of these timber baffles becomes evident only when troubleshooting a fishway for the cause of poor biological performance. Furthermore, experience suggests that simple rectangular baffles are only marginally effective at redirecting flow (from a horizontal AWS conduit) vertically through a floor diffuser. The comparative performance of simple baffles to true turning vanes is illustrated in Heise (2017). For these reasons, criteria regarding spacing, angle and geometry of turning vanes remains under development.

6.8.7 Sizing Dissipation Pools

An energy dissipation pool is an important component of an AWS that is designed for the sole purpose of dissipating energy from the attraction water (unlike fishway pools which also require resting zones within the pools). The pool(s) must have sufficient volume to properly dissipate the incoming kinetic energy. For gravity-fed pools, Engineering recommends a minimum water volume established by the following formula (similar to Eq. (13)):

$$V = \frac{\gamma Q H}{16.0 \, {}^{ft \cdot lbf}\!/_{s \cdot ft^3}} \qquad \text{Eq. (21)}$$

where V is the dissipation pool volume in cubic feet, γ is the unit weight of water in pounds per cubic feet, Q is the flow through the fish ladder in cfs, H is the differential energy head on the pool in feet, and 16 ft-lbf/s-ft^3 is the acceptable maximum EDF (notably greater than the maximum EDF within fishway pools). Note: in AWS that convey water to the dissipation pool via closed conduit, the differential energy is significantly reduced by frictional and minor losses within the pipe; in such systems, H is rarely more than a few feet of head.

6.8.8 Air Entrainment

Generally, air entrainment should be as low as possible within an AWS to reduce the total amount of entrained air passed on through the fishway. Engineering recommends the following techniques to reduce aeration within the AWS system:

- Proper sizing of the dissipation pools;
- Submerging the intake; if this cannot be achieved, Engineering recommends the use of anti-vortex plates;
- Submerge the outlet.

7 Technical Upstream Fishways

Technical fishways employ engineering designs that are typically concrete, aluminum, polymer, and wood, with standardized dimensions, using common construction techniques. Technical upstream fish passage systems can be categorized as volitional or non-volitional as illustrated in Figure 8 (also refer to Appendix A, Reference Plate 6-1 "Fishway Types"). The distinction refers to whether passage relies upon motivation, performance, and behavior of the fish to ascend over the barrier. Generally, volitional fishways include specific pool-type and chute-type designs such as the pool-and-weir, Ice Harbor, vertical slot, Denil, and steeppass. Non-volitional passage facilities include fish lifts (i.e., elevators), fish locks, and trap-and-transport systems. The following subsections describe each of these fishway designs and any applicable Engineering criteria. Note that the criteria for the serpentine, pool-and-chute, and trap-and-transport systems (listed in Figure 8) remain under development. Fishways specific to American eel passage are discussed in Section 13.

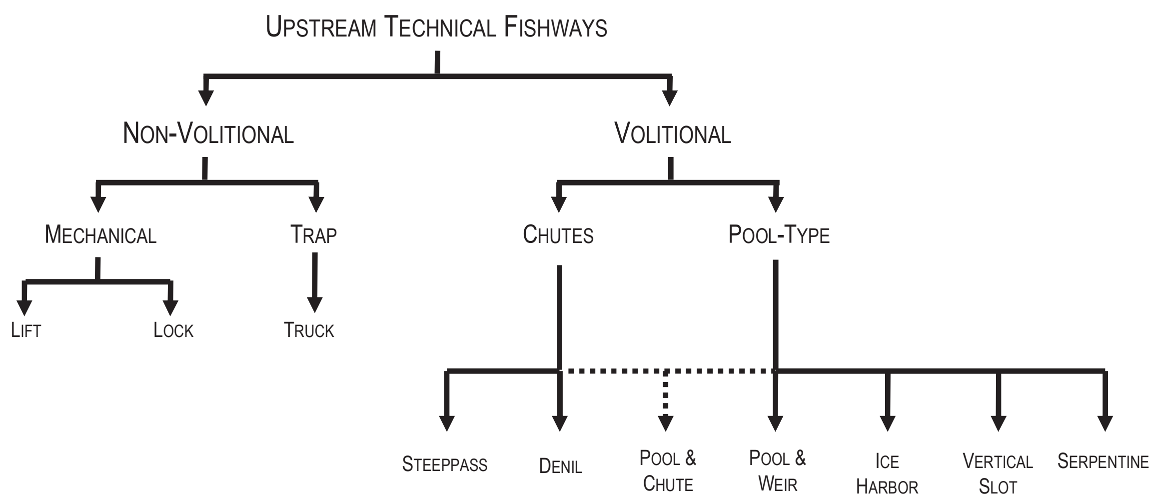


Figure 8: Technical upstream fishway types

7.1 Pool-and-Weir Fishways

Pool-and-weir fishways are characterized by a series of pools separated by overflow weirs that break the total head into discrete, passable increments.

7.1.1 Slope

The slope of a pool-and-weir fishway is calculated by dividing the (exterior) length of the pool by the hydraulic drop per pool.

- The slope of a pool-and-weir fishway should be less than or equal to 10%.
- Pool-and-weir fishways are designed for "uniform-in-the-mean" conditions (Towler et al., 2015). That is, each successive pool maintains the same hydraulic characteristics at the inlet and outlet. Therefore, the slope of the fishway is approximately equal to the friction slope (slope of the energy grade line).

7.1.2 Pool Geometry

Resting pools create hydraulic conditions that promote fish recovery from energy demanding high speed swimming before ascending the next step pool section.

- Typically, a resting pool is rectangular in shape. The specific geometry is dependent upon velocity, flow, depth, streaming/plunging conditions, and EDF criteria. In addition, a biological capacity requirement must be met.
- For large streams or rivers, biological capacity and EDF criteria often require pools 8-feet long or greater.

7.1.3 Weirs

The design of the weir must take into account both the flow depth and the velocity of the jet over the weir crest in relation to the size of the target species and any ability to leap over obstructions.

- To safely pass fish, weirs should provide a minimum of two body depths of flow over the weir crest with, at a minimum, sufficient submergence of the crest to promote streaming flow. Additional submergence of the weir crest may further enhance passage of alosines provided velocities over the weir are not excessive.
- The velocity of the jet over the weir crest must be low enough to permit passage of all target fish species at the site. The velocity of the jet is proportional to the square root of

the hydraulic head on the crest. Thus, knowledge of the target fish species swimming capabilities is required to determine the maximum flow depth over the weir in which passage can occur.

- The weir-to-weir alignment of the low flow notch must be designed to reduce momentum loss in the jet through the interstitial pool.

7.1.4 Hydraulic Drop

The hydraulic drop from pool to pool is a function of several factors, including the water surface elevation of the downstream pool, flow rate and velocity over the weir, and weir width. The maximum hydraulic drop between pools should be approximately 1.0 foot; however, actual drop is determined by ensuring the fishway meets all other hydraulic criteria including velocity and streaming flow.

7.1.5 Orifices

Submerged orifices are often included as an alternate route of passage (for salmonids) and may also promote streaming flow under threshold conditions.

- Orifices can be aligned on one side or alternating side-to-side.
- Often built with a deflecting baffle design immediately downstream to redirect the flow towards the center of the pool.
- The dimensions of orifices should be sized to maintain streaming flow and adequate fish passage conditions (e.g., velocities, width).
- The top and sides should be chamfered 0.75 inches on the upstream side and chamfered 1.5 inches on the downstream side of the orifice.
- The orifices must be void of debris at all times during the migration season. Blockages can create high velocities at the orifice and other complex hydraulic conditions which can reduce the efficacy of the fishway.

7.1.6 Turning Pools

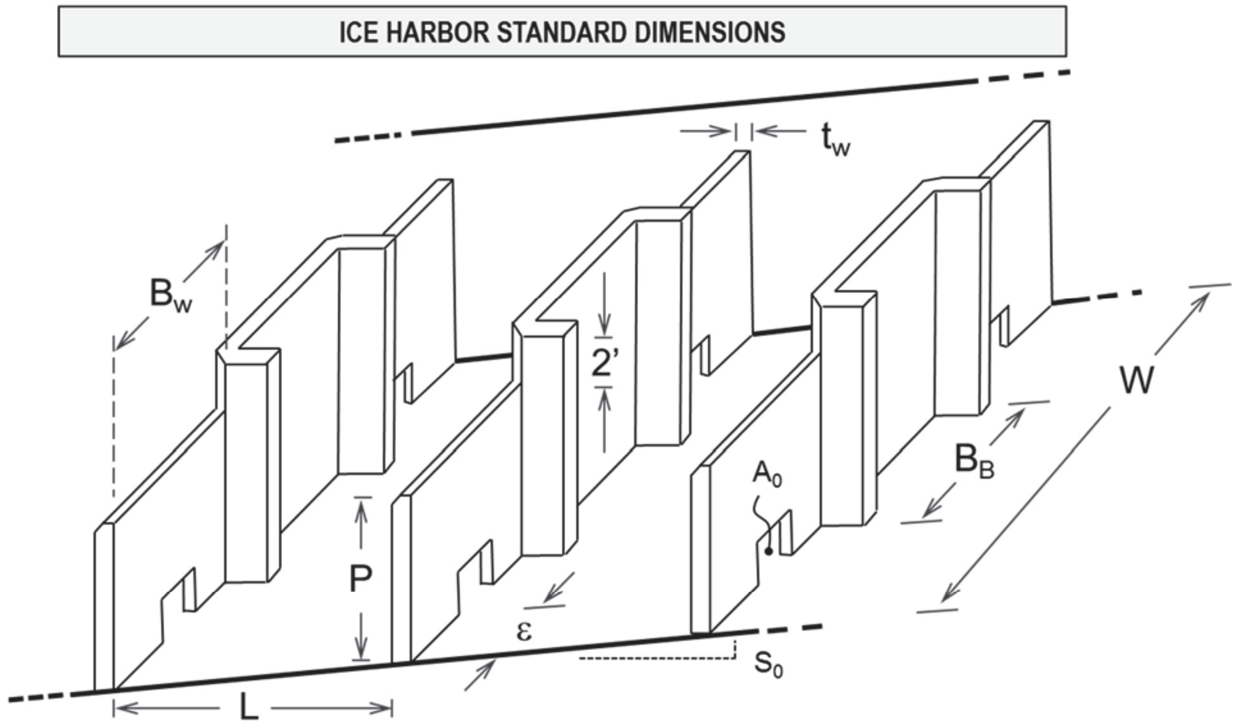
Turning pools are locations within the fishway where bends are required. These pools are often curved in shape or rectangular with chamfered walls. This shape differs from linear resting pools and, consequently, can create much more complex hydraulic conditions. Turning pools often also act as a resting pool.

- The design of the fishway should limit the number of turning pools to a feasible minimum.
- The hydraulic conditions within a turning pool must be designed to elicit a rheotactic response from the upstream migrating fish.
- The flow field should be nearly uniform throughout the turning pool.
- Turning pools should be designed to minimize flow separation and turbulence. The walls should be chamfered (ideally circular).
- The upstream pool width should be maintained throughout the entirety of the bend.
- Ideally, turning pools should have bends of 90 degrees or less. Greater than 90 degrees increases risk for poor hydraulic conditions and can cause confusion to fish, especially American shad, as they attempt to migrate upstream through the fishway.
- For turning pools which require a bend greater than 90 degrees, a weir should be placed at the midpoint of the pool creating a jet of water designed to motivate fish to continue ascending the fishway.

7.2 Ice Harbor Fishways

An Ice Harbor fishway is a modified pool-and-weir ladder that has two weir crests separated by a non-overflow central baffle and two submerged orifices centered below the crests.

The Appendix A, Reference Plate 7-1 "Ice Harbor Fishway" illustrates design schematic and provides a list of standard dimensions. Figure 9 displays the Ice Harbor standard dimension parameters, pertinent geometric ratios, and design criteria.



$$L \geq 9\,ft \qquad S_0 \leq \frac{1}{10} \qquad B_B = 0.375W \qquad B_W = 0.625\frac{W}{2}$$

Figure 9: Ice Harbor fishway standard dimensions.

Ice Harbor fishway standard dimensions; where B_W is the overflow weir crest width, B_B is the non-overflow baffle width, A_0 is the area of the orifice opening, S_0 is the floor slope, L is the pool length, W is the pool width, P is the overflow weir crest height, t_W is the overflow weir crest thickness, and ε is the distance from the center of the orifice to the side wall.

7.2.1 Slope

The slope of a pool-type fishway is calculated by dividing the length of the pool by the hydraulic drop per pool.

- The slope of an Ice Harbor fishway should be less than or equal to 10%.
- Ice Harbor fishways are designed for "uniform-in-the-mean" conditions (Towler et al., 2015). That is, each successive pool maintains the same hydraulic characteristics at the inlet and outlet. Therefore, the slope of the fishway is approximately equal to the friction slope (slope of the energy grade line).

7.2.2 Pool & Central Baffle Geometry

- The pool width, W, typically ranges from 10 to 25 feet. The pool length, L, must be greater than or equal to 9 feet. However, the specific pool geometry is dependent upon velocity, flow, depth, streaming/plunging conditions, and EDF criteria.
- The difference in height between the top of the non-overflow central baffle and the weir crest is typically 2 feet.
- Typically, the width of the central baffle, B_B, is 37.5% of the pool width, W.
- The central baffle is equipped with flow stabilizers which take the form of stub walls facing upstream at each end. Typically, the length of the two stub walls is 1.5 feet.

7.2.3 Weirs

An Ice Harbor fishway has two symmetrical weir crests, separated by a central baffle.

- The width of each weir crest, B_W, is typically 31.25% of the pool width, W. This results in an effective weir width of 62.5% of W.

7.2.4 Orifices

Similar to weirs, the Ice Harbor fishway has two symmetrical orifices, rectangular in shape, below the weir crests. The bottom of the orifice is the fishway floor. The two orifices provide an alternate route for upstream movement through the structure, although most fish swim over the weirs.

- The size of the orifice opening typically varies from 12 in. x 12 in. for a 10 foot wide pool to 18 in. x 18 in. for a 25 foot wide pool.

7.2.5 Turning Pools

Refer to Section 7.1.6, Turning Pools of Pool-and-Weir Fishways.

7.3 Alternating Ice Harbors

The Alternating Ice Harbor is a low flow variant of the Ice Harbor fishway. In each pool, one of the weirs and one of the orifices is blocked, in alternating arrangement. This effectively reduces the flow, increasing the relative volume available for energy dissipation.

Alternating Ice Harbors are not designed as such; they are post-construction modifications to (poorly performing) Ice Harbor fishways.

7.3.1 Slope

The slope of a pool-type fishway is calculated by dividing the length of the pool by the hydraulic drop per pool.

- The slope of an Alternating Ice Harbor fishway should be less than or equal to 10%.
- Alternating Ice Harbor fishways are designed for "uniform-in-the-mean" conditions (Towler et al., 2015). That is, each successive pool maintains the same hydraulic characteristics at the inlet and outlet. Therefore, the slope of the fishway will approximate the friction slope (slope of the energy grade line).

7.3.2 Pool & Central Baffle Geometry

Criteria in development.

7.3.3 Weir and Weir Arrangement

Criteria in development.

7.3.4 Orifice and Orifice Arrangement

Criteria in development.

7.3.5 Turning Pools

Criteria in development.

7.4 Half Ice Harbor Fishways

The Half Ice Harbor is a low flow variant of the Ice Harbor fishway. The geometry of a Half Ice Harbor is, as the name implies, equivalent to a lateral section of the full Ice Harbor cut along a plane of symmetry defined by its central axis. Accordingly, the low flow fishway consists of one weir crest, one orifice, and a non-overflow baffle between fishway pools.

Engineering's experience is that it is challenging to maintain streaming flow conditions in a Half Ice Harbor fishway. For this reason, Half Ice Harbor fishways are not recommended for American shad.

7.4.1 Slope

The slope of a pool-type fishway is calculated by dividing the length of the pool by the hydraulic drop per pool.

- The slope of a Half Ice Harbor fishway should be less than or equal to 10%.
- Half Ice Harbor fishways are designed for "uniform-in-the-mean" conditions (Towler et al., 2015). That is, each successive pool maintains the same hydraulic characteristics at the inlet and outlet. Therefore, the slope of the fishway will approximate the friction slope (slope of the energy grade line). Engineering's experience is that the typical geometry of the Half Ice Harbor (e.g., 1 foot drop, 10% slope) does not adequately dissipate energy. As a result, high approach velocities at the weir often inhibit the ascent of American shad and river herring.

7.4.2 Pool & Central Baffle Geometry

Criteria in development.

7.4.3 Weir and Weir Arrangement

Criteria in development.

7.4.4 Orifice and Orifice Arrangement

To reduce the turbulence and air entrainment in Half Ice Harbors, Engineering recommends blocking the orifice. American shad, river herring, and American eel do not generally pass through submerged orifices. Closing the orifice significantly reduces fishway flow, and consequently the EDF.

7.4.5 Turning Pools

Refer to Section 7.1.6.

7.5 Vertical Slot Fishways

A vertical slot fishway is a pool-type fish ladder characterized by a rectangular channel with a sloping floor in which a series of regularly spaced baffles separate the pools. Water flows from pool to pool via a vertical slot at each baffle. These designs are applicable to medium head dams and, unlike pool-and-weir fishways, may accommodate large fluctuations in headwater and tailwater levels. Another advantage of the vertical slot is that it offers passage along the full depth of the slot, thus it theoretically provides passage to a wider variety of species.

Engineering recommends vertical slot Design #1 (Rajaratnam et al., 1986) as the standard vertical slot fishway design. Figure 10 and Appendix A, Reference Plate 7-2 "Vertical Slot Fishway" illustrate this design with its dimensions as a function of slot width, b. Vertical slot fishways produce complex hydraulics; refer to studies by Rajaratnam et al. (1986), Rajaratnam et al. (1992), and Wu et al. (1999) for a view of the flow field within multiple vertical slot configurations.

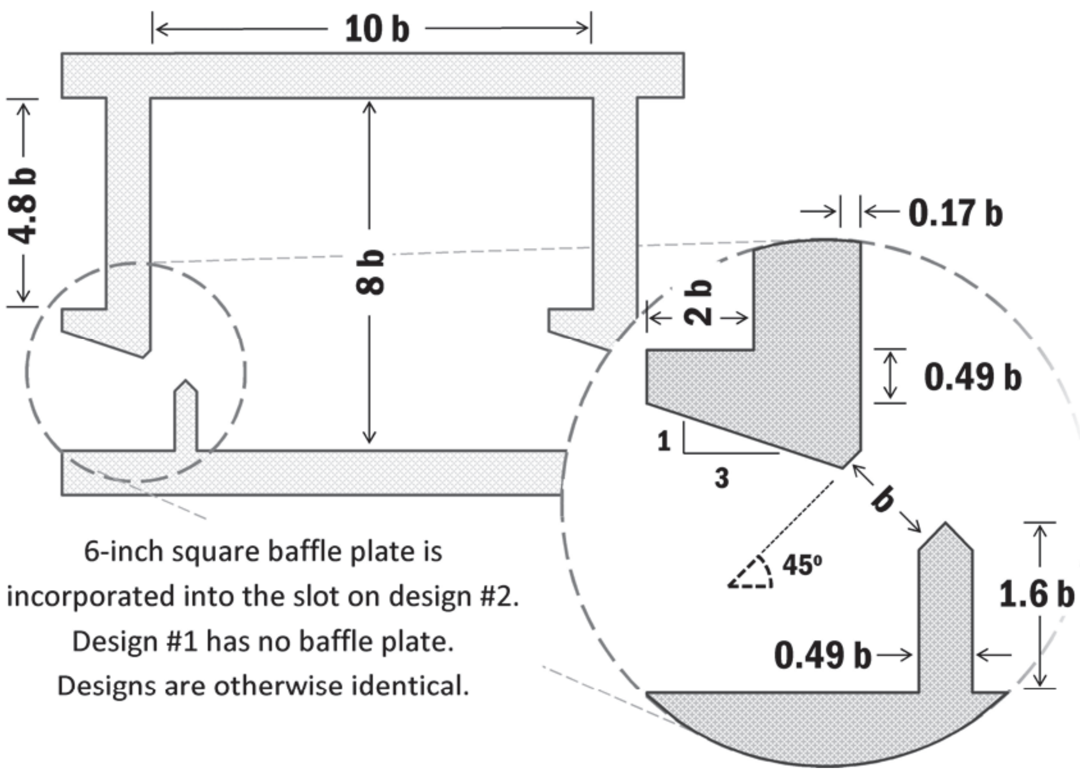


Figure 10: Geometric ratios for the vertical slot fishway designs #1 and #2.

(Rajaratnam et al., 1986)

7.5.1 Slope

The slope of a vertical slot fishway is calculated by dividing the length of the pool by the hydraulic drop per pool.

- The fishway slope typically ranges between 4% and 10%.

- In the case of a vertical slot, the maximum hydraulic drop (typically corresponding to low river flows) is used to establish the design water surface profile and friction slope which, in the absence of flow development, is equivalent to the friction slope.

7.5.2 Pool Geometry

The design and dimensions of a standard vertical slot fishway (with one slot per baffle) are shown in Figure 10 (Rajaratnam et al., 1986). The dimensions are given in relation to the slot width, b. At each site, the sizing and arrangement of the slot and walls is influenced by hydraulics, discharge, and the biological needs of fish. The design is intended to redirect the water into the center of the pool rather than allowing it to pass down from slot to slot. This allows the flow to stabilize and creates a zone where energy is dissipated.

7.5.3 Slot Width Requirements

The slot width, b, is often based upon a biological (width) criterion that is typically proportional to the fish size (Katopodis, 1992, page 58).

- For most species, the slot width should be significantly wider than the width of the target species in order to avoid injury and/or abrasion along the wall; Engineering recommends a slot width equal to 1/3 the length of the largest target species.
- Experience suggests that American shad fare poorly in narrower slots (Atlantic States Marine Fisheries Commission, 2010, page 9); slots should be a minimum of 18 inches wide (Larinier et al., 2002, page 138).
- Average velocities through slots should be less than burst speeds of all target species.

7.5.4 Baffle Plates

Baffle plates, when used, are suspended within the slot and provide the ability to further throttle the flow though the slot. It is critical that the baffle plate is suspended high enough in the slot to provide safe passage for fish to exit the fishway during any fishway shutdown. Rajaratnam et al. (1986) provides a discharge equation for the inclusion of a 6 inch square baffle plate, designated "Design #2." Appendix A, Reference Plate 7-2 "Vertical Slot Fishway" provides additional details. Note that baffle plates may inadvertently exacerbate the collection of debris and create blockages at the vertical slot.

7.5.5 Turning Pools

Refer to Section 7.1.6, Turning Pools of Pool-and-Weir Fishways.

7.6 Standard Denil Fishways

Denil designs are a family of baffled-chute ladders that utilize roughness elements (i.e., baffles) to dissipate the kinetic energy of water moving through a flume to create a low velocity zone of passage for migratory fish. The baffles turn a portion of the flow to oppose the main current in the flume. This change in inertia results in a decrease in flume velocity but also generates considerable turbulence that can reduce passage efficiency. Though limited in biological capacity, Denil fishways have demonstrated an efficacy in the passage of salmonids, alosines, and other species at relatively steep slopes.

A Standard Denil, displayed in Figure 11, is typically composed of a 2-4 feet wide prismatic concrete, steel or wood channel. The Denil fishway can operate over a moderate range of impoundment water level fluctuation. A minimum flow depth of 2 feet or two body depths (whichever is greater) should be maintained throughout the entirety of the fishway. The maximum operating water depth is set to ensure that 1) the average water velocity not exceed the target species' swimming capability and 2) the water surface remains 3.0 inches below any cross-support members on the upper portion of the baffles. See Appendix A, Reference Plate 7-4, "Standard Denil Operating Range" for additional details.

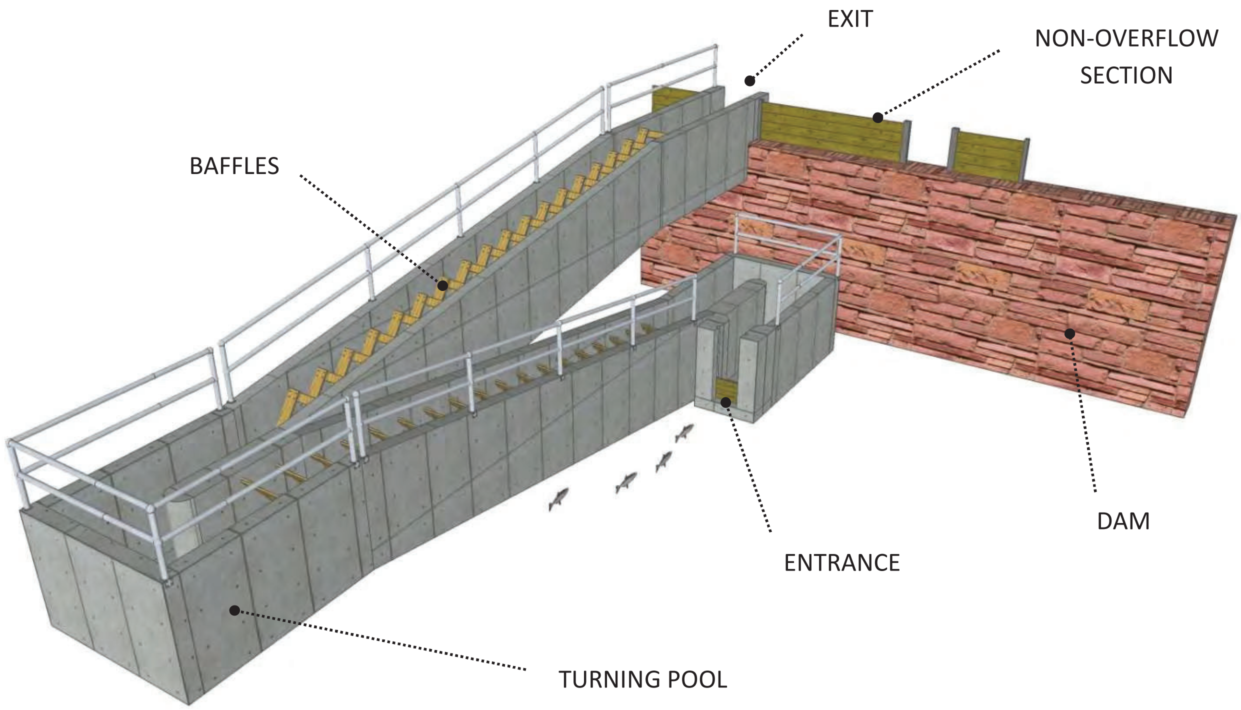


Figure 11: A Standard Denil fishway illustration.

7.6.1 Entrance

- At all times, the flow depth at the entrance (measured above the channel floor, gate lip, or weir boards) must be at least 2 feet or two body depths (whichever is greater). In practice, this typically requires a fishway be designed to maintain this depth during low operating TW (i.e., tailwater elevation at the low design flow).
- Entrances, particularly those without significant flow contributions from an AWS, should be laterally contracted at the entrance to promote a strong entrance jet. The contracted entrance should be 62.5% (5/8th) of the channel width.

- In the absence of a lateral contraction or other mechanism to promote a strong attraction jet, weir boards at the entrance may be used to create a hydraulic drop and locally accelerate flow. However, this arrangement limits the depth of passage and is therefore not preferred; at a minimum the weir boards should maintain two body depths of submergence (measured as the vertical distance between weir crest and tailwater).

7.6.2 Slope

Recommended slopes for a Denil vary by target species.

- The slope of a Denil designed to pass only salmonids can be up to 16.7% (1:6).
- The slope of a Denil designed to pass American shad should not be steeper than 12.5% (1:8); a slope of 10% (1:10) is preferred.
- Ignoring the effect of flow development in the upper reach of baffled chutes and conceptualizing the energy-dissipating baffles in steeppasses and Standard Denil fishways as roughness elements, one may treat flow in baffled chutes as essentially uniform between any two sections. Therefore, the slope of the fishway will approximate the friction slope (slope of the energy grade line).

7.6.3 Channel Width

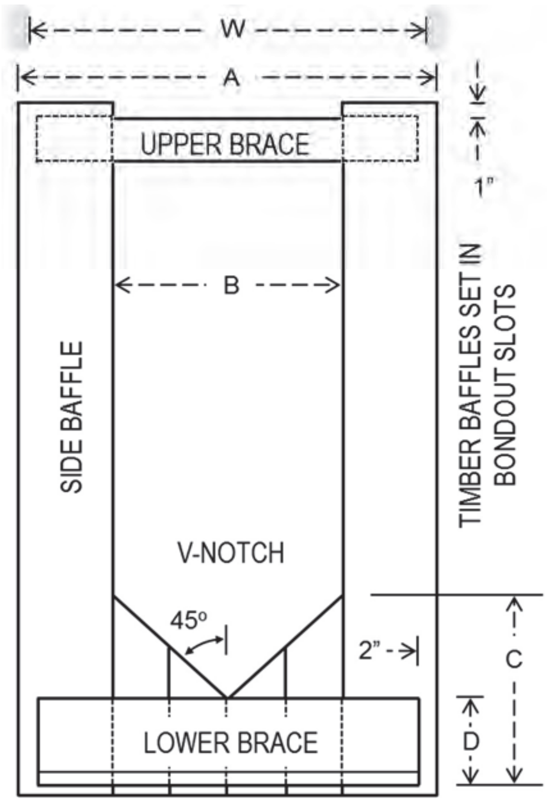
Similar to the fishway slope, recommended widths for Denils vary by target species.

- Standard Denil ladders designed to pass only salmonids are typically 3-feet wide.
- Standard Denil ladders designed to pass American shad should have a width of 4 feet.

7.6.4 Baffle Geometry and Spacing

Figure 12 and Appendix A, Reference Plate 7-3 “Standard Denil Geometry” display the baffle geometry and the horizontal (longitudinal) spacing of baffles in the channel.

- Baffles are typically set at a 45 degree angle to the sloped floor.
- The baffle height is typically 1 foot greater than the high design flow water surface elevation.



STANDARD DENIL GEOMETRY					
W	A	B	C	D	S
4' - 0"	4' - 3"	2' - 4"	2' - 0"	1' - 0"	2' - 6"
3' - 6"	3' - 9"	2' - 0"	1' - 9"	10½"	2' - 4"
3' - 0"	3' - 3"	1' - 9"	1' - 6"	9"	2' - 0"
2' - 6"	2' - 9"	1' - 5½"	1' - 3"	7½"	1' - 8"
2' - 0"	2' - 3"	1' - 2"	1' - 0"	6"	1' - 4"

Figure 12: A Standard Denil baffle geometry.

A Standard Denil baffle geometry, where W is the Denil channel width (typically the inside width of the concrete channel) and S is the horizontal (longitudinal) spacing of baffles in channel.

7.6.5 Baffle Material

The baffles are typically built from dimensional lumber (e.g., 2 x 6, 2 x 8). The lumber is often assembled with stainless carriage bolts. A top cross beam lends support and should remain above the water surface through the operational range. Acceptable lumber material includes oak, white pine, ash, cypress and marine-grade high-density polyethylene (HDPE).

7.6.6 Turning and Resting Pools

Unlike pool-type fishways, baffled-chute designs do not necessarily incorporate resting pools for migrants ascending the ladder. Therefore, Denil fishways must be designed with resting pools at appropriate intervals. Resting pools can be placed between two chute sections or incorporated as turning pools at switchbacks or other directional changes.

- A resting pool should be incorporated every 6 to 9 feet of vertical rise.
- Resting pool volumes must adhere to volume requirements specified in Section 6.7.1.

- Refer to Section 6.7.2 for the sizing of Standard Denil resting pools.
- Refer to Section 7.1.6 for more recommendations regarding turning pools.

7.6.7 Operating Range

The operating range of a Denil is bracketed by the lowest and highest depths over which the fishway may safely pass fish. These depths are measured from the bottom of the exit channel, the effective hydraulic control of a Denil. Ideally, the lowest and highest depths correlate to headpond elevations at the low design flow and high design flow, respectively. Practically, this range is influenced, and often limited, by the width of the channel, the height of the baffle, and size and swimming ability of the target species. If operating levels cannot be set to encompass the entire design flow range, set the exit channel bottom to optimize passage at the site.

Appendix A, Reference Plate 7-4, "Standard Denil Operating Range" provides criteria for the operating range of a Standard Denil fishway. The low operating (water) level was based on providing two body depths of water in the rectangular section of the Denil baffle. A nominal adult body depth of 4 inches was used for river herring; 6 inches for American shad; and 8 inches for Atlantic Salmon. The horizontal projection of C, as shown of Figure 12, was used to identify the starting elevation of the rectangular section of 5 to 8 foot long baffles. The high operating level was based on the horizontal projection of the supporting cross member (located approximately 3 inches below the projected top of all baffles).

It is important to note that the high operating water level may be further limited by the swimming capability of the target species. For example, the high operating level in a 4-foot wide, 8-foot long baffle set in a Denil fishway at a 1:8 slope is approximately 5.75 feet above the exit channel bottom; however, the average velocity in the baffle may exceed the swimming ability of river herring (~5 ft/s) when the water level reaches 4.0 feet above the exit channel bottom. Limitations due to river herring (and weaker resident fish) swimming capabilities typically occur when the depth of flow exceeds 4.0 feet in any 3 or 4-foot wide Denil built at a 1:8 or 1:10 slope. Other combinations of baffle width, channel slope and target species should be specifically analyzed, if appropriate.

7.6.8 Other Considerations

- Denil fishways must be inspected and cleaned on a regular basis and should not be used if clogged with debris.
- A Standard Denil is susceptible to variations in headwater levels. Removable, flow-reducing baffles at the upstream section can be used to help overcome this limitation and extend the headpond operating range.

7.7 Steeppass Fishways

A Denil variant, the steeppass is a baffled-chute type fishway designed to be highly portable and is applicable to low head dams. Typically, this fishway is prefabricated in 10-foot sections made of sheet aluminum or steel and bolted together on site. Compared to a Standard Denil fishway, a steeppass has a lower flow capacity and greater form roughness. It's widely used in the state of Alaska and is commonly used on the East Coast for salmonids and river herring.

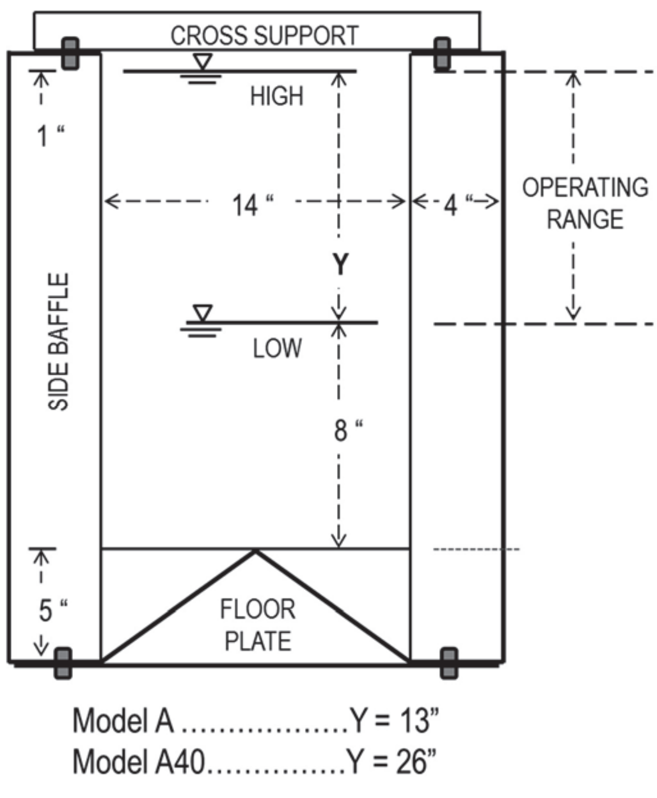


Figure 13: Steeppass fishway baffle geometry.

7.7.1 Slope

The standard slope of a steeppass fishway ranges between 10 and 33%; Engineering recommends steeppasses be installed at a slope of 20% (1V:5H) or milder.

- NMFS (2011a) recommends the slope be less than or equal to 28%.
- Larinier et al. (2002) recommends a slope of 23-33%.
- NRCS (2007) recommends a slope of up to 35%.

Ignoring the effect of flow development in the upper reach of baffled chutes and conceptualizing the energy-dissipating baffles in steeppasses and Denil fishways as roughness elements, one may treat flow in baffled chutes as essentially uniform between any two sections. Therefore, the slope of the fishway will be equal to the friction slope (slope of the energy grade line).

7.7.2 Model A Steeppass

A Model A Steeppass (refer to Figure 13 and Appendix A, Reference Plate 7-5 "Model A Steeppass") is a 21-inch wide, 27-inch tall, baffled aluminum (or steel) channel. The effective zone of passage is the area between the side baffles, above the top of the floor "V" plate (8 inches below the minimum water level for the operating range), and 1 inch below the cross struts. As depicted in Appendix A, Reference Plate 7-5 "Model A Steeppass," a Model A Steeppass can only accommodate a 10-inch fluctuation in headwater level.

7.7.3 Model A40 Steeppass

The Model A40 Steeppass is a 40-inch tall, deepened version of the Model A Steeppass. Consequently, the Model A40 Steeppass can accommodate a 23 inch fluctuation in headwater level, 13 inches greater than the Model A Steeppass. The Model A40 ladder is also known as a "deepened steeppass."

7.7.4 Turning and Resting Pools

Similar to Denil ladders, a steeppass fishway does not necessarily incorporate resting pools. In most cases, the length of the steeppass is short enough such that no resting pools are required. A resting pool should be incorporated every 6 to 9 feet of vertical rise and be a minimum of 6 feet long.

7.7.5 <u>Other Considerations</u>

- A steeppass fishway is limited by its low flow capacity. As a result, steeppasses are only applicable to small (coastal) watersheds; the Model A is limited to locations with a drainage area of 20 square miles or less, whereas the Model A40 is limited to locations with a drainage area of 30 square miles or less.
- The direction of the V-plate within the baffle is critical to the functioning of a steeppass fishway. The apex of the V must be pointed upstream.
- In many cases an entrance structure (concrete, wood, aluminum) is used to maintain adequate flow conditions within the steeppass and at the entrance.
- A critical component of a properly operating steeppass is that the invert of the entrance be submerged a minimum of 13 inches at low tailwater.

7.8 Fish Lifts

Fish lifts or elevators, illustrated in Figure 14 (alternative views are in Figures 2, 3, and 5), are non-volitional upstream fishways that are comprised of numerous mechanical, hydraulic, and electrical components. Generally, fish lifts have a smaller footprint than large volitional passage designs. The cycle of a fish lift consists of the following sequences:

1. Fishing: Fish, attracted to the fishway entrance, enter the fishway through the entrance structure (e.g., gate). Fish swim upstream within the fishway to the holding pool through a V-gate designed to retain the fish within the pool.
2. Crowding: The V-gate (or similar mechanism) is then used to mechanically crowd the fish above the hopper.
3. Lifting: Fish are lifted within the hopper to the exit channel or impoundment.
4. Releasing: Fish are released from the hopper to the exit channel.
5. Returning: The hopper, empty of fish, is returned to the fishing position.

Further information on fish lifts is provided in the Appendix A, Reference Plate 7-6 “Fish Lift Velocities” and Reference Plate 7-7 “Fish Lift Sequence.”

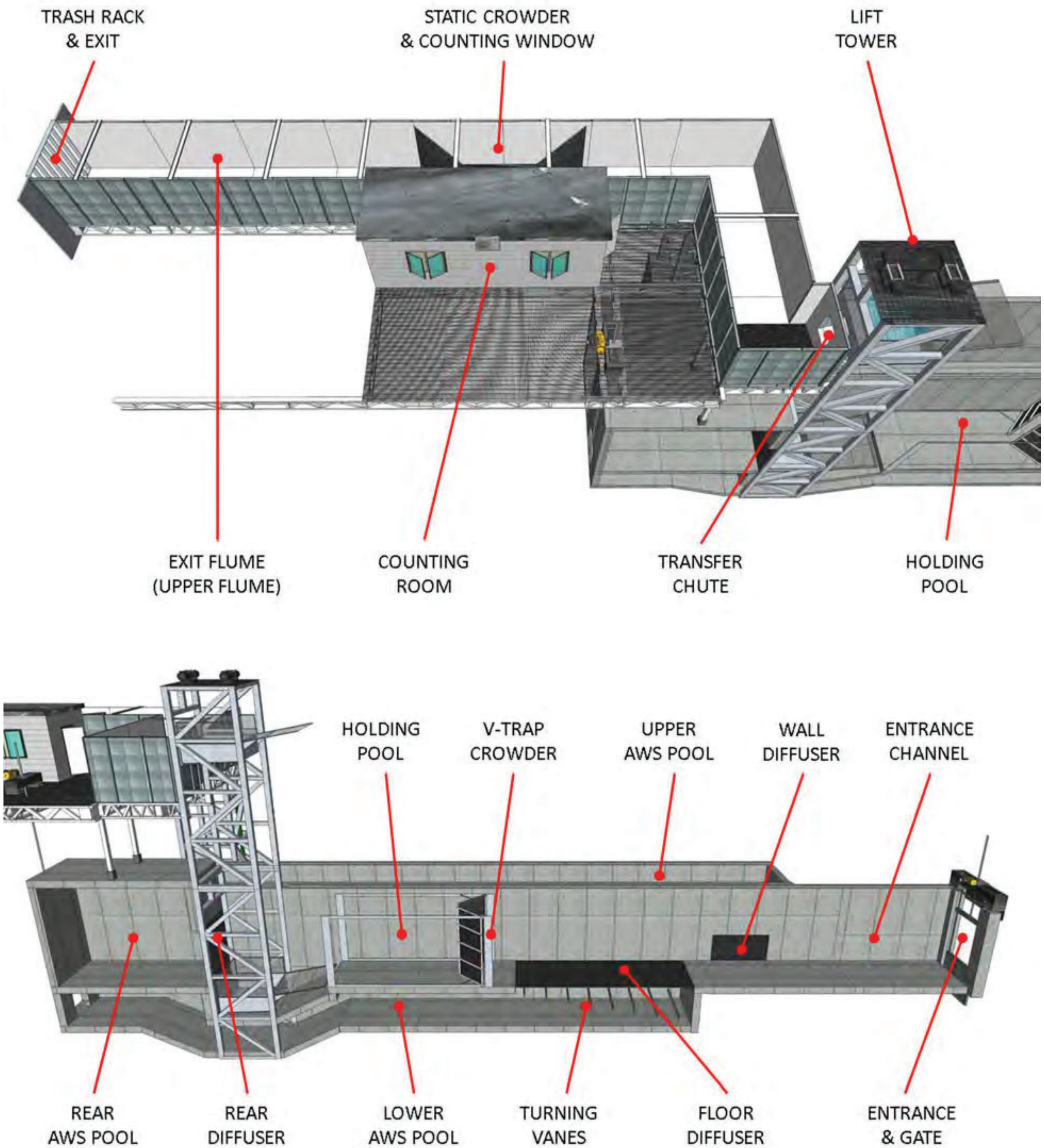


Figure 14: Multiple cross-sectional views of a fish lift.

7.8.1 Hopper

The hopper, displayed in Figure 15 (alternative views are in Figures 3 and 14), is a water retaining vessel that lifts the fish from the lower channel to the upper flume.

- While set in the fishing position, the velocities over the hopper should be within the cruising speed range (1 to 1.5 fps) to allow fish to hold without fatigue.
- Hinged flap valves in the floor of the hopper should be included to facilitate submergence after the lift cycle; it is important to ensure flap gates remain closed during the lift to prevent loss of water.
- The hopper should be free of any sharp corners or protrusions that may injure fish at any stage within the fish lift cycle.
- Fish must be prevented from swimming, leaping, or washing over the hopper sidewalls at all times. Engineering recommends a minimum of 1 foot of freeboard on the hopper sidewalls and/or an automated cover. The freeboard height need not be water-retaining; grating can be used to ensure fish do not leap from the hopper (as shown in Figure 15).
- Side clearances between the hopper and pit sidewalls should not exceed one inch.

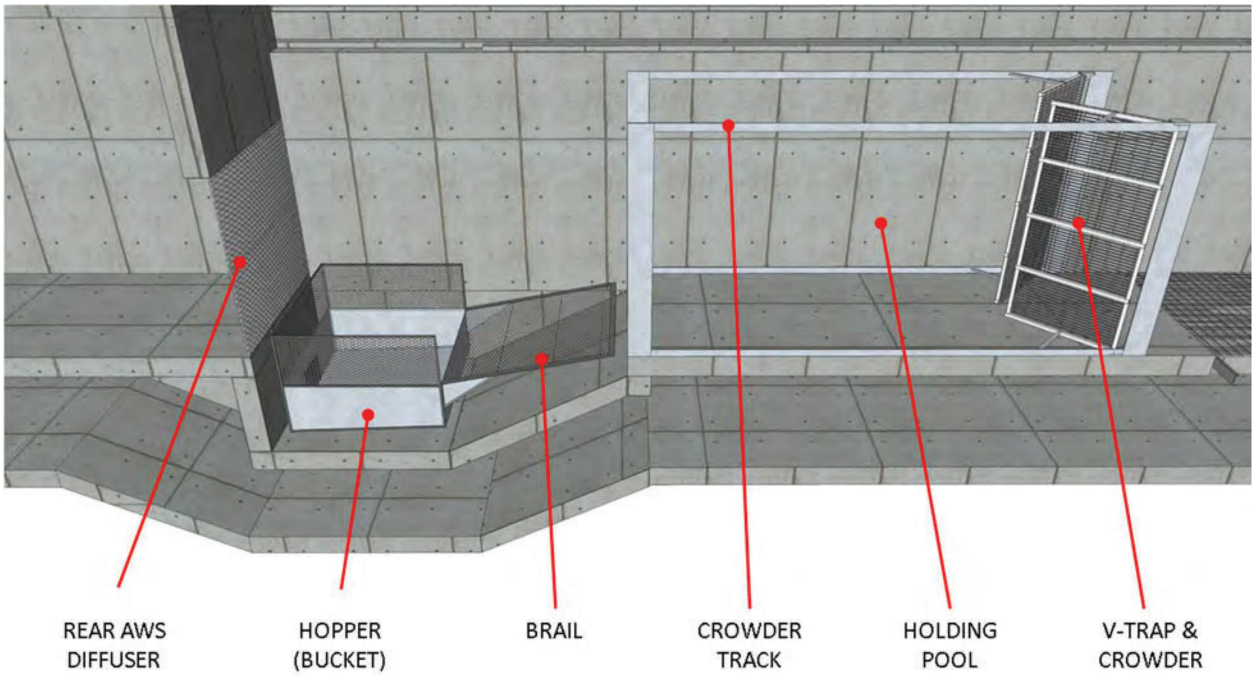


Figure 15: Illustration of fish lift components.

Fish lift components including a fish lift hopper, mechanical crowder track, holding pool, and V-trap mechanical crowder in the fishing position.

7.8.2 Holding Pool

A fish lift's holding pool, illustrated in Figure 15 (alternative views are in Figures 3 and 14), is a section in the lower channel that is downstream of the hopper and bound by the (open) mechanical crowder. The purpose of the holding pool is to retain migrants prior to crowding them into the hopper.

- Section 6.6.3 provides guidance on the proper sizing of holding pools.
- The velocities within the holding pool should be within the cruising speed range (1 to 1.5 fps for most East Coast anadromous species) to allow fish to hold without fatigue.

7.8.3 Crowder

A crowder is a mechanical device designed to move fish from the holding pool into the hopper prior to the lifting sequence. The components of a crowder typically include: 1) a trolley supported V-gate screen; 2) a hoist; and 3) the supporting crowder track on which the V-gate is moved from the entrance of the holding pool to immediately downstream of the hopper and brailling system. In the fishing position (i.e., collecting fish from the entrance), the V-gate is parked at the entrance of the holding pool (as shown in Figure 15) and acts to discourage fish within the holding pool from moving back out into the entrance channel. In this position, the V-gate is open 6 to 24 inches, although specific settings should be adjusted in response to fish behavior and implemented through adaptive management. Prior to lifting, the V-gate is closed and moves linearly toward the holding pool, effectively crowding the fish into the space above the submerged hopper.

Alternatively, the mechanical V-gate crowder can be replaced by an angled screen (or floor brail) that extends from the downstream end of the hopper to a static V-gate. The hopper and angled screen are then lifted simultaneously, forcing fish into the hopper.

- The floor screen (brail) from the hopper to the V-gate is typically set at an angle of 10 to 20 degrees.
- The dimensions of the screens used in the V-gate and floor brail must be sized to retain fish in the holding pool and avoid injury.
- In the case of a rectangular mesh screen, the openings should be sized at a ratio of 3:1 (H:V) to reduce the chance of fish injury.
- The screens must be clear of debris at all times during operation, although the AWS trash racks should prevent most debris from entering the fishway.
- The V-gate should extend at least 12 inches above the high fish passage design flow elevation.
- A typical V-gate installation has a gap between the gate and the location in which it hinges to the inside wall of the entrance flume. Rubber seals should be installed to eliminate a potential avenue around the V-gate and reduce the risk of injury.

7.8.4 Exit Flume

The exit flume is the steel or concrete channel connecting the hopper discharge chute and the fishway exit.

- Flow velocities in the exit channel should be low enough to prevent fatigue, yet high enough to motivate fish to move out of the channel and into the impoundment.

Engineering recommends velocities are maintained in the range of 1.0 to 1.5 fps in this channel.

- It is important to note that velocity in the exit channel is typically created by a screened intake to a return pipe which conveys the water to the lower fishway and contributes to the attraction flow. Engineering recommends that this return pipe be outfitted with a gate or bladder valve; the valve can be used to adjust the exit flume velocity to optimize movement of fish through the exit.
- Where possible, the exit flume design should avoid sudden transitions in lighting or hydraulics that could induce an adverse behavioral reaction in fish leaving the fishway.

7.8.5 Cycle Time

Lift cycle time is defined in Section 6.6.2.4. Refer to Appendix A, Reference Plate 7-7 "Fish Lift Sequence" for a detailed view of the standard fish lift cycle sequence of events.

7.8.6 Hopper to Flume Transfer

The hopper discharge chute (i.e., the chute through which fish are emptied into the exit channel) should be large enough to empty the hopper rapidly (about 15 to 20 seconds). The discharge chute, shown in Figure 16, should also have rounded corners or a bell mouth to provide a gradual hydraulic transition to promote fish movement from the hopper to the exit channel. The transfer must provide safe passage into the receiving water of the exit flume. Engineering prefers that the fish always remain in an adequate depth of water during the transfer. In the event that trapping is required, the hopper may be configured with a secondary discharge to trapping and holding facilities.

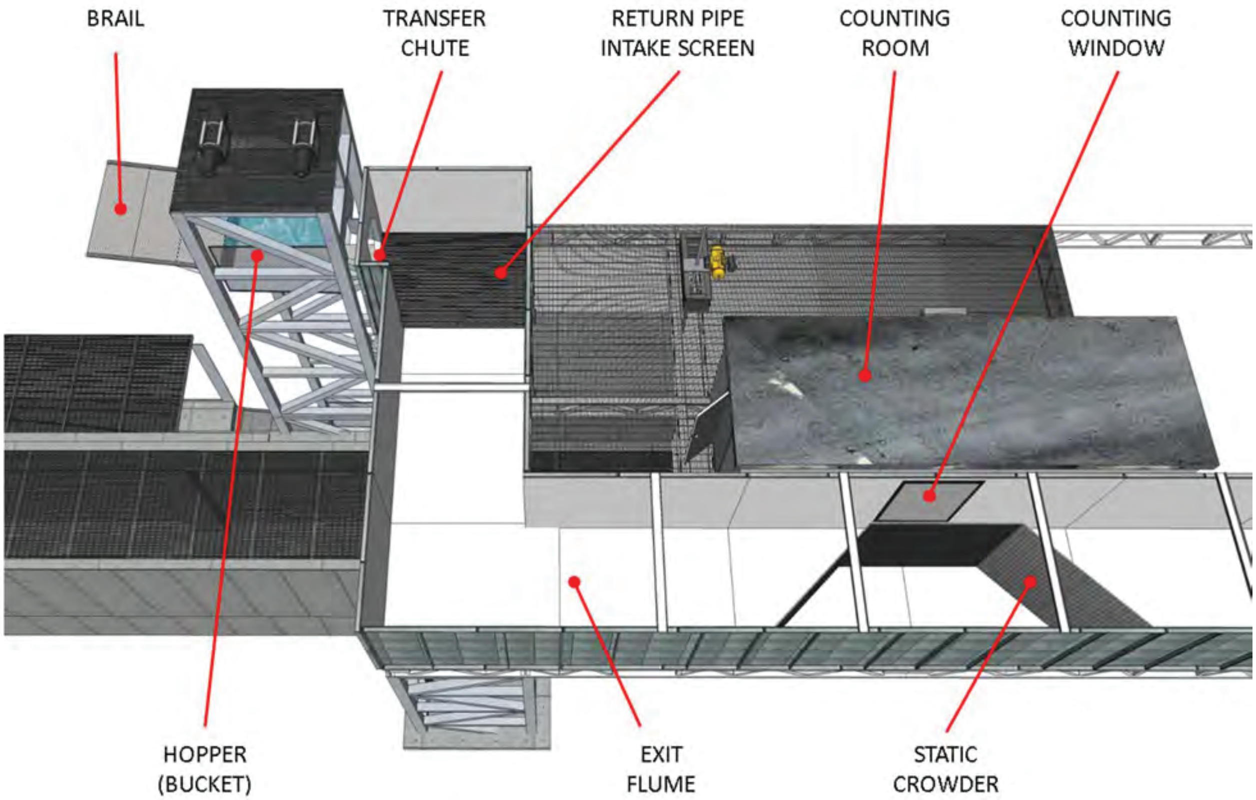


Figure 16: An illustration of fish lift transfer of fish components.

7.8.7 Lift Velocity

Engineering's recommendations for velocities within each lift component are as follows:

- Entrance weir/gate: 4 to 6 fps (for multi-species fishways);
- Entrance channel: 1.5 to 4 fps;
- Wall diffuser (part of AWS): 0.5 fps;
- Floor diffuser (part of AWS): 0.5 fps;
- Holding pool and mechanical crowder: 1 to 1.5 fps;
- Hopper pit: 1 to 1.5 fps;
- Rear diffuser (part of AWS): 1 to 3 fps;
- Exit channel: 1 to 1.5 fps.

For more information, refer to Appendix A, Reference Plate 7-6 "Fish Lift Velocities."

7.8.8 Other Considerations

- An entrance attraction jet (combined fishway and AWS discharge) is created by acceleration due to entrance (lift) gate operations; the jet typically results in a 0.5 – 2.0 foot hydraulic drop into the TW. The drop must not impede fish passage and should produce streaming flow. Actual site-specific settings should be based on total attraction flow, tailwater fluctuations, fish behavior and attraction efficiency.
- Flood walls and other lift components should be designed to protect against a 50-year flood event.
- Flow in the entrance channel, downstream of the diffusers, should be streamlined and relatively free of eddies and aeration.
- Diffuser velocities are maximum point velocities; localized upwelling and aeration from the AWS should be minimal.
- Water depth in the lower flume should be greater than 4 feet at all times.
- Flow above hopper and in holding pool should be free of aeration (i.e., visible bubbles).
- As much AWS flow as possible should be discharged behind the hopper through the rear diffuser, without exceeding maximum water velocity at the hopper pit or the holding pool.
- AWS dissipaters should be designed to remove excess energy from flow.

7.9 Fish Locks

A fish lock is a non-volitional fishway consisting of a columnar structure that, when filled with water, acts as a passage route for migrating fish. The design principle of the columnar structure within a fish lock is similar to the hopper and lift tower within a fish lift. Controllable gates at the headwater and tailwater openings are used to fill the structure with water. Locks are characterized by the particularly long cycle times required to evacuate fish from the lock. Fish locks are rare on the East Coast and are not typically endorsed by Engineering.

8 Counting and Trapping

A minority of fishways are equipped with counting rooms and trapping facilities. While not integral to the passage of fish, these elements may support critical fisheries management, monitoring, and research programs. It is critical that counting and trapping facilities are designed to minimize any interference with fish passage operations.

8.1 Counting Facilities

A counting station, illustrated in Figure 16 and 17, is a section of a technical fishway constructed with the purpose of tallying fish (by species and life stage) as they ascend or descend the fishway. Typically, fish are counted as they pass a window located in the fishway exit channel. The viewing room is equipped with a counting window and camera. In some instances, the camera is replaced by a fish count technician and/or a fish count software. Under limited circumstances, an array of fish counting tubes employing a Wheatstone bridge principle (a circuit measuring differential electrical resistance over a balanced resistivity bridge) may be used to estimate the number of fish passing the crowder.

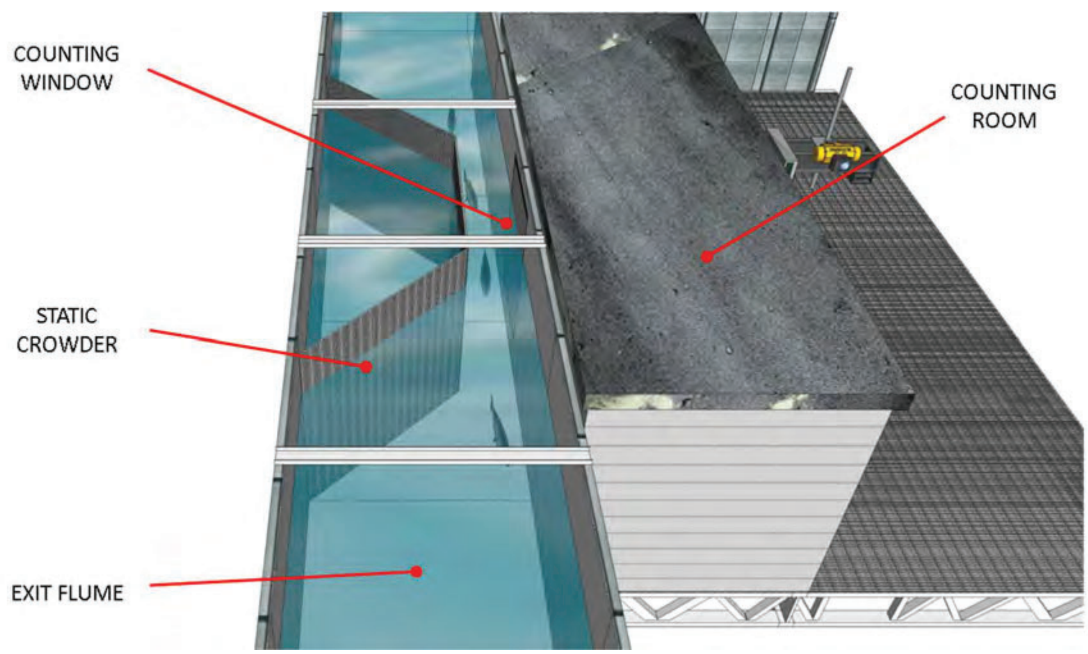


Figure 17: Illustration of fish lift counting facilities.

8.1.1 Location

The viewing room should be built alongside a section of the fishway (most often the fishway exit channel) where velocities are less than 1.5 fps.

8.1.2 Windows

- The counting window must be clean at all hours of operation. The window should be designed with adequate abrasion resistance to permit recurrent cleaning.
- The counting window must be properly lit at all hours of operation. If artificial lighting is included in the design, it must not affect passage.
- The window must be vertically oriented to allow for lateral observation.
- The observable area through the window should be a minimum of 5 feet wide and cover the full depth of the water column for manually counted facilities. For facilities where only video counts will occur, the window should be sized such that adequate field of view for the camera is provided.

8.1.3 Counting Panel

A counting panel, or observation plate, should be placed within the fishway, oriented vertically and extending from above the water surface to the fishway floor. The counting panel should be parallel to the counting window. The panel should be designed to create a strong contrast between the background and the fish when viewed through the window from the viewing room. The distance from the window to the counting panel depends upon site-specific factors (e.g., turbidity); although the typical range is 12 to 30 inches. The clarity of the counting plate can be enhanced through the use of reflective tape.

8.1.4 Static Crowder

Static crowders, or deflectors, should be installed to ensure fish pass within the observable space through the window.

- A vertically oriented static crowder that is angled from the fishway wall opposite the counting window to the counting panel is designed to guide fish to in front of the window.
- A static crowder acting as a ramp from the fishway floor is designed to guide fish into the observable space of the window.

- Crowders must be frequently cleaned of debris. When there is too much debris buildup, velocities are higher through the static crowder (possibly causing impingement) and flows can be increased in front of the window (increasing velocities above the design velocity). Cleaning the crowder should not necessitate shutting down the fishway.
- Static crowder panels should be sized to prevent to movement of small fish (e.g., alewife) through the panel. Typically, panels are constructed of galvanized steel or aluminum grating oriented with the longer dimension in the horizontal plane. However, experience shows that river herring will move through 1” x 4” grating, even when oriented horizontally. For this reason, Engineering recommends 1” x 3” grating or smaller.

8.1.5 Gates

A gate within a counting facility is typically used to temporarily halt the movement of fish through the fishway as needed by a fish count technician. A gate should never remain closed for long durations while fish are migrating. If installed, a gate should follow the same protocols as trapping facilities gates (see Section 8.3.4).

8.1.6 Video

The use of a video camera and/or other recording technology enables continuous, long-term recordings of fish.

- Motion detection software is recommended to reduce review times of the video recordings.
- Any use of light should not alter fish behavior. For night time recordings, Engineering recommends specialized low-light cameras or infrared illumination systems.
- If water turbidity is high through the fishway, imaging technologies (e.g., hydroacoustic monitoring, sonar imaging cameras) may be required.
- Frequent checks must be made to ensure that the quality of recordings is high.

8.2 Biotelemetry Installations

Biotelemetry is defined as the remote monitoring of individual fish or other organisms through space and time with electronic identification tags (e.g., radio tags, acoustic tags, passive integrated transponder, or PIT tags). Biotelemetry may be evaluate the efficiency of a new fishway, or to reexamine an existing fishway upon relicensing of a hydroelectric project.

Biotelemetry methods may also be used to assess a specific fisheries management goals related to passage.

- Selection of the biotelemetry technology for a site must consider both hydraulic conditions (e.g., water depth, conductivity) and other constraints such as detection range.
- The electronic identification tags should be carefully selected such that they do not alter behaviors or survival of the monitored fish.
- The design of the biotelemetry study must ensure that the flow field within the fishway is not altered. For instance, antennas should always be recessed 2-4 inches into the wall of the fishway (new designs should include bond-outs for this purpose) or installed someplace else outside of the flow path (e.g., above the upper cross member of a Denil).
- Antennas should not be placed on or around steel structures due to the increased likelihood of impaired signal detection (PIT tags) or unwanted signal transmission (radio telemetry).

8.3 Trapping Facilities

A trapping facility is a section of a technical fishway constructed with the purpose of trapping select fish as they ascend the fishway. Typically, a trapping facility is built to also operate as a counting station (see Section 8.1).

8.3.1 Location

The trapping facility must be built alongside a section of the fishway where velocities are low (less than 1.5 fps), often within the fishway exit channel. Trapping facilities at lifts should be located at the primary hopper discharge. Secondary lifts to a trapping facility should be avoided.

8.3.2 Windows

Trapping facility windows require the same protocols as counting facilities (see Section 8.1.2).

8.3.3 Static Crowder

If installed, trapping facility static crowders require the same protocols as counting facilities (see Section 8.1.4).

8.3.4 Gates

Design considerations for gates within the trapping facility (installed on both the trap and bypass) largely pertain to safety concerns for the fish.

- The opening/closing speed of the gate must be slow enough such that it does not injure fish in its path.
- The amount of pressure applied at the pinch point (i.e., the point of contact between the gate and the opposing surface) should be low enough to minimize fish injury if a gate is closed directly on a fish.
- Neoprene padding (or equivalent) should be used on sharp edges, protuberances, and pinch points that may injure fish.
- The gate, when closed, should have no gap between it and the opposing surface.
- When closed, the gate is designed to exclude fish, not water. The gate mesh should be sized to reduce the chance of impingement and fish injury by maintaining velocities through mesh of less than 1.5 fps. The rectangular mesh openings should be sized at a ratio of 3:1 (H:V) to reduce the chance of fish injury.

8.3.5 Bypass and Trap Design

The bypass and trap are the two routes for a fish to move through a trapping facility. Engineering recommends the following:

- Installing a series of traps and bypasses to provide for redundant control/capture.
- Locating the trap within the main flow path of the fishway.
- Installing the counting window within the wall of the trap.
- Properly sizing the bypass to ensure velocities remain low enough to allow for fish to pass within the constricted area if the bypass gates are open.
- To the degree possible, “water-to-water” transfers are preferable; handling and netting should be minimized.

8.3.6 False Weirs

False weirs are used, often at the exit of a steeppass fishway, to volitionally capture fish in a trap or bypass.

- Depth over the crest of the false weir should be maintained at least 6 inches.
- Streaming (rather than plunging) conditions should be maintained over the weir to minimize leaping/jumping behavior.
- Where feasible, a gravity driven water supply should be used for false weirs; pumps may create noise and vibration that could induce an adverse behavioral reaction in fish that leads to injury or rejection.
- Due to the confined space within a false weir, neoprene padding (or equivalent) should be used on any metal edges in the flow path to prevent injury from leaping/jumping.

9 Downstream Passage

9.1 Site Considerations

At a typical hydropower facility there are three primary routes of downstream passage for a fish. These three routes, ordered by typical proportion of average annual river flow, are: 1) through the turbine intakes; 2) over a spillway; and 3) through a fish bypass system. In the absence of better information (i.e., site-specific studies), Engineering does not recognize passage through the turbine intakes as an acceptable downstream route for fish. Fish injuries and mortalities may occur within this route as a result of rapid pressure changes, cavitation, turbine blade strikes, grinding, shear, and excessive turbulence. Delayed impacts to migration may result from sub-lethal injuries (e.g., barotrauma) or chronic effects from turbine passage at multiple hydroelectric dams. Fish may pass safely over the spillway and through gates, but generally only during high flow events and the degree to such passage is “safe” will vary with several factors (e.g., height, velocity, landing area). Conversely, the fish bypass system is designed to provide safe, timely, and effective passage to out-migrating fish throughout the entire migration season.

Design of downstream fish passage facilities varies with site-specific characteristics and the timing and movement of the migratory fish of interest. Typically, these systems consist of four primary components (Towler ed., 2014):

- Physical/behavioral guidance screen or rack;
- One or more bypass openings (e.g., weir, chute, sluice, or orifice);
- Conveyance structure (i.e., open channel or pressurized conduit);
- Receiving pool (e.g., plunge pool).

9.2 Zone of Passage for Downstream Migration

The ZOP (defined in Section 2.2) for downstream migration encompasses a far-field attraction zone, a near-field attraction zone (within the impoundment and/or power canal), the fish bypass system, and the tailrace (or surrounding river channel) downstream of the barrier. Numerous other conceptual models have been developed to describe the regions influenced by a hydroelectric project. For example, Johnson and Dauble (2006) classified the flow upstream of a typical hydroelectric facility as consisting of three separate zones; the approach, discovery, and decision zone. The first zone an out-migrating fish will enter is the approach zone, located about 100-10,000 meters upstream of the dam. Next is the discovery zone, located about 10-100 meters from the dam, where the fish are expected to encounter the flow field of the fish bypass system and turbine intakes. Last is the decision zone, located about 1-10 meters from the dam. Key features here that impact fish behavior are velocity, acceleration, turbulence, sound, light, structures, other fish (Larinier, 1998), and total hydraulic strain (Nestler et al., 2008).

9.3 Attraction, False Attraction and Bypasses

The fish bypass system is intended to function as a safe outlet for fish migrating downstream beyond the barrier. For this to occur, the bypass must be designed to provide sufficient attraction flow such that fish will sense the bypass route and pass through it in a timely manner to avoid undue delay, fatigue, injury, and/or mortality.

9.3.1 Attraction Flow Requirement

The flow fields created by project elements (i.e., turbine intakes, spillways, gatehouses, flood gates, and trash/log sluices) may attract (or dissuade) out-migrating fish and thus, compete with the directional cues created by the fish bypass system. Successful fish bypass systems must create hydraulic signals strong enough to attract fish to one or multiple entrances in the presence of these competing flows (i.e., false attraction), in particular the turbine intakes. Therefore, the downstream fish bypass flow requirement is based on a fraction of the maximum station hydraulic capacity.

- The downstream bypass should be designed to pass a minimum of 5% of station hydraulic capacity or 25 cfs, whichever is larger. For example, a new powerhouse with a hydraulic capacity of 7,800 cfs should be designed to provide a downstream bypass flow of at least 390 cfs.
- The bypass should be designed to pass this flow under all headpond levels and station operating conditions that occur during the migration season.

9.3.2 Flow Recapture Systems

Generally, flow recapture systems introduce an increased hazard potential for fish and are not recommended. A proposal for such a device or configuration should be reviewed by Engineering.

9.4 Conveyance to Receiving Waters

A conveyance structure (i.e., open channel or pressurized conduit) creates a safe passage route hydraulically connecting the bypass opening to the receiving pool (when directly discharging from the bypass opening to the receiving pool is not possible).

9.4.1 Conveyance by Flume

Downstream migrating fish may be conveyed to the plunge pool through a flume.

- Bypass channels should be non-pressurized (i.e., open channel flow).
- The spatial velocity acceleration within the bypass channel should be within the range of 0 to 0.2 fps per foot of travel.
- Bypass flumes should maintain a flow depth of 1 foot or two body depths of the largest fish, whichever is greater.
- Fish should be conveyed at 25 fps or less.
- It is critically important that the wetted perimeter of a bypass flume be smooth and free of protuberances (e.g., sharp corners, exposed bolts).

9.4.2 Conveyance by Conduit

Downstream migrating fish may be conveyed to the plunge pool via a conduit, particularly when the bypass route must penetrate a power canal wall or other structure. Engineering recommends the following:

- For conduits discharging into tailraces, a horizontal outlet 6 to 10 feet above normal tailwater is desirable; where the outlet is not horizontal, the plunge pool depth must account for the vertical component of (outlet) velocity.
- For outflows of less than 40 cfs, the conveyance pipe must be a minimum of 2 feet in diameter. Conduit diameters of 3 feet or larger are advisable for flow rates greater than 40 cfs.
- Bypass conduits should be designed to have free surface flow conditions within the pipe (i.e., non-pressurized). The flow depth should be greater than or equal to 40% of the pipe diameter at all points within the conduit. If required by site-specific conditions, pressurized bypass conduits should be evaluated by Engineering prior to installation. Sub-atmospheric pressures are not permitted within the conduit in this case.

- Bypass conduits should be designed at the smallest feasible length. If the bypass conduit is long (e.g., greater than 150 feet) it should include multiple access points to allow for inspection and debris removal.
- Fish should never free fall or be pumped within the conduit.
- To reduce the potential for debris clogging and excessive turbulence, bends in the pipe should be at a minimum of a 10 foot radius and the ratio of bend radius to pipe diameter should be five or greater.
- No hydraulic jump should exist at any location or during any time within the conduit.
- Fish should be conveyed at 25 fps or less.
- It is critically important that the wetted perimeter of a bypass flume be smooth and free of protuberances (e.g., sharp corners, exposed bolts).
- The conduit design should avoid the use of valves and/or gates. If required by site-specific conditions, valves and/or gates should be evaluated by Engineering prior to installation.
- Bypass conduits should be designed to allow trapped air to escape.

9.4.3 General Considerations

- The conveyance structure design must take measures to minimize any debris or sediment build-up.

9.5 Receiving Waters

9.5.1 Location

The receiving water, often referred to as the "plunge pool," is the body of water downstream of the barrier where the conveyance outlet discharges both fish and water.

- Bypass conduits/flumes must discharge into safe receiving waters that minimize exposure to predation.
- Transition from the conveyance outlet to the receiving water may temporarily stun fish creating a higher risk of predation. To reduce this increased risk of predation, Engineering recommends that bypass outfalls be located at the thalweg or where the receiving waters are moving in excess of 4 fps.

9.5.2 Plunge Pool Requirements

Whether natural or engineered, the conveyance structure outfall must discharge into a pool of adequate depth and volume to provide a safe transfer for fish from the bypass system to the waters downstream of the barrier.

- Plunge pools depth should be equal to 25% of the fall height or 4 feet, whichever is greater. For sloped outlets, the equivalent fall height is measured from the height of 0 initial vertical velocity (V_y).

These Engineering criteria are illustrated in Figure 18.

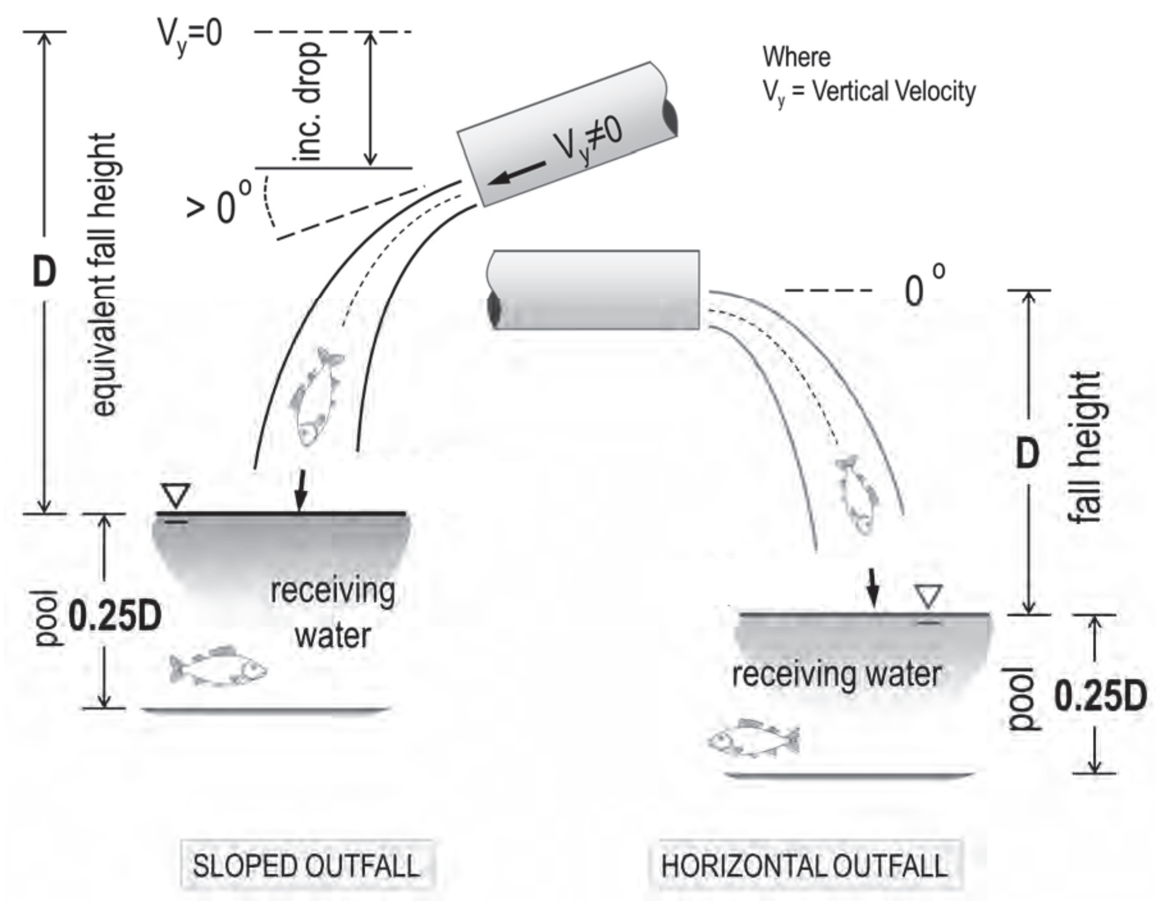


Figure 18: Fall height and plunge pool requirements

9.6 Guidance Technologies

Guidance technologies rely on the rheotactic response of fish, among other factors, to improve downstream passage efficiency and reduce migration delay. Rheotaxis is defined as a fish's behavioral orientation to the water current (Montgomery et al., 1997). A fish's movement with (or against) the water current is referred to as a negative (or positive) rheotaxis, respectively. If guidance is successful, the fish will avoid entrainment in a dangerous intake structure (i.e., turbine intakes) while passing from the headpond to the tailwater of a hydroelectric facility through a safer passage route (i.e., the bypass). The following sub-sections provide Engineering's recommendations for each guidance device.

9.6.1 Angled Bar Screen

An angled bar screen (or bar rack) is a guidance structure constructed of a series of vertical slats, placed along a diagonal line within a power canal or forebay and terminating at a downstream fish bypass (illustrated in Figure 19). This type of guidance screen is angled in plan to promote a sweeping flow towards the bypass. Where powerhouse intakes are oriented perpendicular to the prevailing streamflow and approach velocity, the angled bar screen is installed at 45 degrees, or greater, to ensure the sweeping flow dominates the normal flow through the screen. Similarly, the broad faces of the slats are generally oriented at 45 degrees to the approach flow.

9.6.1.1 Velocity Considerations

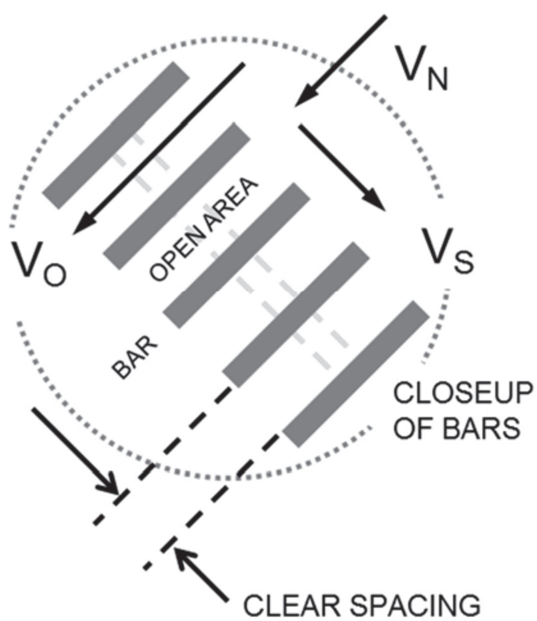
In the case of a full-depth guidance structure (e.g., louvers and angled bar screen), a 2-dimensional velocity vector is often used to inform the design. These two velocity components, displayed in Figure 19, are referred to as the sweeping velocity (velocity component parallel to the guidance structure pointing in the direction of the bypass) and the normal velocity (velocity component perpendicular to the guidance structure pointing directly at the face of the structure). Normal velocities should not exceed 2 fps measured at an upstream location where velocities are not influenced by the local acceleration around the guidance structural members. This criterion was established to minimize or eliminate fatigue in weaker species (e.g., riverine species, American eel) and allow fish to escape entrainment/impingement without resorting to burst swimming speed. Typically, the normal velocity is measured 1 foot upstream and at a right angle to the guidance structure. The spacing and the normal velocity influence the head loss through an angled bar screen. Appendix A, Reference Plate 9-1 "Angled Bar Screens" provides a nomograph-based method for estimating these losses.

9.6.1.2 Angle

A guidance structure installed at 45 degrees or less to the upstream flow field will result in a sweeping velocity greater than or equal to the normal velocity, thereby reducing the likelihood of impingement and entrainment. For this reason, guidance technologies are typically set at a maximum angle of 45 degrees to the flow field, thus creating a hydraulic cue designed to elicit a negative rheotactic response from migrating fish (encouraging their movement downstream towards the bypass). In the case of angled bar screen, Engineering recommends an angle to flow between 30 and 45 degrees.

9.6.1.3 Bar Spacing

Engineering recommends a clear spacing between bars (illustrated in Figure 19) of 1 in. for adult Atlantic salmon smolts. For American eels, 3/4 in. (20 mm) clear spacing is recommended based on the findings of Travade et al. (2005).



<u>Velocity components at the screen:</u>

- Sweeping velocity, V_S
- Normal Velocity, V_N

$$V_S \geq V_N$$

- Open Velocity, V_O

Clear spacing between bars:

- smolts: less than or equal to 1 inch
- eels: less than or equal to ¾ inch

Figure 19: Spacing and velocity components at angled bar screen.

9.6.2 <u>Louvers</u>

A louver system is constructed of a series of vertical slats placed along a diagonal line within a power canal terminating at the bypass. As fish approach the louvers, the turbulence and flow field that is created by the bars tend to elicit an avoidance response resulting in lateral movement away from the louvers and guiding fish toward a bypass.

9.6.2.1 Angle

In the case of louvers, Engineering recommends an angle to flow between 10 and 20 degrees. A study by Bates and Vinsonhaler (1957) recommends louvers to be set at an angle between 10 and 16 degrees.

9.6.2.2 Louver Geometry

- The vertical slats of louvers are typically full-depth.
- The broad face of the slat is at a right angle to the approach flow.
- The slat width is 2.5 inches and thickness is 3/16 inches.
- The spacing between slats should be 1 inch.

9.6.2.3 Velocity Considerations

Refer to Section 9.6.1.1.

9.6.3 <u>Inclined Bar Screen</u>

An inclined bar screen is a guidance structure characterized by a vertically sloped exclusion screen that prevents entrainment while simultaneously directing migrants around the powerhouse through a fish bypass. This technology has been installed in Europe and demonstrated effectiveness in protecting eels (Calles et al., 2013). In North America, inclined screens have been installed in diversion canals (Bomford and Lirette 1991) and powerhouse intakes (Amaral et al., 1999) to bypass salmon and other species. However, such guidance systems are not in common use in the northeastern U.S. As such, Engineering considers the technology experimental.

Criteria in development.

9.6.4 <u>Floating Guidance Systems and Booms</u>

A floating guidance system for downstream fish passage is constructed as a series of partial-depth panels or screens anchored across a river channel, reservoir, or power canal. These structures are designed for pelagic fish which commonly approach the guidance system near the upper levels of the water column. While full-depth guidance systems are strongly preferred, partial-depth guidance systems may be acceptable at some sites (e.g., for protection of salmonids, but not eels). Site-specific considerations will influence the selection and design of guidance systems and booms. The use of such downstream passage systems should be done in consultation with Engineering.

9.6.4.1 Velocity Considerations

In the case of a partial-depth floating guidance system, a strong downward vertical velocity component may be present upstream of the wall (Mulligan et al., 2017). The vertical velocity component may compete with, or even overwhelm, hydraulic cues created by the sweeping and normal velocities (defined in Section 9.6.1.1). The downward velocity component upstream of the guidance system is increased as the permeability of the wall is reduced. However, increasing the permeability (through the use of perforated plates or screens as the guidance panels) can exacerbate impingement potential.

9.6.4.2 Depth & Angle

A floating guidance system should be installed at a depth and angle such that sweeping-flow dominant conditions (i.e., greater sweeping velocities than both downward vertical velocities and normal velocities) prevail within the expected vertical distribution of fish approaching the structure.

9.6.5 Behavioral Barriers

A behavioral barrier is any device, structure or operation that requires response, or reaction (volitional taxis) on the part of the fish to avoid entrainment. The following subsections include examples of behavioral barriers.

9.6.5.1 Acoustic

The use of acoustics to guide or create a barrier to fish is considered experimental. Any use of such device should be done in consultation with Engineering. Criteria are in development.

9.6.5.2 Electric

The use of electricity to guide or create a barrier to fish is considered experimental. Any use of such device should be done in consultation with Engineering. Criteria are in development.

9.6.5.3 Lights

The use of light to guide or create a barrier to fish is considered experimental. Any use of such device should be done in consultation with Engineering. Criteria are in development.

9.7 Surface Bypasses

A surface level bypass targets surface-oriented out-migrating fish species, such as Atlantic salmon, blueback herring, alewife, and American shad. However, potential diel movements in deeper water areas around intakes and in the forebay areas should be considered and examined. Appendix A, Reference Plate 9-2 “Bypass and Plunge Pool” provides numerous details on downstream bypass systems.

9.7.1 Location and Orientation

Downstream bypass flow must be discernable in the presence of unit intakes (a competing flow). Typically, the bypass is located in close proximity to the turbine intakes and oriented in line with the flow field. Where possible, the bypass should be located such that the downstream migrants will likely encounter the bypass before exposure to the intake racks.

9.7.2 Bypass Geometry

Surface bypasses operate as overflow weirs. Bypasses should be a minimum of 3-feet wide and 2-feet deep. Depth and width may be increased to meet other design criteria specified in this document. Further, Engineering recommends uniform acceleration weirs over sharp-crested weirs to minimize regions of high acceleration. As described by Haro et al. (1998), Kemp et al. (2005), Johnson et al. (2000), and Taft (2000), several surface-oriented juvenile fish species prefer to avoid regions of high acceleration. Therefore, the geometry of a surface level bypass weir should create a uniform spatial flow velocity increase (1 m/s per m of linear distance), similar to the NU-Alden weir as tested in Haro et al. (1998). Figure 20 displays the uniform acceleration weir in comparison to a sharp-crested weir.

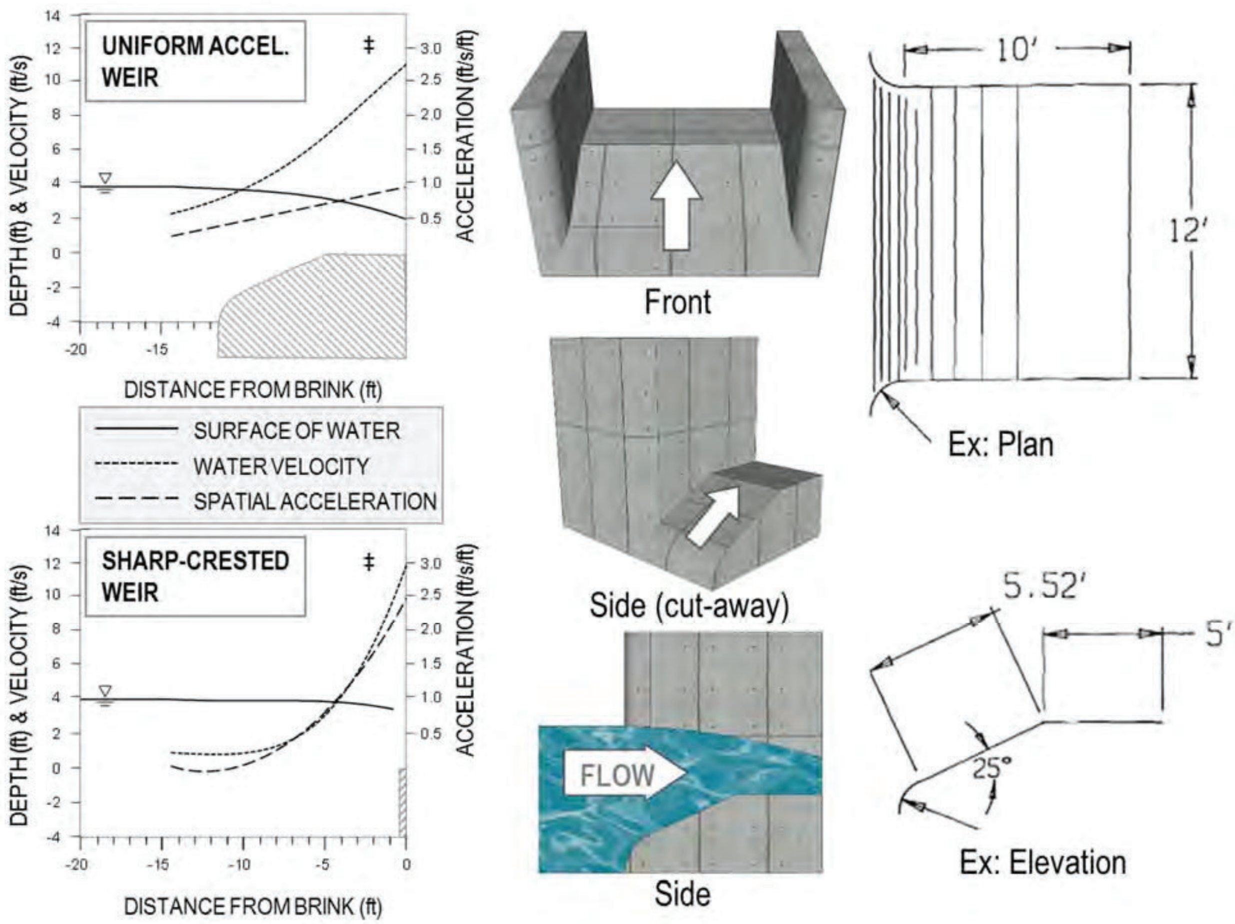


Figure 20: Comparison of uniform acceleration and sharp-crested weirs.

The left column displays the depth, velocity, and acceleration versus the distance from the brink of the weir for both a sharp-crested weir (bottom) and uniform acceleration weir (top). The center column shows a sketch of the uniform acceleration weir from the front (top), side cut-away (middle), and side (bottom). The right column displays a plan (top) and elevation (bottom) view of the uniform acceleration weir with example dimensions in ft.

9.7.3 Hydraulic Considerations

The bypass must generate velocities higher than the ambient flow to attract and capture fish without eliciting an avoidance response in fish.

9.7.4 Trash Racks

Coarse trash racks, if required, should not disrupt downstream passage of fish through the bypass. If trash racks are not used, then conduits should be designed with large diameter, straight runs and rounded corners in order to pass large trash.

9.8 Low Level Bypasses

A low level bypass targets benthic-oriented out-migrating fish species, such as American eel and shortnose sturgeon. Eel-specific design criteria are described in Section 13.0.

9.8.1 Location and Orientation

Criteria in development.

9.8.2 Bypass Geometry

Criteria in development.

9.8.3 Hydraulic Considerations

Criteria in development.

9.8.4 Trash Racks

Criteria in development.

10 Nature-Like Fishways

Nature-like fishways (NLFs) are artificial instream structures that (longitudinally) span stream barriers. NLFs are constructed of boulders, cobble, and other natural materials to create diverse physical structures and hydraulic conditions that dissipate energy and provide efficient passage to multiple species including migratory and resident fish assemblages, refer to Appendix C, "Federal Interagency Nature-like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes" (Turek et al. 2016). They typically consist of a wide, low gradient channel (usually less than 1:20 slope) with a concave stream channel cross section (Haro et al. 2008). NLFs represent a new fish passage technology, on which, relatively little evaluation has been performed. While many of the concepts are similar, Engineering does not categorically support application of technical fishway criteria presented in Chapters 6, 7 and 9 to the design of NLFs.

10.1 Layout and Function

In terms of layout and function, nature-like fishways may be categorized as:

- Rock ramp: sloped watercourse that links two pools of different elevation (e.g., headwater and tailwater of a dam) constructed in the existing channel and spanning the entire river. The entire stream flows through a (full width) rock ramp, thus eliminating competing flows and reducing concerns related to attraction. Where possible, Engineering recommends rock ramps over partial rock ramps and bypasses.
- Partial-width rock ramp: constructed in the existing channel and similar in composition to a (full-width) rock ramp, a partial-width rock ramp does not span the entire river width. As a result, the partial rock ramp is subject to false attraction from gates, spill, and other adjacent watercourses. Detailed analyses that estimate flow distribution through all paths (e.g., spill, gates, NLF) under varying hydrologic conditions (e.g., low design flow, high design flow) should be performed to evaluate the magnitude, persistence and location of competing and attraction flows.
- Bypass: channels designed to convey water and pass fish around a dam or other barrier. The primary distinction is that this fishway is constructed outside of the existing river channel. Assuming flow continues to pass over the adjacent stream barrier, bypasses are prone to attraction problems. Detailed analyses that estimate flow distribution through all

paths (e.g., spill, gates, NLF) under varying hydrologic conditions (e.g., low design flow, high design flow) should be performed to evaluate the magnitude, persistence and location of competing and attraction flows.

10.2 Hydraulic Design

The hydraulic design of NLFs can be categorized as:

- Roughened channel: hydraulically functions as gravity-driven, free-surface flow under uniform or gradually varied conditions. Depending on the complexity of design, roughened channel NLFs are designed using a 1-D hydraulic software (e.g., HEC-RAS) or 2-D/3-D computational fluid dynamics software. Accurate estimates of channel roughness (e.g., Manning's n, Nikuradse's k_s) are critical to this hydraulic design.
- Step-pool: hydraulically functions as a series of pools and control structures (e.g., rock weirs) under rapidly varied conditions. Accurate estimates of weir coefficients are critical to this hydraulic design.
- Hybrid: may function as a roughened channel or step-pool depending on depth, approach velocity and flow conditions (e.g., pool and riffle structure). Hybrid NLFs are complex and should be analyzed accordingly.

10.3 Roughened Channel NLF

Roughened channels include rock ramps, arch rapids and similar channelized structures that use natural boulders, bedrock outcroppings or engineered materials (e.g., pre-cast concrete) to moderate high water velocities driven by gravitational forces. In general, the slopes of roughened channels are milder than step-pool structures. Consequently, this type has a larger construction footprint requiring more space. The final design of any roughened should be based on parameters that influence passage such as velocity and turbulence (e.g., eddy viscosity, formation of large scale eddies).

10.3.1 Slope

Under uniform and gradually varied flows conditions, roughened channels with steep slopes produce higher velocities that cannot be mitigated by larger roughness elements (e.g., boulders, arch rapids) without producing tortuous secondary flows and unacceptable levels of turbulence and air entrainment. The adverse effects of these phenomena on American shad may be particularly pronounced; recent studies (Raabe at al., 2014) suggest that shad passage efficiency over roughened channels of 1:30 may not exceed 65%. For roughened channel type NLFs, Engineering recommends:

- average channel bottom slope (measured at the thalweg) must be less than 3%;
- at sites designed to pass American shad, milder slopes may be warranted; additional hydraulic or biological analyses may be required to inform the design of an efficient NLF;
- stream barriers taller than 10 feet may require resting pools, boulder clusters, or other structures producing velocity shadows, in which fish may rest and recover;
- for larger streams and rivers subject to a wide range of design flows, the channel design should include both a low flow channel and a roughened bench to provide passage at higher flows.

10.4 Step-Pool NLF

Step-pool designs approximate pool-and-weir technical fishways. Notionally, fish move through these structures by bursting over a weir then momentarily resting in the upstream pool.

10.4.1 Slope

Suitable fish passage conditions (e.g., flow velocity) can often be created in step-pools with slopes of 5% or less. Species-specific recommendations on slope for step-pool NLFs are provided by Turek et al. (2016), Appendix C. At grades steeper than 5%, NLFs are generally not recommended.

10.4.2 Pool width

Full-width rock ramps (i.e., full-width pools) are preferred. For partial width rock ramps and bypasses, species-specific recommendations for step pools are provided by Turek et al. (2016), Appendix C.

10.4.3 Weir Geometry

Rock weir geometry is dictated by stability, hydraulic, and biological considerations. Rock weirs used to partition pools are typically braced upon footer stones and sized to ensure stability under flood flow conditions (e.g., 50-year flood event). Hydraulically, these rocks should be of sufficient longitudinal thickness to function as broad-crested weirs. Refer to Appendix A, Reference Plate 10-1 “Rock Weir Hydraulics” for additional details. Species-specific recommendations for weir depths and widths are provided by Turek et al. (2016), Appendix C.

11 Dam Removal and Channel Design

A significant number of aging dams in the U.S. are beyond their designed life span and may no longer provide any societal value. In such cases, dam removal is Engineering's preferred method of restoring fish passage to an impacted watershed.

11.1 Channel Adjustments

Dam removal often leads to temporary increases in sediment transport and, over time, channel adjustments (widening, bed profile changes, alterations in grain size distribution). The Shields Number provides a method of predicting the initial of motion of sediment. Appendix A, Reference Plate 11-1 "Initiation of Motion" serves as a convenient screening tool for such predictions. For detailed predictions that account for the influence of grain angularity, embedment, and periphyton cover, more complex sediment-transport models are warranted.

12 Road-Stream Crossings

Road-stream crossings act as critical infrastructure for multiple purposes such as protection of embankments, roadways, and property. Yet, if these crossings are not designed with aquatic organism passage (AOP) in mind, they can cause a break in the continuity of vital ecosystems that rely on the habitat within our streams and rivers. Fragmentation of this habitat can have detrimental effects on the life cycles, population dynamics, and overall survival of numerous species.

There is a multitude of ways in which road-stream crossings can hinder successful passage of critical species; some of the most common are listed below:

1. High Velocity – road-stream crossings that constrict the natural width of the river induce velocities that are higher than those witnessed within the natural reaches of the stream or river. Most crossing structures do not maintain an appropriate roughness within the structure to dissipate the energy of the constricted flow and therefore can produce velocities that exceed the swimming capabilities of various species.
2. Perched Culvert – over time, higher than natural velocities (especially during flood events) can promote scour downstream of the culvert. Depending on the composition of the streambed, this degradation can become extensive and the crossing can become perched (i.e., a drop in water surface elevation from the outlet of the crossing to the stream).
3. Outlet Pool Too Shallow – in cases where culverts do become perched, it is important that the outlet pool is deep enough for the species to generate the momentum necessary to make the jump into the culvert. It is important to note, that once perched, the crossing will hinder successful passage of any species that does not naturally leap, especially juveniles.
4. Shallow Water Depth – if the crossing is set at an elevation that does not meet the natural grade of the streambed, depths within the crossing can become too shallow for successful fish passage.

5. Debris Accumulation – an undersized culvert that constricts the river flow becomes a high risk location for debris accumulation. Debris accumulation can cause hydraulic conditions, such as a drop in water surface elevation that may hinder fish passage.

12.1 Design Methods

There are three common design methods for providing AOP at road-stream crossings that seek to overcome the aforementioned issues for successful fish passage:

- Hydraulic Design: This approach is analogous to the development of technical fishways and the criteria in Chapters 4 and 5 may inform design methods. Through careful selection of culvert diameter, slope, material (and in-culvert baffles and weirs), the designer seeks to create hydraulic conditions that meet fish passage criteria (e.g., velocity, depth, EDF) for one or more target species. The scale and prismatic geometry of a culvert, make it challenging to achieve hydraulic conditions that pass all species (especially weaker, resident fish). Hydraulic design is typically used to retro-fit existing culverts where site conditions or economics prohibit other options.
- "No Slope" Method: This technique, described by the Washington Department of Fish and Wildlife (2003), involves counter-sinking a culvert such that the bed within is at least as wide as the channel bank-full width. It represents a relatively low cost replacement for impassable culverts, but its application is limited to mild slopes and, over time, may suffer from head-cutting at the inlet.
- Stream Simulation: These structures have a continuous bed that approximates the natural streambed (or reference reach) up to bank full flows. In so doing, aquatic species generally experience no greater difficulty moving through the structure than through the adjacent stream channel.

Engineering's preferred method for providing passage at road-stream crossings is stream simulation. Forest Service Stream-Simulation Working Group (2008) developed the stream simulation method for a national audience working on forested lands using unimpaired reference reaches. In Region 5, many watersheds are heavily urbanized and restoration priorities focus on coastal, diadromous species.

13 American Eel Passage

Eel migratory biology is characterized by the following:

- Panmictic populations (i.e., no homing to natal stream or river);
- Catadromous; elvers migrate upstream from ocean between spring and fall; immature yellow eels may move upstream for several years after entering freshwater;
- Juvenile eels may move repeatedly, irregularly or seasonally, between freshwater and marine habitat;
- Demersal, moderate swimmers (strong sprint swimming); non-schooling but aggregating;
- Small eels can climb wet surfaces and pass through some technical fishways;
- Ascend structures during day or night, but primarily at night;
- Typically eels initiate climbing behaviors at temperatures above 50°F (NMFS, 2011b, page 60);
- Late summer, fall, and possibly spring downstream movements of silver phase (i.e., mature eels); primarily during rain events and high flows.

13.1 Types of Upstream Eel Passes

Eel passes or eelways are specialized structures that provide a path over the dam for elvers and juvenile eels. An eel ramp is the most common technology and may terminate in a trap or provide volitional passage into the headpond. Other variants include the eel lift, the Delaware-style eel pass, the laterally sloped ramp, and the helical ramp.

Technical upstream fishways, such as fish ladders and fish lifts, are often ineffective at passing juvenile eels and specialized passage structures for this species are needed (Atlantic States Marine Fisheries Commission, 2013, page 1). While eels may move through technical fishways, they generally do not do so in large numbers. Therefore, Engineering does not regard technical fishways (i.e., conventional fish ladders and fish lift) as preferred methods of passing eels.

13.1.1 Eel Ramps

As shown in Figure 21, conventional eel ramps consist of linear metal, plastic or wooden channels lined with climbing substrate and equipped with an attraction water delivery system.

Eels utilize the wetted substrate to propel themselves up the ramp. Engineering recommends the following design guidelines for volitional ramps:

- Capacity: maximum capacity of 5,000 eels/day per inch of ramp width; assumes mean eel size of 150 millimeter (mm) total length (TL);

width	8	10	12	14	16	18	*inches*
capacity	40,000	50,000	60,000	70,000	80,000	90,000	*eels/day*

- Construction Materials: ramps, pools, and supporting structural elements should be built of: a) rust-resistant metal (typically aluminum) or UV-stable plastic for permanent facilities; b) wood may be used for temporary ramps;
- Cover: to minimize predation, a fully secured, opaque cover on the entire unsubmerged length of ramp (and resting sections) is recommended; the cover should remain open at entrance below high water level to allow entry at the water surface;
- Entrance: the following specifications apply to the lowermost end of the eel ramp:
    - the entrance should match the surface upon which it rests; this may necessitate shaping the entrance lip to meet an irregular bedrock surface, or providing a level sill upon which the entrance invert may rest;
    - the climbing substrate should run down through the entrance to the minimum tailwater elevation (i.e., tailwater at the minimum design flow);
    - the entrance should be uncovered up to the maximum tailwater elevation (i.e., tailwater at the maximum design flow) so that eels may enter at any depth;
    - if appropriate, the entrance should be equipped with fencing, netting or other material to guard against predation by birds and carnivorous mammals.
- Exit: the following specifications apply to the upstream terminal end of the eel ramp:
    - *Elevation*: the ramp should accommodate fluctuations in headpond levels; exit should terminate above the maximum headpond elevation (i.e., impoundment elevation at the maximum design flow) ;
    - *Location*: the exit should be situated away from turbine intakes, gates, and spillways and other structures that may entrain eels;

- Ramp: the following specifications apply to the sloped ramp channel:
  - *Height*: 4 in. to 6 in. high sidewalls;
  - *Width*: typically, 8 in. to 18 in. wide; wider ramps may be used provided they adhere to other criteria (e.g., depth of flow);
  - *Length*: dependent on slope; uninterrupted runs (i.e., without resting/turning pool) of sloped ramp should not exceed 10 vertical feet; total sloped length preferably less than 100 feet;
  - *Slope*: slopes must be 45 degrees or less;
  - *Depth of Water*: ramp should remain wetted across the surface at all times; depth is dependent on ramp width, flow, slope and influenced by substrate; 1/16 in. to 1/8 in. of water should be maintained across a flat ramp;
- Resting Section: the following specifications apply to the resting area in the ramp. Turns in the ramp layout may serve as resting pools if they are designed to this same standard:
  - *Placement*: a minimum of one horizontal resting section (resting pool) per 10 vertical feet of ramp;
  - *Width*: equal to ramp width;
  - *Length*: equal to the pool width, or longer;
  - *Depth of Water*: at least 1 inch of water should be maintained in resting pools; to accommodate uniform depth, the resting pools floors may need to be level and deeper than ramp sections to which they are connected.

13.1.1.1 Climbing Substrate

Ramps are equipped with roughened channel-bottom liners resembling gravel, geotextiles, fibrous material, bristles, studs, or other media that enhance the climbing ability of eels (Knights and White, 1998). Climbing substrates may be purpose-designed for eel passes (e.g., FISHPASS, Milieu, Inc., Berry and Escott Engineering) or manufactured materials intended for other purposes (Anwar, 2017, page 4). Based on a review of existing materials, the following describes the general trend between media type, size and spacing:

- Geotextile mats, netting, and other fibrous materials may be appropriate for glass eels and elvers in the 50 to 150 mm range;

- Bristle and brush substrates have the widest range of applicability with some dependence on bristle spacing; bristle spacing of 12 to 18 mm for eels in the 50 to 150 mm range, while spacing 18 to 24 mm for eels of 150 to 300 mm in length;
- Stud or peg-type media with spacing of 30 to 80 mm is often appropriate for yellow eels of 150 mm in length or larger; increased spacing correlates to larger eel size;
- At sites with eels of varying size, a ramp may be outfitted with two or more longitudinally arranged substrate types.

Regardless, the substrate should be carefully matched to the size of eels at a specific site to avoid size-selectivity of the pass (NMFS, 2011b, Page 56). Engineering recommends that the site selection of substrates be made in close consultation with Service biologists.

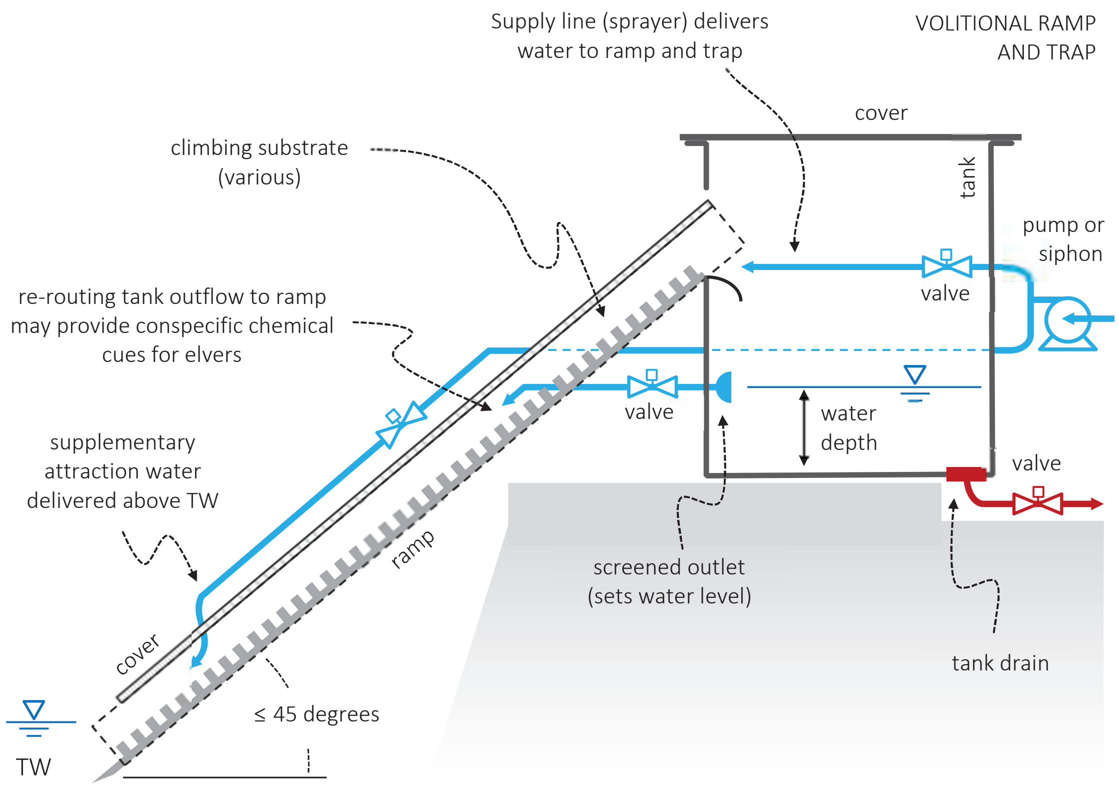


Figure 21: Conventional arrangement of an eel ramp and trap assembly

13.1.2 Eel Lifts

Analogous to fish lifts, eel lifts or “eelevators” are non-volitional passes applicable to higher head barriers. The lower portion of an eel lift typically consists of a ramp (or ramps) terminating in a trap that also serves as the elevator carriage (i.e., hopper). Unlike a simple ramp and trap that requires manual collection, the trap-carriage can be mechanically lifted above the barrier through a “hoistway” (i.e., lift tower) and flushed to the headpond. Both traps and lifts are attractive options for passage at barriers taller than 15-20 feet; however, lifts are typically reserved for the highest dams where routine trap collection presents a safety hazard or is labor intensive.

- Trap-carriage volume based on eel holding capacity; approximately 350 eels per gallon (2,625 eels per ft^3 or 92 eel per liter); minimum tank size is 15 gallons (2 ft^3);

volume	15	20	25	30	35	40	*gallon*
	2	$2\ ^{2}/_{3}$	$3\ ^{1}/_{3}$	4	$4\ ^{2}/_{3}$	$5\ ^{1}/_{3}$	ft^3
capacity	5,250	7,000	8,750	10,500	12,250	14,000	*eels*

- Lifting frequency is dependent on capacity of the carriage; at a minimum, eel lifts should be cycled at least once every day;
- To eliminate the risk of delay and over-crowding, lifting is recommended when the carriage (i.e., bucket) reaches 50% capacity (NMFS, 2011b, page 61).

13.1.3 Delaware-Style Eel Pass

The Delaware-style eel pass has successfully passed glass eels and elvers on the Mianus River in New York and on many other waterways (Jackman et al., 2009). This eel pass can be constructed by providing a hole through flashboards, surface gates, or other structures near the crest of the dam. By passing trawl netting or similar rope-like material though the hole (and optionally sheathed in a length of PVC pipe to train the flow), a roughened route for eels to ascend over the dam is created. The hole should penetrate the barrier below the normal headpond level; this ensures a consistent flow and wetted netting. Though inexpensive, Delaware-style passes may suffer from debris blockage, biofouling, and require routine maintenance. This style of upstream eelway provides limited attraction flow, and therefore, must be optimally sited.

13.1.4 Laterally Sloped Eel Ramp

Generally, conventional eel ramps are not hydraulically connected to the headpond due to the influence of fluctuating water levels. Fluctuating headponds will result in variable flows and high velocities in any eel ramp directly connected to the dam crest or other water-retaining (control) structure. Furthermore, a conventional eel ramp with a rectangular cross section and vertical side walls provides no purchase for eels when the fluctuating water levels submerge the substrate. Alternatively, an eel ramp with sloped side walls may be effective when connected to the headpond. Laterally tilting a substrate-covered ramp floor in this manner ensures substrate is available to the eel at the water surface through varying impoundment levels. This concept is described qualitatively in NMFS (2011b, page 55-56).

Based on successful implementation of this concept in the northeastern U.S., Engineering recommends the following (see Figure 22):

- The horizontal control section at the exit, and the ramp should be designed with a lateral slope of approximately 22 degrees or a width-to-depth aspect ratio of 2.5 to 1;
- A minimum channel depth of 2 feet; this depth can be increased to extend the operating range over larger headwater (HW) fluctuations;
- The ramp should be designed to provide a depth of flow (h) equal to 1.0 feet at normal HW elevation (normal HW shown as dam crest in Figure 22);
- The laterally sloped eel ramp discharges more flow and produces higher velocities than conventional eel ramps; for these reasons, the ramp slope (i.e., grade) should be restricted to 20 degrees or less.

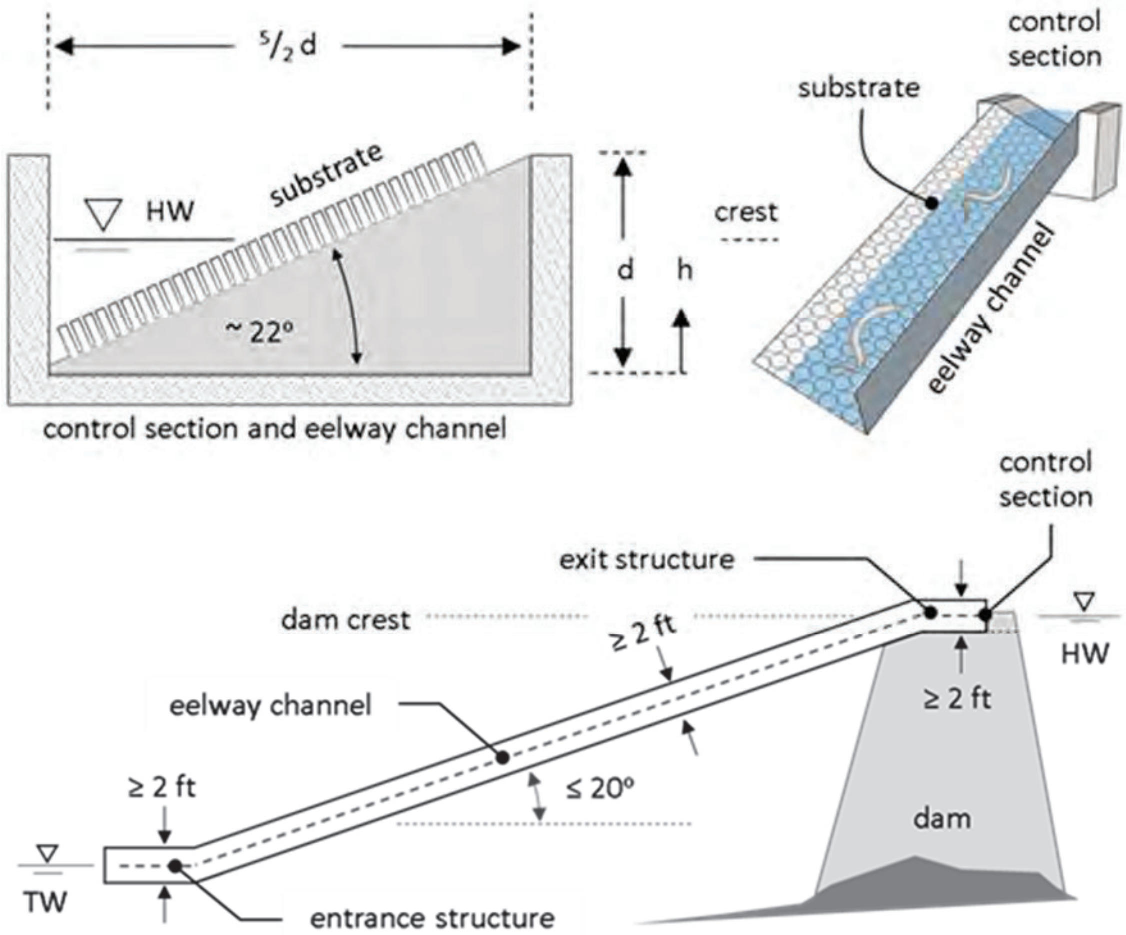


Figure 22: Design parameters for a laterally sloped eel ramp

13.1.5 Helical Eel Ramp

A helical eel ramp consists of a water-retaining channel coiled around a central shaft, with climbing substrate installed on the channel bottom. The unit is installed vertically, thereby connecting the headpond to the tailwater at a climbing angle equivalent to the pitch of the helix. Initial tests of this eel pass at a hydropower project on the Saco River (Lakeside Engineering, 2014) demonstrated passage above 90% for some treatments. Engineering recommends the following:

- Limit total vertical lift to 12 feet; lift may be extended with inclusion of resting sections;

- Pitch of the helix should limit outside climbing angle to 9 degrees, mid-ramp angle to 18 degrees, and inside angle to 45 degrees;
- Based on the variable pitch across a helical ramp, stud-type substrates may create adverse hydraulics near the axis; for sites with smaller juveniles, a substrate with high hydraulic resistance, such as geotextile or brush type, may be warranted;
- Entrance, resting sections, exit and trap criteria for conventional ramps may be transferable to the helical eel ramp.

13.2 Attraction to Upstream Eel Passes

The effectiveness of an eelway will depend on the three components to attraction: location, flow and velocity. The following considerations generally apply to all design variants.

13.2.1 Location

Typically, Engineering consults with Service, state, and other federal agency biologists to determine the best location of the eel pass. Suitable locations may be found at spillways, dam abutments, or other locations where leakage and rock outcrops can concentrate eels attempting to move upstream. Locations in deep water or at spillways may also pass upstream migrating eels. If possible, installing temporary eel passes in a variety of locations along the barrier is recommended in order to determine which of the locations attract the most eels. Nighttime surveys for migrating eels below dams can also be effective at identifying areas where eels are congregating. Locating eelways in or near technical fishways may benefit from conspecific chemical cues (i.e., odors).

13.2.2 Attraction Flow

The need for attraction flow is dependent on competing flows and the size of the river or, if the eelway is located in the tailrace, on the turbine discharge. Engineering recommends the following:

- a minimum 50 gallons per minute (gpm) for any eel pass;
- for conventional eel ramps, an additional 5 gpm is recommended for each inch of ramp width above 8 inches;

width	8	10	12	14	16	18	*inches*
flow	50	60	70	80	90	100	*gpm*

- for large rivers and high capacity plants, up to 300 gpm may be necessary;
- where eel passes are sited adjacent to technical fishways, the discharge from such facilities may also serve as an attraction flow for the eel pass.

13.2.3 Attraction Velocity

Eelways do not require the moderate-to-high attraction velocities characteristic of technical fishways. Eels do not possess the swimming capacity of salmon, shad and other anadromous species and high velocity attraction jets may actually inhibit eel passage. Ideally, the attraction velocity should be greater than the surrounding water velocity, but sufficiently limited to ensure smaller eels can successfully enter the pass. To the degree possible, the attraction velocity should be unaffected by competing flows.

13.3 Eel Traps

Volitional ramps may terminate in a trap at larger dams and/or at sites where enumerating migrants is required as part of a monitoring plan. Generally, a barrier higher than 15-20 feet may require a trap or lift. Engineering endorses the following design guidelines for traps:

- *Tank volume*: approximately 350 eels per gallon (2,625 eels per ft^3 or 92 eel per liter); minimum tank size is 15 gallons (2 ft^3);

volume	15	20	25	30	35	40	*gallon*
	2	2 $^2/_3$	3 $^1/_3$	4	4 $^2/_3$	5 $^1/_3$	*ft^3*
capacity	5,250	7,000	8,750	10,500	12,250	14,000	*eels*

- *Trap depth:* minimum of 1 foot depth maintained in the tank at all times;
- *Tank flow*: minimum 1 gpm of fresh water (i.e., from source river); 0.5 gpm per additional ft^3 of box volume (minimum 2 ft^3 volume); adequate flow to maintain sufficient oxygen for maximum capacity and ambient water temperatures;

volume	15	20	25	30	35	40	*gallon*
	2	$2\,^{2}/_{3}$	$3\,^{1}/_{3}$	4	$4\,^{2}/_{3}$	$5\,^{1}/_{3}$	ft^3
flow	1	$1\,^{1}/_{3}$	$1\,^{2}/_{3}$	2	$2\,^{1}/_{3}$	$2\,^{2}/_{3}$	*gpm*

- *Trap clearing frequency*: daily if possible; no longer than every 2-3 days. Recommended clearing when trap reaches > 50% capacity; eels should be released at night, if possible;
- *Freeboard*: Trap should be designed with sufficient depth between waterline and any opening to ensure eels cannot escape (e.g., adequate wall height, interior lip, dry walls to inhibit climbing); a minimum 12 inches of freeboard is recommended.

13.4 Downstream Eel Passage

Duration and timing of migration may vary in different parts of a watershed. In addition, a latitudinal trend persists in emigration dates of American eels (Haro, 2003). General downstream migratory behaviors are listed below:

- Movements primarily at night;
- Occupy all depths during migration;
- Selective tidal stream transport in tidal reaches;
- Tend to follow dominant flows;
- Reactive to some physical, visual, chemical, and sound stimuli;
- Environmental conditions can initiate, suspend or terminate downstream migration.

13.4.1 Physical Barriers and Guidance

Angled bar screens may be used as a guidance device to a safe passage route (i.e., bypass) for downstream migrating (silver) eels. Travade et al. (2005) found that a bar spacing of 20 mm is able to prevent 88% of European eels, an acceptable surrogate for American eels, from passing through trashracks. The bar screen should be installed at no greater than 45 degrees to the flow field and spacing should be a maximum of ¾ inches for adult American eels (Environment Agency UK, 2017, page 2). The racks must be designed and maintained so there are no voids between rack panels and adjacent forebay structures. Structural members comprising the rack should not easily bend (as seen with some plastic materials); bent or damaged bars can create wider gaps in the rack. Angled bar screens must be frequently checked and cleaned of debris. Other physical barriers include screens and louvers (with and without bottom overlays).

13.4.2 Surface Bypass

Unless otherwise indicated, surface bypasses for American eel should meet the general downstream design criteria described in Section 9.0.

13.4.3 Low-Level Pressurized Bypass

Gravity driven submerged bypasses, including siphons, perform as pressurized conduits. Such bypasses often penetrate new or existing intake screens (i.e., bar racks) or cannibalize existing low level outlets. Due to potentially high velocities in conduit flow, these systems are subject to rapid spatial accelerations near the bypass entrance. To prevent injuries to adult silver eels (and other aquatic organisms) entering and moving through a pressurized bypass, Engineering recommends the following:

- bypass intake opening width should be one half the maximum body length of an adult silver eel, 18 inches, or larger; this width requirement may be reduced if testing or modeling demonstrates approach velocities measured 1 foot in front of the entrance are maintained below 5 fps under all headpond conditions;
- conveyance pipes must be 8 inches in diameter or greater, and free of protuberances that may injure fish;
- contractions from the bypass entrance to conveyance pipe must be gradual: a concentric conical reducer with a taper angle (i.e., angle between the pipe axis and inner cone wall) of 30 degrees, or less, is recommended;
- bends in conveyance pipes must maintain a bend-radius-to-pipe-diameter (R/D) ratio of 5.0 or greater;
- conveyance velocity in the conduit must be maintained at 25 fps or less.

13.4.4 Conte Airlift Bypass

The injection of air into submerged conduits has been has proved successful in providing a controlled flow field, attracting downstream migrants, and safely transporting live fish. The Conte Airlift Bypass (CAB) is a deep-entrance airlift designed to attract and transport adult downstream migrating eels over a stream barrier. The CAB concept is described in Haro et al. (2016); additional design details can be provided by Engineering upon request. Based on successful laboratory testing (Haro et al. 2016) and subsequent field scale deployments in the northeast, Engineering recommends the following criteria in the design and construction of the CAB:

- if installed on a turbine intake rack (or other screen), adjacent rack intake velocity must be maintained at 2 fps or less;
- intake velocity must be maintained between 3.5 to 5 fps, measured 1 foot in front of the intake opening;
- conveyance pipes must be 8 inches in diameter or greater, and free of protuberances that may injure fish;
- entrance must be 9 in diameter or larger;
- bends in conveyance pipe must maintain a bend-radius-to-pipe-diameter (R/D) ratio of 5.0 or greater;
- contractions from the bypass entrance to conveyance pipe must be gradual: a concentric conical reducer with a taper angle (i.e., angle between the pipe axis and inner cone wall) of 30 degrees, or less, is recommended;
- Air injection ports must be flush or countersunk in the conveyance pipe inner wall.

13.4.5 Behavioral Barriers and Guidance

Behavioral barriers such as light, sound, and bubble screens are considered experimental and have not shown consistent performance in guiding American eels. Engineering does not generally endorse these technologies.

13.4.6 Operational Measures

Operational alternatives such as nightly project shutdowns can be effective at passing eels provided an alternative egress (e.g., spillway, bypass) is available.

14 Hydroelectric Facilities

14.1 Flow Management

River flows should always be prioritized to meet fishway requirements before any other project element (i.e., spill, generation, consumptive withdrawal).

14.1.1 Spill

Criteria in development.

14.1.2 Turbine Efficiency

Criteria in development.

14.1.3 Bypassed Reach

Criteria in development.

14.2 Turbine Mortality

Hydroelectric plants dramatically influence the flow fields in a river upstream and downstream of the project. Turbine discharge typically serves as the significant and persistent source of far-field attraction to migrating fish above and below dams.

Turbine passage is hazardous to both juveniles and post-spawn adult anadromous fish and out-migrating catadromous eels. Fish that pass through the turbine intakes are subject to injury and mortality resulting from the following mechanisms (Cada, 1990; USACE, 1995; Cada et al., 1997; Cada, 2001):

- Rapid and extreme pressure changes: water pressures within the turbine may increase to several times atmospheric pressure, then drop to sub-atmospheric pressure, all in a matter of seconds;
- Cavitation: the (injurious) effect of water vapor bubble collapse;
- Shear stress: forces applied to the fish's surface resulting from the incidence of two bodies of water at different velocities;

- Turbulence: irregular motions of the water, which can cause localized injuries, or at larger scales, disorientation;
- Strike: collision with structures including runner blades, stay vanes, wicket gates, and draft tube piers;
- Extrusion: squeezing through narrow gaps under hydraulic pressure;
- Grinding: mechanical trauma between fixed and moving structures.

Each of these injury mechanisms can result in direct or indirect (i.e., delayed) mortality. Due to the inherently hazardous nature of hydroelectric turbines, turbine passage should generally be avoided. The conventional mitigation strategy is to install a dedicated downstream fishway that allows juvenile and post-spawn adult anadromous fish and silver eels to safely bypass the turbines.

Where the efficacy of a downstream bypass is low (or the bypass is non-existent), careful analysis of the mortality of fish entrained through turbines should be made. Field studies (e.g., mark-recapture, balloon-tags) that empirically measure survival of entrained fish are preferred. Moreover, site-specific studies are recommended; extrapolating total entrainment rates from samples of other species or from other sites may be less precise (FERC, 1995). Where field studies are impractical, infeasible, or cost prohibitive, desktop analyses may prove a useful predictive tool.

14.2.1 Desktop Evaluations

Numerous desktop techniques have been documented and generally fall into one of two categories: empirically derived regression equations and fundamental methods that relate fish physiology and turbine physics. The so-called Von Raben method and Franke method are examples of the latter type. Both methods yield equations that predict the probability of blade strike depending largely on turbine geometry and fish length (Franke et al. 1997). The Franke method, an extrapolation and improvement upon Von Raben approach, is the preferred fundamental desktop analyses method. Engineering recommends the following best practices:

- the Franke method should only be used for Francis, Kaplan, and fixed propeller turbines;

- where possible, use engineering drawings (rather than reports) to determine the inlet and outlet diameters on a Francis turbine;
- in the absence of better information, assume mid-blade paths for fish moving through Kaplan and fixed propeller turbines;
- where accurate turbine efficiency curves for a site are not available, typical turbine efficiency curves can be used and, perhaps, discounted depending on the condition of the runner;
- care should be taken in selecting a value of the mortality correction factor or correlation coefficient, Lambda; unless Lambda has been calibrated, a conservative value of 0.2 is recommended.

Desktop methods can be computationally complex and are well suited for a spreadsheet solution. To facilitate this, in 2018 Engineering developed a computer implementation of the methods outlined in "Development of Environmentally Advanced Hydropower Turbine System Design Concepts" by G. Franke et al. (1997) for evaluating fish mortalities due to turbine entrainment. This model, provided "as is" and without warranty of any kind, may be downloaded from:

www.fws.gov/northeast/fisheries/fishpassageengineering.html

14.2.2 Field Evaluations

Criteria in development.

15 Experimental Technologies

Applied and theoretical research provides valuable insight into the refinement of existing methods and the development of new fish passage technologies. Engineering encourages the development of technologies that further minimize the ecological impact of anthropogenic in-stream activities and structures. Until new technologies are proven *in-situ* to be safe, timely and effective (see Section 2.3), Engineering refers to them as “experimental.”

The purpose of the experimental designation is to communicate to the proponent (e.g., researcher, developer, dam owner, licensee) that upon implementation, the Service may require a higher level of evaluation than it would for a conventional fish passage device or method. To avoid delays in implementation of fish passage at a project site, proponents of experimental technologies are encouraged to consider, in advance, alternative (conventional) options. The experimental designation is not intended to: 1) initiate any specific regulatory action; 2) label the technology as categorically unacceptable under any policy or statute; nor 3) suggest the technology is known to be deficient in any way.

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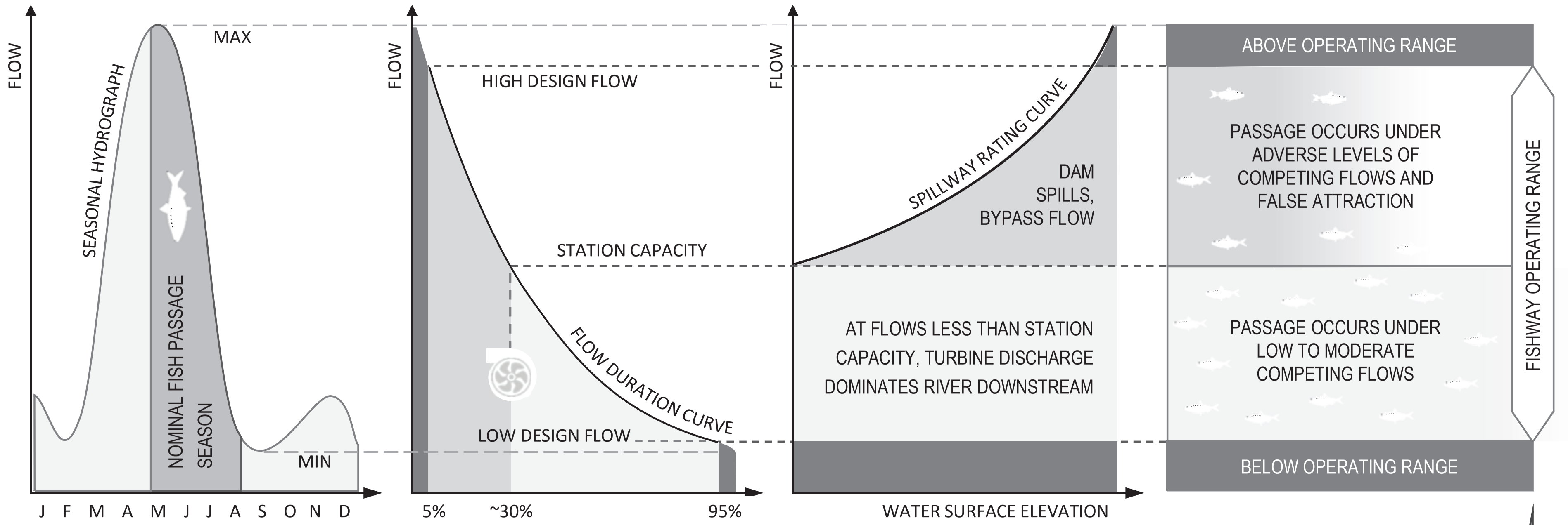
Appendix A
Reference Plates



Linear Proration of Drainage Area

Daily average river flows at ungaged project sites can be linearly prorated from hydrologically similar gaged sites.

$$Q_u = Q_g\left(A_u/A_g\right)$$

where: Q_u is the ungaged flow (cfs)
Q_g is the gaged flow (cfs)
A_u is the site drainage (mi^2)
A_g is the gage drainage (mi^2)

Note: the linear relationship is valid only when the drainage area of the ungaged project site is of **comparable size** to the drainage of the gage site.

Weibull Exceedance Probability

Fish passage design flows, and associated **exceedance probabilities**, are developed using daily average river flows recorded during the fish passage season over a sufficiently long period of record (i.e., 10 to 30 years). High (5%) and low (95%) design flows can be compared to station capacity (~30%).

$$P_m = m/(n+1)$$

where: P is the probability of rank m
m is the rank of the flow event
n is the number of flow events

Head-Discharge Relationship

The spillway rating curve can be related to fish passage design flows (and station capacity). For simple, uncontrolled spill, the weir equation relates **water surface elevation (or head above crest) to discharge**.

$$Q_S = CLH^{3/2}$$

where: Q_s is the total spillway flow (cfs)
L is the length of spillway crest (ft)
C is the weir coefficient (-)
H is the head above crest (ft)

Note: head is **offset** from the water surface elevation by the crest elevation

Fish Passage Operating Range

The **operating range describes the river flows and associated water surface elevations under which the fish passage facility is safe, timely, and effective**. Additionally, it illustrates when the fishway discharge competes with false attraction created by the power station and spillway. To mitigate adverse effects of competing flows, the **Service recommends total fishway discharge**:

$$Q_T \geq Q_P\,(3-5\%)$$

where: Q_T is the total fishway flow (cfs)
Q_P is the station capacity (cfs)

USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler, K. Mulligan
Issued 1/6/2017; replaces "Fishway Operating Range" 11/12/2015

FISHWAY OPERATING RANGE

REFERENCE PLATE 4-1

BURST

PROLONGED

CRUISING

Burst or Dart or Sprint Speed is the swim speed that a fish can maintain for mere seconds V_B

- Burst speed engages anaerobic white muscle tissues
- Bell (1990) suggests can be maintained for 5-10 sec.; Bain (1999) 2-3 sec.; Beamish (1978) < 20 sec.
- Speed used for predator avoidance or feeding; in fishways, use to ascend weir crests
- For fish passage design, velocities should be kept below V_B for the weakest target species at all times

Many published swimming speeds are derived from lab tests on handled fish; such values may underestimate *in situ* performance.

$$V_B = 2\,V_P$$

$$2\ sec \leq \Delta t \leq 10\ sec$$

Prolonged (or Sustained Speed *) is the swim speed that a fish can maintain for minutes; V_P

- Prolonged speed engages both red and white muscle tissues
- Bain (1999) suggests speed can be maintained for 5-8 minutes; Beamish (1978) suggests 20 sec. to 200 min.
- Critical swim speed, U_{crit}, is a sub-category of prolonged speed measured by Brett (1964)
- For fish passage design, V_P can be used in conjunction with Δt to estimate travel distance, D, before fatigue

$$4BL\ sec^{-1} \leq V_P \leq 7BL\ sec^{-1}$$

$$V_g = V_w - V_P$$

$$D = V_g \Delta t$$

$$5\ min \leq \Delta t \leq 8\ min$$

Cruising or Sustained Speed is the swim speed that a fish can maintain for hours; V_C

- Cruising speed engages aerobic red muscle tissues
- Speed used for extended periods of travel at low speeds
- Influenced by temperature, oxygen; Bell (1990) suggested swim speeds reduced by 50% at temp. extremes
- For fish passage design, V_C should be used for transport flumes, holding pools, etc.

*** Literature on the definition of Sustained Speed is inconsistent. e.g., Bain (1999) refers to the speed that fish can maintain for minutes as "sustained"; contradicting Bell (1990) and others. For this reason, the cruising-prolonged-burst naming convention is used here.**

$$V_C = \frac{1}{3}\,V_P = \frac{1}{6}\,V_B$$

Bell, M. (1990) "Fisheries Handbook of Engineering Requirements and Biological Criteria"
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Bain, M. and Stevenson, N. (1999) "Aquatic Habitat Assessment: Common Methods"
Brett, J. (1964) "The respiratory metabolism and swimming performance of young sockeye salmon"

ENERGY DISSIPATION FACTOR (EDF)

FT-LB/S/FT^3 — RECOMMENDATIONS & REQUIREMENTS

16
- AWS dissipation, max. (31.33 ft-lb/s/ft^3); EA UK (2010)
- AWS dissipation, min. (20.89 ft-lb/s/ft^3); EA UK (2010)

AWS POOLS (16.0 ft-lb/s/ft^3) †

- check weirs, salmon (10.44 ft-lb/s/ft^3); Larinier et al. (1999)

7
- roughened culverts (7.0 ft-lb/s/ft^3); WA DFW (2003)
- baffled culverts, max. (5.0 ft-lb/s/ft^3); CalTrans (2013)
- salmonids (5.0 ft-lb/s/ft^3); Maine DOT (2008)
- vertical slot pools (4.18 ft-lb/s/ft^3); FAO and DWVK (2002)

5

4 — **ATLANTIC SALMON (4.0 ft-lb/s/ft^3) †**

- salmonids, adult (3.13 ft-lb/s/ft^3); NOAA (2011)

3 — **AMERICAN SHAD (3.15 ft-lb/s/ft^3) †**

- trout (3.13 ft-lb/s/ft^3); EA UK (2010)
- non-salmonids (2.09 ft-lb/s/ft^3); EA UK (2010)

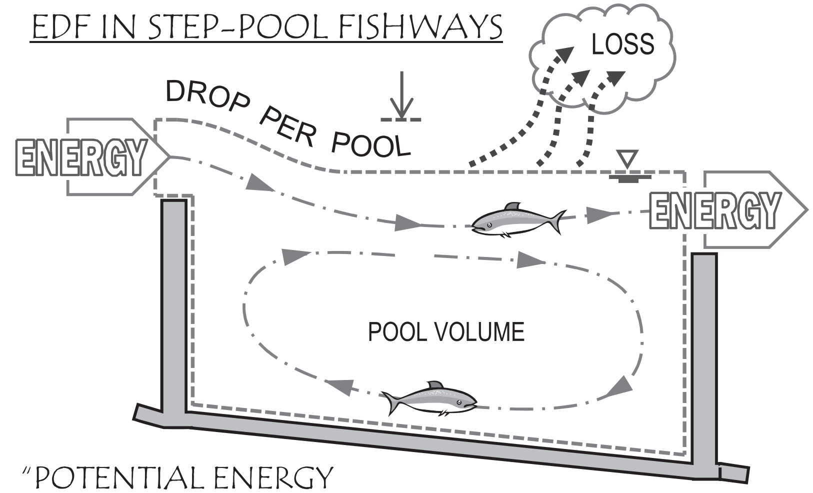
2
- step-pools at turns (2.09 ft-lb/s/ft^3); EA UK (2010)
- salmonids, juvenile (2.0 ft-lb/s/ft^3); NOAA (2011)

1
- resting pools (1.04 ft-lb/s/ft^3); FAO and DWVK (2002)

0
- Denil resting pools (0.52 ft-lb/s/ft^3); FAO and DWVK (2002)

† U.S. Fish and Wildlife Service criteria

EDF IN STEP-POOL FISHWAYS



"POTENTIAL ENERGY DISSIPATION RATE PER UNIT VOLUME"

DESIGN

$$\forall = \frac{\gamma Q D}{EDF}$$

EVALUATE

$$EDF = \frac{\gamma Q D}{\forall}$$

where:

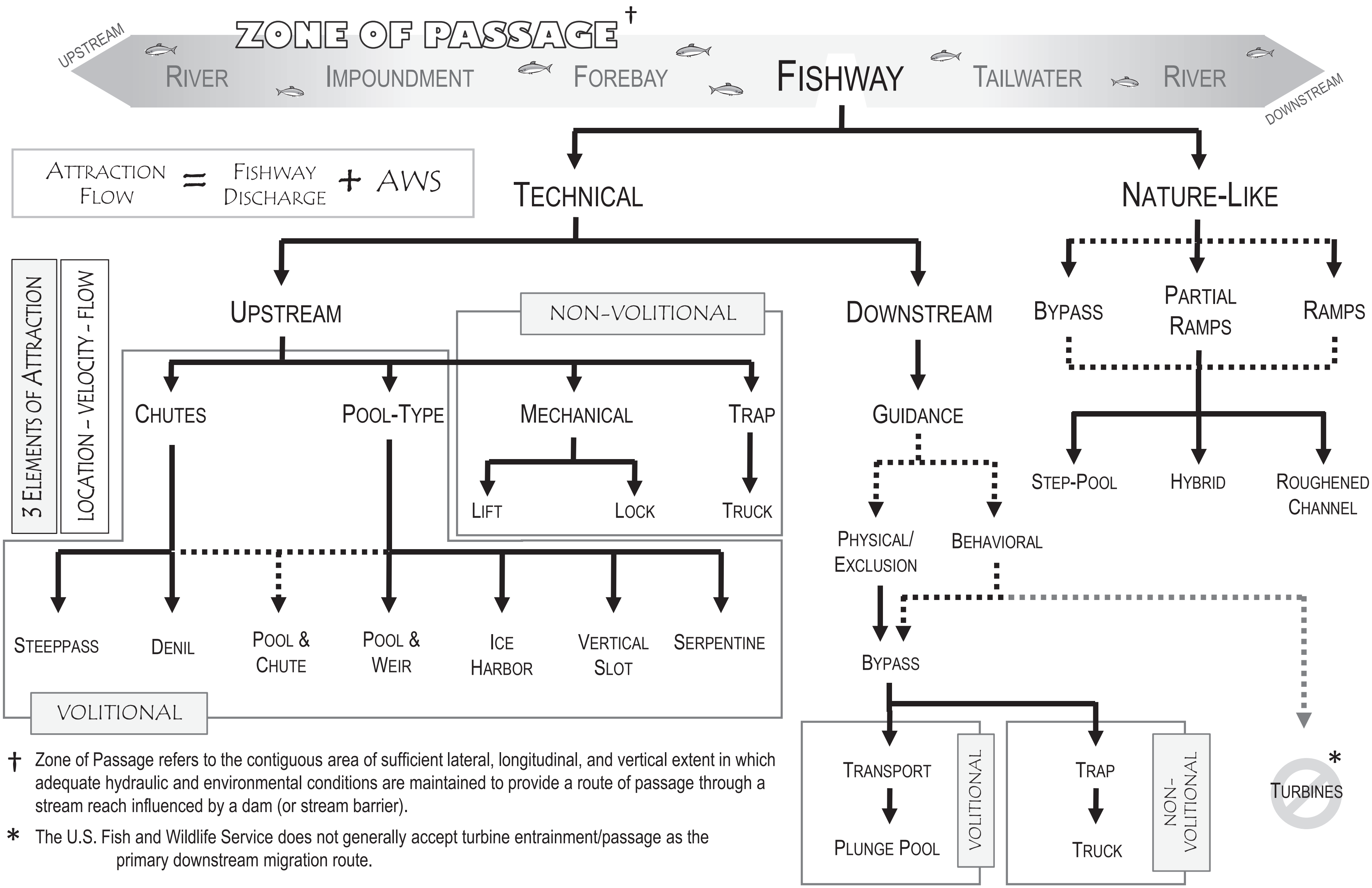
EDF is the volumetric power dissipation rate in ft-lb/s/ft^3
$\forall$ is the water volume in the fishway step pool in ft^3
D is the hydraulic drop from one pool to the next in ft
Q is the flow over the weir crests, through the fishway, in cfs
γ is the unit weight of water (62.4 lbs/ft^3)

- Larinier et al. (1999) "Passes a Poissons"
- WA DFW (2003) "Design of Road Culverts for Fish Passage"
- FAO and DWVK (2002) "Fish Passes"
- EA UK (2010) "Fish Pass Manual"
- NOAA (2011) "Anadromous Salmonid Passage Facility Design"
- CalTrans (2013) "Fish Passage Design for Road Crossings"
- Maine DOT (2008) "Waterway & Wildlife Crossing Policy & Design Guide"

USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler
Issued 1/6/2017; replaces "Power Dissipation Rates" 7/26/2014

POWER DISSIPATION RATES

REFERENCE PLATE 5-2



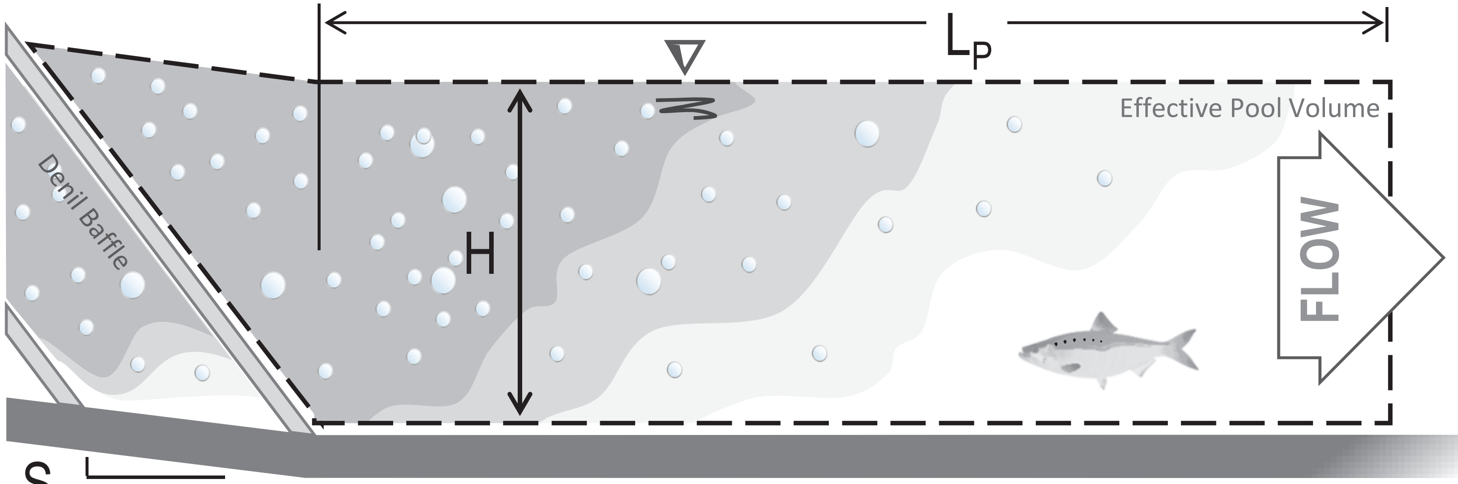
† Zone of Passage refers to the contiguous area of sufficient lateral, longitudinal, and vertical extent in which adequate hydraulic and environmental conditions are maintained to provide a route of passage through a stream reach influenced by a dam (or stream barrier).

* The U.S. Fish and Wildlife Service does not generally accept turbine entrainment/passage as the primary downstream migration route.

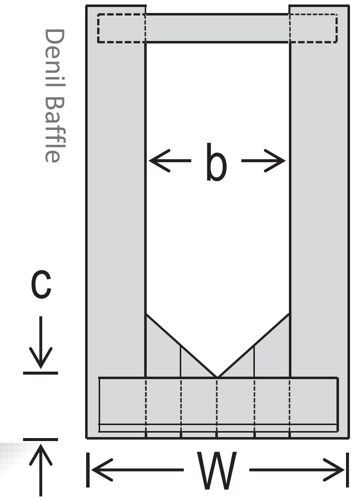
USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler
Issued 1/6/2017; replaces “Fishway Types” 7/30/2014

FISHWAY TYPES

REFERENCE PLATE 6-1



Denil Fishway Resting Pool Geometry



Generalized Power Dissipation in Denil Resting Pools

$$EDF = \left[\frac{Q}{2}\left(\frac{1}{A_1} - \frac{1}{HW}\right) + gH\left(\sqrt{2}\cos\frac{-\pi + 4\tan^{-1} S_0}{4} - 1\right)\right]\frac{Q\gamma}{HWL_P}$$

$$A_1 = \begin{cases} \frac{bc}{2} + \left(\frac{H}{\sin\left(\frac{\pi}{4}\right)} - 2c\right)b & H > 2c\sin\left(\frac{\pi}{4}\right) \\ \frac{b}{2c}\left(\frac{H}{\sin\left(\frac{\pi}{4}\right)} - c\right)^2 & \sin\left(\frac{\pi}{4}\right) < H \leq 2c\sin\left(\frac{\pi}{4}\right) \end{cases}$$

Energy Dissipation Factor is the volumetric power dissipation in foot-pounds per second per cubic feet

- "Derivation and Application of the Energy Dissipation Factor in the Design of Fishways" B. Towler, K. Mulligan and A. Haro. Ecological Engineering 83 (2015) 208-217

Pool Sizing for Standard Denil Fishways

$$EDF \times L_P = K_1(H - h_v)^{K_2}$$

Width		1:8 slope	1:10 slope
3 (ft)	h_v	0.592 (ft)	0.5805 (ft)
	K_1	9.728355	7.697128
	K_2	1.802865	1.773244
4 (ft)	h_v	0.7894 (ft)	0.774 (ft)
	K_1	9.166344	7.160788
	K_2	1.779516	1.765067

h_v is the vertical (installed) height of the notch in the Denil baffle

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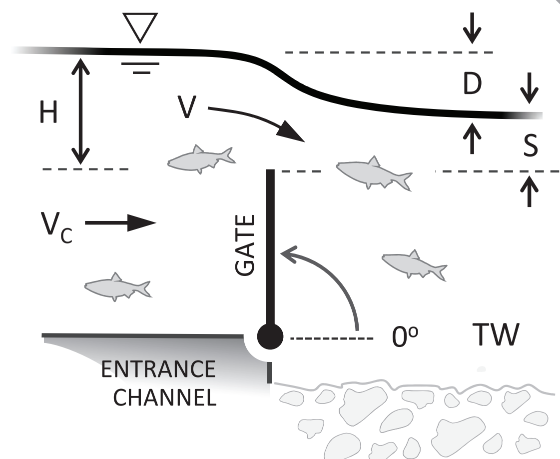
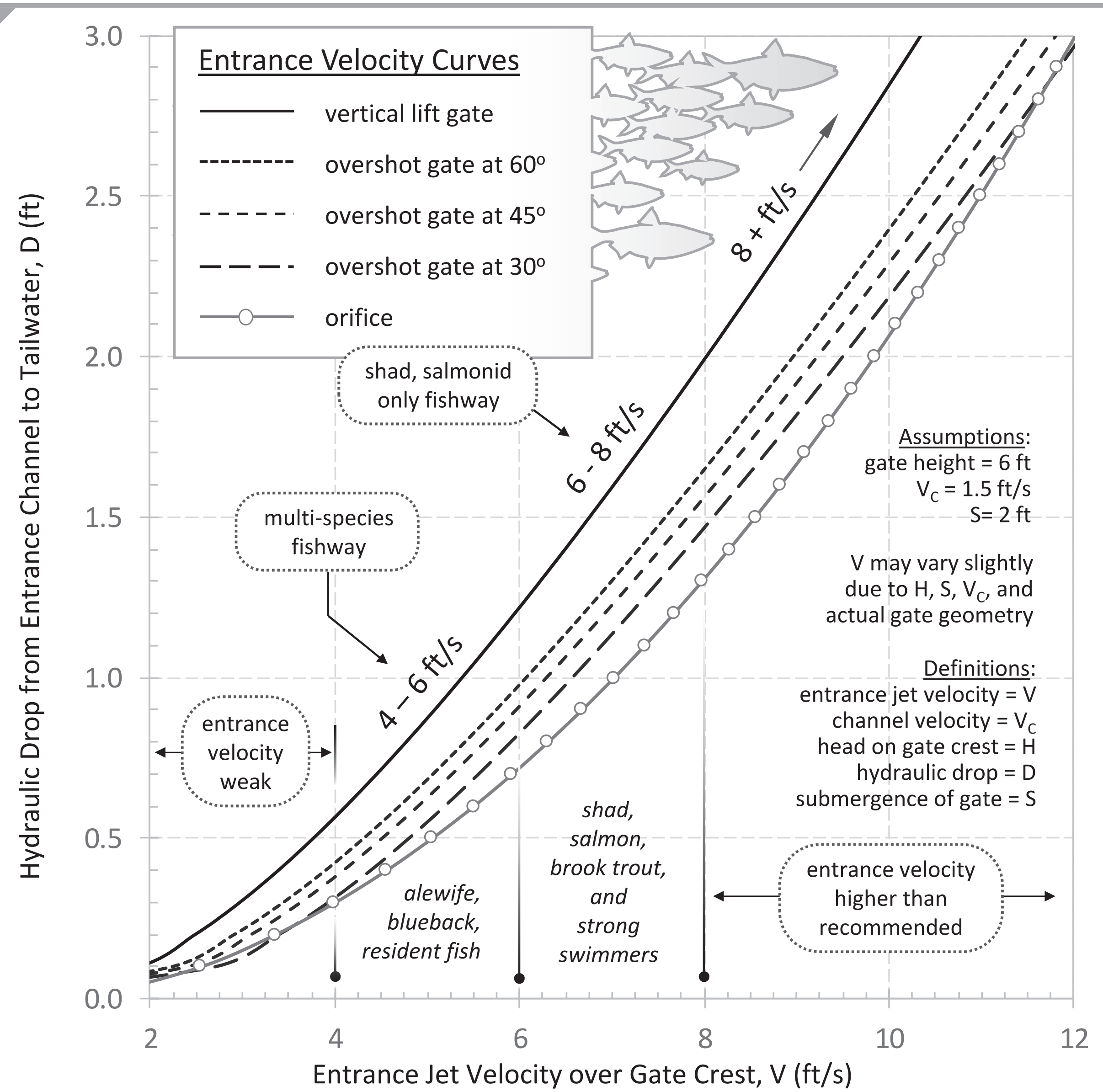
DENIL RESTING POOLS

REFERENCE PLATE 6-2

For operational simplicity, drop (D) is used as a surrogate for velocity (V). Drop vs. velocity estimates for vertical and overshot gates are shown below.

Gate Type	D (in)	V (ft/s)
Vertical Lift	7	4
	15	6
	24	8
60° Overshot	5	4
	12	6
	20	8
45° Overshot	5	4
	11	6
	19	8
30° Overshot	4	4
	10	6
	18	8





*estimated curves based on Rehbock eqn. and Wahlin & Replogle (1994);

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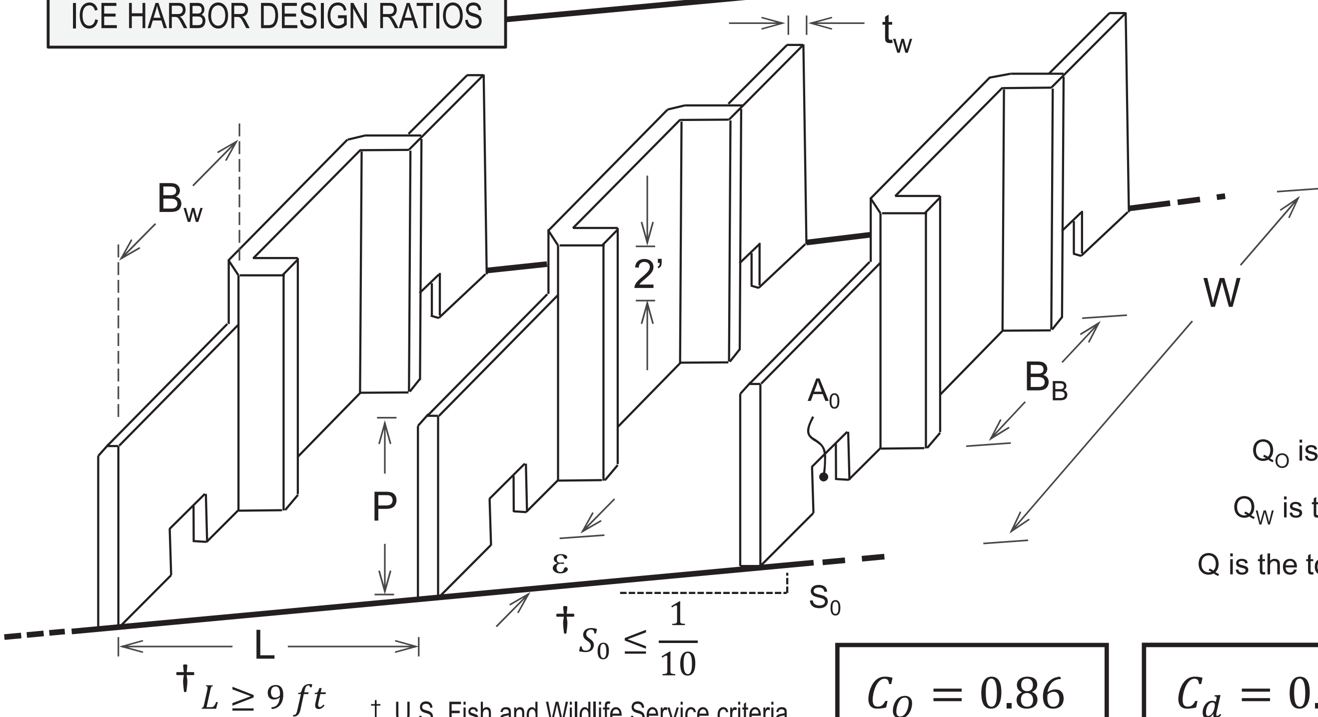
FISHWAY ENTRANCE GATES

REFERENCE PLATE 6-3

ICE HARBOR STANDARD DIMENSIONS									
W	10’	11’	12’	13’	14’	16’	18’	20’	25’
B_W	3’ – 1”	3’ – 5”	3’ – 9”	4’ – 1”	4’ – 4”	5’ – 0”	5’ – 8”	6’ – 3”	7’ – 10”
B_B	3’ – 10”	4’ – 2”	4’ – 6”	4’ – 10”	5’ – 4”	6’ – 0”	6’ – 8”	7’ – 6”	9’ – 4”
ε	1’ – 10"	2’ – 0”	2’ – 3”	2’ – 5”	2’ – 7”	3’ – 0”	3’ – 0”	3’ – 0”	3’ – 0”
A_O	12” x 12”	13” x 13”	14” x 14”	15” x 15”	16” x 16”	18” x 18”	18” x 18”	18” x 18”	18” x 18”

ICE HARBOR DESIGN RATIOS



† U.S. Fish and Wildlife Service criteria

$$Q_W = C B_W {H_W}^{1.5}$$

$$Q_O = C_O A_O \sqrt{2 g H_O}$$

$$Q = 2Q_W + 2Q_O$$

H_O is the head on the orifice in feet

H_W is the head on the weir crest in feet

Q_O is the discharge though each orifice in cfs

Q_W is the discharge over each weir crest in cfs

Q is the total discharge through the fishway in cfs

$$C_O = 0.86$$

$$C_d = 0.68$$

$$C = \frac{2}{3}\sqrt{2g}\, C_d$$

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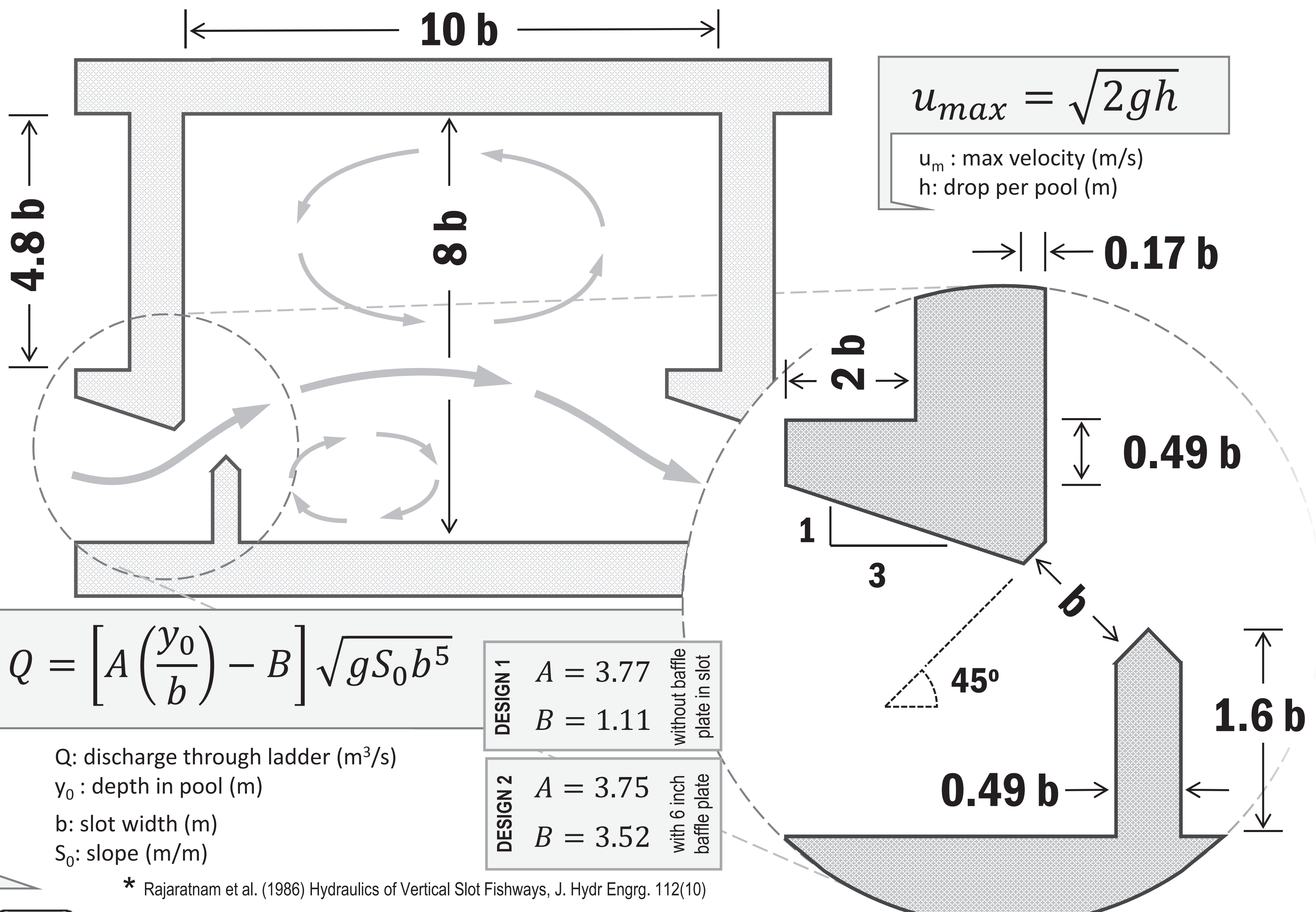
ICE HARBOR FISHWAY

REFERENCE PLATE 7-1



$$u_{max} = \sqrt{2gh}$$

u_m : max velocity (m/s)
h: drop per pool (m)

*

$$Q = \left[A\left(\frac{y_0}{b}\right) - B\right]\sqrt{gS_0b^5}$$

Q: discharge through ladder (m^3/s)
y_0 : depth in pool (m)
b: slot width (m)
S_0: slope (m/m)

DESIGN 1	$A = 3.77$ $B = 1.11$	without baffle plate in slot
DESIGN 2	$A = 3.75$ $B = 3.52$	with 6 inch baffle plate

* Rajaratnam et al. (1986) Hydraulics of Vertical Slot Fishways, J. Hydr Engrg. 112(10)

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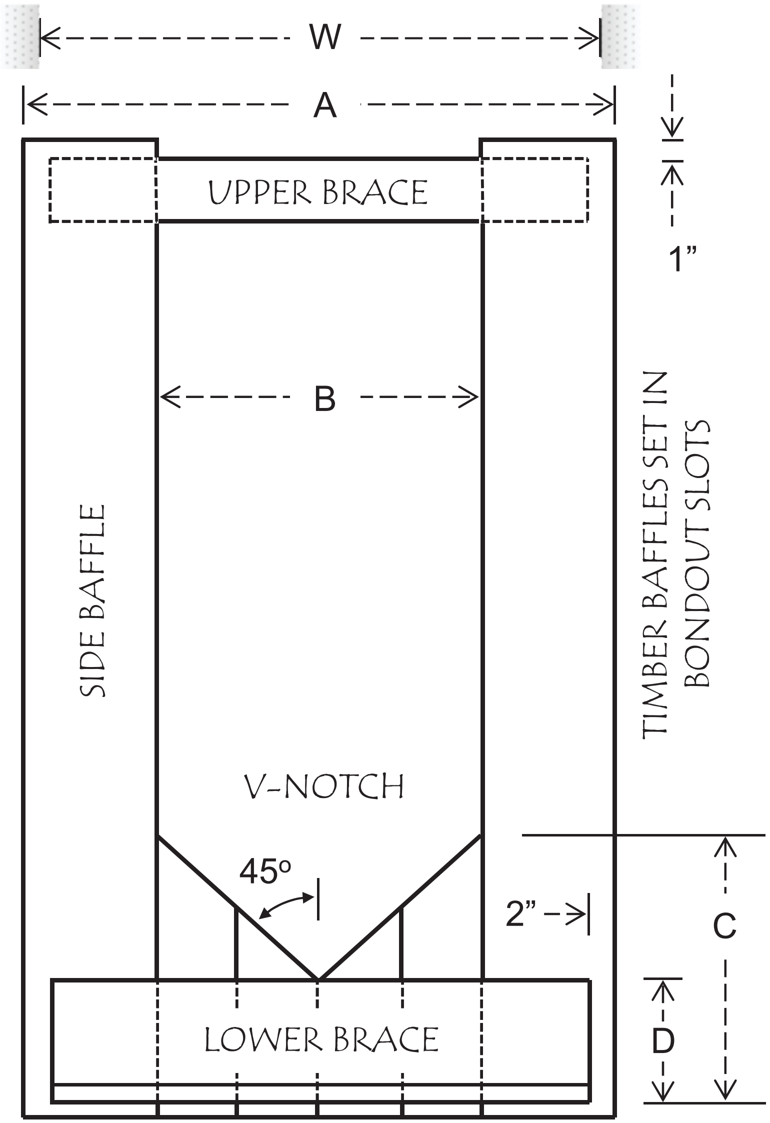
VERTICAL SLOT FISHWAY

REFERENCE PLATE 7-2



STANDARD DENIL GEOMETRY *					
W **	A	B	C	D	S ***
4’ - 0”	4’ - 3”	2’ - 4”	2’ - 0”	1’ - 0”	2’ - 6”
3’ - 6”	3’ - 9”	2’ - 0”	1’ - 9”	10½”	2’ - 4”
3’ - 0”	3’ - 3”	1’ - 9”	1’ - 6”	9”	2’ - 0”
2’ - 6”	2’ - 9”	1’ - 5½”	1’ - 3”	7½”	1’ - 8”
2’ - 0”	2’ - 3”	1’ - 2”	1’ - 0”	6”	1’ - 4”

* U.S. Fish and Wildlife Service criteria
** Denil channel width denoted by W; typically inside width of concrete channel
*** Horizontal (longitudinal) spacing of baffles in channel denoted by S

$$Q = (1.34 - 1.84S_0) {h_u}^{1.75} B^{0.75} \sqrt{g\, S_0}$$

$$h_u = H - D\sin[45^o + \tan^{-1}(S_0)]$$ †

h_u is the vertical depth of water (or head) above the v-notch in the timber baffle in feet

H is the vertical depth of water (or head) above fishway channel bottom at exit in feet

† Odeh (2003) “Discharge Rating Equation and Hydraulic Characteristics of Standard Denil Fishways”

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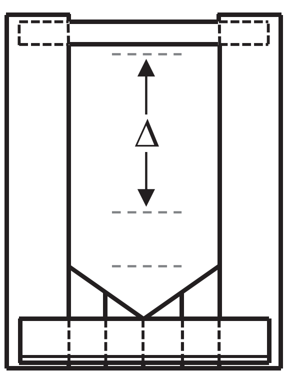
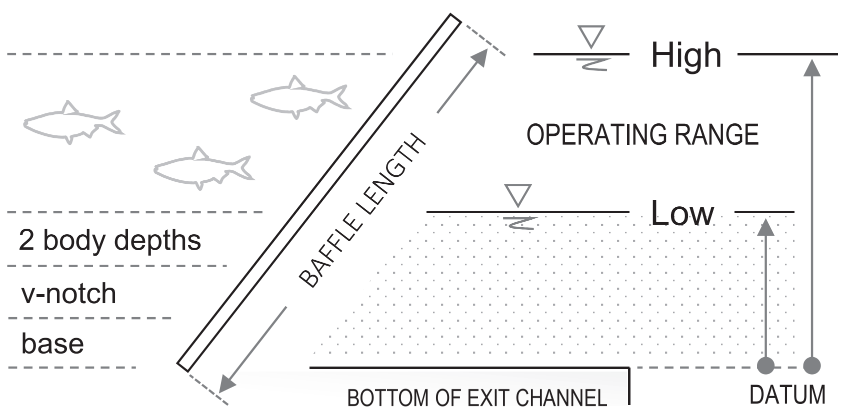
STANDARD DENIL GEOMETRY

REFERENCE PLATE 7-3

OPERATING RANGES FOR 3 FT. AND 4 FT. DENIL FISHWAYS AT 1:8 OR 1:10 SLOPES

SPECIES	OPERATING RANGE	BAFFLE LENGTH (ft) 5	6	7	8
River Herring (nominal 4" body depth)	High (ft)	3.25	4.0*	4.0*	4.0*
	Low (ft)	1.75	1.75	1.75	1.75
	Δ (ft)	1.5	2.25	2.25	2.25
American Shad (nominal 6" body depth)	High (ft)	3.25	4.25	5	5.75
	Low (ft)	2.25	2.25	2.25	2.25
	Δ (ft)	1	2	2.75	3.5
Atlantic Salmon (nominal 8" body depth)	High (ft)	3.25	4.25	5	5.75
	Low (ft)	2.5	2.5	2.5	2.5
	Δ (ft)	0.75	1.75	2.5	3.25





NOTES:

The uppermost Denil baffle is installed at the break in slope between the exit channel and the sloped channel.

Low and high operating levels are measured from the bottom of the exit channel.

High operating level is set below 3 inches below the top of the baffle to avoid impact with the cross support.

Ideally, the low and high operating levels correlate to headpond elevations at the low design flow and high design flow, respectively.

* UPPER LIMIT IS BASED ON A MAXIMUM VELOCITY CRITERION FOR RIVER HERRING (5 FT/S)

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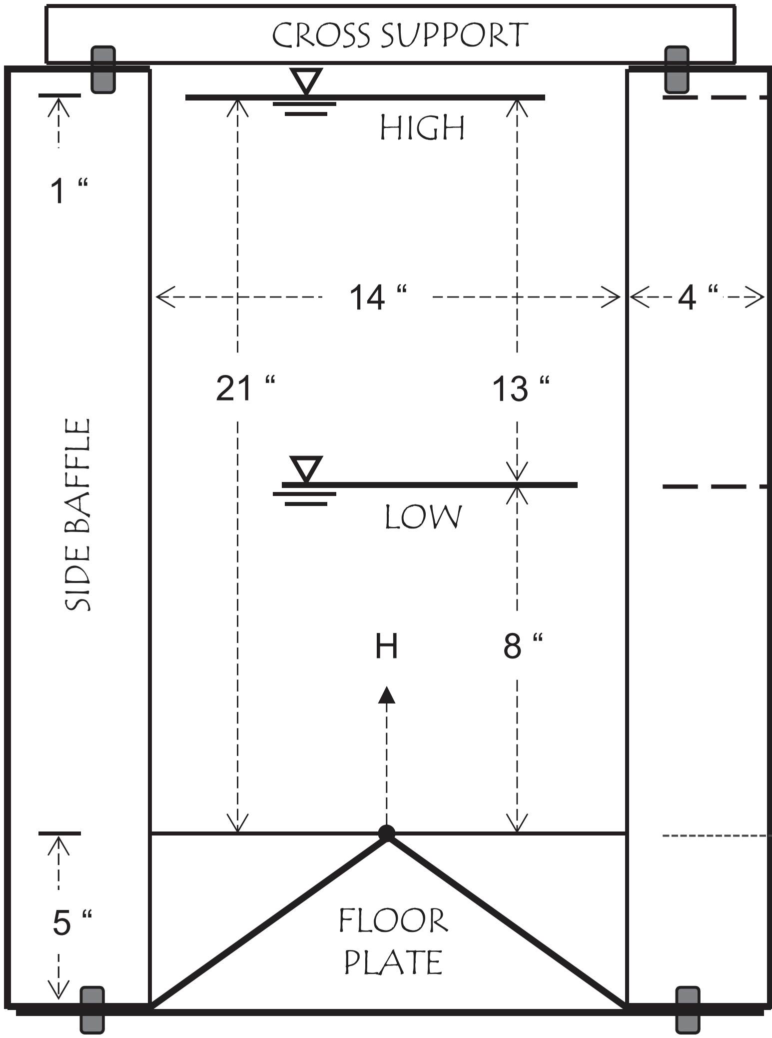
STANDARD DENIL OPERATING RANGE

REFERENCE PLATE 7-4

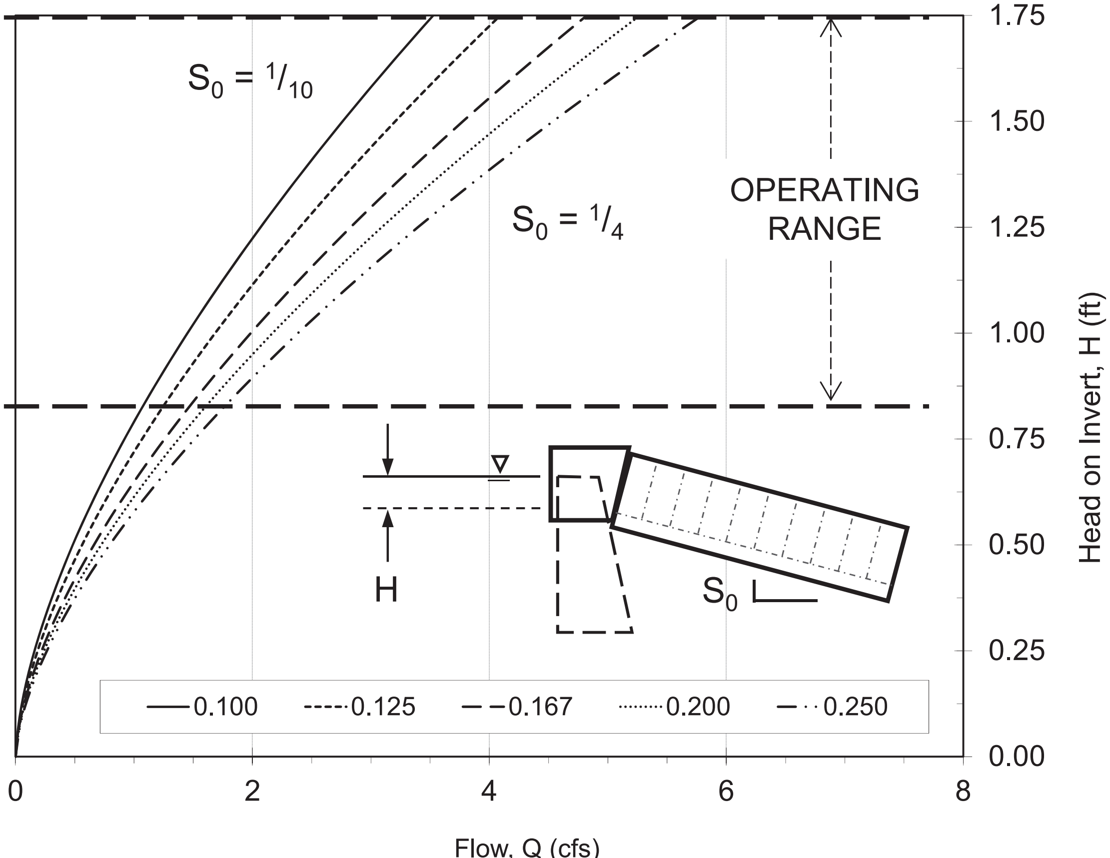
MODEL A CROSS-SECTION



Note: the cross-section of a Model A40 steeppass comprises a 5" floor plate with extended vertical side walls and baffles; horizontal dimensions are similar.

MODEL A & MODEL A40 DISCHARGE RATING CURVES

† Odeh (1993) "Hydraulics of Alaska Steeppass Fishway Model A40"



$$Q = \left(\frac{H}{0.0354\,S_0^{-1} + 0.4364}\right)^{\frac{1}{0.6307}}$$ †

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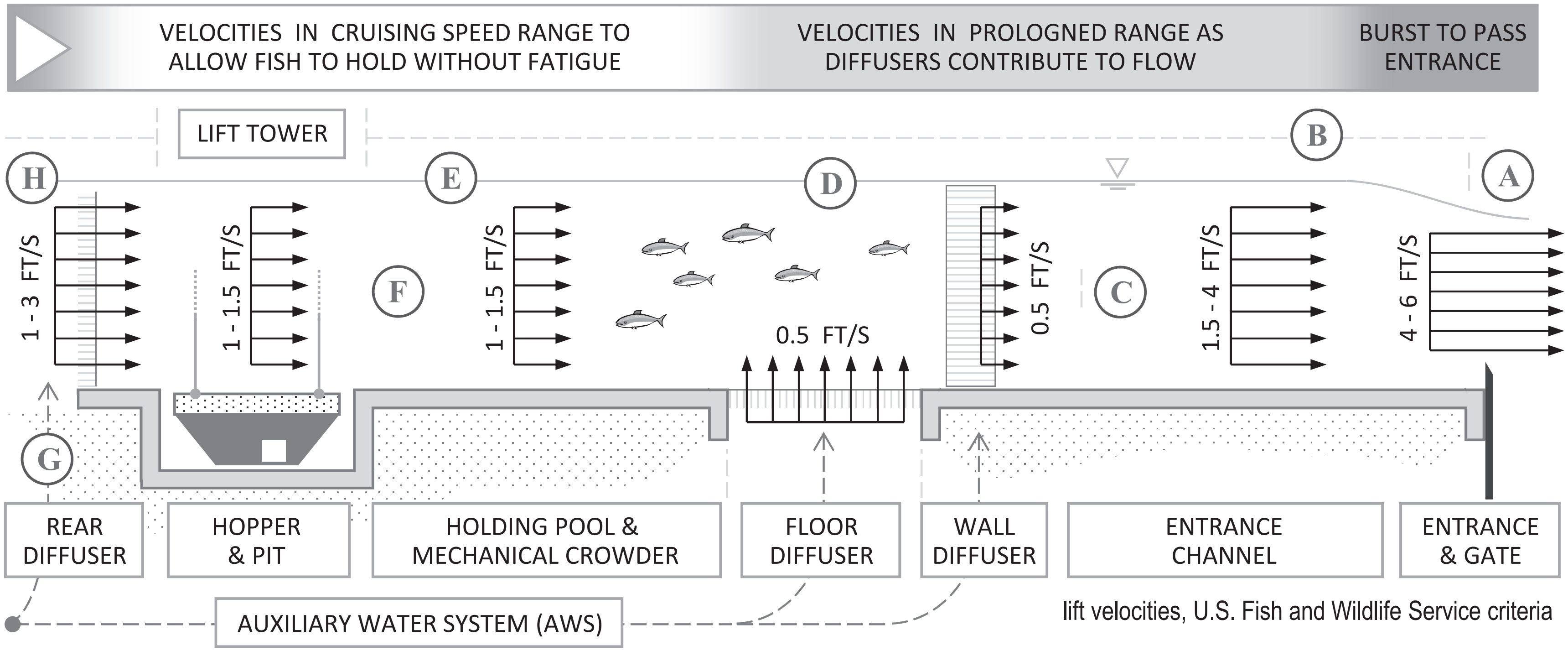
MODEL A STEEPPASS

REFERENCE PLATE 7-5



lift velocities, U.S. Fish and Wildlife Service criteria

BIOLOGICAL LIFT CAPACITY

$$n_H = \forall \left(\frac{60\ min}{1\ hr}\right) \frac{r}{w_f \forall_c [1 + C_n]}$$

n_H is the lift biological capacity in fish per hour
V is the volume of the component in ft^3
r is the cycle time in lifts per minute
w_f is the nominal weight of the target species in lbs
C_n is the non-target species allowance
$\forall_c$ is the crowding limit: hopper = 0.10 ft^3/lb †
holding pool = 0.25 ft^3/lb

† crowding limit is valid for lift cycle times of 15 m or less

A. Attraction jet is created by acceleration due to entrance (lift) gate operations; jet typically results in 0.5 – 2 foot hydraulic drop into TW.
B. Flood walls and other lift components should be design to protect against a 50-year flood event.
C. Flow in the entrance channel, downstream of the diffusers, should be streamlined and free of eddies and aeration.
D. Diffuser velocities are maximum point velocities; upwelling and aeration from the AWS should be minimal.
E. Depth in lower flume should be greater than 4 ft. at all times.
F. Flow above hopper and in holding pool should be free of aeration.
G. As much AWS flow as possible should be discharge behind the hopper.
H. AWS dissipators should be design to remove excess energy from flow.

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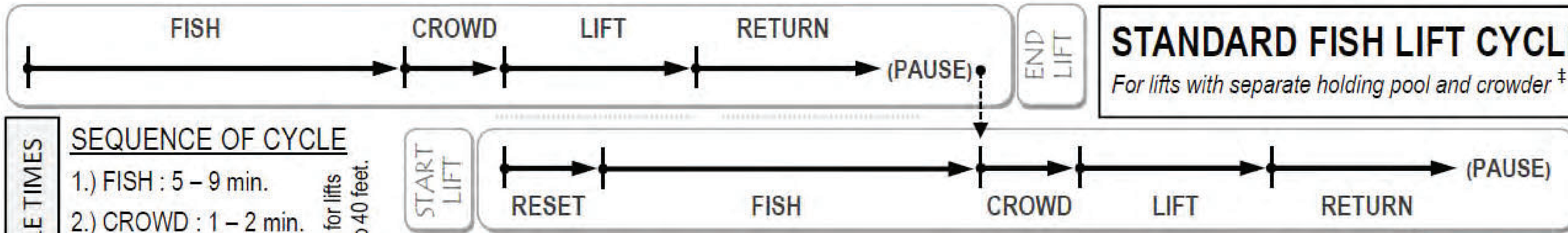
Issued 2/28/2017; replaces “Fish Lift” 7/27/2014

FISH LIFT VELOCITIES

REFERENCE PLATE 7-6

STANDARD FISH LIFT CYCLE

For lifts with separate holding pool and crowder ‡

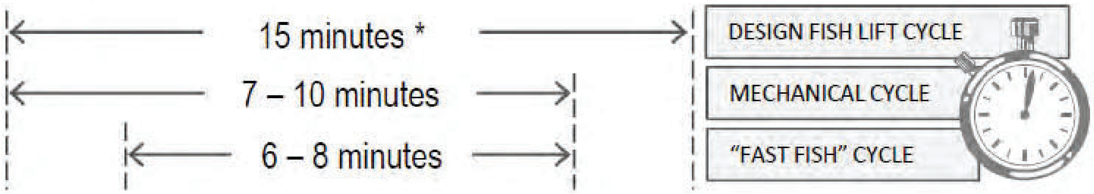


TYPICAL CYCLE TIMES

SEQUENCE OF CYCLE

1.) FISH : 5 – 9 min.
2.) CROWD : 1 – 2 min.
3.) LIFT : 3 – 4 min.
4.) RETURN : 3 – 4 min.
5.) PAUSE : 5 – 8 min.
6.) RESET : 1 – 2 min.

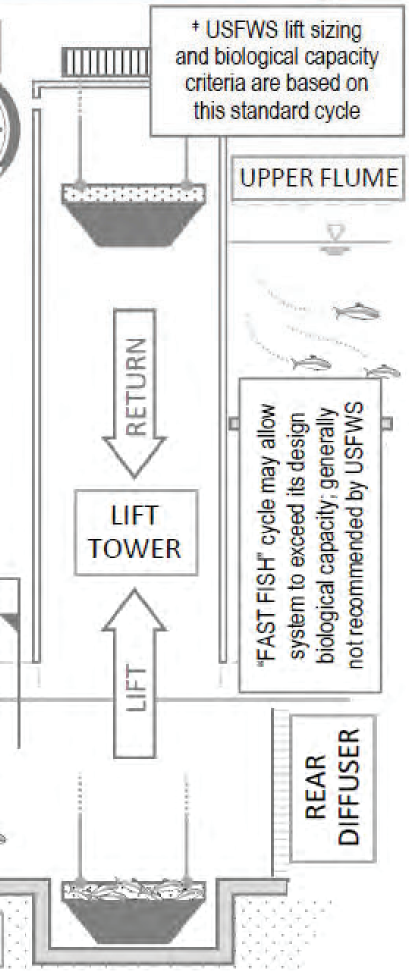
* times are typical for lifts less than or equal to 40 feet.

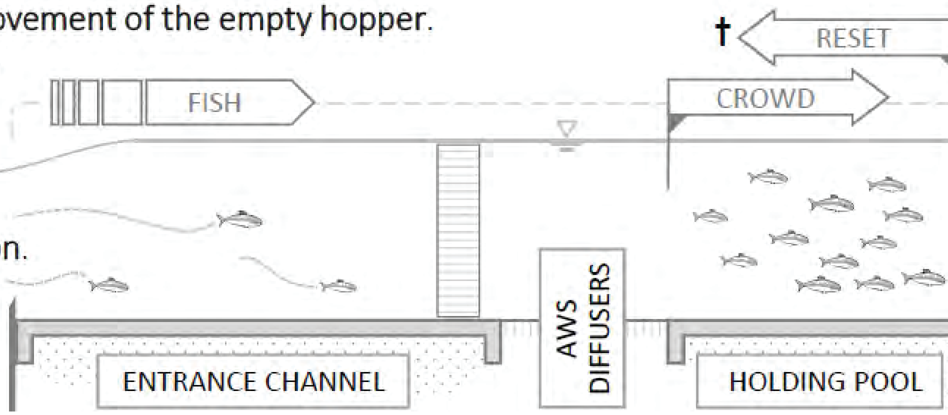


‡ USFWS lift sizing and biological capacity criteria are based on this standard cycle

1. **FISH** is the part of the cycle dedicated to **volitionally luring fish into the holding pool** in a safe, timely and effective manner. Time required can be influenced by behavior and channel length.
2. **CROWD** is the time required to safely **brail fish in the holding pool to volume above a submerged hopper**. Time is dependent on the safe mechanical operation of the crowder.
3. **LIFT** is the **upward vertical movement of the hopper** (or bucket) and release of fish into the upper flume. Most designs incorporate a two speed winch to reduce this time (especially for tall lift towers); the higher speed engages during vertical movement through lift tower.
4. **RETURN** is the downward vertical **movement of the empty hopper**.
5. **PAUSE** in the cycle **may be necessary** when the mechanical cycle is of insufficient length to complete FISH.
6. **RESET** occurs as the mechanical crowder **returns to the fishing position**.

† NOTE: in standard designs, the "crowd" and "reset" steps are the only times when the lift is not in FISH mode (due to closed exclusion gate OR assumption that crowder movement spooks fish.)





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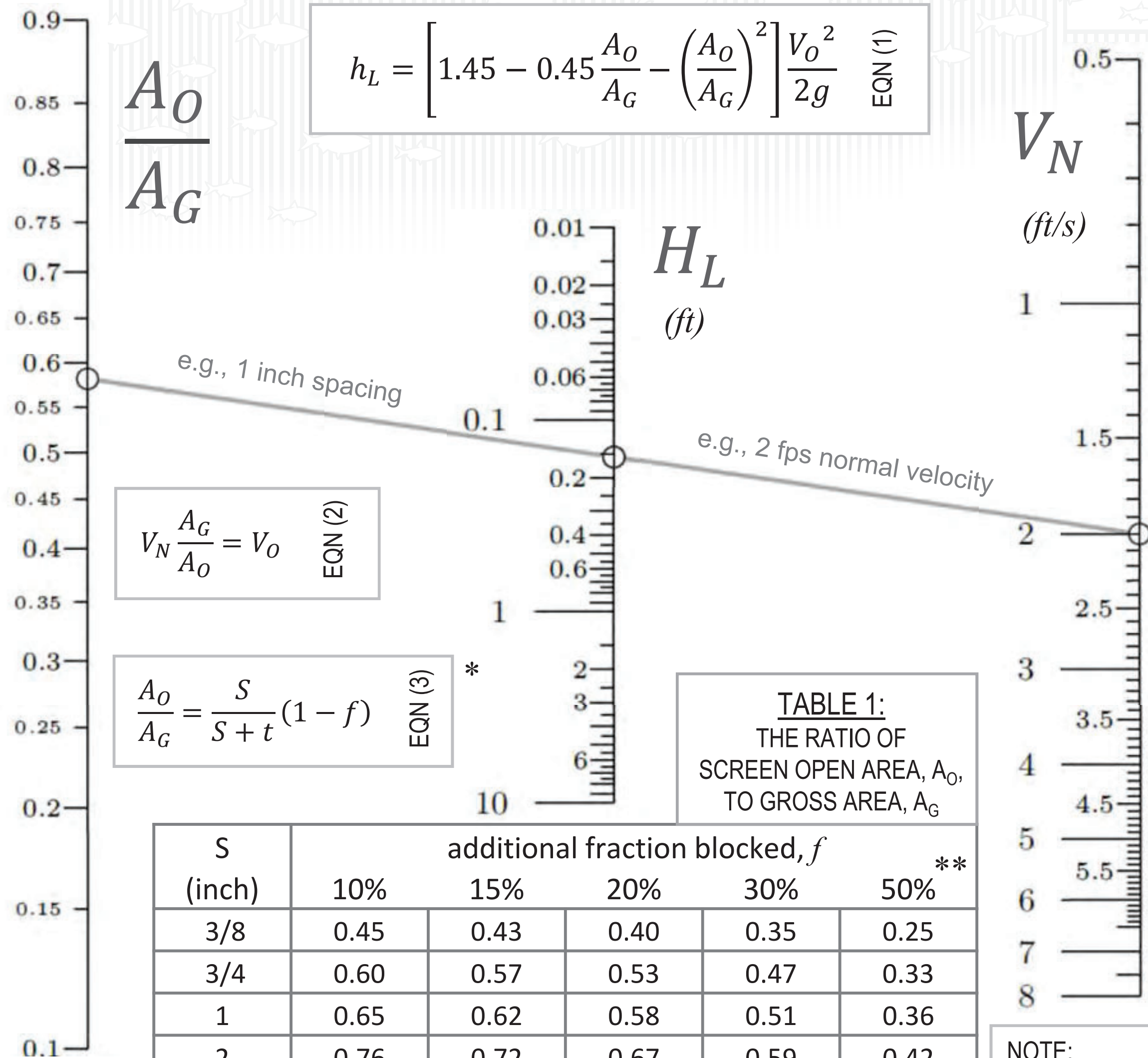
Issued 2/28/2017; replaces "Fish Lift Cycle" 11/17/2014

FISH LIFT SEQUENCE

REFERENCE PLATE 7-7

ANGLED BAR SCREEN HEADLOSS NOMOGRAPH



$$h_L = \left[1.45 - 0.45\frac{A_O}{A_G} - \left(\frac{A_O}{A_G}\right)^2\right]\frac{{V_O}^2}{2g} \quad \text{EQN (1)}$$

$$V_N\frac{A_G}{A_O} = V_O \quad \text{EQN (2)}$$

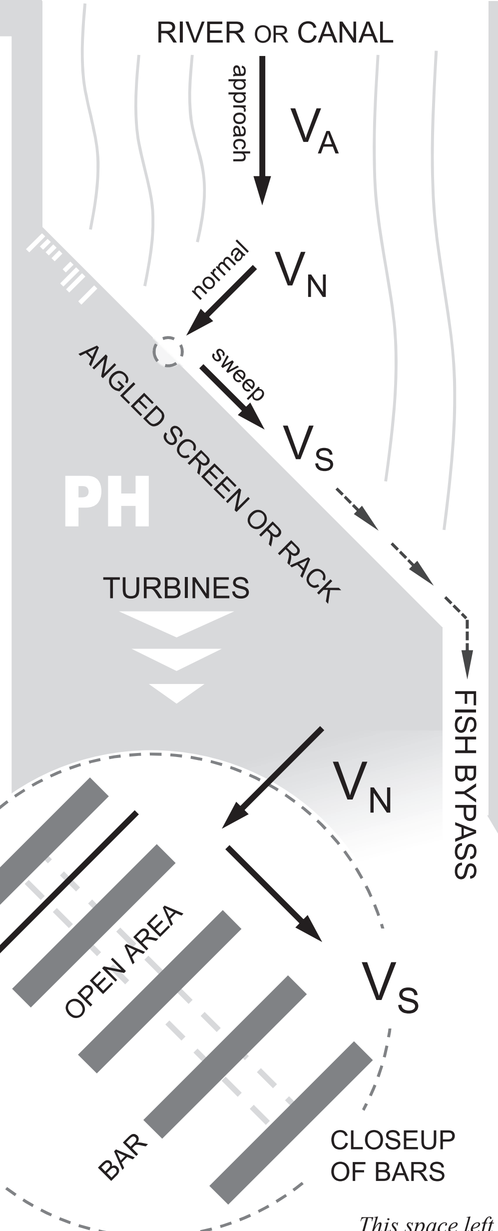
$$\frac{A_O}{A_G} = \frac{S}{S+t}(1-f) \quad \text{EQN (3)} \; *$$

TABLE 1: THE RATIO OF SCREEN OPEN AREA, A_O, TO GROSS AREA, A_G

S (inch)	additional fraction blocked, f 10%	15%	20%	30%	50% **
3/8	0.45	0.43	0.40	0.35	0.25
3/4	0.60	0.57	0.53	0.47	0.33
1	0.65	0.62	0.58	0.51	0.36
2	0.76	0.72	0.67	0.59	0.42
4	0.82	0.78	0.73	0.64	0.46
6	0.85	0.80	0.75	0.66	0.47

** bar thickness, t = 3/8 inch; ** f = 50% blockage typical of heavy debris*

HOW TO USE THIS ANGLED BAR SCREEN HEADLOSS NOMOGRAPH:
Read the ratio of screen open area, A_O, to gross area, A_G, from Table 1 given the clear bar spacing, S, and the fraction, f, blocked by structural elements (assume 15-20%); use a straight edge to connect area ratio (left scale) to normal velocity (right scale), read headloss from the center scale.



NOTE:
EQN (1) from page 457 USBR, 1987, "Design of Small Dams"
EQN (2) from Conservation Of Mass
EQN (3) from angled bar screen geometry

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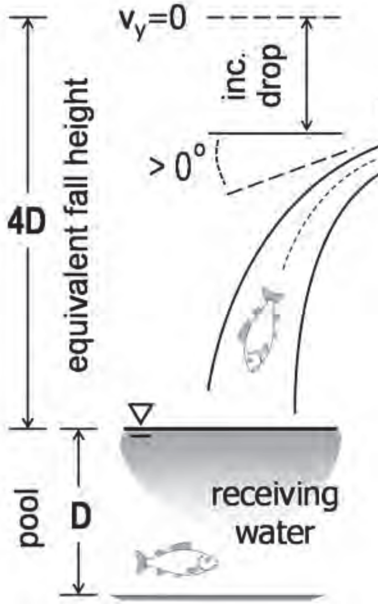
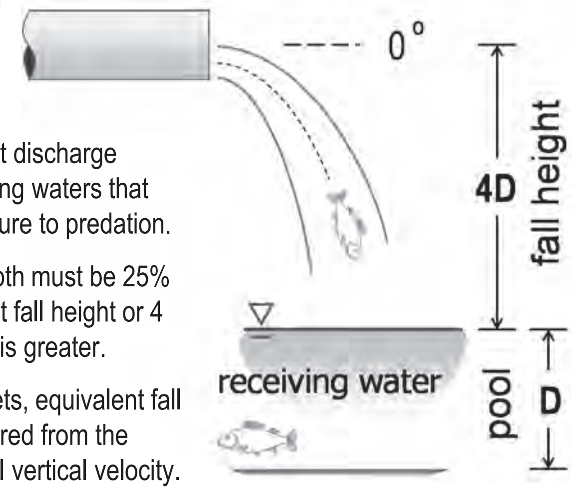
Issued 1/6/2017; replaces "Angled Bar Screens" 12/21/2016

ANGLED BAR SCREENS
REFERENCE PLATE 9-1

FALL HEIGHT AND PLUNGE POOL



- DS bypass must discharge into safe receiving waters that minimize exposure to predation.
- Plunge pool depth must be 25% of the equivalent fall height or 4 feet, whichever is greater.
- For sloped outlets, equivalent fall height is measured from the height of 0 initial vertical velocity.



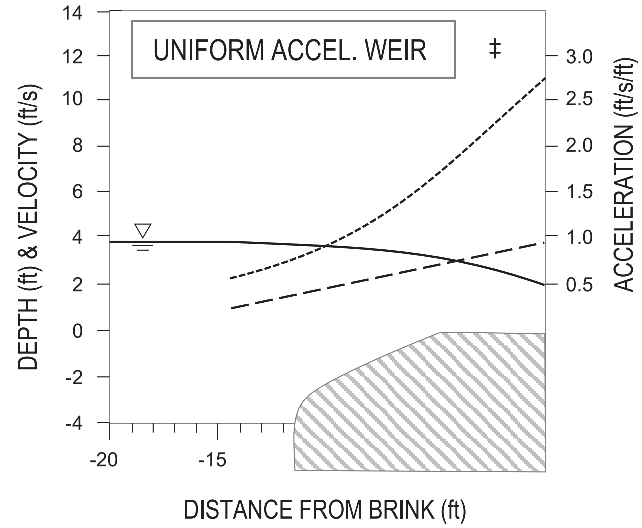
†

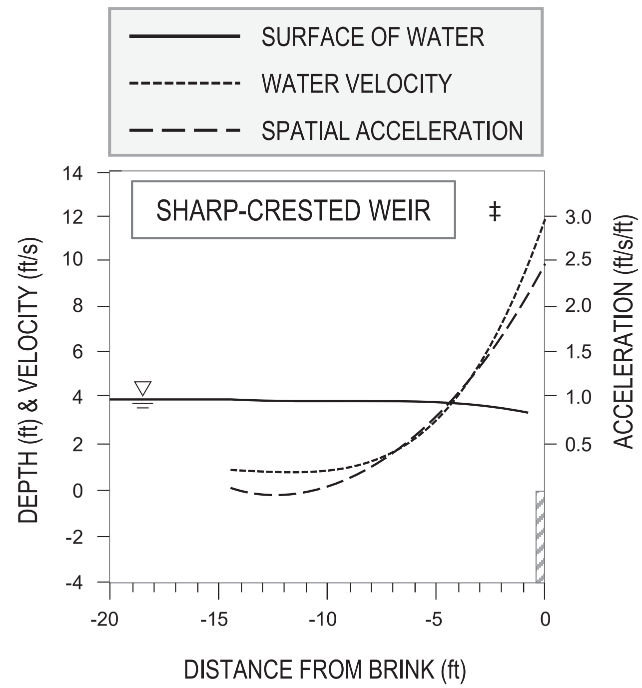
DOWNSTREAM BYPASSES SHOULD BE DESIGNED TO DISCHARGE A MINIMUM OF 5% OF STATION CAPACITY

$$Q_W = CB_W H_W^{1.5}$$

$$3.14 \leq C \leq 3.34$$ *

- Q_W is flow over weir in cfs
- B_W is the width of the weir in ft
- H_W is head on weir in ft
- C is the weir coefficient



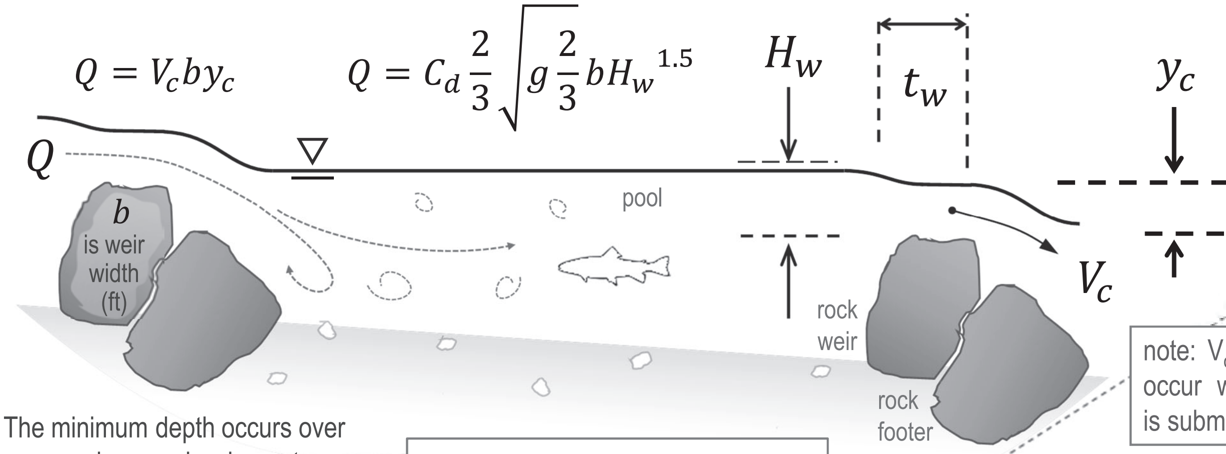


* Uniform acceleration weir coefficient based on Johnson et al. (1995)

‡ Johnson et al. (1995) "Development of a Downstream Fish Passage Weir"

† U.S. Fish and Wildlife Service criteria

HYDRAULICS OF STEP-POOL TYPE, NATURE-LIKE FISHWAYS CAN BE APPROXIMATED AS BROAD-CRESTED WEIRS.



The minimum depth occurs over a non-submerged weir crest:

$$y_c = \sqrt[3]{Q^2 / gb^2}$$

The maximum velocity occurs at this minimum depth:

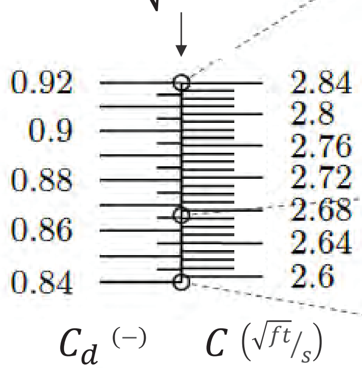
$$V_c = \sqrt{g y_c}$$

Expressed in terms of the discharge coefficient and head:

$$V_c = \sqrt[3]{C_d}\sqrt{\tfrac{2}{3} g H_w}$$

DISCHARGE & WEIR COEFFICIENTS

$$C_d \frac{2}{3}\sqrt{g\frac{2}{3}} = C$$



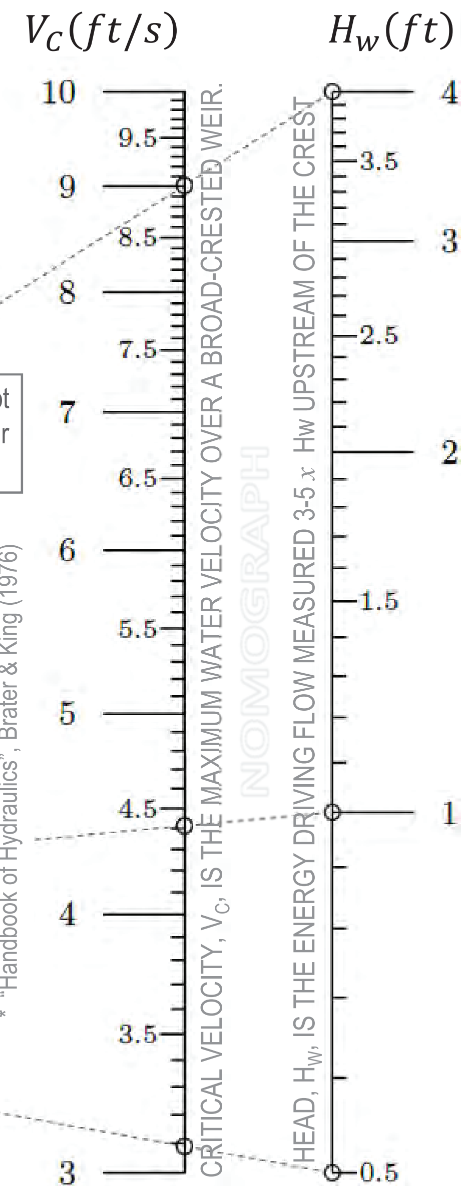
Weir Thickness, t_w (ft)

Head Over Weir Crest, H_w (ft)	5	4	3	2.5	2
0.6	2.7	2.69	2.68	2.6	2.61
0.8	2.68	2.68	2.67	2.6	2.6
1	2.68	2.67	2.65	2.64	2.66
1.2	2.66	2.67	2.64	2.65	2.7
1.4	2.65	2.65	2.64	2.68	2.77
1.6	2.65	2.66	2.68	2.75	2.89
1.8	2.65	2.66	2.68	2.74	2.88
2	2.65	2.68	2.72	2.76	2.85
2.5	2.67	2.72	2.81	2.89	
3	2.66	2.73	2.92		
3.5	2.68	2.76			
4	2.7	2.79			

C ($\sqrt{ft}/s$)

* "Handbook of Hydraulics", Brater & King (1976)

note: V_c may not occur when weir is submerged



NOMOGRAPH EXAMPLE

With the aid of this nomograph, table, and a straight edge, one can quickly estimate the maximum velocity over a rock weir. Given a weir thickness of 4 feet and a head of 1 foot, the table indicates C = 2.67. Aligning the straight edge from C = 2.67 on the left scale to H_w = 1 foot on the right scale indicates V_c = 4.4 feet per second on the center scale (values shown on dotted line).

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Issued 2/17/2017; replaces "Rock Weir Hydraulics" 21/6/2017

ROCK WEIR HYDRAULICS

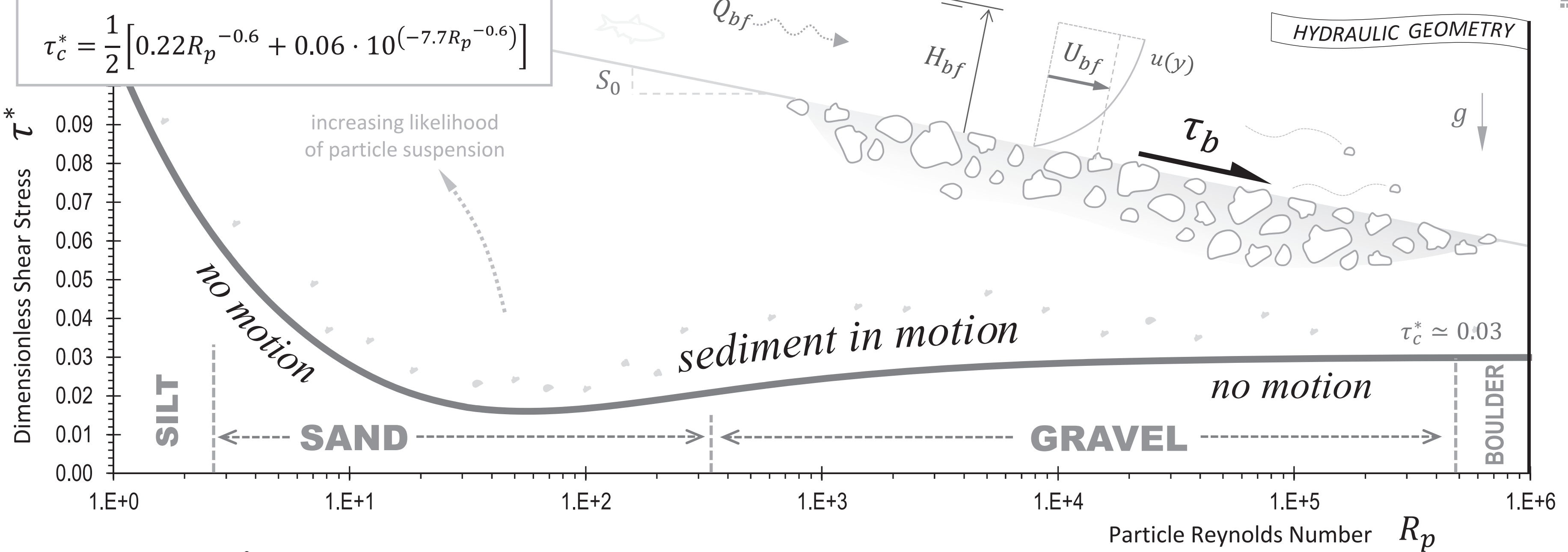
REFERENCE PLATE 10-1

INITIATION OF MOTION

REFERENCE PLATE 11-1

MODIFIED SHIELDS-PARKER FUNCTION

$$\tau_c^* = \frac{1}{2}\left[0.22{R_p}^{-0.6} + 0.06 \cdot 10^{\left(-7.7{R_p}^{-0.6}\right)}\right]$$



$g = 32.174 \quad ft/s^2$

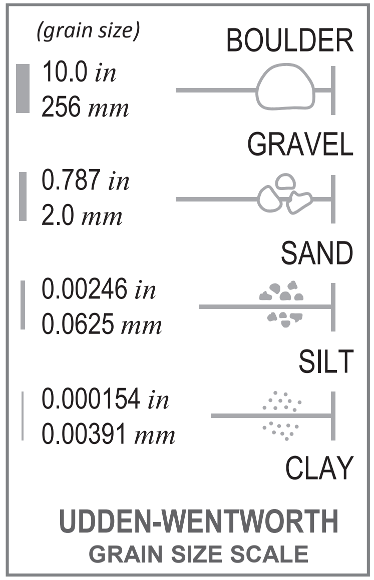
$\nu = 1.13 \cdot 10^{-5} \quad ft^2/s$ { water at 65F

$R = \frac{\rho_s}{\rho_w} - 1 \cong 1.65$ { for silica

$$\tau^* = \frac{\tau_b}{\rho g R D_{50}} = \frac{H_{bf} S_0}{1.65 D_{50}}$$

$$R_p = \frac{\sqrt{RgD_{50}}D_{50}}{\nu} \cong \frac{\sqrt{1.65\ gD_{50}}D_{50}}{\nu}$$

The **Shields Diagram** is a graphical representation of the Shields Criterion, a critical shear stress parameter used to calculate the **initiation of motion of sediment** in fluid flow (Shields, 1936). Initiation of motion can be predicted through the relationship between the Shields Criterion, or **Shields Number**, and the particle **Reynolds Number**. Brownlie (1981) and Parker et al. (2003) provided analytical forms of this shear stress-grain size relationship that can be expressed in terms of the hydraulic geometry of rivers.



<u>EXAMPLE</u>: A small stream, with a mean bank-full depth of 4 feet, falls 2 vertical feet for every 1000 horizontal feet. Water temperature is 65 degrees F. Determine if a median grain size of 1 inch meets the Shields Criterion for threshold of motion.

$R_p = 1.57 \cdot 10^4$; $\tau^* = 0.0577$ ⇨ *motion!*

Shields (1936) "Appl. of Similarity Princ. & Turb. Res. to Bed Load Movement"
Parker et al, (2003) "Effect of Floodwater Extr. on Mountain Stream Morphology"

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Issued 1/6/2017

Appendix B
Fishway Inspection Guidelines

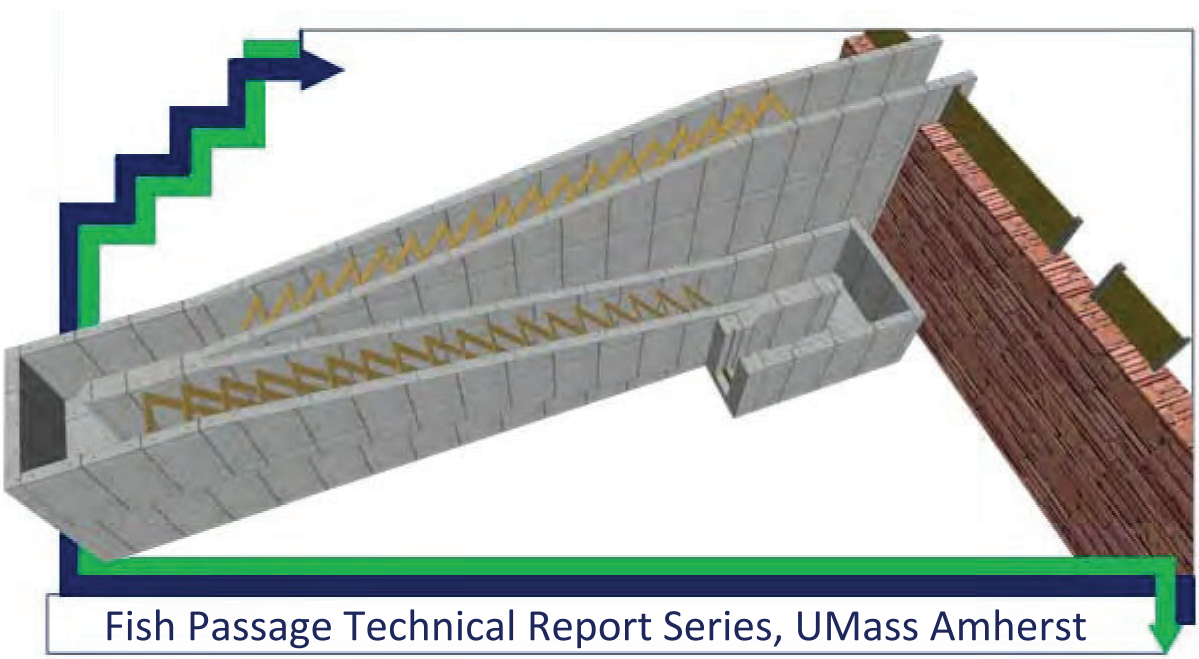
FISHWAY INSPECTION GUIDELINES

TR-2013-01

June 5, 2013

Brett Towler [1], Curtis Orvis [1], Donald Dow [2], Alex Haro [3]

[1] U.S. Fish and Wildlife Service, Fisheries, Northeast Regional Office, Hadley, Massachusetts
[2] NOAA National Marine Fisheries Service, Maine Field Station, Orono, Maine
[3] U.S. Geological Survey, Conte Anadromous Fish Research Center, Turners Falls, Massachusetts



UMASS AMHERST

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1.0 General

This technical report provides guidance for engineers, biologists, operators, regulators and dam owners involved in the inspection of fishways at dams. Volitional fish ladders, fish lifts, and other fish passage and protection facilities are devices of varying complexity frequently integrated into sophisticated reservoir management and hydropower installations. As with any device, maintenance of fish passage facilities is necessary to ensure their proper operation. Improper operation of fishways may limit or eliminate entire year classes of diadromous fish. Routine fishway inspections are a critical component of an overall fish passage operation and maintenance plan.

2.0 Definition of a Fishway

Fishway (or fish pass) is a generic term for those structures and measures which provide for safe, timely, and effective upstream and downstream fish passage. Fishways include physical structures, facilities, or devices necessary to maintain all life stages of fish, and operations and measures related to such structures, facilities, or devices which are necessary to ensure their effectiveness. Examples include, but are not limited to, volitional fish ladders, fish lifts, bypasses, guidance devices, and operational shutdowns.

3.0 Types of Fishways

Fish passes can be broadly categorized as either technical fishways or nature-like fishways. Nature-like fishways include bypass channels, rock ramps and other passage structures that approximate (either functionally or aesthetically) natural river reaches. Technical fishways employ engineering designs that are typically concrete, aluminum, polymer, and wood, with standardized dimensions, using common engineering construction techniques. The physical and hydraulic structure of nature-like fishways is markedly different from technical fishways, and the inspection of nature-like fishways is beyond the scope of this report. Technical fishways (hereafter, simply fishways) can be further categorized as upstream or downstream passes. Figure 1 shows these categories and common types of fishways.

<u>Baffled-Chute Fishways</u>: Baffled chutes are a subset of upstream volitional ladders designed to reduce velocities in a sloping channel to levels against which fish can easily ascend. Baffled chutes common to the Eastern United States include:

- Steeppass Model A — 21-inch wide, 27-inch tall, baffled aluminum channel
- Steeppass Model A40 — 40-inch tall, deepened version of the Model A steeppass
- Standard Denil — 2-to-4 foot-wide (typically concrete) channel with wooden baffles

<u>Pool-Type Fishways</u>: Pool-type upstream fishways are designed to link headwater and tailwater through a series of (typically concrete) pools through and over which water cascades slowly. Pool-types include:

- Pool-and-Weir — pools often separated by rectangular weirs; may also include orifices
- Ice Harbor — variant of the pool-and-weir type; characterized by two weirs separated by central C-shaped vertical baffle

- Half Ice Harbor — modified Ice Harbor; characterized by one weir opposite an L-shaped vertical baffle
- Vertical Slot — flow through pools via deep, narrow, full-depth slots rather than an overflow weir
- Serpentine — similar to a vertical slot with a winding, tortuous horizontal flow path

<u>Fish Lifts/Locks</u>: Fish lifts or elevators are non-volitional upstream fishways that attract fish into an entrance channel and mechanically crowd them above a hopper before lifting them into an impoundment (or alternatively, into an exit channel hydraulically linked to an impoundment). Fish lifts differ from volitional ladders in that they usually possess numerous mechanical, hydraulic, and electrical components. A fish lock is similar to a lift where the hopper and lift tower is replaced with a full-height, columnar structure (i.e., lock) that can be filled with water. Fish locks are rare on Atlantic coast and are therefore not addressed directly in this document.

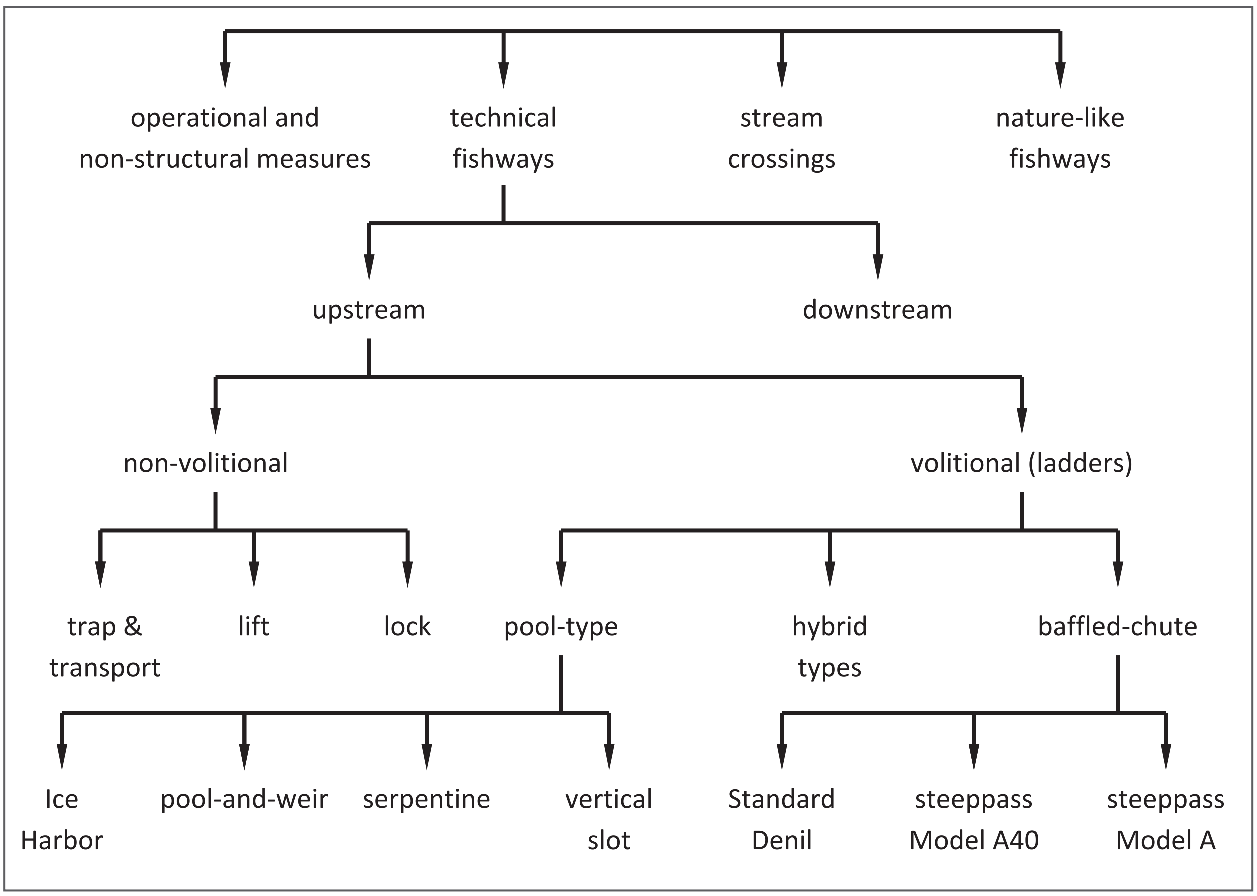

Figure 1. Common fishway types in the eastern U.S.

Downstream Passage: Facilities designed to protect and pass out-migrating fish are varied and diverse ranging from simple overflow weirs to highly complex guidance screens with attraction water recycling systems, bypasses, plunge pools, and fish sampling systems. Typically, these systems consist of four primary components:

- Physical/behavioral guidance screen or bar rack
- Bypass opening (e.g., weir, chute, sluice, or orifice)
- Conveyance structure (i.e., open channel or pressurized conduit)
- Receiving pool

The bypass opening is intended to function as a safe outlet for fish migrating downstream past the dam. Exclusion screens or behavioral guidance screens (or racks) are designed to create physical and/or hydraulic cues that encourage fish to move towards and pass through the bypass opening. Receiving waters or plunge pools are typically necessary to safely transition fish to waters below the dam. Receiving waters generally refer to the existing tailrace or tailwater below the dam; plunge pools are separately excavated pits, or built-up basins, which provide adequate depth to prevent plunging fish from impacting the channel bottom, concrete apron, or other submerged feature.

Eel Pass: Eel passes (or eelways) are upstream passage structures that provide a path over the dam for catadromous elvers and juvenile eels. These structures typically consist of an attraction water delivery system incorporated into ramp lined with various wetted media which eels use to propel themselves up the ramp. They may provide a full volitional pathway for up-migrating eels or terminate in a trap or lift.

The above list represents some of the more common fishways used to mitigate the impacts of stream barriers on the east coast of the United States. However, the reader should be aware that there are numerous other types, variations of these technologies, and auxiliary components not described herein.

4.0 An Approach to Fishway Inspection

The holistic definition of a fishway (as described in Section 2.0) should convey the importance of assessing fishway conditions in a comprehensive manner that considers a) the path of fish past a barrier, and b) the aggregate passage conditions and timing due to the interaction of numerous (non-fishway) structures and operations. Unfortunately, such myriad interactions cannot be enumerated or described in a generalized way. Consider these examples:

- the strength of the hydraulic cue created by a fishway entrance jet may be influenced by tailwater elevation (which, in turn, may be affected by turbine discharge);
- salmonids may ascend over weirs under plunging flow conditions, clupeids may not;
- the efficacy of fishway attraction flow may be compromised by the sequence of turbine operations resulting in delays in upstream migration;
- sweeping velocities in front of a downstream bypass guidance screen may be influenced by generation, trash loading, or spill; and

- water surface elevations throughout a ladder may be influenced by flashboard failure at the upstream spillway.

Therefore, the reader is strongly encouraged to keep the broadest definition of a fishway in mind when performing inspections so as to avoid a myopic view of individual fishway components that may obscure the integrated functionality critical to the proper operation of these facilities.

Certain anomalous conditions or occurrences are seen at more frequently fishways. Inspectors should be keenly aware of, and document, these issues:

- Damage to, or degradation of, structural components
- Visual or auditory evidence of poorly functioning mechanical components
- Leaf litter, large woody debris, or sediment in the fishway
- Adverse water levels in and adjacent to the fishway
- Eddies, jumps, aeration and other unusual hydraulic phenomena
- Evidence of fish delay, entrainment, impingement, injury, or mortality
- Original design deficiencies

5.0 Equipment

Inspectors should anticipate the equipment needed to properly perform the inspection. Furthermore, ensuring the equipment is in proper working order is a prudent step in pre-inspection planning. Battery operated electronic equipment (e.g., total station, camera) should be charged. Digital instruments (e.g., acoustic Doppler velocity meter) may require calibration. In general, all equipment should be checked prior to traveling to the site of the dam or barrier.

The following is a list of items which may prove useful during inspection:

- Inspection checklist — Suggested checklist attached to this document
- Pencil and field book — Checklist may be insufficient to document anomalous conditions
- Voice recorder — Digital recordings can augment notes
- Digital camera — Photographs and video of field conditions are essential to inspection
- Staff gage — Gage (e.g. survey rod) used to measure water surface elevations
- Tape measure — Allows measurement of relevant fishway geometry
- Flashlight — Covered channels and transitions may not be lit
- Lumber crayon — Inspector may wish to mark water levels during operational changes
- Watertight boots — Recommended for inspecting de-watered fishways
- Velocity meter — Useful in assessing velocity barriers and impingement “hot spots”
- Survey/hand level — For precise measurement of HGL or elevation changes

Given the proximity to moving water, heavy equipment, and the steep terrain associated with dams, fishways are potentially hazardous sites. Safety equipment is always recommended. Moreover, fishways are often located at large hydroelectric facilities where rigorous safety programs have been

implemented. Safety plans which identify anticipated risks and possible hazards are becoming a more common practice and should be reviewed prior to assessing the facilities. If you are unfamiliar with the site, be sure to contact the dam owner to ensure proper safety protocols are met.
Standard safety equipment may include:

- Hard hat
- Steel-toed boots
- Safety glasses
- Hearing protection (if entrance to the powerhouse is necessary)
- Harness and fall protection
- Personal floatation device (PFD)
- High-visibility orange safety vest
- First-aid kit (equipped bee sting treatment)

6.0 Performing an Inspection

Fishway inspections are best performed in a systematic fashion. The inspection checklist included with this document is intended to guide the reader through a logical sequence from exit to entrance. However, the checklist is intended only as a guide and should not replace good observational skills, adequate record keeping, or site-specific experience. The inspector is strongly encouraged to review any standard operating procedures (SOP) and as-built drawings of the fish passage structures prior to arriving on site. Figures 2 and 3, which illustrate major components of fishways, may help orient the novice inspector.

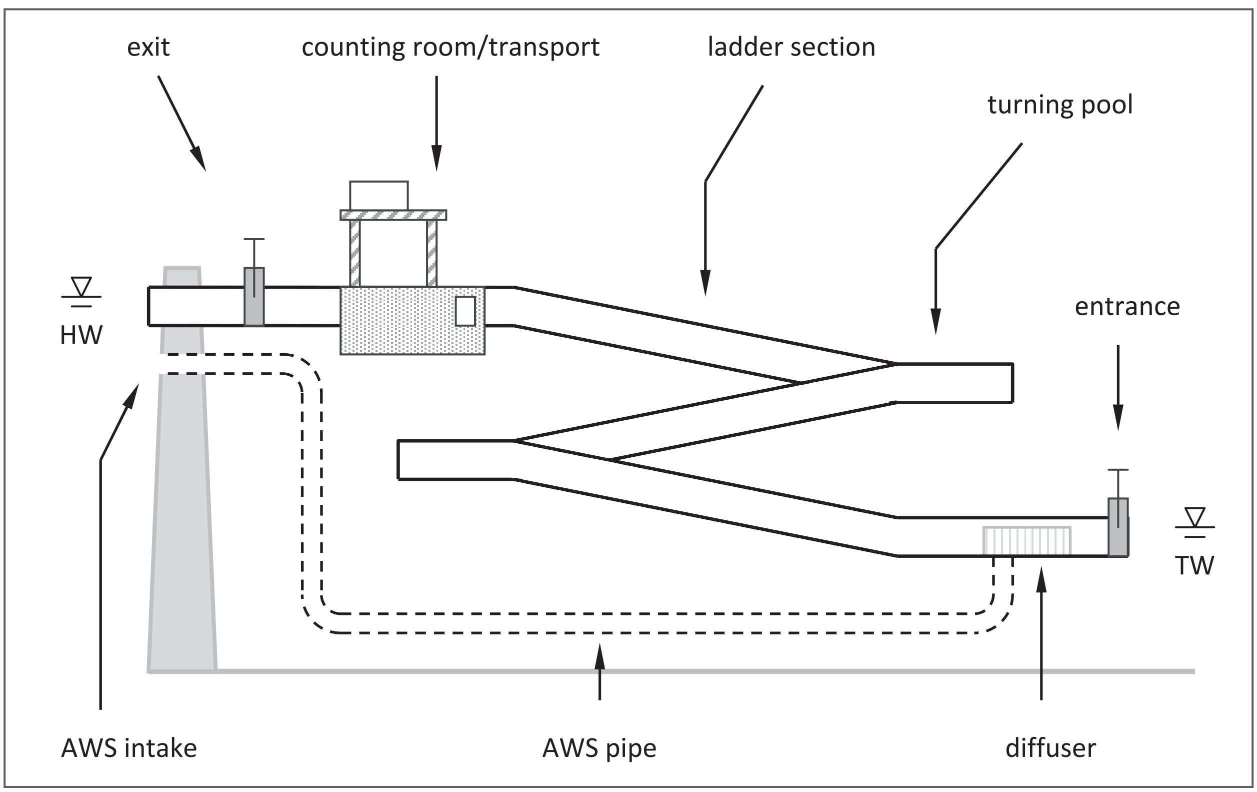

Figure 2. Major components in typical volitional fish ladders

Information gathered on anomalous conditions (either on this checklist or in supplemental records) should include these three important elements:

1. **Location**: Record the location where conditions are of interest. If the location is a standard fishway component then identify it as such:
   - "fishway entrance gate"
   - "3rd turning pool upstream of the entrance"
   - "downstream bypass plunge pool"

   If the location possesses no standard name, describe it in relation to a clearly identifiable, datum or nearby feature:
   - "… 7 feet upstream of the antenna array bond-out"
   - "… overflow pool at elevation 110.5 feet USGS"
   - "… on intake rack 30 feet out from right abutment"
2. **Extent**: Measure or estimate the dimension(s) of the problem or condition:
   - "2-foot by 3-foot section of the wedge-wire screen"
   - "overtopping of 3-feet of water"
   - "6 inches of sediment"
3. **Detail**: A brief description of the condition should be included:
   - "a swirling horizontal eddy forms in the turning pool during operation"
   - "an impassable hydraulic drop forms over the weir crest"
   - "fish trapped behind skimmer wall

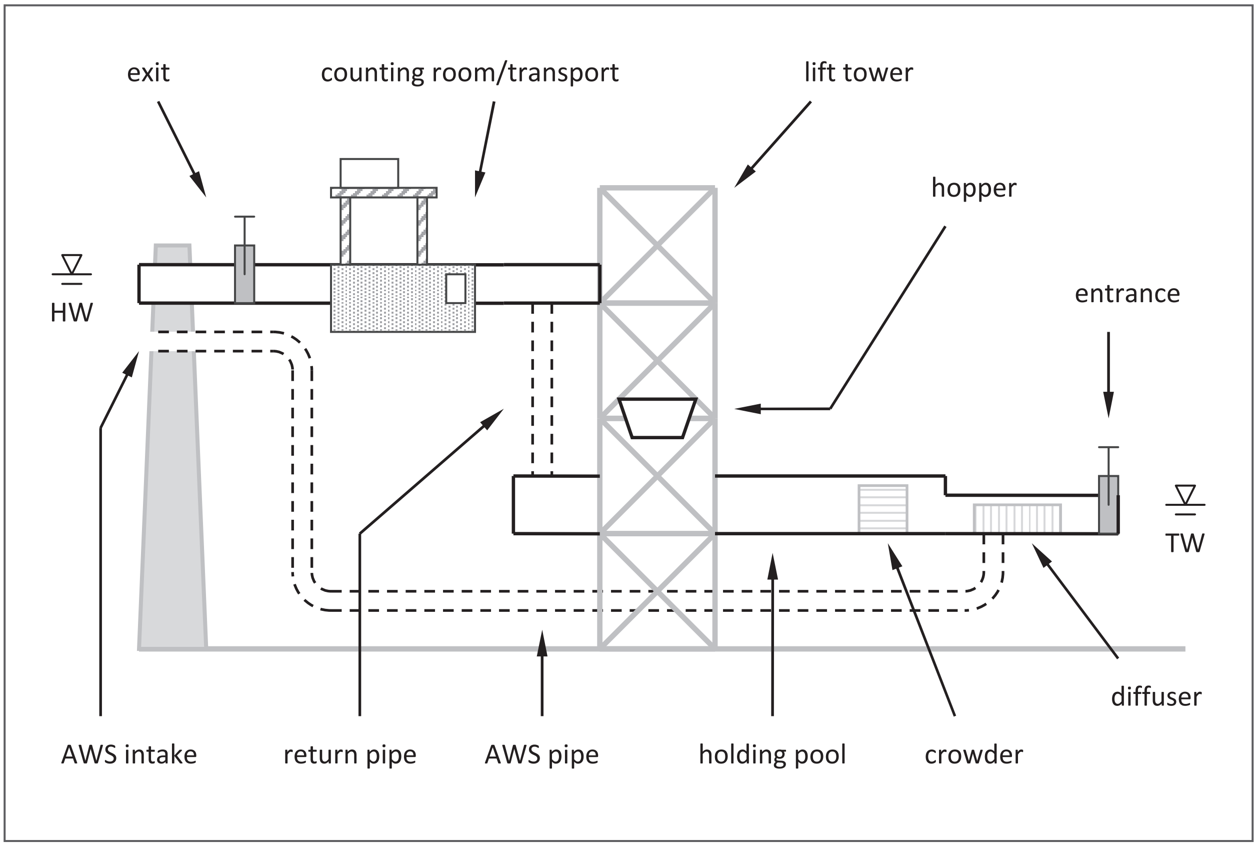

Figure 3. Major components in typical non-volitional fish lifts

7.0 Checklist

The FISHWAY INSPECTION CHECKLIST included in this technical report is formatted to guide the inspector in a sequential manner moving down-gradient from the fishway exit to the fishway entrance. Numbered checklist items are written as questions requiring the user to verify the structural, hydraulic, or operational functionality of fishway components. Comment space is provided at the end of each major section. These major sections are:

Reason for Inspection: Fishways are often inspected during the peak of a migratory fish run to evaluate the facility while operating at design capacity. However, they may be inspected at opening (i.e., start of the season), shut-down, or post-flood to assess damage. Recording the reason for the inspection provides important context for the subsequent notes.

Fishway Status: It is equally important to note whether or not the fishway is de-watered and whether or not it is operating at the time of the site visit. For pre- (or post-) season inspections, the need to examine specific components may dictate the status of the fishway. For instance, a watered, operating fishway may allow for an assessment of the hydraulics, but will also obscure potential problems below the waterline.

Hydrology & Ecology: Fishways vary according to site hydrology and the target species for which they were designed. The inspector should note the target species and mark the approximate migration periods on the upstream (U/S) and downstream (D/S) migration scales. Comments on fish health issues (i.e. VHS, descaling, parasitism) and noting the presence of invasive species may prove useful to resource agencies.

The river flow influences numerous operational aspects of fishway operation including the headpond and tailwater elevation, adjustable gate settings, and entrance jet velocities. The USGS is the principal agency tasked with maintaining stream gages in the U.S. If the dam owner/operator cannot provide the current river flow, the USGS stream gage network should be used:

http://waterdata.usgs.gov/nwis

Additionally, the inspector may consider recording the water temperature at the fishway entrance channel and in the headpond. The movement of many migratory species is linked to water temperature. Surface water temperatures in the impoundment are typically higher than the river and may be further influenced municipal treatment plants and industrial cooling water. A significant difference in fishway temperature versus headpond temperature could indicate undue solar warming in the AWS or fishway pools.

Hydropower Operations: It is well known that dams are barriers to the passage of riverine and migratory aquatic species. Hydroelectric facilities present additional fishway operational challenges and represent a significant hazard to down-migrating fish. Inspectors should document powerhouse capacity, unit type, methods of remote operation, and any operational links between the fishway and turbine sequencing. For example, turbines adjacent to the fishway entrance may be prioritized to enhance attraction flow. Similarly, Kaplan units (which may be less harmful to some species than comparable Francis units) may be preferentially operated during the downstream migration period. Turbine rotational speed often correlates to mortality, and could be documented if the information is available on site. For estimates of approach velocity (in the forebay), inspectors may choose to estimate the turbine intake dimensions. For inspections of dams without powerhouses, users may strike through this section.

Upstream Fishway Exit: The exit typically refers to those components that connect the ladder or lift to the headpond or river upstream of the barrier. It is important to note that the upstream fishway exit is also the hydraulic intake to the fishway (and these seemingly contradictive definitions can cause confusion). The inspector should look for conditions that may prevent or delay fish from quickly exiting the fishway such as debris accumulation, partially opened gates, dark shadows, bright lights and noise-inducing structures. One should also document any evidence that fish are not quickly moving up into the impoundment (and beyond the immediate hydraulic influence of adjacent flood gates, turbines, or other water intakes). If possible, record the headpond water surface elevation.

Ladder: The chute, channel, or pools connecting the entrance to exit are commonly called the ladder. Debris, sediment and failure of wooden water-retaining structures (e.g., blocking boards, weir crests) are the most common causes of operational failure in otherwise-effective fishways. Though time-consuming, the entire ladder can be rigorously inspected for problems in a de-watered state. In an operating and watered state, blockages and board failures can be more quickly identified by the anomalous water surface elevations and flow patterns these problems create. For inspections of lifts, users may strike through this section.

Fishlift: The lift includes the lift tower, holding pool, hopper (i.e., bucket), crowder, brail, and any associated electrical, hydraulic and mechanical components. It also includes any water conveyance between the exit and the entrance (e.g., transfer from hopper to exit flume). Grating on the crowder and exclusion gate behind the hopper are particularly susceptible to debris blockage. Debris can lead to altered flow patterns and velocities, but sharp woody debris lodged in the grating may also injure fish. It is recommended that the inspector observe a complete lift cycle while on site; if possible, the lift cycle should be timed to ensure it is operating within design parameters. Unusual sounds, binding, and vibration during operation are indicators of a problem. Where possible, the operators should accompany the inspectors; operators can provide invaluable insight into the condition of the equipment. For inspections of ladders, users may strike through this section.

Upstream Fishway Entrance: For both lifts and ladders, the entrance consists of a channel of varying length leading fish into the ladder/lift from the tailwater below the dam. Larger hydropower facilities may include collection galleries that consist of a flume with manifold gated entrances. Regulating the attraction jet velocity is perhaps the most critical aspect influencing the effectiveness of the entrance. In the presence of varying tailwater, velocities are controlled through installation of (overflow) weir boards in a slot at the entrance. Alternatively, larger facilities may be equipped with an (overflow) lift gate. Regardless, the gate or boards serve as submerged weirs that locally accelerate the flow to create an attraction jet. The water surface elevations between the entrance channel and the tailwater correlate to the strength of the attraction jet and should be diligently recorded by the inspector. If possible, record the tailwater elevation.

Auxiliary Water System: The fishway must produce a sufficiently strong attraction jet at the entrance often in the presence of other competing flows (e.g., spill, powerhouse discharge). Lifts generate no flow by themselves, and ladders may not discharge enough flow to create an adequate attraction signal. Auxiliary Water Systems (AWS) provide an additional source of water to augment the attraction flow. AWS commonly consist of an intake at the headpond, anti-vortex devices, a headgate, a conveyance pipe, valves, a diffuser chamber, and diffuser outlets. Most of these components are underground or underwater; however the inspector should examine the intake screen for blockages and, if possible, verify the current AWS discharge (with the dam owner or operator).

Downstream Passage Facilities: Access to much of the downstream passage system (e.g., floating boom, intake racks) may be problematic. At a minimum, fishway inspectors should examine the accessible racks/screens, downstream bypass, bypass weir, any fish sampling systems, conveyance structures, and plunge pool. For rack or screens that cannot be measured directly, inspectors may estimate depths and widths (or inquire of the dam owner and/or operator). Unfavorable hydraulic conditions (e.g., lack of guidance, excessive velocities, impinging jets), debris blockages, partially open gates which obstruct fish movement, and incorrectly installed bypass weirs are among the more common deficiencies.

Counting & Trapping: A minority of fishways are equipped with counting rooms and trapping facilities. While not integral to the passage of fish, these elements may support critical monitoring and research programs. Where appropriate, trap gates and lift mechanisms should be operated and examined for serviceability and fish safety. A courtesy engineering assessment of the counting room may be welcomed by the operator and/or resource agency biologist.

Eel Pass: This section is intended to capture elements related to upstream eel passage. Downstream eel passage (if it exists) can be addressed in the "Downstream Passage Facilities" section. Critical elements of the eelway include ensuring the ramp is sufficiently wet and that the media is clean of debris. If the ramp terminates in a trap, check to ensure the trap box receives adequate flow and that eels cannot escape. If the trap box appears overcrowded, notify the project or agency biologist immediately. Uncovered ramps may be susceptible to predation. Additionally, make observations on the attraction water supply system (e.g., water source, approximate flow, flow conditions at the base of the ramp, leakages)

Inspections are time-consuming and demand one's full attention. Advance preparation will enhance the quality of the inspection. Therefore, it is recommended that the inspector fill out as much of the form as possible prior to arriving on site. As discussed in Section 6.0, fishway SOPs and as-built drawings are valuable sources of information that should be reviewed in advance.

8.0 Disclaimer

These fishway inspection guidelines were developed by the authors with input from other subject-matter experts. They are intended for use by persons who have the appropriate degree of experience and expertise. The recommendations contained in these guidelines are not universally applicable and should not replace site-specific recommendations, limitations, or protocols.

The authors have made considerable effort to ensure the information upon which these guidelines are based is accurate. Users of these guidelines are strongly recommended to independently confirm the information and recommendations contained within this document. The authors accept no responsibility for any inaccuracies or information perceived as misleading. The findings and conclusions in these guidelines are those of the authors and do not necessarily represent the views of the University of Massachusetts Amherst, Integrated Statistics, the U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration, or the United States Geological Survey.

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FISHWAY INSPECTION CHECKLIST

Dam/Project Name: ______________________ Waterway: ______________________

Owner (Organization): ______________________ Date/Time: ______________________

Inspector(s): ____

Owner's Representative(s) On-site: ____

Comments: ____

STATUS

Reason for inspection: ☐ opening ☐ during season/run ☐ shutdown ☐ construction ☐ other ______________________

Fishway Status:
- ☐ de-watered/non-operational
- ☐ watered/operational
- ☐ watered or underwater/non-operational
- ☐ damaged/operational
- ☐ unknown damaged/non-operational

HYDROLOGY & ECOLOGY

1. Target species for fishway: ____

2. U/S migration period: J F M A M J J A S O N D

3. U/S fish passage design flow: HIGH ______ (cfs) LOW ______ (cfs)

4. D/S migration period: J F M A M J J A S O N D

5. Drainage & current river flow (if known): ______ (mi^2) ______ (cfs)

Comments on Hydrology & Ecology: ____

____

HYDROPOWER OPERATIONS

6. Is the fishway and dam part of a hydroelectric project? ☐ YES ☐ NO
7. Is there a powerhouse at this location? ☐ YES ☐ NO
8. Powerhouse hydraulic capacity: ______ (cfs)
9. Project generating capacity: ______ (MW)
10. Number and type of hydroelectric turbines:

Francis:	Kaplan:	Bulb:	Other:

11. Are units sequenced on/off to enhance fish passage? ☐ YES ☐ NO

If YES, describe operations: ____

____

Comments on Hydropower Operations: ____

____

UPSTREAM FISHWAY EXIT

12. Waterway upstream of the exit is clear of debris: ☐ YES ☐ NO
13. Headgate and/or headboards are in good condition ☐ YES ☐ NO ☐ n/a
14. If operational, have headboards been removed or gates raised? ☐ YES ☐ NO ☐ n/a
15. Are adjustable weirs/baffles set to track HW? ☐ YES ☐ NO ☐ n/a
16. Trashrack is in place and clean? ☐ YES ☐ NO ☐ n/a
17. Trashbooms are in place? ☐ YES ☐ NO ☐ n/a
18. Is a staff gage installed in the fishway exit channel? ☐ YES ☐ NO
19. Is a staff gage installed in the headpond? ☐ YES ☐ NO
20. Differential head measured between exit and headpond: ________ (ft.)

Comments on Exit: ____

____

LADDER (Not Applicable for Lifts or Locks)

21. Ladder type: ☐ Vertical Slot ☐ Ice Harbor ☐ Pool&Weir ☐ Denil ☐ Steeppass
☐ other: ____
22. Fishway is free of trash and large woody debris: ☐ YES ☐ NO
23. Was the fishway de-watered during inspection? ☐ YES ☐ NO ☐ n/a
24. Concrete walls/floors are free of cracks, erosion, leaks, spalling: ☐ YES ☐ NO ☐ n/a
If NO, describe extent and location: ____

____

25. Pools are free of sand, rocks, and other material: ☐ YES ☐ NO ☐ n/a
If NO, describe accumulations, locations and plan to remove: ________________________

____

26. Baffles, baffles plates, and/or or weirs are installed properly, installed at the correct elevation, and were found in good condition: ☐ YES ☐ NO ☐ n/a
If NO, describe problems and locations (e.g., number from entrance): ________________________

____

27. Has the fishway been inspected for damage that created sharp edges, formed wooden splinters, or resulted in new obstacles (in the flow field) that could injure fish? ☐ YES ☐ NO ☐ n/a
Comments: ____
28. Is the protective grating cover in place and structurally sound? ☐ YES ☐ NO ☐ n/a
29. Representative head measurement (over weir crest, through vertical slot): ________ (ft.)

If measured, describe location and method (e.g., pool number from entrance, with staff gage):

____

____

Comments on Ladder: ____

____

____

____

____

____

Dam/Project Name: ______________________________

FISHLIFT (Not applicable for Ladders)

30. Was the lift cycled (operated) during this inspection? ☐ YES ☐ NO
31. Holding pool is relatively free of debris: ☐ YES ☐ NO
32. Hopper raises smoothly without binding or vibrating: ☐ YES ☐ NO ☐ n/a
33. Mechanical crowder opens/closes/operates properly: ☐ YES ☐ NO ☐ n/a
34. Crowding proceeds in a manner consistent with design: ☐ YES ☐ NO

If NO, describe problems and locations: ______________________________

____

35. Hopper properly aligns with chute during exit channel transfer: ☐ YES ☐ NO ☐ n/a
36. Is the exit channel (between lift and exit) free of debris? ☐ YES ☐ NO ☐ n/a
37. Other mechanical components appear in good working order: ☐ YES ☐ NO

If NO, describe problems and locations: ______________________________

____

38. Lift appears free of sharp corners that could injure fish: ☐ YES ☐ NO
39. Lift cycles manually or automatically: ☐ Manual ☐ Automatically
40. Cycle time of lift (fishing to fishing): ________ (min.)
41. Hopper volume (if known): ________ (ft^3)

Comments on Lift: ______________________________

____

____

UPSTREAM FISHWAY ENTRANCE

42. Is the approach to the entrance(s) free of debris and obstructions? ☐ YES ☐ NO
43. Are boards properly installed in the entrance? ☐ YES ☐ NO ☐ n/a
44. Are adjustable gates tracking TW? ☐ YES ☐ NO ☐ n/a
45. If operational, does the entrance jet appear appropriate? ☐ YES ☐ NO ☐ n/a
46. Is a staff gage installed in the fishway entrance channel? ☐ YES ☐ NO
47. Is a staff gage installed in the tailwater area? ☐ YES ☐ NO
48. Differential head measured between entrance and tailwater: ________ (ft.)

Comments on Entrance: ______________________________

____

____

AUXILLIARY WATER SYSTEM

49. If the fishway is operational, is the AWS operating? ☐ YES ☐ NO ☐ n/a
50. AWS flow is driven by: ☐ Gravity ☐ Pump ☐ Other
51. The AWS intake screen is undamaged and free of debris: ☐ YES ☐ NO ☐ n/a
52. AWS appears free of debris or other blockages: ☐ YES ☐ NO
53. AWS flow (in cfs or % of turbine discharge) ________
54. Has this flow been verified? ☐ YES ☐ NO ☐ n/a

If YES, by whom and/or how? ______________________________

Comments on AWS: ______________________________

____

DOWNSTREAM PASSAGE FACILITIES

55. Are there facilities specifically design for d/s passage on site? ☐ YES ☐ NO
56. If so, are d/s facilities open and operational? ☐ YES ☐ NO ☐ n/a
57. Identify all possible SAFE routes for d/s passage at this site:
☐ d/s bypass ☐ spillway ☐ floodgate ☐ logsluice ☐ surface collect.

If other routes, describe: ____

58. Flow field in impoundment appears conducive to d/s passage: ☐ YES ☐ NO ☐ n/a
If NO, describe problems and locations: ____

____

59. If appropriate, are overlays in place on trash racks? ☐ YES ☐ NO ☐ n/a
60. Are screens (or overlays on trashracks) relatively free of debris? ☐ YES ☐ NO ☐ n/a
61. Is there any evidence of fish impingement on racks or screens? ☐ YES ☐ NO
If YES, describe problems and locations: ____

____

62. Is the d/s bypass intake adequately lit and free of debris? ☐ YES ☐ NO ☐ n/a
63. Is the d/s conveyance free of debris and obstructions? ☐ YES ☐ NO ☐ n/a
64. Are sharp corners evident in the bypass which could injure fish? ☐ YES ☐ NO ☐ n/a

65. Approximate depth of flow over bypass crest: ________ (ft.)

66. Does d/s bypass discharge into sufficiently deep pool/water? ☐ YES ☐ NO ☐ n/a

67. Approximate plunge height from d/s bypass crest to receiving pool/water: ________ (ft.)

68. Is there evidence of significant predation at receiving pool/water? ☐ YES ☐ NO
If YES, describe: ____

69. D/S Bypass flow (in cfs or % of turbine discharge) ________ (cfs/%)

Comments on D/S Passage: ____

____

____

____

COUNTING & TRAPPING

70. Is the facility equipped for trapping & sorting? ☐ YES ☐ NO
71. Systems for transfer from tank to truck appear in order? ☐ YES ☐ NO ☐ n/a
72. Do mech. components (e.g., winches, gates) appear serviceable? ☐ YES ☐ NO ☐ n/a
73. Were gates/winches tested during inspection? ☐ YES ☐ NO
Note any concerns: ____

____

74. Is there a counting house/room at the site? ☐ YES ☐ NO
75. Is the counting window clean and properly lit? ☐ YES ☐ NO ☐ n/a
76. Is CCTV and camera system operating properly? ☐ YES ☐ NO ☐ n/a
77. If counts are automated (e.g. resistance), is it functioning? ☐ YES ☐ NO ☐ n/a

Comments on Counting & Trapping: ____

78. Is there an eel pass on site? ☐ YES ☐ NO ☐ n/a
79. If YES, what is the type of eel pass:
    ☐ volitional ramp (TW to HW) ☐ permanent ramp & trap/lift ☐ temporary ramp & bucket

80. Describe the eel pass substrate media type:
    ☐ stud (peg) ☐ bristle ☐ geotextile mat ☐ other: ________________________

81. Is the eel pass currently operating (i.e., wetted and installed)? ☐ YES ☐ NO ☐ n/a
    Identify the water source (i.e., gravity, pump): ____

82. Is the media clean of debris and watered throughout? ☐ YES ☐ NO ☐ n/a
    Describe depth of flow and adequacy of attraction: ____

    Comments on Eel Pass: ____
    ____

EEL PASS

OBSERVATIONS ON THE PRESENCE AND/OR MOVEMENT OF FISH DURING INSPECTION:

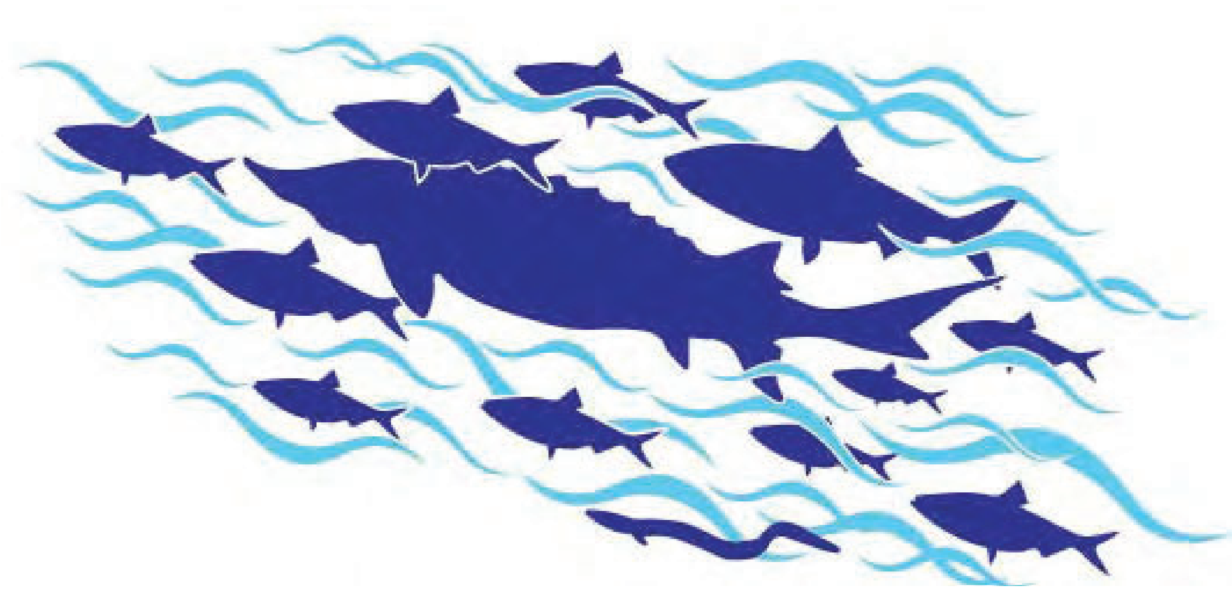
GENERAL COMMENTS:

RECOMMENDATIONS:

Appendix C
Federal Interagency
Nature-like Fishway
Passage Design Guidelines
for
Atlantic Coast Diadromous Fishes

Technical Memorandum

Federal Interagency
Nature-like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes



May 2016

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION · NOAA · U.S. DEPARTMENT OF COMMERCE

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U.S. FISH & WILDLIFE SERVICE · DEPARTMENT OF THE INTERIOR

Technical Memorandum
Federal Interagency Nature-like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes

May 2016

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Abstract: The National Marine Fisheries Service (NMFS), the U.S. Geological Survey (USGS) and the U.S. Fish and Wildlife Service (USFWS) have collaborated to develop passage design guidance for use by engineers and other restoration practitioners considering and designing nature-like fishways (NLFs). The primary purpose of these guidelines is to provide a summary of existing fish swimming and leaping performance data and the best available scientific information on safe, timely and effective passage for 14 diadromous fish species using Atlantic Coast rivers and streams. These guidelines apply to passage sites where complete barrier removal is not possible. This technical memorandum presents seven key physical design parameters based on the biometrics and swimming mode and performance of each target fishes for application in the design of NLFs addressing passage of a species or an assemblage of these species. The passage parameters include six dimensional guidelines recommended for minimum weir opening width and depth, minimum pool length, width and depth, and maximum channel slope, along with a maximum flow velocity guideline for each species. While these guidelines are targeted for the design of step-pool NLFs, the information may also have application in the design of other NLF types being considered at passage restoration sites and grade control necessary for infrastructure protection upstream of some dam removals, and in considering passage performance at sites such as natural bedrock features.

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Disclaimer: The efficacy of any fish passage structure, device, facility, operation or measure is highly dependent on local hydrology, target species and life history stage, barrier orientation, and a myriad of other site-specific considerations. The information provided herein should be regarded as generic guidance for the design of NLFs for the Atlantic Coast of the U.S. The guidelines described are not universally applicable and should not replace site-specific recommendations, limitations, or protocols. This document provides generic guidance only and is not intended as an alternative to proactive consultation with any regulatory authorities. The use of these guidelines is not required by NMFS, USFWS or USGS, and their application does not necessarily imply approval by the agencies of any site-specific design.

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Introduction

Diadromous fishes spend portions of their lives in marine, estuarine and freshwater environments and migrate great distances throughout their life cycles. All diadromous fish species require unimpeded access between their rearing and spawning habitats. Diadromous fishes that use freshwater rivers and streams of the Atlantic Coast of the U.S. as spawning habitats include a diverse anadromous species assemblage, and the catadromous American eel (*Anguilla rostrata*) which spends much of its life in freshwater rearing habitat with adults out-migrating to spawn in the Sargasso Sea. These fishes deliver important ecosystem functions and services by serving as forage for higher trophic-level species in both marine and freshwater food webs (Collette and Klein-MacPhee 2002; Ames 2004; McDermott et al. 2015) and providing an alternative prey resource (i.e., prey buffer benefitting other species) to predators in estuaries and the ocean (Saunders et al. 2006). In rivers and streams, services provided by this diadromous fish assemblage include relaying energy and nutrients from the marine environment (Guyette et al. 2013),transferring energy within intra-species life stages in streams (Weaver 2016), providing benthic habitat nutrient conditioning and beneficial habitat modification (Brown 1995; Nislow and Kynard 2009; West et al. 2010), serving as hosts to disperse and sustain populations of freshwater mussel species (Freeman et al. 2003; Nedeau 2008), and enhancing stream macro-invertebrate habitat (Hogg et al. 2014).

Diadromous fishes are also recognized in contributing significant societal values. Historically, Native Americans, European colonists, and post-settlement America relied heavily on these species as sources of food and for other uses (McPhee 2003). Many of these diadromous fish species are highly valued in supporting commercial and recreational fisheries, with some species prized as sportfish and/or food sources including culinary delicacies (Greenberg 2010). They also contribute to important passive recreational opportunities where people can observe spring fish runs, learn about their life histories, and appreciate these migratory fishes and their key roles in riverine, estuarine and marine ecosystems (Watts 2012).

Many populations of Atlantic Coast diadromous fishes have been in serious decline for decades due to multiple factors including hydro-electric dams and other river barriers preventing access to spawning and rearing habitats, water and sediment quality degradation, overharvesting, parasitic infestations and other fish health effects, body injuries due to boat strikes and other human-induced impacts (Limburg and Waldman 2009; Hall et al. 2011; Waldman 2014). Shortnose sturgeon (*Acipenser brevirostrum*), Atlantic salmon (*Salmo salar*), and Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) (NMFS 1998, 2009, 2013a) have been designated as endangered under the Endangered Species Act (ESA) (Atlantic sturgeon are currently listed as threatened in the Gulf of Maine). American eel were recently considered for listing under the ESA (USFWS 2011, 2015) and are currently designated as a Species of Concern. Both alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) were designated as Species of Concern in 2006 (NMFS 2006), and NMFS was petitioned in 2011 to list both as ESA species. NMFS completed its review for the candidate ESA listing in 2013 and determined that listing either river herring species was not warranted as either threatened or endangered. NMFS continues to collect and assess monitoring data on the status of populations and abundance trends of and threats to each river herring species (NMFS 2013b). Rainbow smelt (*Osmerus mordax*) were also previously designated by NMFS as a Species of Concern (NMFS 2007).

To address these precipitously declining diadromous fish populations, pro-active restoration has been implemented by many agencies and non-governmental organizations to help restore diadromous fish runs by removing dams and other barriers, installing technical and nature-like fishways, or a combination of these passage restoration alternatives. Improving habitat access through dam removal and other measures may also contribute to diadromous species recolonizing historic freshwater habitats and increasing abundance and distribution of target species locally (Pess et al. 2014). Federal regulatory programs also seek to minimize upstream and downstream mortality of diadromous fishes passing hydro-electric dams or other river and stream barriers by requiring mitigative passage measures.

The NMFS and USFWS have well-established programs to address diadromous restoration by providing funds for and/or technical assistance in the planning, design and implementation of fish passage restoration. Both NMFS and USFWS along with USGS seek to advance engineering design and technology in providing safe (from both physical injury and predator avoidance), timely, and effective upstream and downstream passage for all diadromous species targeted for restoration. At many passage barrier sites, complete removal of the obstruction presents the best alternative for restoring diadromous fish passage and watershed populations.

For sites where barriers cannot be fully removed or modified, other passage alternatives can be considered. Nature-like fishways (NLFs) include a wide variety of designs such as step-pools, roughened ramps, rock-arch rapids, rocky riffles, and cross vanes which are typically constructed of boulders, cobble, and other natural materials to create diverse physical and hydraulic conditions providing efficient passage to multiple species including migratory and resident fish assemblages. NLFs also provide greater surface roughness and flow complexity than typical technical (or structural) fishways (e.g., Denil, steep-pass fishways), creating attractive flow cues to passing fish. Interstitial spaces and surface irregularities associated with NLFs also provide cover and spawning microhabitats, which may be particularly important in watersheds where these specific habitats are limited. The use of natural materials in NLFs such as fieldstone boulders and cobble is also beneficial in lessening the likelihood of fish injury from sharp-edge structures such as those typically associated with structural fishways. NLF designs such as partial or full-river width or bypass channels around barriers can result in effective passage if appropriately designed and constructed for passing fish over a wide range of flows throughout the anticipated seasonal run period for a target species or run periods for targeted fish species assemblage.

Rationale for Passage Guidelines

Fish passage guidelines contribute to best design practices, promote design consistency, and facilitate time and cost-efficiency and quality in engineering design of NLFs and related passage supporting ecological restoration of river systems. NMFS, USGS and USFWS initiated a collaborative effort in 2010 to compile and review existing information from published journals, reports and other unpublished literature on body dimensions and the swimming and leaping capabilities of 14 Atlantic Coast diadromous fish species, and passage and hydraulic functioning of existing fishways. Published data on critical swim speed for each species were also secured, when available. NMFS subsequently organized and held a technical workshop including fish passage biologists and engineers from USGS, USFWS and state agencies experienced with diadromous fish passage in the Northeast region to discuss knowledge and experiences in species passage success and challenges. Subsequent federal agency meetings were held and follow-up consultations were made with professionals from state agencies, academia, and private industry to secure supplemental information on the biology of these target species and their experience with and data available for or analysis of fish swimming performance and/or passage evaluation of the Atlantic Coast diadromous fish species.

Compiling and assessing species data and information from expert knowledge and field and flume laboratory experiences, NMFS, USGS and USFWS applied the collective dataset in developing science-based guidelines when fish swimming and leaping data were available, or best professional judgment when scientific data were limited or unavailable. Compiled information includes the ranges in body length and depth for each of the 14 target diadromous species, to derive body depth-to-total length ratios. These data were then applied in developing a set of six dimensional guidelines for designing passage openings and resting pools. To date, swim speed data from controlled respirometer experiments are available for 10 of the 14 species. Swim data from controlled open-channel swimming flume experiments were available for 8 of the 14 species (data for shortnose sturgeon and Atlantic salmon from USGS Conte Laboratory open flume are forthcoming). Swimming performance data from both respirometer and open-channel swimming flume research was then used to derive maximum through-weir velocity guidelines for each species. Where performance data for a species are minimal, more conservative estimates have been applied in developing the guidelines. The rationales for the guidelines presented in this document include published references or other source of information, as indicated; otherwise, guidelines presented herein are based on best professional judgment.

These guidelines are primarily for purposes of informing the design of NLFs, and in particular, nature-like, step-pool fishways that include resting pools formed by boulder weirs with passage notches specifically designed for the intended target species. One or more of these passage guidelines may also have application to other types of NLFs. These guidelines may also be considered for application in evaluating potential passage alternatives at low-head dams and other barrier sites (e.g., flow diversion and gauging station weirs) and in designing grade control structures upstream of potential dam removals to improve fish passage and/or to protect upstream infrastructure (e.g., bridges and utilities buried in channel bed and bordering floodplain). At some dam removal sites, passage design features may be required upstream of barrier removals to take into account channel bed adjustments which may otherwise result in exposure of and damage to existing infrastructure and/or re-exposure of natural bedrock features. These guidelines may also have application for assessing the likelihood of safe, timely and effective passage at existing natural barriers considered in the context of passage restoration throughout a watershed. As additional studies on fish swimming performance and fish passage effectiveness are completed, these guidelines may be subject to further updates and revisions.

Existing Fish Passage Design Criteria and Guidance

During development of these guidelines, a thorough review was conducted to evaluate other efforts in establishing criteria for fish passage design. To date, a science-based application of fish body morphology, swimming and leaping capabilities, and behavior for passage design has been limited, with most early studies and publications focused on salmonid passage through culverts in the U.S. Pacific Northwest. Bell (1991) presents a synopsis of biological requirements of a limited number of fish species which are then applied to developing biological design guidance including swimming speeds of both juvenile and adult life stages; the published swimming speeds are based primarily on limited and non-standardized experimental methods. Clay (1995) provides an overview of fishway types and examples of installed technical fishways on the Atlantic Coast of North America and elsewhere, with passage guidance that targets hydraulics over weirs, through slots or orifices, and in resting pools which are related to varying fish swims speeds. Beach (1984) and Pavlov (1989) note that body length and water temperature influence swim speeds which in turn help to define passage design guidance.

The Food and Agriculture Organization (FAO 2002) released guidance on European upstream fish passage design, as a follow-up to a 1996 publication prepared by the German Association for Water Resources and Land Improvement (‘DVWK’). The FAO document addresses general fish body size and swim speed of a number of European species, along with designated river “fish zones” in which diadromous and resident fishes are found. The FAO guidance also addresses both nature-like and technical fishways, and general design and detailed guidelines for, and completed examples of (e.g., design dimensions, construction materials and fishway sizes) nature-like fishways. The FAO document is the first guidance for nature-like fishway design, taking into account the swimming and leaping capabilities of fishes.

The Maine DOT (2008) presents both a fish passage policy and design guidelines for passage of diadromous and freshwater fishes through culverts including a minimum-depth guideline applied to low flows, and a maximum-flow velocity guideline based primarily on body-length derived from sustained swimming speeds of target species. The Maine DOT guidance does not address design guidance for fishways. Similar culvert design guidance was released by the Vermont DFW (2009) discussing Atlantic salmon and resident freshwater species biometric and swimming information for passage design including maximum jump height, and a minimum passage water depth of 1.5 times the maximum body depth of the target species. Other states (Washington, California) have released guidance materials for anadromous fish passage design of culverts (Bates et al. 2003, California Department of Fish and Game 2009). The guidelines for velocity and jump height thresholds in these design documents are typically intended to provide passage conditions for the weakest fishes and smallest individuals of each species, while the minimum passage depth guideline for a species is based on the largest-sized fish expected to pass.

There are several sources of passage design for the construction of nature-like fishways. NMFS' Northwest Region provides guidance for passage specifically for Pacific salmonids (primarily genus *Oncorhynchus*) (NMFS 2008, updated 2011), with fish biological requirements and specific design guidelines (prescriptive unless site-specific, biological rationale is provided and accepted by NMFS) and general guidelines (specific values or range in values that may vary when site-specific conditions are taken into consideration) to address a variety of passage types including both technical fishways and nature-like ramps. Aadland (2010) addresses dam removal and nature-like structures for achieving fish passage targeting Mid-Western region warm and cool water fish assemblages, with nature-like fishways serving as features to emulate natural rapids and providing a range of passage conditions and in-fishway habitats benefitting diverse fish assemblages with varying species' swimming capabilities. The document also presents a review of engineering design practices for rock ramp, rock arch rapids and bypass channels. The U.S. Department of Interior's Bureau of Reclamation (Mooney et al. 2007) provides detailed guidelines for nature-like rock ramp design, although species-specific body metrics and swimming and leaping requirements are not addressed in detail.

This existing published passage guidance literature contributes valuable input on how criteria and guidelines have been developed for a number of fish species and variety of fish assemblages and river systems. Conversely, none of the guidelines are targeted specifically for Atlantic Coast diadromous fishes which each have specific body morphology and swimming and leaping capabilities. NMFS, USGS and USFWS thus seek to provide a set of guidelines addressing this diadromous fish assemblage for use by passage restoration practitioners.

Federal Interagency Guidance with Science-Based Application

As noted above, the federal interagency team reviewed and evaluated relevant published journal articles, reports and gray literature, summarized and selected more recent data gained through controlled experiments (e.g., USGS Conte Anadromous Fish Laboratory and other open channel flumes), utilized past performance data from constructed NLFs (primarily in the Northeast), and advanced hydraulic formulae pertinent to nature-like fishway design (e.g., SMath model; See Towler et al. 2014) to develop these science-based guidelines. These guidelines are intended to benefit passage design professionals with information to provide safe, timely and effective passage for Atlantic Coast diadromous fish species targeted in using step-pool and other NLFs.

Target Species

Biological information has been compiled and evaluated for fourteen diadromous species in developing these passage design guidelines. The species addressed in this memorandum include species endemic to the Atlantic Coast. The species are listed according to an evolutionary taxonomic hierarchy (**Table 1**). While not currently addressed by this document, other anadromous (e.g., sticklebacks), amphidromous, and/or potamodromous fish species may be added in future interagency updates, as more research-based swimming and leaping performance data become available and are evaluated.

Table 1. Atlantic Coast Diadromous Fish Species, Common and Scientific Names

Common Name	Scientific Name
Sea lamprey	*Petromyzon marinus*
Shortnose sturgeon	*Acipenser brevirostrum*
Atlantic sturgeon	*Acipenser oxyrinchus oxyrinchus*
American eel	*Anguilla rostrata*
Blueback herring	*Alosa aestivalis*
Alewife	*Alosa pseudoharengus*
Hickory shad	*Alosa mediocris*
American shad	*Alosa sapidissima*
Gizzard shad	*Dorosoma cepedianum*
Rainbow smelt	*Osmerus mordax*
Atlantic salmon	*Salmo salar*
Sea-run brook trout	*Salvelinus fontinalis*
Atlantic tom cod	*Microgadus tomcod*
Striped bass	*Morone saxatilis*

Fish passage engineers and other practitioners should consult with fishery biologists familiar with diadromous fish populations on a regional basis and with the watershed targeted for restoration to secure reliable species and meta-population-specific information on run timing and projected restored run size for each targeted species. Information should include the range of earliest to latest dates of passage, including documented or anticipated earlier season runs or truncated run periods due to climatic change effects on in-stream water temperatures and/or peak discharges. The identification and agreement on the target species to be restored in a watershed and passed at a proposed restoration site should be a principal project objective and central to the initial step in the design process (See Palmer et al. 2005).

Run Timing and Passage Flows

Seasonal timing of fish migrations is a key consideration in fishway design, and needs to be thoroughly considered in determining fish passage design flows and fishway discharge. Fish run timing is often highly variable throughout each species' geographical range, between watersheds, and over years. Run timing, encompassing the beginning, peak, and end of a fish species migratory run period (or spring and fall run periods), is influenced by multiple factors. These factors include genetics; environmental conditions such as precipitation and other weather events and patterns; freshwater, estuarine or oceanic conditions; river flows including the effects of hydro-electric impoundment releases or water withdrawals; in-stream turbidity, dissolved oxygen levels and water temperatures including short-term fluctuations in air and water temperatures; time of day and ambient light conditions; and the specific passage site location within a watershed. Changes in the timing (along with changes in species range and recruitment and habitat change due to sea-level rise) of Atlantic Coast migratory fish runs due to climate change have been identified in a number of locations (Huntington et al. 2003; Juanes et al. 2004; Fried and Schultz 2006; Ellis and Vokoun 2009; Wood and Austin 2009).

For purposes of this document, the federal agencies recommend that a NLF be designed to function in providing passable conditions over a range of flows from the 95% to 5% flow exceedance during the targeted species migratory run period or the collective run periods for multiple target species. The range of river flows used to inform the design of a fishway can be graphically represented by a flow duration curve (FDC). The FDC should be based on the historic probability of flows at the site, or scaled to the project site from an appropriately similar reference site. Active, continuously operated USGS stream gages typically provide the most reliable and complete record of flows for rivers and streams in the U.S. To reasonably estimate future conditions, a sufficiently long period of record (POR) is required. In general, a POR of 10 to 30 years is recommended. Furthermore, the use of post-1970 flow data is preferred to account for documented increasing peak flows over time due to climatic change (See Collins 2009). Additional considerations that influence the length of the POR may include, but are not limited to, gauge data availability, alterations in upstream water management, and changing trends in watershed hydrology.

Body Morphology, Swimming and Leaping Capabilities and Behaviors

Diadromous fishes vary greatly in body shape and size and swimming and leaping capabilities. General body size in fish populations may be affected by genetics, environmental conditions and other factors. Historic fishery catch data indicate decreasing trends in average body size of anadromous fishes that have resulted from overharvesting and natural mortality factors (ASMFC 2012; Waldman 2014; Waldman et al. 2016). Fish body shape and anatomy are determinants of how a fish moves, functions, and adapts to its river environment. Fish body size also affects swimming performance, and swimming ability is largely a function of fish biomechanics and hydrodynamics of its environment (Castro-Santos and Haro 2010). Larger fish have proportionally more propulsive area and a larger muscle mass, and are thus able to move at greater absolute speeds (i.e., the absolute distance through water covered over time). For example, a 10-cm long striped bass swimming at 5 body lengths per second will move through the water at 50 cm per second, while a 50 cm striped bass swimming at 5 body lengths per second will move through the water at 250 cm per second. Larger fish may also have a greater likelihood of injury from coming in contact with boulders or other structures. Fish age, physiological state, and environmental conditions such as water temperature, are additional factors influencing fish movement, behavior (e.g., propensity to pass in schools or groups), passage efficiency, and ultimately passage effectiveness.

In addition to swimming biomechanics, fish exhibit an equally important variety of behavioral responses to their physical and hydraulic environment such as motivation, attraction, avoidance, orientation, maneuvering, station-holding, depth selection, and schooling. In particular, schooling behavior occurs with some species and should be accommodated in fish passage design (e.g., passage opening dimensions and/or multiple openings within each boulder weir). Although basic behaviors of fish have been studied in both laboratory and field environments, only a modest number of behavioral studies have directly addressed fish passage. Most behavioral observations in reference to passageways have been a secondary outcome of passage evaluation studies, where study objectives or experimental designs were not focused on the evaluation of the causes of the behavioral responses.

Understanding the swimming capability of a target species is critical to designing fish passage sites. Swimming performance depends greatly on the relationship between swim speed and fatigue time. At slower speeds, fish can theoretically swim indefinitely using aerobic musculature. Once swim speed exceeds a certain threshold, fish begin to recruit different muscle fibers that function without using oxygen. This condition is noticeable by the onset of *burst-and-coast swimming* – a kinematic shift, whereby fish use both aerobic and anaerobic muscle fibers to power locomotion (Beamish 1978). Anaerobic muscle fibers can only perform for brief periods before running out of metabolic fuel; thus, high-speed swimming results in fatigue and is usually of very short duration. This physiological condition affects potential passage by a fish through high-velocity zones in rivers and fishways. In general, fish swim at speeds requiring anaerobic metabolism infrequently, given the energetic demands of this swimming mode.

Three operationally-defined swimming modes exist in fish: sustained, prolonged, and sprint speeds. Sustained swimming occurs at low or sustained speeds that are maintained for greater than 200 minutes (Beamish 1978). Prolonged swimming occurs at speeds that fish can maintain for 20 seconds to 200 minutes, and sprint swimming can only be maintained for periods of less than 20 seconds. Determining these swim modes and the critical swim speed – the threshold at which a fish changes from sustained to prolonged swim speeds (U_{crit}) is challenging. For many species, quantitative measures of these swimming modes are unknown, and only a few fish species have been comprehensively evaluated for all three modes.

Laboratory respirometer experiments are used to determine the thresholds for a species' swim speeds, but these tests tend to underestimate maximum swimming speed, and may therefore, be limited in accurately measuring burst-speed swimming. Determining burst swimming speeds is usually conducted in open channel flumes, but these experiments can also be biased by fish behavior, stress, or motivation (Webb 2006). Nonetheless, open channel flume studies usually provide better estimates of true swimming performance than results from studies of fish in respirometers, and are the preferred data source for determining fish swimming capabilities and for establishing passage guidelines presented in this document. Existing experimental swim data are also limited in terms of the size range of fish, species life history stage, and experimental water temperatures. Swimming capabilities of fish may also be significantly influenced by turbulence, air entrainment, or other hydraulic/physical factors that influence swimming efficiency and fish motivation.

Leaping (or "jumping") is another component of swimming performance that must be considered in designing and assessing fish passage sites. Leaping height is positively correlated with swimming speed and water depth of the pool from which fish leap. Larger or deeper pools allow higher swimming velocities (i.e., a "running start") to be attained before leaping. Larger fish tend to have greater absolute leaping heights, but also require corresponding increased depths from which to leap. Leaping behavior can be initiated by the fall or plunging flow into a pool creating strong submerged water jets which serve as a stimulus and orientation cue for the direction and speed of an ensuing leap. While salmonids are known to leap during their upstream passage, many non-salmonid fish species are poor leapers or do not leap at all, being physically restricted by body morphology or maximum swimming speed, or more commonly, being behaviorally reluctant to do so. Leaping increases the potential risk of injury or stranding. Typically, leaping or sprint swimming behavior are expressed only when other behaviors are ineffective in passing a velocity or structural barrier. The design of fishways should present conditions that minimize leaping behaviors.

Federal Interagency Passage Design Guidelines

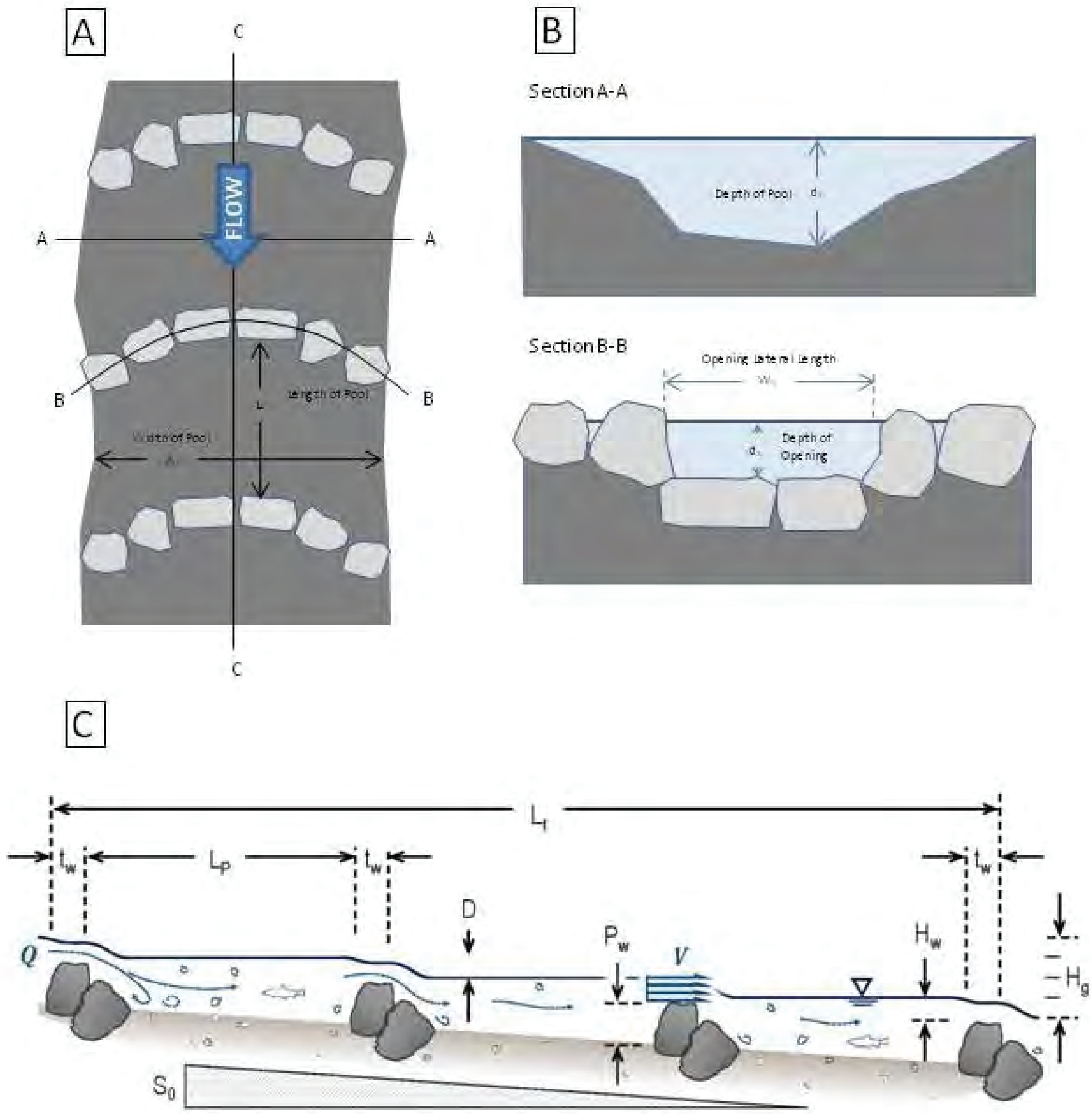
The following are key passage design guidelines that have been identified by the federal interagency team for application to passage of Atlantic Coast diadromous species, and for some species, more discrete guidelines according to life stage/body size categories for the species. These guidelines may be updated by the agencies as additional flume experiments, respirometer and other laboratory studies, and/or field research are completed and results become available that address the physiological and/or behavioral requirements, swimming and leaping capabilities, and passage efficiency of these diadromous fishes and/or other migratory species.

General Design Rationale

This section describes body morphologic dimensions which are determinants of passage, followed by a set of seven design guidelines for each species based on these fish biometrics, plus a maximum velocity criterion based on each species swimming capability. Schematic illustrations are provided in **Figure 1** to accompany and help explain the descriptions of these passage guidelines. Some variables labeled in the graphics are not passage guidelines, but relate to the guidelines. Following the set of passage guidelines descriptions, we present **Table 2** which summarizes the passage guidelines for each of the 14 Atlantic Coast diadromous species, including two length categories for American eel and smaller-sized salmonids; and the basis for, and rationales used in developing this set of guidelines for each of the 14 target fish species.

Figure 1. Plan view (A), cross section (B), and profile (C) illustrations of physical features and nominal measures relating to passage design guidelines for a typical boulder step-pool type fishway.

Note: Schematic profile includes variables that relate to passage guidelines including: Q= flow, t_w= thickness of boulder weir, D= hydraulic drop, P_w= height of rock weir crest, H_w= head over the rock weir, H_g= gross head between headpond and tailwater water surface elevations, and L_t= total length of fishway.



Fish Body Morphology (TL_{min}, TL_{max}, BD/TL Ratio): Maximum and minimum total lengths (TL_{max} and TL_{min}, respectively) and body depth (BD) to total length ratio (BD/TL) for each species were determined to the nearest cm from values published in the literature for diadromous fishes in the Atlantic Coast region. For species with limited or no published data available, unpublished data from recent field investigations were used (Refer to sources cited in species rationales section).

Pool Dimensions

Dimensions of a pool are based on the need to create full- or partial-width channels and pools or bypass channels with pools of sufficient size to serve as resting areas for the target fish species and provide for their protection from predators during passage. Larger fish or species that school in large numbers (hundreds to thousands) require wider, deeper, and longer pools.

The anticipated total run size of the target species and co-occurring species assemblages also need to be thoroughly considered in dimensioning pools.

As a guideline, pool dimensions should also be scaled relative to the size of the stream or river channel and existing pool conditions in nearby unaltered reach or reaches of the study river as a reference, and river flows for the specific design reach. This scaling guideline should be applied regardless of whether the design involves a full or partial width of the stream or river targeted for passage restoration, or is a nature-like bypass channel around a dam or other passage barrier that cannot be removed or modified. Each of the following dimensions should be considered in NLF design:

Minimum Pool Width (W_P): For full river-width structures, minimum pool width will vary depending on the size of the river or stream channel. For bypass channels, pool width will depend on maximum design width of the bypass, taking into account the proportion of the river flows used to design safe, timely and effective passage through the bypass during the full range of fish run flows at the subject river reach. To maximize energy dissipation, pool volume, and available resting areas, pool widths should generally be made as wide as practicable.

Minimum Pool Depth (d_P): In general, pools should be sufficiently deep to serve as resting areas, allow for maneuverability, accommodate deep-bodied and schooling species, and offer protection from terrestrial predators. For small streams (e.g., site with watershed area <5 mi^2), the stream/river channel scaling guideline may be difficult to achieve, and the project design team should assess normal pool depth range in nearby reference reach(es) during the fish passage season. For downstream passage, a minimum depth of pools is needed to provide safe passage of fish and prevent injury or stranding of fish passing over a weir or through a weir opening, especially during low-flow outmigration conditions. Height of the fall as well as body mass of each species needs to be taken into account to minimize the potential for injury to out-migrating fish. For all species, a formula for minimum pool depth was derived which includes a minimum depth of 1 ft, plus 3 body depths, plus one additional body depth as a bottom buffer (to accommodate bottom unconformities and roughness); thus, d_p = 1 ft + 4 BD. Final values of the d_p guideline have been rounded up from the calculated value to the nearest 0.25 ft.

Minimum Pool Length (L_P): Pool length dimensions follow design guidelines similar to the pool widths, but also depths (i.e., maximize energy dissipation, pool volume and available resting areas; accommodate fish body size(s), run size(s), and resting and schooling behaviors). More importantly, pool length also determines overall slope of the fishway for a given drop per pool, so slope must be taken into account when determining minimum pool length (as well as the number of pools for a given design and overall drop). Refer to the Maximum Fishway Channel Slope (S_0) criterion which takes into account both pool length and drop-per-pool.

Minimum Weir Opening Width (W_N): The weir opening width (i.e., weir notch lateral length) relative to fish passage is based on providing a primary passage opening wide enough to accommodate fish body size and swimming mode and schools of upstream migrating target species adults. For sea lamprey and American eel (anguilliform swimmers), W_N equals 2 times the tailbeat amplitude (values from published literature) for the largest sized individual. For sturgeons, which possess a relatively wide body with broad pectoral fins, W_N equals 2 times the body width of the largest-sized individual, including maximum pectoral fin spread during passage. For all other target species, W_N equaled 2 times the maximum total body length. Final values of W_N were rounded up from the calculated value to the nearest 0.25 ft.

The opening width should also be designed for downstream migrating fish that may be oriented obliquely to the flow in a worst-case condition, to minimize potential body contact with (and subsequent injury) the weir-opening sidewall boulders. Wide weir openings also facilitate location of and attraction to the weir opening by fish in broader river reaches and passage sites by providing a flow jet that spans a larger proportion of the total pool width. Weirs will optimally have multiple passage openings, particularly on larger rivers, with varying invert elevations to function over a range of river flows during the passage season(s) and to benefit multiple species with varying swimming capabilities.

Conversely, the passage opening width needs to take into account the pool depth and hydraulics to accommodate the target species. For small streams with limited flows, the passage opening may need to be limited in width to maintain a minimum depth for passage due to very low flows over weirs, and in particular through a notch especially with lowest flows (e.g., flows <5 cfs) during the fish run period. Weirs should be properly designed such that modeled flows through a passage reach should result in submerged weirs or other grade control structures with passage openings, even during the lowest fish run flows. Such a design will result in streaming flow into a pool with water surface elevation at or above the upstream weir opening invert elevation, and preferably backwatering to the weir crest elevation.

Minimum Weir Opening Depth (d_N): Weir opening depths (i.e., weir notch) need to at least accommodate the full depth (vertical depth of body when swimming horizontally) of the body of the largest-sized target species, including extended dorsal and ventral fins to minimize potential for injury. We conservatively established d_N as 3 times the body depth of the largest-sized individual, rounded up to the nearest 0.25 ft. Minimum depths allow freedom of swimming movements and assurance that propulsion and maneuverability by the tail and fins will allow maximum generation of thrust and the ability of fish to maneuver. If limited river flows during the passage season(s) are not a concern, greater passage opening water depth is preferred at locations where schooling fish, like American shad, are passing simultaneously or passing fish are at high risk to predation. Sufficient water depths are also needed to create a low-velocity bottom zone to facilitate ascent by bottom-dwelling or smaller, weaker-swimming species.

The calculated low stream-flow for the target species run period is most critical to designing the weir opening dimensions and to ensure the minimum water depth guideline is attained. Thus, depths of weirs, openings and other passageway features should be designed to accommodate minimum fish-run period flows and low-flow depths. This passage design need is most critical on small streams and watersheds where normal stream flow is limited (e.g., <20 cfs) and flow through a weir opening would be very limited (e.g., <2 cfs).

Maximum Weir Opening Water Velocity (V_{max}): The ability of fish to traverse zones of higher water velocity, particularly through passage openings, is dependent on motivation, physiological capability (sprint swimming speed), and size range of the target species, and the overall distance that the fish must swim through a high-velocity passage zone. For most weir openings in typical fishway designs, the distances and durations that fish must swim to make upstream progress is relatively short (i.e., tens of feet), so fish may be able to swim over weirs or through these openings at prolonged or brief sprint speeds resulting in minimal fatigue. The probability of fish passing upstream through velocity barriers at prolonged or sprint speeds can be calculated for some species based on known high-speed swimming performance or empirical high-speed swimming model data, particularly the critical swim speed for a species (e.g., Weaver 1965, McAuley 1996, Haro et al. 2004). Sprint swimming data, if available, are usually the best data to use to infer maximum weir opening water velocity. However, sprint swimming research has not been conducted and/or sprint swimming curves have not been developed for most Atlantic Coast diadromous fish species, in which case, alternative methods for determining maximum weir opening velocity were used for developing this guideline.

The following rationale was used to determine V_{max} for each species:

1. When sprint swimming data are available, then U_{max} = the sprint swimming speed sustained for 60 sec, for fish of minimum size (TL_{min}).
2. When no sprint swimming data are available, but critical swimming speed (U_{crit}) values have been determined (i.e., from respirometer studies), then U_{max} = 2 times U_{crit} for fish of minimum size (TL_{min}).
3. When no swimming data are available, U_{max} is calculated for a nominal value of 5 BL/sec for subcarangiform swimmers or 3 BL/sec for anguilliform swimmers, for fish of minimum size (TL_{min}).
4. The initial value of U_{max} was adjusted (if necessary) by assessing calculated U_{max} values within the context of other direct fish swimming observations of each species and known velocity barriers (if available; i.e., observed ability to pass a velocity barrier with known water velocity, or best professional judgment, based on experience).
5. V_{max} = U_{max}, rounded down to the nearest 0.25 ft/sec.

The V_{max} applied in each project should be the value associated with the weakest swimming target species. The V_{max} values presented herein for each species are specifically provided for the targeted species expecting to pass over a weir, through a weir opening or other short-distance high velocity zone and into an effective resting area. A V_{max} value should not be misapplied as the guideline for the overall design or diagnostic evaluation of an entire fishway or fish passage reach, where passage length and time of passage would exceed the capability of the target species in sprint swimming mode to pass the site without available resting pools or sites. Such an example may include a rock ramp nature-like fishway constructed at too steep a slope for the target species, and which lacks resting pools, large boulders, or other features providing adequate resting areas.

Maximum Fishway Channel Slope (S_0): The channel slope, S_0, influences energy loss and water velocity over weirs, through weir notches, in pools, and around other in-stream features. In turn, velocity and energy dissipation influence fish behavior and passage efficiency. The friction slope, S_f, is the rate at which this energy is lost along the channel. In prismatic-shaped channels, uniform flow (i.e., flow that is unchanging in the longitudinal direction) occurs when $S_0 = S_f$. In step-pool fishway structures, the average friction slope is equal to the ratio of hydraulic drop-per-pool, D, to pool length plus weir thickness, $L_p + t_w$ (Figure 1). Thus, quasi-uniform or "uniform-in-the-mean" flow is achieved in step-pool fishways when S_0 and the average S_f are equal over the length of the fishway. In most cases, step-pool fishways are designed for this quasi-uniform condition to limit longitudinal flow development (e.g., accelerating flow) and ensure predictable hydraulic conditions in each pool and over each weir.

Quasi-uniform flow establishes a relationship between S_0 and S_f in step-pool structures; however, an additional constraint on S_0 is necessary to safeguard against unacceptably steep fishway designs. Both the pool length and drop-per-pool criteria are based on a species' need for adequate resting space and swimming capability, respectively. Fishway channel slopes based solely on quasi-uniform flow and a friction slope established by the recommended maximum D and minimum L_p may still result in excessive energy dissipation, propagation of velocity from pool to pool, and/or other undesirable conditions. Therefore, a maximum fishway channel slope, S_0, is also recommended. These channel slopes presented herein (Table 1) are conservative estimates based on natural river gradients and sites known to be passable or populated by the target species.

The reader is cautioned that these slope relationships and associated pool and hydraulic drop criteria create an over-determined system (i.e., more equations than unknowns). To avoid conflicting slope constraints, the following procedure is recommended:

1. Based on a species' V_{max} (Refer to Table 2, below), calculate an appropriate D;
2. Based on D and L_p (Table 2), estimate the friction slope, S_f;
3. If $S_f \leq$ channel slope S_0 (Table 2), then set $S_0 = S_f$ and proceed;
   If $S_f > S_0$, then lengthen L_p or add pools to the design to reduce D (while ensuring minimum depth of flow criterion is also met) until $S_f \leq S_0$, and proceed.

Consider the following example for the passage of alewife over a step-pool structure: For this target species, a V_{max} of 6 ft/sec is recommended (Table 2). To provide structural stability, a 3-ft wide rock weir is selected. Using this V_{max} and t_w, a hydraulic analysis results in a maximum drop-per-pool of D= 1.25 ft. For alewife as the target species, a minimum pool length of L_p = 10 ft is recommended (Table 2). This results in a friction slope, S_f = 0.092 which exceeds the specified maximum pool slope of S_0 = 0.05 or 1:20 (Table 2). Accordingly, the geometry needs to be revised to ensure the maximum channel slope criterion is met. The L_p must be increased, D must be decreased, or both until $S_f \leq S_0$.

In general, consistent pool geometry is preferred, but may not be feasible for some passage sites. When site constraints necessitate pools of varying geometry, the procedure above should be applied, iteratively, to each pool-and-weir combination to ensure S_0, S_f, and the other passage criteria are met.

The above methodology integrates species-specific biological criteria from Table 2 and engineering hydraulics. However, it is important to note that fishway geometry is also influenced by other site conditions and target fish species behavioral factors. Additional considerations include substrate stability, channel morphology, immovable boulders/ledge and other natural features that may further constrain the slope of the fishway. Excessively long pool length, which may otherwise meet slope criteria, may decrease motivation of a target species to pass, thus, compromising passage efficiency. As fish passage planning progresses from conceptual to final design, it is critical to verify these parameters with each design modification to ensure that criteria are still met for the weakest target species and over the greatest possible range of hydrologic conditions at the project site.

Other Design Considerations: For moderate and large-sized rivers, multiple weir openings should be provided for safe passage by multiple target species and schools of a species that behaviorally pass in groups (e.g., American shad). The design should consider the diversity of the fish community present in the stream or river. Large rivers with greater spatial habitat diversity typically support a greater number of both resident and anadromous species, with large numbers of fishes seasonally passing upriver often during coincidental, overlapping spawning run periods. A diverse fish assemblage and large numbers of fish passing necessitate multiple passage openings, and benefitting from varying invert elevations and locations along the weir to account for changes in river flow, especially in larger rivers with a diverse fish assemblage and/or widely varying fish run flow range. Weaker-swimming species will use passage openings closer to the river edge and inside river bends where lower flow velocities occur. Weak-swimming species (e.g., minnows, darters) and some species life-stages (e.g., American eel elvers and yellow-phase juveniles) seek out low-velocity, near-bottom conditions not only for passage sites but often as habitat (Aadland 1993).

Regarding passage at weirs, fish will preferentially pass through weir openings, rather than over weir crests. Fish preferentially use streaming flow through openings, as opposed to plunging flows passing over weirs and into resting pools which are often impassible for species with limited leaping capabilities. Although an in-line configuration of weir openings is preferred, primary openings along multiple weirs can be off-set in alignment to prevent propagation of increasing flow velocities through successive weirs or other grade control structures.

Channel size and flow (e.g., bypass channels) should be referenced to both river size and projected run size of the target fish species or fish community assemblage. For example, nature-like bypass fishways sited on large rivers would need to be appropriately sized for flow and run-size capacity. Fishways which are expected to support large runs of target species should include longer and deeper pools to provide sufficient resting areas to accommodate large numbers of fish during peak passage periods.

Figure 2 provides examples of photographed NLF sites in the Northeast region targeted for passage by Atlantic coast diadromous fish species.

Table 2. Summary of design guidelines for NLFs and related to swimming capabilities and safe, timely and efficient passage for Atlantic Coast diadromous fish species. Note: units are expressed in both metric (cm) and English units (feet or feet/sec). See text for informational sources.

Species	Minimum TL (cm)	Maximum TL (cm)	Body Depth/ TL Ratio	Maximum Body Depth (cm)	Minimum Pool/Channel Width (ft)	Minimum Pool/Channel Depth (ft)	Minimum Pool/Channel Length (ft)	Minimum Weir Opening Width (ft)	Minimum Weir Opening Depth (ft)	Maximum Weir Opening Water Velocity (ft/sec)	Maximum Fishway Channel Slope
	TL_{min}	TL_{max}	BD/TL	BD_{max}	W_p	d_P	L_p	W_N	d_N	V_{max}	S_0
Sea Lamprey	60	86	0.072	6.2	10.0	2.00	20.0	0.75	0.75	6.00	1:30
Shortnose Sturgeon	52	143	0.148	21.2	30.0	4.00	30.0	2.75	2.25	5.00	1:50
Atlantic Sturgeon	88	300	0.150	45.0	50.0	7.00	75.0	5.50	4.50	8.50	1:50
American Eel ≤ 15 cm TL	5	15	0.068	1.0	3.0	1.25	5.0	0.25	0.25	0.75	1:20
American Eel >15 cm TL	15	116	0.068	7.9	6.0	2.00	10.0	0.75	1.00	1.00	1:20
Blueback Herring	20	31	0.252	7.8	5.0	2.00	10.0	2.25	1.00	6.00	1:20
Alewife	22	38	0.233	8.9	5.0	2.25	10.0	2.50	1.00	6.00	1:20
Hickory Shad	28	60	0.221	13.3	20.0	2.75	40.0	4.00	1.50	4.50	1:30
American Shad	36	76	0.292	22.2	20.0	4.00	30.0	5.00	2.25	8.25	1:30
Gizzard Shad	25	50	0.323	16.2	20.0	3.25	40.0	3.50	1.75	4.00	1:30
Rainbow Smelt	12	28	0.129	3.6	5.0	1.50	10.0	1.00	0.50	3.25	1:30
Atlantic Salmon	70	95	0.215	20.4	20.0	3.75	40.0	6.25	2.25	13.75	1:20
Sea Run Brook Trout	10	45	0.255	11.5	5.0	2.50	10.0	1.50	1.25	3.25	1:20
Juvenile Salmonid ≤ 20 cm TL	5	20	0.250	5.0	5.0	1.75	10.0	1.25	0.50	2.25	1:20
Atlantic Tomcod	15	30	0.202	6.1	5.0	2.00	10.0	2.00	0.75	0.75	1:30
Striped Bass	40	140	0.225	31.5	20.0	5.25	30.0	9.25	3.25	5.25	1:30

Figure 2. Captioned photographs of nature-like fishways (NLFs) in the Northeast targeting passage of Atlantic coast diadromous fishes (Photo sources: J. Turek, M. Bernier)

Saw Mill Park step-pool fishway, Acushnet River, Acushnet, MA

Fields Pond step-pool fishway, Sedgeunkedunk Stream, Orrington, ME

Kenyon Mill step-pool fishway, Pawcatuck River, Richmond, RI

Homestead dam removal and NLF cross-vanes, Ashuelot River, West Swanzey, NH

Water Street tidal rock ramp, Town Brook, Plymouth, MA

Lower Shannock Falls NLF weirs, Pawcatuck River, Richmond, RI

Species-Specific Rationales

The following passage guidelines rationales for each species are based upon best professional judgment, unless otherwise noted by referenced published literature or other source(s). We applied our experiences with laboratory flume experiments and field observations, and queried other state and federal agency experts in fishery biology and/or fishway engineering design. We note that there is a general paucity of experimental research available, and substantial additional species information is required to verify or refine these guidelines.

Sea Lamprey

TL_{min} = 60 cm (Collette and Klein-MacPhee 2002)
TL_{max} = 86 cm (USFWS Connecticut River Coordinator's Office, unpub. data)
Body Depth/TL Ratio = 0.072 (A. Haro, USGS; unpub. data)

Minimum Pool/Channel Width: 10.0 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Lamprey tends to rest in pool environments more so than other species, and often aggregate in large numbers while resting. Larger run sizes (hundreds to thousands) will require resting pools wider than this minimum dimension.

Minimum Pool/Channel Depth: 2.0 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(86 cm * 0.072)* 0.0328) = 1.8 ft. This value was rounded up to d_p = 2.0 ft. Lamprey tends to rest in pool environments more so than other species, and often aggregate in large numbers while resting. Larger run sizes (hundreds to thousands) will require pools deeper than this minimum dimension.

Minimum Pool/Channel Length: 20.0 ft
The guideline is based on creation of pools large enough to accommodate lamprey body size, run size, and resting and schooling behavior, as well as meeting minimum weir velocity and maximum energy dissipation and slope guidelines. Lampreys tend to rest in pool environments more than other species, and often aggregate in numbers while resting. Larger run sizes (hundreds to thousands) will require pools longer than this minimum dimension.

Minimum Weir Opening Width: 0.75 ft
The minimum opening width guideline is based on a dimension wide enough to accommodate the two times the tailbeat amplitude of the maximum total length (TL) of adult lamprey. Because adult sea lamprey die after spawning, there is no design consideration for downstream passage. Tailbeat amplitude for sea lamprey has been measured as 10% of total length (Bainbridge 1958). Therefore WN = 86 cm * 2 * 0.1 = 17.2 cm = 0.56 ft. This value was rounded up to WN = 0.75 ft.

Minimum Weir Opening Depth: 0.75 ft
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, lamprey maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max} =3 * 6.15 cm = 18.5 cm = 0.61 ft. This value was rounded up to d_N = 0.75 ft.

Maximum Weir Opening Water Velocity: 6.0 ft/sec
The guideline takes into consideration laboratory sprint swimming studies in an open channel flume (McAuley 1996): approximately 1.0 m/sec swimming speed for a maximum of 60 sec duration for adult lamprey (TL_{min} = 60 cm; U=2 BL/sec). Therefore U_{max} = (2 * 60 cm) = 120 cm/sec = 3.94 ft/sec. However, adult sea lampreys are known to have the capability to free-swim ascend surface weirs in technical fishways at velocities of 8.0 ft/sec (Haro and Kynard 1997). Since laboratory studies and field observations suggest strong but varying swimming capabilities, V_{max} was conservatively established at 6.0 ft/sec.

Maximum Fishway/Channel Slope: 1:30
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by sea lamprey, or is a conservative estimate of maximum slope based on known sea lamprey swimming behavior and river hydro-geomorphologies in which sea lamprey occurs.

Shortnose Sturgeon

TL_{min} = 52 cm (Collette and Klein-MacPhee 2002)
TL_{max} = 143 cm (Dadswell 1979)
Body Depth/TL Ratio = 0.148 (M. Kieffer, USGS; unpub. data)

Minimum Pool/Channel Width: 30.0 ft
The guideline is based on pools large enough to serve as sturgeon resting areas and protection from terrestrial predators. Sturgeons typically require larger than average pools, especially if multiple sturgeon are migrating simultaneously through a passageway. While data are lacking for shortnose sturgeon, lake sturgeon are known to use and pass nature-like fishways in groups (L. Aadland, pers. commun.).

Minimum Pool/Channel Depth: 4.0 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(143 cm * 0.148)* 0.0328) = 3.8 ft. This value was rounded up to d_p = 4.0 ft. Sturgeons typically require larger than average-sized pools, especially if multiple sturgeon are migrating simultaneously through a passageway.

Minimum Pool/Channel Length: 30.0 ft
The guideline is based on pools large enough to accommodate sturgeon body size, run size, and resting and schooling behavior, as well as meeting minimum weir velocity and maximum energy

dissipation and slope guidelines. Shortnose sturgeon may aggregate in large numbers while resting in pools. Larger run sizes (hundreds or greater) will require pools longer than this minimum dimension.

Minimum Weir Opening Width: 2.75 ft
The minimum opening width guideline is based on a dimension wide enough to accommodate two times the total body width (including pectoral fin spread) of the maximum total length (TL) of adult shortnose sturgeon. Data are lacking for total body span (including pectoral fins) for shortnose sturgeon, but have been estimated as 27% of TL in lake sturgeon (L. Aadland, Minnesota Department of Natural Resources, pers. comm.). Therefore, W_N = 143 cm * 2 * 0.27 = 77.2 cm = 2.53 ft. This value was rounded up to W_N = 2.75 ft.

Minimum Weir Opening Depth: 2.25 ft
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, sturgeon maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max} =3 *21.19 cm = 63.6 cm = 2.09 ft. This value was rounded up to d_N = 2.25 ft.

Maximum Weir Opening Water Velocity: 5.0 ft/sec
No sprint swimming data are available for adult shortnose sturgeon; U_{crit} for adult shortnose sturgeon is unknown. Based on maximum U=3 BL/sec for anguilliform swimmers and affording passage of smallest sized adults, U_{max} = 3 * 52 cm = 156 cm/sec = 5.12 ft/sec. This value was rounded down to V_{max} = 5.0 ft/sec.

Maximum Fishway/Channel Slope: 1:50
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by shortnose sturgeon, or is a conservative estimate of maximum slope based on known shortnose sturgeon swimming behavior and river hydro-geomorphologies in which this sturgeon species occurs.

Atlantic Sturgeon

TL_{min} = 88 cm (M. Kieffer, USGS, unpub.data)
TL_{max} = 300 cm (M. Kieffer, USGS, unpub.data)
Body Depth/TL Ratio = 0.150 (M. Kieffer, USGS, unpub.data)

Minimum Pool/Channel Width: 50.0 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Sturgeons typically require larger than average pools, especially if multiple sturgeon are migrating simultaneously through a passageway.

Minimum Pool/Channel Depth: 7.0 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1

ft + $4BD_{max}$: d_p = 1 ft + (4*(300 cm * 0.150)* 0.0328) = 6.9 ft. This value was rounded up to d_p = 7.0 ft. Sturgeons typically require larger than average-sized pools, especially if multiple sturgeon are migrating simultaneously through a passageway.

Minimum Pool/Channel Length: 75.0 ft
The guideline is based on creation of pools large enough to accommodate sturgeon body size, run size, and resting and schooling behavior, as well as meeting minimum weir velocity and maximum energy dissipation and slope guidelines. Atlantic sturgeon may aggregate in large numbers while resting in pools. Larger run sizes (hundreds or greater) will require pools longer than this minimum dimension.

Minimum Weir Opening Width: 5.50 ft
The minimum opening width guideline is based on a dimension wide enough to accommodate two times the total body width (including pectoral fin spread) of the maximum total length (TL) of adult Atlantic sturgeon. Data are lacking for total body span (including pectoral fins) for Atlantic sturgeon, but have been estimated as 27% of TL in lake sturgeon (L. Aadland, Minnesota Department of Natural Resources, pers. comm.). Therefore, W_N = 300 cm * 2 * 0.27 = 162 cm = 5.31 ft. This value was rounded up to W_N = 5.50 ft.

Minimum Weir Opening Depth: 4.5 ft
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, sturgeon maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max} = 3 * 45.00 cm = 135.0 cm = 4.43 ft. This value was rounded up to d_N = 4.5 ft.

Maximum Weir Opening Water Velocity: 8.5 ft/sec
No sprint swimming data are available for adult Atlantic sturgeon; U_{crit} for adult Atlantic sturgeon is unknown. Based on U=3 BL/sec for anguilliform swimmers; U_{max} = (3 * 88 cm) = 264 cm/sec = 8.66 ft/sec. This value was rounded down to V_{max} = 8.5 ft/sec.

Maximum Fishway/Channel Slope: 1:50
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by Atlantic sturgeon, or is a conservative estimate of maximum slope based on known Atlantic sturgeon swimming behavior and river hydro-geomorphologies in which sturgeon occur.

American Eel ≤ 15 cm (≤6 inch) TL

TL_{min} = 5 cm (Haro and Krueger 1991)
TL_{max} = 15 cm (upper limit of specified range)
Body Depth/TL Ratio = 0.068 (A. Haro, USGS, unpub.data)

Small (≤15 cm TL) American eels (elvers and small juveniles) are usually upstream migrants, passing through low-velocity flows along river edges and through openings, voids, and crevices in natural and man-made barriers and other riverside structures. Small eels can also climb wetted surfaces for significant distances, aided by water-surface tension. Small eels therefore may only require small openings or passageways, preferably along low-velocity river edges, where they commonly congregate. Design guidelines were developed for two eel size classes since eels continue upstream migration for multiple years and eels may not ascend to distant upstream sites during elver/small juvenile eel stage. These upstream sites are more likely to only pass larger, older eels; guidelines for elvers and small eels would therefore not apply. Size distribution of eels should be assessed at sites considered for nature-like fishway planning before guidelines for upstream eel passage are applied in design. Guidelines for this size range do not take into account downstream passage; see next Section (American Eel > 15 cm TL) for downstream passage guidelines relevant to adult ("silver" phase) or larger juvenile or downstream migrant ("yellow phase") American eel.

Minimum Pool/Channel Width: 3.0 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. American eels tend to rest in pool environments more so than other species, and young eels often aggregate in large numbers while resting, particularly within the substrate. Larger run sizes (hundreds to thousands) will require pools wider than this minimum dimension.

Minimum Pool/Channel Depth: 1.25 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(15 cm * 0.068)* 0.0328) = 1.1 ft. This value was rounded up to d_p = 1.25 ft. American eel tend to rest in pool environments more so than other species, and young eels often aggregate in large numbers while resting, particularly within the substrate. Larger run sizes (hundreds to thousands) will require pools deeper than this minimum dimension.

Minimum Pool/Channel Length: 5.0 ft
The guideline is based on creation of pools large enough to accommodate eel body size, run size, and resting and schooling behavior, as well as meeting minimum weir velocity and maximum energy dissipation and slope guidelines. American eel tend to rest in pool environments more so than other species, and young eels often aggregate in large numbers while resting in pools. Larger run sizes (thousands or greater) will require pools longer than this minimum dimension.

Minimum Weir Opening Width: 0.25 ft
The minimum opening width guideline is based on a dimension wide enough to accommodate the two times the tailbeat amplitude of the maximum total length (TL) of small American eels. Tailbeat amplitude for American eels has been measured as 8% of total length (Gillis 1998). Therefore W_N = 15 cm * 2 * 0.08 = 2.4 cm = 0.08 ft. This value was rounded up to W_N = 0.25 ft. However, as adults, eels may migrate downstream through weir openings, so a larger weir opening width may be required.

Minimum Weir Opening Depth: **0.25 ft**
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max} =3 *1.02 cm = 3.1 cm = 0.10 ft). This value was rounded up to d_N = 0.25 ft. However, as adults, eels may migrate downstream through weir openings, so a larger opening may be required (See *American Eel > 15 cm TL; Minimum Weir Opening Depth*).

Maximum Weir Opening Water Velocity: **0.75 ft/sec**
The guideline is based on laboratory sprint swimming studies (McCleave 1980): U=4.6 BL/sec swimming speed for maximum 60 sec duration for 5 cm TL elvers in an open channel test flume. Therefore, U_{max} = 4.6 * 5 cm = 23 cm/sec = 0.75 ft/sec. V_{max} was established at 0.75 ft/sec.

Maximum Fishway/Channel Slope: **1:20**
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by juvenile American eel, or is a conservative estimate of maximum slope based on known eel swimming behavior and river hydro-geomorphologies in which eel occur.

American Eel > 15 cm (>6 inch) TL

TL_{min} = 15 cm (lower limit of specified range)
TL_{max} = 116 cm (Tremblay 2009)
Body Depth/TL Ratio = 0.068 (A. Haro, USGS, unpub.data)

Minimum Pool/Channel Width: **6.0 ft**
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. American eels tend to rest in pool environments more so than other species, and often aggregate in large numbers while resting, particularly within the substrate. Larger run sizes (hundreds to thousands) will require pools wider than this minimum dimension.

Minimum Pool/Channel Depth: **2.0 ft**
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(116 cm * 0.068)* 0.0328) = 2.0 ft. American eels tend to rest in pool environments more so than other species, and often aggregate in large numbers while resting, particularly within the substrate. Larger run sizes (hundreds to thousands) will require pools deeper than this minimum dimension.

Minimum Pool/Channel Length: **10.0 ft**
The guideline is based on creation of pools large enough to accommodate fish size, run size, and resting and schooling behavior, as well as meeting minimum weir velocity and maximum energy dissipation and slope guidelines. American eel tend to rest in pool environments more so than other species, and often aggregate in large numbers while resting in pools. Larger run sizes (thousands or greater) will require pools longer than this minimum dimension.

Minimum Weir Opening Width: **0.75 ft**

The minimum opening width guideline is based on a dimension wide enough to accommodate the two times the tailbeat amplitude of the maximum total length (TL) of larger American eels. Tailbeat amplitude for American eels has been measured as 8% of total length (Gillis 1998). Therefore, W_N = 116 cm * 2 * 0.08 = 18.6 cm = 0.61 ft. This value was rounded up to W_N = 0.75 ft. However, as adults, eels may migrate downstream through weir openings, so a larger weir opening width may be required.

Minimum Weir Opening Depth: **1.0 ft**

The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max} =3 * 7.9 cm = 23.4 cm = 0.76 ft. This value was rounded up to d_N = 1.0ft.

Maximum Weir Opening Water Velocity: **1.0 ft/sec**

The guideline is based on mean U_{crit} = 0.43 m/s for eels of mean length 44 cm eel; U= 0.97 BL/sec in respirometer experiments (Quintella et al. 2010). Therefore, U_{max} = 2 * 0.97 * 15 cm = 29.1 cm/sec = 0.95 ft/sec. This value was rounded up to V_{max} = 1.0 ft/sec.

Maximum Fishway/Channel Slope: **1:20**

This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by American eel, although juvenile eels are capable of ascending substrates with steeper slopes having roughened surfaces and/or interstitial spaces within boulders, cobbles or other structures.

Blueback Herring

TL_{min} = 20 cm (Collette and Klein-MacPhee 2002)

TL_{max} = 31 cm (S. Turner, NMFS, unpub. data)

Body Depth/TL Ratio = 0.252 (A. Haro, USGS, unpub. data)

Minimum Pool/Channel Width: **5.0 ft**

The guideline is based on pools large enough to serve as resting areas and protection of adults from terrestrial predators. Blueback herring is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands or more) will require pools wider than this minimum dimension.

Minimum Pool/Channel Depth: **2.0 ft**

The guideline is based on pools large enough to serve as resting areas and protection of adults from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(31 cm * 0.252)* 0.0328) = 2.0 ft. Blueback herring is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (thousands or more) will require pools deeper than this minimum dimension. This depth guideline may not be feasible on very small-sized, first- and second-order streams with small watersheds (e.g., <5 mi^2), limited stream flows, and smaller run sizes (hundreds of fish or less).

Minimum Pool/Channel Length: 10.0 ft
The guideline is based on pools large enough to accommodate herring body size, run size, and resting and schooling behavior, as well as meeting minimum weir velocity and maximum energy dissipation and slope guidelines. Blueback herring is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (thousands or greater) will require pools longer than this minimum dimension.

Minimum Weir Opening Width: 2.25 ft
The guideline is based on a weir dimension wide enough to accommodate downstream movement of adult blueback herring oriented in "worst case" perpendicular orientation to the flow, equivalent to 2 times TL_{max} or 2 * 31 cm = 62 cm = 2.03 ft. This value was rounded up to W_N = 2.25 ft. In the case of larger populations (thousands or greater), entrance dimensions should be greater than 2.25 ft, or multiple openings of this minimal dimension should be constructed in weirs to accommodate multiple groups of fish simultaneously passing through the weir opening(s).

Minimum Weir Opening Depth: 1.0 ft
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, herring maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max} =3 * 7.81 cm = 23.4 cm = 0.77 ft. This value was rounded up to d_N = 1.0 ft.

Maximum Weir Opening Water Velocity: 6.0 ft/sec
The guideline is based on laboratory sprint swimming studies in an open channel flume (Haro et al. 2004, Castro-Santos 2005): U=6 BL/sec swimming speed for a maximum 60 sec. Therefore U_{max} = (6 * 20 cm) = 120 cm/sec = 3.94 ft/sec. However, adult blueback herring are known to ascend surface weirs, natural ledge drops, and technical fishways at velocities of 8.0 ft/sec or higher (Reback et al. 2004). To address the varying data currently available, V_{max} was established at 6.0 ft/sec.

Maximum Fishway/Channel Slope: 1:20
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by blueback herring (Franklin et al. 2012), or is a conservative estimate of maximum slope based on known blueback herring swimming behavior and river hydro-geomorphologies in which blueback herring occur.

Alewife

TL_{min} = 22 cm (Collette and Klein-MacPhee 2002)
TL_{max} = 38 cm (Collette and Klein-MacPhee 2002)
Body Depth/TL Ratio = 0.233 (G. Wippelhauser, Maine Div. Marine Fisheries, unpub. data)

Minimum Pool/Channel Width: **5.0 ft**
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Alewife is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools wider than this minimum dimension.

Minimum Pool/Channel Depth: **2.25 ft**
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(38 cm * 0.233)* 0.0328) = 2.2 ft. This value was rounded up to d_p = 2.25 ft. Alewife is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools deeper than this minimum dimension. This depth guideline may not be feasible on very small-sized, first- and second-order streams with small watersheds (e.g., <5 mi^2), limited stream flows, and smaller run sizes (hundreds of fish or less).

Minimum Pool/Channel Length: **10.0 ft**
The guideline is based on creation of pools large enough to accommodate alewife body size, run size, and resting and schooling behavior, as well as meeting maximum weir opening velocity and maximum energy dissipation and slope guidelines. Alewife is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (thousands or greater) will require pools longer than this minimum dimension.

Minimum Weir Opening Width: **2.50 ft**
The guideline is based on a weir dimension wide enough to accommodate downstream movement of adult alewife oriented in a "worst case" perpendicular orientation to the flow, equivalent to 2 times TL_{max} or 2* 38 cm: = 76 cm = 2.49 ft. This value was rounded up to W_N = 2.50 ft. In the case of larger stream populations (thousands or greater), entrance dimensions should be increased above 2.5 ft or multiple openings should be constructed in weirs to accommodate large numbers of fish simultaneously passing through the weir opening(s).

Minimum Weir Opening Depth: **1.0 ft**
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max}: 3 * 8.86 cm = 26.6 cm = 0.87 ft. This value was rounded up to d_N = 1.0 ft.

Maximum Weir Opening Water Velocity: **6.0 ft/sec**
The guideline is based on laboratory sprint swimming studies in an open channel test flume (Haro et al. 2004, Castro-Santos 2005): U=5.5 BL/sec swimming speed for a maximum 60 sec. Therefore U_{max} = 5.5 * 22 cm = 121 cm/sec = 3.97 ft/sec. In contrast, field observations have revealed adult alewives may ascend surface weirs in technical fishways at velocities of 8.0 ft/sec or higher (Reback et al. 2004) . To address the varying test data available, V_{max} was established at 6.0 ft/sec.

Maximum Fishway/Channel Slope: 1:20
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by alewife (Franklin et al. 2012), or is a conservative estimate of maximum slope based on known alewife swimming behavior and river hydro-geomorphologies in which alewives occur.

Hickory Shad

TL_{min} = 28 cm (Collette and Klein-MacPhee 2002)
TL_{max} = 60 cm (Klauda et al. 1991)
Body Depth/TL Ratio = 0.221 (FishBase; www.fishbase.org; BD = 22.1% of TL)

Minimum Pool/Channel Width: 20.0 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Hickory shad is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools wider than this minimum dimension.

Minimum Pool/Channel Depth: 2.75 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(60 cm * 0.221)* 0.0328) = 2.7 ft. This value was rounded up to d_p = 2.75 ft. Hickory shad is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools deeper than this minimum dimension.

Minimum Pool/Channel Length: 40.0 ft
The guideline is based on creation of pools large enough to accommodate shad body size, run size, and resting and schooling behavior, as well as meeting maximum weir opening velocity and maximum energy dissipation and slope guidelines. Hickory shad is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools longer than this minimum dimension.

Minimum Weir Opening Width: 4.0 ft
The guideline is based on a weir dimension wide enough to accommodate downstream movement of adult hickory shad oriented in a "worst case" perpendicular orientation to the flow, equivalent to 2 times TL_{max} or 2*60 cm = 120 cm = 3.94 ft. This value was rounded up to W_N = 4.00 ft. In the case of larger populations (thousands or greater), entrance dimensions should be greater than 4.00 ft, or multiple openings should be constructed in weirs to accommodate multiple shad simultaneously passing through weir opening(s).

Minimum Weir Opening Depth: 1.5 ft
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high

flows; equivalent to 3 times BD_{max} =3 * 13.3 cm = 39.8 cm = 1.31 ft. This value was rounded up to d_N = 1.50 ft.

Maximum Weir Opening Water Velocity: 4.5 ft/sec

No sprint swimming data are available for hickory shad. U_{crit} for hickory shad is unknown. Based on U=5 BL/sec for subcarangiform swimmers, U_{max} = 5 * 28 cm = 140 cm/sec = 4.59 ft/sec. This value was rounded down to V_{max} = 4.50 ft/sec.

Maximum Fishway/Channel Slope: 1:30

This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by hickory shad, or is a conservative estimate of maximum slope based on known hickory shad swimming behavior and river hydro-geomorphologies in which hickory shad occur.

American Shad

TL_{min} = 36 cm (MacKenzie 1985)
TL_{max} = 76 cm (Klauda et al. 1991)
Body Depth/TL Ratio = 0.292 (A. Haro, USGS, unpub. data (Connecticut River fish))

Minimum Pool/Channel Width: 20.0 ft

The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. American shad is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools wider than this minimum dimension, typically on moderate to large-sized Atlantic Coast rivers (i.e., >200-1,000+ mi^2 watersheds).

Minimum Pool/Channel Depth: 4.0 ft

The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(76 cm * 0.292)* 0.0328) = 3.9 ft. This value was rounded up to d_p = 4.0 ft. American shad is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools deeper than this minimum dimension, typically on moderate to larger-sized rivers (i.e., >200-1,000+ mi^2 watersheds).

Minimum Pool/Channel Length: 30.0 ft

The guideline is based on creation of pools large enough to accommodate shad body size, run size, and resting and schooling behavior, as well as meeting maximum weir opening velocity and maximum energy dissipation and slope guidelines. American shad is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (thousands or greater) will require pools longer than this minimum dimension, typically on moderate to large-sized rivers (i.e., >200-1,000+ mi^2 watersheds).

Minimum Weir Opening Width: **5.0 ft**
The guideline is based on a weir dimension wide enough to accommodate downstream movement of adult American shad oriented in a "worst case" perpendicular orientation to the flow, equivalent to 2 times TL_{max} or 2*76 cm: = 152 cm = 4.99 ft. This value was rounded up to W_N = 5.00 ft. In the case of larger populations (thousands or greater), entrance dimensions should be greater than 5.00 ft or multiple openings should be constructed. Multiple fish simultaneously passing through weir openings are frequently observed in passage structures designed for large runs of America shad (Haro and Kynard 1997).

Note, in the southern portion of its range, particularly from Florida north to North Carolina, mature American shad are somewhat smaller (lengths: 35-47 cm; 1.2-1.6 ft) and have a higher percentage of single-time spawners than adult shad comprising more northerly populations (Facey and Van Den Avyle 1986). South of Cape Hatteras, North Carolina, American shad die after spawning (termed, semelparous), with increasing repeat spawning (iteroparous) with increasing latitude north of Cape Hatteras (Leggett and Carscadden 1978).

Minimum Weir Opening Depth: **2.25 ft**
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max}: 3 * 22.2 cm= 66.6 cm = 2.18 ft. This value was rounded up to d_N = 2.25 ft. As noted above, smaller-sized adults in the southern Atlantic Coast populations may support a lesser passage opening depth based on the body depth of adults in these populations.

Maximum Weir Opening Water Velocity: **8.25 ft/sec**
The guideline is based on laboratory sprint swimming studies in an open channel test flume (Haro et al. 2004; Castro-Santos 2005): U=7.0 BL/sec swimming speed for a maximum 60 sec. Therefore U_{max} = 7.0 * 36 cm = 252 cm/sec = 8.27 ft/sec. This value was rounded down to V_{max} = 8.25 ft/sec.

Maximum Fishway/Channel Slope: **1:30**
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by American shad, or is a conservative estimate of maximum slope based on known American shad swimming behavior and river hydro-geomorphologies in which shad occur.

Gizzard Shad

TL_{min} = 25 cm (Miller 1960)
TL_{max} = 50 cm (Able and Fahay 2010)
Body Depth/TL Ratio = 0.323 (FishBase; www.fishbase.org; BD = 32.3% of TL)

Minimum Pool/Channel Width: **20.0 ft**
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Gizzard shad is a schooling species and often aggregates

in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools wider than this minimum dimension.

Minimum Pool/Channel Depth: 3.25 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(50 cm * 0.323)* 0.0328) = 3.1 ft. This value was rounded up to d_p = 3.25 ft. Gizzard shad is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools deeper than this minimum dimension.

Minimum Pool/Channel Length: 40.0 ft
The guideline is based on creation of pools large enough to accommodate shad body size, run size, and resting and schooling behavior, as well as meeting maximum weir opening velocity and maximum energy dissipation and slope guidelines. Gizzard shad is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (thousands or greater) will require pools longer than this minimum dimension.

Minimum Weir Opening Width: 3.5 ft
The guideline is based on a weir dimension wide enough to accommodate downstream movement of adult gizzard shad in a "worst case" perpendicular orientation to the flow, equivalent to 2 times TL_{max} or 2*50 cm: = 100 cm = 3.28 ft. This value was rounded up to W_N = 3.5 ft. In the case of larger populations (thousands or greater), entrance dimensions should be greater than 3.5 ft or multiple openings provided to accommodate multiple fish simultaneously passing through the weir opening(s).

Minimum Weir Opening Depth: 1.75 ft
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max}: 3 * 16.2 = 48.5 cm = 1.59 ft, to provide additional depth for maneuvering, passage by shad schools, and use of lower velocity zone. This value was rounded up to d_N = 1.75 ft.

Maximum Weir Opening Water Velocity: 4.0 ft/sec
No known sprint swimming data are available for gizzard shad; U_{crit} for gizzard shad is unknown. The guideline is therefore based on U= 5 BL/sec for subcarangiform swimmers; U_{max} = 5 * 25 cm = 125 cm/sec = 4.10 ft/sec. This value was rounded down to V_{max} = 4.0 ft/sec.

Maximum Fishway/Channel Slope: 1:30
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by gizzard shad, or is a conservative estimate of maximum slope based on known gizzard shad swimming behavior and river hydro-geomorphologies in which gizzard shad occur.

Rainbow Smelt

TL_{min} = 12 cm (C. Enterline, Maine Department of Marine Resources, unpub. data)
TL_{max} = 28 cm (C. Enterline, Maine Department of Marine Resources, unpub. data; Data from O'Malley (2016) for anadromous smelt from four Maine rivers (2010-2014) indicate maximum length of 24 cm, perhaps suggesting a temporal trend in decreasing mean length in Northeast smelt populations)
Body Depth/TL Ratio = 0.129 (FishBase; www.fishbase.org; BD = 12.9% of TL)

Minimum Pool/Channel Width: 5.0 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Rainbow smelt is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools wider than this minimum dimension.

Minimum Pool/Channel Depth: 1.5 ft
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(28 cm * 0.129)* 0.0328) = 1.5 ft. Rainbow smelt is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools deeper than this minimum dimension.

Minimum Pool/Channel Length: 10.0 ft
The guideline is based on creation of pools large enough to accommodate fish size, run size, and resting and schooling behavior, as well as meeting minimum weir velocity and maximum energy dissipation and slope guidelines. Rainbow smelt is a schooling species and often aggregates in large numbers while resting in pools. Larger run sizes (hundreds to thousands) will require pools longer than this minimum dimension.

Minimum Weir Opening Width: 1.0 ft
The guideline is based on a weir dimension wide enough to accommodate downstream movement of adult rainbow smelt in a "worst case" perpendicular orientation to the flow, equivalent to 2 times TL_{max} or 2*28 cm = 56 cm = 1.84 ft . This value was reduced to W_N = 1.0 ft to offset potential flow limitations during low fish-run flow periods for passageways on small to very small (first or second-order) coastal streams where wider openings may result in shallow water depths not meeting the passage opening depth guideline (See minimum weir opening depth guideline, below) . In the case of larger populations (thousands or greater), entrance dimensions should be greater than1.0 ft to accommodate multiple fish simultaneously passing through the weir opening.

Minimum Weir Opening Depth: 0.50 ft
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max}: 3 * 3.6 cm = 10.8 cm = 0.35 ft. This value was rounded up to d_N = 0.50 ft.

Maximum Weir Opening Water Velocity: **3.25 ft/sec**
The guideline is based on mean U_{crit} = 0.30 m/s for 7 cm, smaller-sized adult rainbow smelt in respirometer experiments (Griffiths 1979); U_{crit} = 4.29 BL/sec. Therefore U_{max} = 2 * 4.29 * 12 cm = 103.0 cm/sec = 3.38 ft/sec. Velocity barriers have been observed for rainbow smelt at water velocities greater than 3.9 ft/sec (B. Chase, MADMF, pers. comm., 8/30/2011). V_{max} was rounded down to 3.25 ft/sec.

Maximum Fishway/Channel Slope: **1:30**
Rainbow smelt spawning runs are typically associated with low-gradient streams and rivers near the head-of-tide. Slope guidelines have not been previously established for rainbow smelt, so a conservative slope was selected. This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by rainbow smelt, or is a conservative estimate of maximum slope based on known rainbow smelt swimming behavior and river hydro-geomorphologies in which smelt occur.

Atlantic Salmon

TL_{min} = 70 cm (T. Sheehan, NMFS, unpub. data)
TL_{max} = 95 cm (T. Sheehan, NMFS, unpub. data)
Body Depth/TL Ratio = 0.215 (T. Sheehan, NMFS, unpub. data; these data were applied to best represent current Northeastern U.S. populations)

Minimum Pool/Channel Width: **20.0 ft**
The guideline is based on creation of pools large enough to serve as resting areas and protection from terrestrial predators.

Minimum Pool/Channel Depth: **3.75 ft**
The guideline is based on creating pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(95 cm * 0.215)* 0.0328) = 3.7 ft. This value was rounded up to d_p = 3.75 ft.

Minimum Pool/Channel Length: **40.0 ft**
The guideline is based on creation of pools large enough to accommodate salmon body size, run size, and resting and schooling behavior, as well as meeting maximum weir opening velocity and maximum energy dissipation and slope guidelines.

Minimum Weir Opening Width: **6.25 ft**
The guideline is based on a weir opening dimension wide enough to accommodate downstream movement of adult Atlantic salmon in a "worst case" perpendicular orientation to the flow, equivalent to 2 times TL_{max} or 2*95 cm = 190 cm = 6.23 ft. This value was rounded up to W_N = 6.25 ft. This width dimension may be reduced to offset potential flow limitations not meeting the minimum weir opening water depth guideline (See water depth guideline, below) associated with low-flow (e.g., autumn post-spawn downstream passage) conditions during the passage season.

Minimum Weir Opening Depth: **2.25 ft**
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max}: 3 * 20.41 cm = 61.2 cm = 2.01 ft. This value was rounded up to d_N = 2.25 ft.

Maximum Weir Opening Water Velocity: **13.75 ft/sec**
The guideline is based initially on mean U_{crit} = 1.70 m/s for 57 cm adult Atlantic salmon in respirometer experiments (Booth et al. 1997). The 57 cm body length approximates the smallest-sized, sea-run adult salmon (grilse) and is not based on smaller-sized spawning adult landlocked salmon; U_{crit}= 3.0 BL/sec. Therefore, U_{max} = 2 * 3.0 * 70 cm = 420 cm/sec = 13.78 ft/sec. This value was rounded down to V_{max} = 13.75 ft/sec.

Maximum Fishway/Channel Slope: **1:20**
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by Atlantic salmon, or is a conservative estimate of maximum slope based on known Atlantic salmon swimming and leaping behavior and river hydro-geomorphologies in which Atlantic salmon occur.

Sea-Run Brook Trout

TL_{min} = 10 cm (M. Gallagher, Maine Department of Inland Fisheries, unpub. data)
TL_{max} = 45 cm (M. Gallagher, Maine Department of Inland Fisheries, unpub. data)
Body Depth/TL Ratio = 0.255 (M. Gallagher, Maine Dept. Inland Fisheries, unpub. data)

Minimum Pool/Channel Width: **5.0 ft**
The guideline is based on creating pools large enough to serve as resting areas and protection from terrestrial predators. Streams and rivers with larger runs (hundreds or more) will require greater passage widths.

Minimum Pool/Channel Depth: **2.5 ft**
The guideline is based on creating pools large enough to serve as resting areas and protection from terrestrial predators, as well as accommodating trout leaping capabilities and needs for passing over weirs or through openings. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(45 cm * 0.255)* 0.0328) = 2.5 ft.

Minimum Pool/Channel Length: **10.0 ft**
The guideline is based on creation of pools large enough to accommodate trout body size, run size, and resting and schooling behavior, as well as meeting maximum weir opening velocity and maximum energy dissipation and slope guidelines.

Minimum Weir Opening Width: **1.5 ft**
The guideline is based on a weir dimension wide enough to accommodate downstream movement of adult sea-run brook trout in a “worst case” perpendicular orientation to the flow,

equivalent to 2 times TL_{max} or 2*45 cm: = 90 cm = 2.95 ft. However, this dimension was reduced to W_N = 1.5 ft. to offset potential flow limitations not meeting the minimum weir opening water depth guideline (See minimum weir opening water depth guideline, below) associated with low-flow (e.g., autumn post-spawn downstream passage) conditions during the passage season for passages on small or very small (first or second-order) coastal streams.

Minimum Weir Opening Depth: 1.25 ft
The guideline is based on provision of sufficient water depth through the weir opening to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max}: 3 * 11.5 cm = 34.4 cm = 1.12 ft. This value was rounded up to d_N = 1.25 ft.

Maximum Weir Opening Water Velocity: 3.25 ft/sec
The guideline is based initially on laboratory sprint swimming studies in an open channel flume (Castro-Santos et al. 2013): U=10.0 BL/sec swimming speed for a maximum 60 sec. Therefore, U_{max} = 10.0 * 10 cm = 100 cm/sec = 3.28 ft/sec. This value was rounded down to V_{max} = 3.25 ft/sec.

Maximum Fishway/Channel Slope: 1:20
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by sea-run brook trout, or is a conservative estimate of maximum slope based on known brook trout swimming behavior and river hydro-geomorphologies in which brook trout occur.

Smaller-sized Salmonids ≤20 cm (≤8 inch) TL

TL_{min} = 5 cm (lower limit of specified range)
TL_{max} = 20 cm (upper limit of specified range)
Body Depth/TL Ratio = 0.250 (generalized BD/TL ratio)

We present guidelines for smaller-sized salmonids which may include both non-migratory phase Atlantic salmon parr (juveniles) using low-order, high-gradient streams with limited seasonal flows; and native sea-run brook trout which may mature as adults as small as 8.5-cm length, and are typically found in Northeast streams and rivers at smaller-size lengths.

Minimum Pool/Channel Width: 5.0 ft
The guideline is based on creating pools large enough to serve as resting areas and protection from terrestrial predators.

Minimum Pool/Channel Depth: 1.75 ft
The guideline is based on creating pools large enough to serve as resting areas and protection from terrestrial predators, as well as accommodating leaping capabilities and needs of juvenile salmonids. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(20 cm * 0.250)* 0.0328) = 1.7 ft. This value was rounded up to d_p = 1.75 ft.

Minimum Pool/Channel Length: 10.0 ft
The guideline is based on creation of pools large enough to accommodate fish size, run size, and resting and schooling behavior, as well as meeting maximum weir opening velocity and maximum energy dissipation and slope guidelines.

Minimum Weir Opening Width: 1.25 ft
The guideline is based on a weir dimension wide enough to accommodate downstream movement of upstream passage by a larger juvenile or young adult, and the downstream movement of juvenile salmonids and smolts in a "worst case" perpendicular orientation to the flow, equivalent to 2 times TL_{max} of 20 cm: = 40 cm = 1.31 ft. However this value was rounded down to W_N = 1.25 ft to offset potential flow limitations not meeting the minimum weir opening water depth guideline (See minimum weir opening water depth guideline, below) associated with low fish-run flow conditions for passageways on small or very small (first or second-order) coastal streams and streams with substantially varying ("flashy") seasonal flow conditions.

Minimum Weir Opening Depth: 0.50 ft
The guideline is based on provision of sufficient water depth through the weir opening to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max}: 3 * 5.0 cm = 15.0 cm = 0.49 ft. This value was rounded up to d_N = 0.50 ft.

Maximum Weir Opening Water Velocity: 2.25 ft/sec
The guideline is based on mean U_{crit} = 0.62 m/s for 8.5 cm brook trout in respirometer experiments (McDonald et al. 1998); U= 7.3 BL/sec. This guideline is based on the approximate smallest body length for adult brook trout. Therefore, U_{max} = 2 * 7.3 * 5.0 cm = 73.0 cm/sec = 2.40 ft/sec. This value was rounded down to V_{max} = 2.25 ft/sec.

Maximum Fishway/Channel Slope: 1:20
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by juvenile salmonids, or is a conservative estimate of maximum slope based on known salmonid swimming and leaping behavior and river hydro-geomorphologies in which salmonids occur.

Atlantic Tomcod

TL_{min} = 15 cm (Collette and Klein-MacPhee 2002)
TL_{max} = 30 cm (Collette and Klein-MacPhee 2002, Stevens et al., 2016)
Body Depth/TL Ratio = 0.202 (FishBase; www.fishbase.org; BD = 20.2% of TL)

Minimum Pool/Channel Width: 5.0 ft
The guideline is based on creating pools large enough to serve as resting areas and protection from terrestrial predators.

Minimum Pool/Channel Depth: 2.0 ft
The guideline is based on creating pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(30 cm * 0.202)* 0.0328) = 1.8 ft. This value was rounded up to d_p = 2.0 ft.

Minimum Pool/Channel Length: 10.0 ft
The guideline is based on creation of pools large enough to accommodate tomcod body size, run size, and resting and schooling behavior, as well as meeting maximum weir opening velocity and maximum energy dissipation and slope guidelines.

Minimum Weir Opening Width: 2.0 ft
The guideline is based on a weir dimension wide enough to accommodate upstream passage by multiple adult Atlantic tomcod migrating upstream in small tidal, coastal streams, including during ebbing-tide periods in tidal streams; as well as downstream movement of adult Atlantic tomcod in a "worst case" perpendicular orientation to the flow; equivalent to 2 times TL_{max} or 2*30 cm: = 60 cm = 1.97 ft. This value was rounded up to W_N = 2.0 ft.

Minimum Weir Opening Depth: 0.75 ft
The guideline is based on provision of sufficient water depth through the weir opening to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max}: 3 * 6.06 cm = 18.2 cm = 0.60 ft. This value was rounded up to d_N = 0.75 ft.

Maximum Weir Opening Water Velocity: 0.75 ft/sec
No sprint swimming data are available for Atlantic tomcod. U_{crit} for Atlantic tomcod is unknown. Water velocities in excess of 30 cm/sec are known to be barriers for Atlantic tomcod (Bergeron et al. 1998); therefore, U_{max} = 30 cm/sec = 0.98 ft/sec. This value was rounded down to V_{max} = 0.75 ft/sec. If a passage site is affected by tidal flooding, tom cod may alternatively passively move over project site weirs or through weir openings or other hydraulic features during diurnal flood tide events.

Maximum Fishway/Channel Slope: 1:30
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by tom cod, or is a conservative estimate of maximum slope based on known tom cod swimming behavior and river hydro-geomorphologies in which tom cod occur.

Striped Bass
TL_{min} = 15 cm (Fay et al. 1983)
TL_{max} = 30 cm (Collette and Klein-MacPhee 2002)
Body Depth/TL Ratio = 0.225 (FishBase; www.fishbase.org; BD = 22.5% of TL)

Minimum Pool/Channel Width: 20.0 ft
The guideline is based on creating pools large enough to serve as resting areas and protection from terrestrial predators.

Minimum Pool/Channel Depth: 5.25 ft
The guideline is based on creating pools large enough to serve as resting areas and protection from terrestrial predators. Minimum pool depth was calculated using the formula 1 ft + $4BD_{max}$: d_p = 1 ft + (4*(140 cm * 0.225)* 0.0328) = 5.1 ft. This value was rounded up to d_p = 5.25 ft.

Minimum Pool/Channel Length: 30.0 ft
The guideline is based on creation of pools large enough to accommodate bass body size, run size, and resting and schooling behavior, as well as meeting maximum weir opening velocity and maximum energy dissipation and slope guidelines.

Minimum Weir Opening Width: 9.25 ft
The guideline is based on a weir dimension wide enough to accommodate upstream migration by adult striped bass on migratory spawning runs (principally tidal rivers with varying tidal prism, or larger (fourth+-order) non-tidal rivers); and downstream movement of adult striped bass in a "worst case" perpendicular orientation to the flow; equivalent to at least 2 times TL_{max} or 2*140 cm: = 280 cm = 9.19 ft. This value was rounded up to W_N = 9.25 ft.

Minimum Weir Opening Depth: 3.25 ft
The guideline is based on provision of sufficient water depth over the weir to enable protection from terrestrial predators, maneuvering in low flows, and use of lower velocity zone in high flows; equivalent to 3 times BD_{max}: 3 * 31.5 cm= 94.5 cm = 3.10 ft. This value was rounded up to d_N = 3.25 ft.

Maximum Weir Opening Water Velocity: 5.25 ft/sec
The guideline is based on laboratory sprint swimming studies in an open channel test flume (Haro et al. 2004; Castro-Santos 2005): U=4.0 BL/sec swimming speed for a maximum 60 sec. Therefore U_{max} = 4.0 * 40 cm = 160 cm/sec = 5.25 ft/sec. V_{max} was therefore established as 5.25 ft/sec for smaller-sized striped bass.

Maximum Fishway/Channel Slope: 1:30
This nominal slope guideline approximates the maximum slope at natural river sites known to be passable by striped bass, or is a conservative estimate of maximum slope based on known striped bass swimming behavior and river hydro-geomorphologies in which striped bass occur.

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Appendix D

Glossary of Terms

List of Unit Abbreviations

List of Acronyms

Glossary of Terms

Aeration	Process by which air is mixed into water. Typically used in reservoirs, tailraces, and turbines to mitigate low dissolved oxygen conditions.
Anadromous	A fish life history strategy whereby fish are born in fresh water, spends most of life at sea, and returns to freshwater to spawn.
Angled bar screen	A guidance structure constructed of a series of vertical slats, placed along a diagonal line within a power canal or forebay and terminating at a downstream fish bypass.
Approach velocity	The prevailing free stream velocity in a river or channel; typically parallel to the longitudinal direction of the waterway.
Aquatic organism passage	The ability for fish and other aquatic fish and other aquatic creatures to move up or downstream under road crossings.
Attraction flow	The flow that emanates from a fishway entrance with sufficient velocity and in sufficient quantity and location to attract upstream migrants in the fishway. Attraction flow consists of gravity flow from the fish ladder, plus any auxiliary water system flow added at points within the lower fish ladder.
Auxiliary water	Portion of attraction flow that is diverted through the auxiliary water system (AWS) prior to flowing out of the fishway entrance.
Auxiliary water system	A hydraulic system that augments fish ladder flow at various points in the upstream passage facility. Typically, large amounts of auxiliary water flow are added in the fishway entrance pool in order to increase the attraction of the fishway entrance.
Behavioral barrier	Any device, structure, or operation that requires response, or reaction (volitional taxis) on the part of the fish to avoid entrainment. Examples include acoustic, electric, and light.
Behavioral devices	Requires a decision, response, or reaction (volitional taxis) on the part of the fish to avoid entrainment.
Benthic-oriented	Fish that live and feed on or near the bottom of oceans or lakes (the benthic zone). Lower than demersal zone.
Biological capacity	Maximum number of fish that can safely, timely, and effectively pass through the fishway.

Biomass	The total mass of organisms in a given area or volume.
Biotelemetry	Remote monitoring of individual fish or other organisms through space and time with electronic identification tags.
Brail	A device that moves upward (vertically) through the water column, crowding fish into an area for collection.
Burst speed	Swim speed a fish can maintain for seconds, primarily an anaerobic muscle activity.
Bypassed reach	The portion of the river between the point of flow diversion and the point of flow return to the river.
Catadromous	A fish life history strategy whereby a fish spawn at sea and move to and spend most of their lives in fresh water.
Cavitation	In to the context of turbine mortality, the injurious effect of water vapor bubble collapse.
Channel roughness	Measure of the amount of frictional resistance water experiences when passing over land and channel features.
Climbing substrate	Eelway channel-bottom liners resembling gravel, geotextiles, fibrous material, bristles, studs, or other media that enhance the climbing ability of eels.
Conte airlift bypass	A deep-entrance airlift designed to attract and transport adult downstream migrating eels over a barrier.
Crowder	A combination of static and/or movable picketed and/or solid leads installed in a fishway for the purpose of moving fish into a specific area for sampling, counting, broodstock collection, or other purposes.
Cruising speed	The swim speed a fish can maintain for hours without causing any major physiological changes, an aerobic muscle activity ("red" muscle tissue).
Degradation	Erosion of sediment in a river channel.
Delaware-style eel pass	An eelway that uses trawl netting or similar rope-like material though a hole in flashboards, surface gates, or other structures near the crest of the dam.

Demersal fish	Fish that live and feed on or near the bottom of seas or lakes (the demersal zone).
Denil fishway	Family of baffled-chute ladders that utilize roughness elements (i.e., baffles) to dissipate the kinetic energy of water moving through a flume to create a low velocity zone of passage for migratory fish.
Design flow, high	Nominal upper limit of river flow that can achieve safe, timely, and effective fish passage.
Design flow, low	Nominal lower limit of river flow that can achieve safe, timely, and effective fish passage.
Diadromous	A fish life history strategy whereby fish spend parts of their life cycle in fresh water and other parts in salt water.
Diffuser	Typically, a set of horizontal or vertical bars designed to introduce flow into a fishway in a nearly uniform fashion. Other means are also available that may accomplish this objective.
Discharge	The volume of water per unit time flowing through a structure, a turbine, or a channel cross-section.
Dorsal fin	A fin on the back of a fish.
Downstream bypass	The component of a downstream passage facility that transport fish from the diverted water back into the body of water from which they originated, usually consisting of a bypass entrance, a bypass conveyance, and a bypass outfall.
Downstream passage	The act of moving from upstream of a dam or other hydropower facility to downstream of a dam or other hydropower facility. This can be accomplished through unmitigated passage through turbines or spill gates, or mitigated passage through locks, elevators, sluiceways or channels that bypass turbines or other structures.
Eel lift	A non-volitional eelway applicable to higher head barriers that can be mechanically lifted above the barrier through a hoistway and flushed into the headpond; also known as eelevators.
Eel ramp	A conventional eelway consisting of linear metal, plastic, or wooden channels lined with climbing substrate and equipped with an attraction water delivery system.
Eel trap	A trap (tank) at the exit of a volitional eel ramp.

Eelway	A fishway specifically designed for eel, also known as eel pass. Variants include eel ramp, eel lift, Delaware-style eel pass, laterally sloped ramp, and helical ramp.
Elvers	A young eel, especially when undergoing mass migration upriver from the sea.
EDF	The energy dissipation factor (EDF) is the measurement of energy in a bypass downwell to assist in providing enough water volume in the downwell to dissipate the energy entering the downwell and to limit turbulence and circulation patterns that may trap debris and/or fish.
Energy grade line	A line that represents the elevation of energy head (in feet or meters) of water flowing in a pipe, conduit, or channel. The line is drawn above the hydraulic grade line (gradient) a distance equal to the velocity head of the water flowing at each section or point along the pipe or channel.
Entrance depth	The vertical depth between the invert of the fishway entrance floor to the tailwater (or downstream pool) surface elevation.
Entrainment	The unintended diversion of fish into an unsafe passage route.
Exclusion barriers	Upstream passage facilities that prevent upstream migrants from entering areas with no upstream egress, or areas that may lead to fish injury.
FERC	The Federal Energy Regulatory Commission (FERC) is an independent agency that regulates the interstate transmission of natural gas, oil, and electricity.
Fish ladder	The structural component of an upstream passage facility that dissipates the potential energy into discrete pools, or uniformly dissipates energy with a single baffled chute place between an entrance pool and an exit pool or with a series of baffled chutes and resting pools.
Fish lift	A mechanical component of an upstream passage system that provides fish passage by lifting fish in a water-filled hopper or other lifting device into a conveyance structure that delivers upstream migrants past the impediment.
Fish lock	A mechanical and hydraulic component of an upstream passage system that provides fish passage by attracting or crowding fish

	into the lock chamber, activating a closure device to prevent fish from escaping, introducing flow into the enclosed lock, and raising the water surface to forebay level, and then opening a gate to allow the fish to exit.
Fish passage system	The range of dates when a species migrates to the site of an existing or proposed fishway, based on either available data collected for a site, or consistent with the opinion of an assigned NMFS/USFWS biologist when no data is available.
Fishway	Combination of elements (structures, facilities, devices, project operations, and measures) necessary to ensure the safe, timely, and effective movement of fish past a barrier.
Fishway capacity	A measure of the quantity of fish that the facility can successfully convey, upstream or downstream, in a given period.
Fishway entrance	The component of an upstream passage facility that discharges attraction flow into the tailrace, where upstream migrating fish enter (and flow exits) the fishway.
Fishway exit	The component of an upstream passage facility where flow from the forebay enters the fishway, and where fish exit into the forebay upstream of the passage impediment.
Flashboards	Temporary structures installed at the top of dams, gates, or spillways for the purpose of temporarily raising the pool elevation, and hence, the gross head of a hydroelectric generating plant, thus increasing power output. Normally, flashboards are removed either at the end of the water storage season, or during periods of high stream flow.
Floating guidance system	A series of partial-depth panels or screen anchored across a river channel, reservoir, or power canal for downstream fish passage.
FDC	The flow-duration curve (FDC) is the plot of the relationship between the magnitude of the daily flow and the percentage of the time period for which that flow is likely to be equaled or exceeded. Other time units can be used as well, depending on the intended application of the data.
Forebay	The impoundment immediately above a dam or hydroelectric plant intake structure. The term is applicable to all types of hydroelectric developments (i.e., storage, run-of-river, and pumped storage).

Fork length	A measurement used frequently for fish length when the tail has a fork shape. Projected straight distance between the tip of the snout and the fork of the tail.
Francis turbine	A reaction turbine typically installed at medium head projects characterized fixed blades on a runner (wheel) and paired with an external generator.
Freeboard	The height of a structure that extends above the maximum water surface elevation.
Grinding	In relation to turbine mortality, squeezing through narrow gaps between fixed and moving structures.
Head loss	The loss of energy through a hydraulic structure, device or from one known point to another.
Headwater	Waters located immediately upstream from a hydraulic structure, such as a dam (excluding minimum release such as for fish water), bridge or culvert.
Helical eel ramp	An eelway that consists of a water-retaining channel coiled around a central vertical shaft, with climbing substrate installed on the channel bottom.
Holding pools	Section in the lower channel that is downstream of the hopper and bound by the (open) mechanical crowder in a fish lift. The purpose of the holding pool is to retain migrants prior to crowding them into the hopper.
Hopper (bucket)	Water retaining vessel used to lift fish (in water) from a collection or holding area, for release at a higher elevation.
Hydraulic jump	A hydraulic jump happens when a higher velocity supercritical flow upstream is met by a subcritical downstream flow with a decreased velocity and sufficient depth.
Impingement	A fish’s injurious contact with a screen or bar rack.
Impoundment	A lake formed or enlarged through use of a dam or lock built to store water.
Inclined bar screen	A guidance structure characterized by a vertically sloped exclusion screen that prevents entrainment while simultaneously directing migrants around the powerhouse through a fish bypass.

Kaplan turbine	A propeller turbine in which the angle of the blades to the flow can be adjusted.
Laterally sloped eel ramp	A laterally tilted eelway with substrate-covered ramp floor that is available to eel at the water surface through varying impoundment levels.
Life history	The series of changes over the life of an organism including such events as birth, death and reproduction. Also known as life cycle.
Louver	A louver system is constructed of a series of vertical slats placed along a diagonal line within a power canal terminating at the bypass.
Low-level pressurized bypass	Gravity driven submerged bypasses, including siphons, for downstream passage.
Migration	Seasonal or annual movement of organisms from one area to another.
Migratory run	Seasonal migration undertaken by fish, usually as part of their life history; for example, spawning run of salmon, upstream migration of shad.
Mortality	Measures the rate of death of fish. Mortality occurs at all life stage of the population and tends to decrease with age.
MSL	Mean Sea Level vertical datum, also referred to as USGS datum, obsolete datum.
NAD 27	North American Datum of 1927, obsolete horizontal datum.
NAD 83	North American Datum of 1983, adopted horizontal datum.
NAVD 88	North American Vertical Datum of 1988, adopted datum.
Nature-like fishway (NLF)	Fishway constructed of boulders, cobble, and other natural materials to create diverse physical and hydraulic conditions providing efficient passage to multiple species including migratory and resident fish assemblages (Turek et al., 2016).
NED	National Elevation Dataset, USGS high precision ground surface elevation data for the United States.
NGVD 29	National Geodetic Vertical Datum of 1929, obsolete datum.

Non-volitional passage	Fish passage facilities that include fish lifts (i.e., elevators), fish locks, and trap-and-transport systems.
Normal velocity	Velocity component perpendicular to the guidance structure pointing directly at the face of the structure.
Orifice	An opening through which something may pass.
Overshot gate	An angled gate hinged at the base with the crest facing downstream.
Panmictic	Populations where all individuals are potential partners, assumes no mating restrictions, neither genetic nor behavioral.
Pass rate	The rate of ascent, a measure of how quickly fish of different species can traverse the fishway. This parameter reflects both behavioral characteristics and the swimming speed of the fish.
Passive screens	Juvenile fish screens without an automated cleaning system.
Peak day	Largest number of fish designed to pass during a 24-hour period.
Peak hour	Largest number of fish designed to pass in a 1-hour period during the peak day.
Peak minute	Average number of fish passed per minute during the peak hour.
Pelagic fish	Fish that live in the pelagic zone of ocean or lake waters – being neither close to the bottom nor near the shore.
Periphyton cover	Complex mixture of algae, cyanobacteria, heterotrophic microbes, and detritus that is attached to submerged surfaces in most aquatic ecosystems.
Picket leads or pickets	A set of vertically inclined flat bars or circular slender columns (pickets), design to exclude fish from a specific point of passage (also, see fish weir).
PIT –tag detector	A device that passively scans a fish for the presence of a passive integrated transponder (PIT) tag that is implanted in a fish and read when activated by an electro-magnetic field generated by the detector.
Plunge pool	Body of water downstream of the barrier where the conveyance outlet discharges both fish and water.

Plunging flow	Flow over a weir that falls into the receiving pool with a water surface elevation below the weir crest elevation.
Pool-type fishway	A volitional type of fishway that include pool-and-weir, Ice Harbor, and vertical slot.
Potamodromous	A fish life history strategy whereby fish are migrate entirely within freshwater.
Powerhouse	A structure at a hydroelectric plant site that contains the turbine and generator. (FERC 2016) .
Predation	The act of killing and eating other animals.
Pressure changes	In relation to turbine mortality, water pressures within the turbine may increase to several times atmospheric pressure, then drop to sub-atmospheric pressure, all in the matter of seconds.
Radio telemetry	The use of radio waves for transmitting information from a distant instrument to a device that indicates or records the measurements.
Reservoir	A storage space for water that may be created in multiple ways, such as (1) damming a valley to create an impoundment, (2) siphoning water into bank-side areas lined with impermeable material, or (3) constructing above ground water towers or below ground cisterns known as service reservoirs.
Residence time	The average length of time during which a substance, a portion of material, or an object is in a given location or condition. Also can be regarded as the inverse of pass rate.
Rheotaxis	A form of taxis seen in many aquatic organisms, e.g., fish, whereby they will (generally) turn to face into an oncoming current. In a flowing stream, this behavior leads them to hold position in a stream rather than being swept downstream by the current.
Rheotropism	Movement stimulated by a current of water.
Riffle	An area of a stream or river flowing over cobbles, boulders and gravel where characterized as being relatively shallow and having relatively rapid current velocities generally located downstream of a run. Because riffles have high turbulence, they are areas that provide a good deal of oxygen to the stream or river.
Rock ramp	A sloped watercourse that links two pools of different elevation (e.g., headwater and tailwater of a dam) constructed in the existing

	channel and spanning the entire river. The entire stream flows through a (full width) rock ramp, thus eliminating competing flows and reducing concerns related to attraction.
Run	An area of a stream or river characterized as having relatively rapid current velocities generally located downstream of a pool. Runs generally have relatively greater depths than riffles, but relatively shallower depths than pools.
Scour	The removal of sediment particles by water potentially in the river channel bed or along the shoreline.
Scroll case	A spiral waterway normally made of either reinforced concrete or steel that guides water to the runner of a reaction turbine.
Shear stress	In relation to turbine mortality, forces applied to the fish's surface resulting from the incidence of two bodies of water at different velocities.
Spillway	An outlet from a reservoir or section of a dam designed to release surplus water that is not discharged through a turbine or other outlet works.
Step pool	A fishway designs approximate pool-and-weir technical fishways. Notionally, fish move through these structures by bursting over a weir then momentarily resting in the upstream pool.
Stop log/bulkhead gate	A gate installed at the entrance of a fluid passage and used to dewater the passage for inspection and maintenance. Almost always opened or closed under balanced pressure.
Streaming flow	Flow over a weir which falls into a receiving pool with water surface elevation above the weir crest elevation. Generally, surface flow in the receiving pool is in the downstream direction, downstream from the point of entry into the receiving pool.
Strike	In relation to turbine mortality, collision with structure including runner blades, stay vanes, wicket gates, and draft tube piers.
Submergence	The vertical distance between the crest of the gate or weir to the tailwater (or downstream pool) surface elevation.
Sustained swimming speed	A fish swimming speed that fish can maintain for minutes (see prolonged).

Sweeping velocity	The vector component of canal flow velocity that is parallel and adjacent to the screen face measured 1 foot in front of the screen.
Tailrace	The stream immediately downstream of an instream structure.
Tailwater	Waters located immediately downstream from a hydraulic structure, such as a dam (excluding minimum release such as for fish water), bridge or culvert.
Thalweg	The longitudinal line connecting the lowest points in a streambed.
Total length (TL)	The length of a fish defined as the straight-line distance from the tip of the snout to the tip of the tail (caudal fin) while the fish is lying on its side, normally extended.
Transport channel	A hydraulic conveyance designed to pass fish between different sections of a fish passage facility.
Trap and haul	A fish passage facility designed to trap fish for upstream or downstream transport to continue their migration (AKA trap and transport).
Trash (grizzly) rack	A rack of vertical bars with spacing designed to catch large debris and preclude it from passing. When used on a fishway exit, it must have enough clear spacing for fish to pass in the upstream direction.
Turbidity	Cloudiness or haziness of water created by dissolved or suspended solids. Turbidity upstream and downstream of hydropower facilities is generally reduced relative to free-flowing reaches of river; however, turbidity downstream of the dam is generally reduced compared to that upstream of the dam.
Turbine	A machine which, in the case of a hydroelectric plant, converts energy of water to mechanical energy.
Turbulence	In relation to fish passage, irregular motions of the water, which can cause localized injuries to fish, or on a larger scale disorientation.
Uniform-in-the-mean	Each successive pool maintains the same hydraulic characteristics at the inlet and outlet. Therefore, the slope of the fishway is approximately equal to the friction slope (slope of the energy grade line) (Towler et al., 2015).

Upstream passage	The act of moving from downstream of a dam or other hydropower facility to upstream of a dam or other hydropower facility. This can be accomplished through a variety of means including lifts, locks or elevators, fishways, or trapping target organisms on the downstream side of the dam or other hydropower facility and transporting them to the upstream side of the dam or other hydropower facility where they are released.
Vertical slot fishway	A pool-type fish ladder characterized by a rectangular channel with a sloping floor in which a series of regularly spaced baffles separate the pools. Water flows from pool to pool via a vertical slot at each baffle. These designs are applicable to medium head dams and, unlike pool-and-weir fishways, may accommodate large fluctuations in headwater and tailwater levels. Another advantage of the vertical slot is that it offers passage along the full depth of the slot, thus it theoretically provides passage to a wider variety of species.
Volitional passage	Fish passage facilities that include specific pool-type and chute-type designs such as the pool-and-weir, Ice Harbor, vertical slot, Denil, and steeppass.
Weir	An obstruction over which water flows.
Wicket gate	Adjustable vanes that surround a reaction turbine runner and control the area available for water to enter the turbine.

List of Unit Abbreviations

Unit	**Unit Abbreviation**
cubic foot	ft^3
cubic foot per second	cfs
foot	ft
foot per second	fps
foot pound per second per cubic foot	$ft\text{-}lbf/s\text{-}ft^3$
gallon per minute	gpm
inch	in.
millimeter	mm
pound force	lbf
pound per cubic foot	lbf/ft^3
square foot	ft^2

List of Acronyms

Acronym	
AOP	Aquatic organism passage
AWS	Auxiliary water system
CT DEEP	Connecticut Department of Energy & Environmental Protection
EDF	Energy dissipation factor
Engineering	Fish Passage Engineering
FAC	Fish and Aquatic Conservation program
FDC	Flow-duration curve
FERC	Federal Energy Regulatory Commission
HW	Headwater
MDNR	Maryland Department of Natural Resources
ME DMR	Maine Department of Marine Resources
ME IFW	Maine Department of Inland Fisheries and Wildlife
MPOR	Migratory period of record
NH DFG	New Hampshire Department of Fish and Game
NLF	Nature-like fishway
NMFS	National Marine Fisheries Service
NRCS	Natural Resource Conservation Service
O&M Plan	Operation and maintenance plan
PIT	Passive integrated transponder
POR	Period of record
R5	Region 5 (also Northeast Region)
Service	U.S. Fish and Wildlife Service
TW	Tailwater
USGS	U.S. Geological Survey
ZOP	Zone of Passage

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United States Department of the Interior

FISH AND WILDLIFE SERVICE
New Jersey Ecological Services Field Office
4 E. Jimmie Leeds Road, Suite 4
Galloway, NJ 08205
Phone: (609) 646-9310

In Reply Refer To: 07/10/2025 12:28:38 UTC
Project Code: 2025-0075934
Project Name: Rahway River Flood Risk Management Study

Subject: List of threatened and endangered species that may occur in your proposed project location or may be affected by your proposed project

To Whom It May Concern:

The enclosed species list identifies threatened, endangered, proposed and candidate species, as well as proposed and final designated critical habitat, that may occur within the boundary of your proposed project and/or may be affected by your proposed project. The species list fulfills the requirements of the U.S. Fish and Wildlife Service (Service) under section 7(c) of the Endangered Species Act (Act) of 1973, as amended (16 U.S.C. 1531 *et seq.*).

If the enclosed list indicates that any listed species may be present in your action area, please visit the New Jersey Field Office consultation web page as the next step in evaluating potential project impacts: http://www.fws.gov/northeast/njfieldoffice/Endangered/consultation.html

On the New Jersey Field Office consultation web page you will find:

- habitat descriptions, survey protocols, and recommended best management practices for listed species;
- recommended procedures for submitting information to this office; and
- links to other Federal and State agencies, the Section 7 Consultation Handbook, the Service's wind energy guidelines, communication tower recommendations, the National Bald Eagle Management Guidelines, and other resources and recommendations for protecting wildlife resources.

The enclosed list may change as new information about listed species becomes available. As per Federal regulations at 50 CFR 402.12(e), the enclosed list is only valid for 90 days. Please return to the IPaC website at regular intervals during project planning and implementation to obtain an updated species list. When using IPaC, be careful about drawing the boundary of your Project Location. Remember that your action area under the ESA is not limited to just the footprint of the project. The action area also includes all areas that may be indirectly affected through impacts such as noise, visual disturbance, erosion, sedimentation, hydrologic change, chemical exposure, reduced availability or access to food resources, barriers to movement, increased human intrusions or access, and all areas affected by reasonably foreseeable future that would not occur without ("but for") the project that is currently being proposed.

Additionally, please note that on March 23, 2022, the Service published a proposal to reclassify the northern long-eared bat (NLEB) as endangered under the Endangered Species Act. The U.S. District Court for the District of Columbia has ordered the Service to complete a new final listing determination for the NLEB by November 2022 (Case 1:15-cv-00477, March 1, 2021). The bat, currently listed as threatened, faces extinction due to the range-wide impacts of white-nose syndrome (WNS), a deadly fungal disease affecting cave-dwelling bats across the continent. The proposed reclassification, if finalized, would remove the current 4(d) rule for the NLEB, as these rules may be applied only to threatened species. Depending on the type of effects a project has on NLEB, the change in the species' status may trigger the need to re-initiate consultation for any actions that are not completed and for which the Federal action agency retains discretion once the new listing determination becomes effective (anticipated to occur by December 30, 2022). If your project may result in incidental take of NLEB after the new listing goes into effect this will first need to addressed in an updated consultation that includes an Incidental Take Statement. If your project may require re-initiation of consultation, please contact our office for additional guidance.

We appreciate your concern for threatened and endangered species. The Service encourages Federal and non-Federal project proponents to consider listed, proposed, and candidate species early in the planning process. Feel free to contact this office if you would like more information or assistance evaluating potential project impacts to federally listed species or other wildlife resources. Please include the Consultation Tracking Number in the header of this letter with any correspondence about your project.

Attachment(s):

- Official Species List
- USFWS National Wildlife Refuges and Fish Hatcheries
- Bald & Golden Eagles
- Migratory Birds
- Wetlands

OFFICIAL SPECIES LIST

This list is provided pursuant to Section 7 of the Endangered Species Act, and fulfills the requirement for Federal agencies to "request of the Secretary of the Interior information whether any species which is listed or proposed to be listed may be present in the area of a proposed action".

This species list is provided by:

New Jersey Ecological Services Field Office
4 E. Jimmie Leeds Road, Suite 4
Galloway, NJ 08205
(609) 646-9310

PROJECT SUMMARY

Project Code: 2025-0075934
Project Name: Rahway River Flood Risk Management Study
Project Type: Flooding
Project Description: Fluvial flood risk management study within the Rahway River Watershed.
Project Location:

The approximate location of the project can be viewed in Google Maps: https://www.google.com/maps/@40.6757261,-74.30031898526454,14z

Counties: Essex , Middlesex , and Union counties, New Jersey

ENDANGERED SPECIES ACT SPECIES

There is a total of 5 threatened, endangered, or candidate species on this species list.

Species on this list should be considered in an effects analysis for your project and could include species that exist in another geographic area. For example, certain fish may appear on the species list because a project could affect downstream species.

IPaC does not display listed species or critical habitats under the sole jurisdiction of NOAA Fisheries[1], as USFWS does not have the authority to speak on behalf of NOAA and the Department of Commerce.

See the "Critical habitats" section below for those critical habitats that lie wholly or partially within your project area under this office's jurisdiction. Please contact the designated FWS office if you have questions.

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1. NOAA Fisheries, also known as the National Marine Fisheries Service (NMFS), is an office of the National Oceanic and Atmospheric Administration within the Department of Commerce.

MAMMALS

NAME	STATUS
Indiana Bat *Myotis sodalis* There is **final** critical habitat for this species. Your location does not overlap the critical habitat. Species profile: https://ecos.fws.gov/ecp/species/5949	Endangered
Northern Long-eared Bat *Myotis septentrionalis* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/9045	Endangered
Tricolored Bat *Perimyotis subflavus* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/10515	Proposed Endangered

REPTILES

NAME	STATUS
Bog Turtle *Glyptemys muhlenbergii* Population: Wherever found, except GA, NC, SC, TN, VA No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/6962	Threatened

INSECTS

NAME	STATUS
Monarch Butterfly *Danaus plexippus* There is **proposed** critical habitat for this species. Your location does not overlap the critical habitat. Species profile: https://ecos.fws.gov/ecp/species/9743	Proposed Threatened

CRITICAL HABITATS

THERE ARE NO CRITICAL HABITATS WITHIN YOUR PROJECT AREA UNDER THIS OFFICE'S JURISDICTION.

YOU ARE STILL REQUIRED TO DETERMINE IF YOUR PROJECT(S) MAY HAVE EFFECTS ON ALL ABOVE LISTED SPECIES.

USFWS NATIONAL WILDLIFE REFUGE LANDS AND FISH HATCHERIES

Any activity proposed on lands managed by the National Wildlife Refuge system must undergo a 'Compatibility Determination' conducted by the Refuge. Please contact the individual Refuges to discuss any questions or concerns.

THERE ARE NO REFUGE LANDS OR FISH HATCHERIES WITHIN YOUR PROJECT AREA.

BALD & GOLDEN EAGLES

Bald and Golden Eagles are protected under the Bald and Golden Eagle Protection Act [2] and the Migratory Bird Treaty Act (MBTA) [1]. Any person or organization who plans or conducts activities that may result in impacts to Bald or Golden Eagles, or their habitats, should follow appropriate regulations and consider implementing appropriate avoidance and minimization measures, as described in the various links on this page.

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1. The Bald and Golden Eagle Protection Act of 1940.
2. The Migratory Birds Treaty Act of 1918.
3. 50 C.F.R. Sec. 10.12 and 16 U.S.C. Sec. 668(a)

There are Bald Eagles and/or Golden Eagles in your project area.

Measures for Proactively Minimizing Eagle Impacts
For information on how to best avoid and minimize disturbance to nesting bald eagles, please review the National Bald Eagle Management Guidelines. You may employ the timing and activity-specific distance recommendations in this document when designing your project/ activity to avoid and minimize eagle impacts. For bald eagle information specific to Alaska, please refer to Bald Eagle Nesting and Sensitivity to Human Activity.

The FWS does not currently have guidelines for avoiding and minimizing disturbance to nesting Golden Eagles. For site-specific recommendations regarding nesting Golden Eagles, please consult with the appropriate Regional Migratory Bird Office or Ecological Services Field Office.

If disturbance or take of eagles cannot be avoided, an incidental take permit may be available to authorize any take that results from, but is not the purpose of, an otherwise lawful activity. For assistance making this determination for Bald Eagles, visit the Do I Need A Permit Tool. For assistance making this determination for golden eagles, please consult with the appropriate Regional Migratory Bird Office or Ecological Services Field Office.

Ensure Your Eagle List is Accurate and Complete
If your project area is in a poorly surveyed area in IPaC, your list may not be complete and you may need to rely on other resources to determine what species may be present (e.g. your local FWS field office, state surveys, your own surveys). Please review the Supplemental Information on Migratory Birds and Eagles, to help you properly interpret the report for your specified location, including determining if there is sufficient data to ensure your list is accurate.

For guidance on when to schedule activities or implement avoidance and minimization measures to reduce impacts to bald or golden eagles on your list, see the "Probability of Presence Summary" below to see when these bald or golden eagles are most likely to be present and breeding in your project area.

NAME	BREEDING SEASON
Bald Eagle *Haliaeetus leucocephalus* This is not a Bird of Conservation Concern (BCC) in this area, but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities. https://ecos.fws.gov/ecp/species/1626	Breeds Sep 1 to Jul 31
Golden Eagle *Aquila chrysaetos* This is not a Bird of Conservation Concern (BCC) in this area, but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities. https://ecos.fws.gov/ecp/species/1680	Breeds elsewhere

PROBABILITY OF PRESENCE SUMMARY

The graphs below provide our best understanding of when birds of concern are most likely to be present in your project area. This information can be used to tailor and schedule your project activities to avoid or minimize impacts to birds. Please make sure you read "Supplemental Information on Migratory Birds and Eagles", specifically the FAQ section titled "Proper Interpretation and Use of Your Migratory Bird Report" before using or attempting to interpret this report.

Probability of Presence (■)

Green bars; the bird's relative probability of presence in the 10km grid cell(s) your project overlaps during that week of the year.

Breeding Season (■)

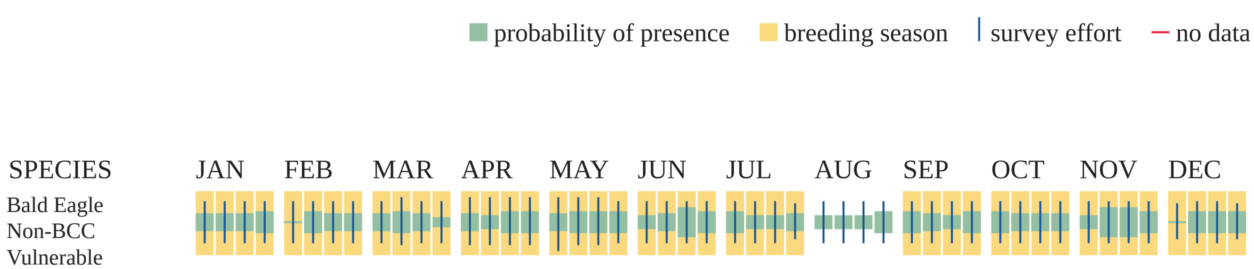
Yellow bars; liberal estimate of the timeframe inside which the bird breeds across its entire range.

Survey Effort (|)

Vertical black lines; the number of surveys performed for that species in the 10km grid cell(s) your project area overlaps.

No Data (–)

A week is marked as having no data if there were no survey events for that week.



Golden Eagle
Non-BCC
Vulnerable

Additional information can be found using the following links:

- Eagle Management https://www.fws.gov/program/eagle-management
- Measures for avoiding and minimizing impacts to birds https://www.fws.gov/library/collections/avoiding-and-minimizing-incidental-take-migratory-birds
- Nationwide avoidance and minimization measures for birds https://www.fws.gov/sites/default/files/documents/nationwide-standard-conservation-measures.pdf
- Supplemental Information for Migratory Birds and Eagles in IPaC https://www.fws.gov/media/supplemental-information-migratory-birds-and-bald-and-golden-eagles-may-occur-project-action

MIGRATORY BIRDS

The Migratory Bird Treaty Act (MBTA) [1] prohibits the take (including killing, capturing, selling, trading, and transport) of protected migratory bird species without prior authorization by the Department of Interior U.S. Fish and Wildlife Service (Service).

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1. The Migratory Birds Treaty Act of 1918.
2. The Bald and Golden Eagle Protection Act of 1940.
3. 50 C.F.R. Sec. 10.12 and 16 U.S.C. Sec. 668(a)

For guidance on when to schedule activities or implement avoidance and minimization measures to reduce impacts to migratory birds on your list, see the "Probability of Presence Summary" below to see when these birds are most likely to be present and breeding in your project area.

NAME	BREEDING SEASON
Bald Eagle *Haliaeetus leucocephalus* This is not a Bird of Conservation Concern (BCC) in this area, but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities. https://ecos.fws.gov/ecp/species/1626	Breeds Sep 1 to Jul 31
Black-billed Cuckoo *Coccyzus erythropthalmus* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/9399	Breeds May 15 to Oct 10

NAME	BREEDING SEASON
Cerulean Warbler *Setophaga cerulea* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/2974	Breeds Apr 28 to Jul 20
Chimney Swift *Chaetura pelagica* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/9406	Breeds Mar 15 to Aug 25
Chuck-will's-widow *Antrostomus carolinensis* This is a Bird of Conservation Concern (BCC) only in particular Bird Conservation Regions (BCRs) in the continental USA https://ecos.fws.gov/ecp/species/9604	Breeds May 10 to Jul 10
Eastern Whip-poor-will *Antrostomus vociferus* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/10678	Breeds May 1 to Aug 20
Golden Eagle *Aquila chrysaetos* This is not a Bird of Conservation Concern (BCC) in this area, but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities. https://ecos.fws.gov/ecp/species/1680	Breeds elsewhere
Grasshopper Sparrow *Ammodramus savannarum perpallidus* This is a Bird of Conservation Concern (BCC) only in particular Bird Conservation Regions (BCRs) in the continental USA https://ecos.fws.gov/ecp/species/8329	Breeds Jun 1 to Aug 20
Kentucky Warbler *Geothlypis formosa* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/9443	Breeds Apr 20 to Aug 20
Prairie Warbler *Setophaga discolor* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/9513	Breeds May 1 to Jul 31
Prothonotary Warbler *Protonotaria citrea* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/9439	Breeds Apr 1 to Jul 31
Red-headed Woodpecker *Melanerpes erythrocephalus* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/9398	Breeds May 10 to Sep 10

NAME	BREEDING SEASON
Rusty Blackbird *Euphagus carolinus* This is a Bird of Conservation Concern (BCC) only in particular Bird Conservation Regions (BCRs) in the continental USA https://ecos.fws.gov/ecp/species/9478	Breeds elsewhere
Wood Thrush *Hylocichla mustelina* This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska. https://ecos.fws.gov/ecp/species/9431	Breeds May 10 to Aug 31

PROBABILITY OF PRESENCE SUMMARY

The graphs below provide our best understanding of when birds of concern are most likely to be present in your project area. This information can be used to tailor and schedule your project activities to avoid or minimize impacts to birds. Please make sure you read "Supplemental Information on Migratory Birds and Eagles", specifically the FAQ section titled "Proper Interpretation and Use of Your Migratory Bird Report" before using or attempting to interpret this report.

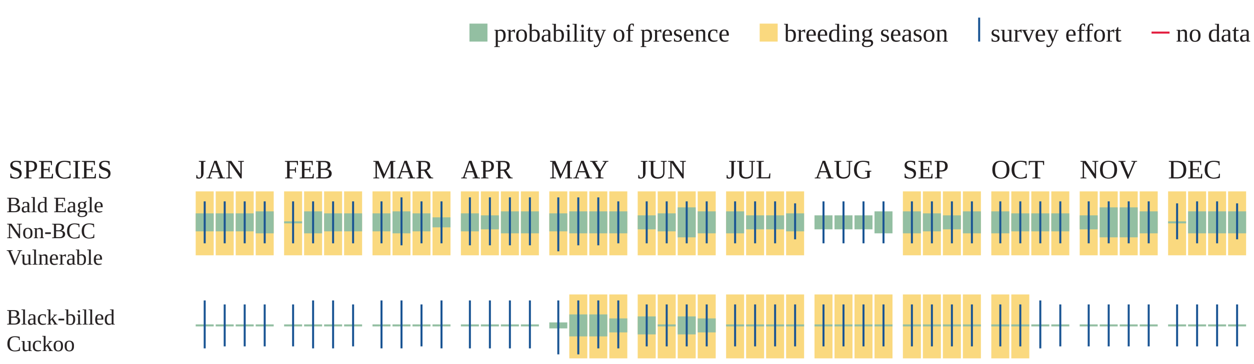
Probability of Presence (■)

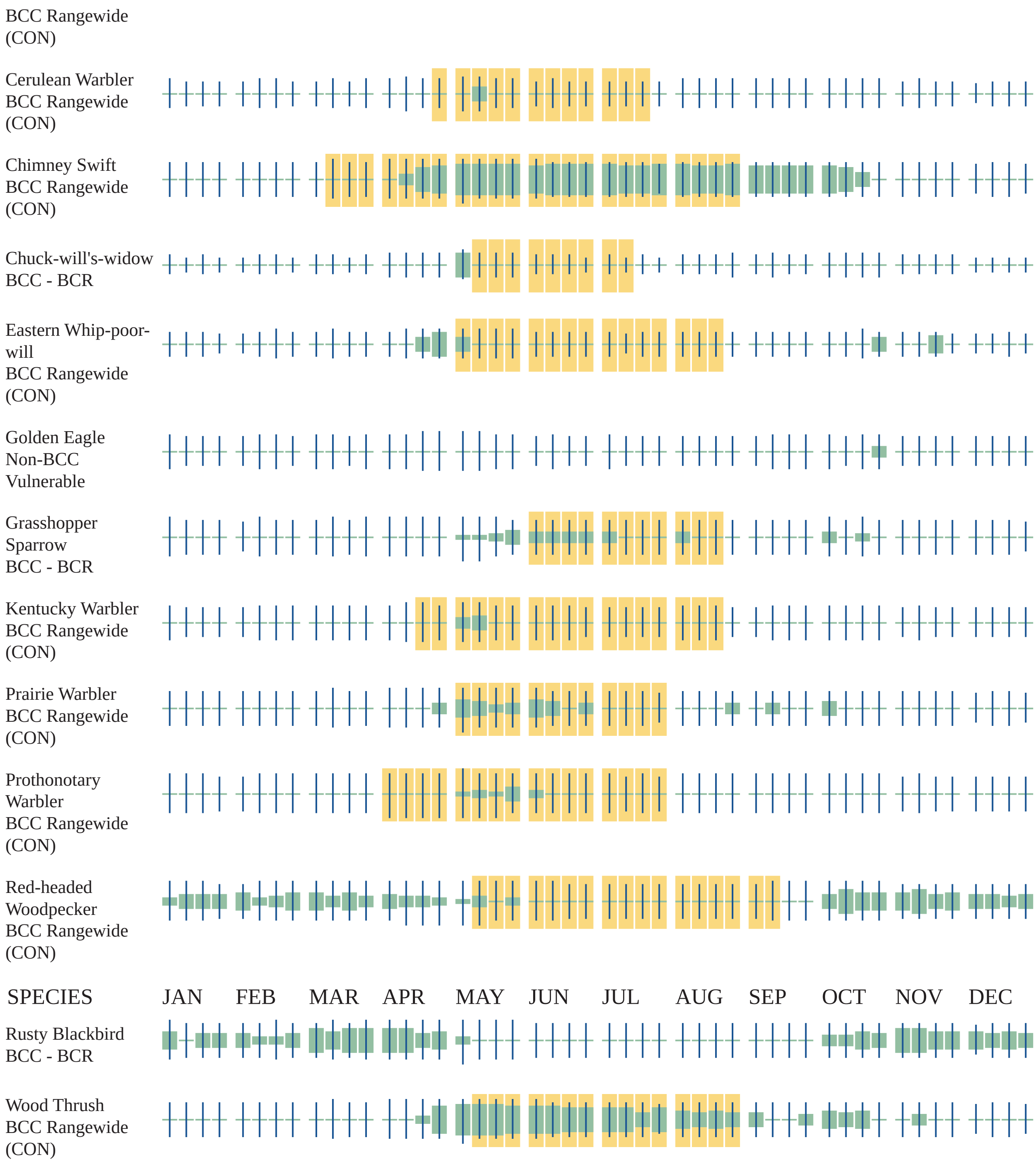
Green bars; the bird's relative probability of presence in the 10km grid cell(s) your project overlaps during that week of the year.

Breeding Season (■)
Yellow bars; liberal estimate of the timeframe inside which the bird breeds across its entire range.

Survey Effort (|)
Vertical black lines; the number of surveys performed for that species in the 10km grid cell(s) your project area overlaps.

No Data (–)
A week is marked as having no data if there were no survey events for that week.





Additional information can be found using the following links:

- Eagle Management https://www.fws.gov/program/eagle-management
- Measures for avoiding and minimizing impacts to birds https://www.fws.gov/library/collections/avoiding-and-minimizing-incidental-take-migratory-birds
- Nationwide avoidance and minimization measures for birds

- Supplemental Information for Migratory Birds and Eagles in IPaC https://www.fws.gov/media/supplemental-information-migratory-birds-and-bald-and-golden-eagles-may-occur-project-action

WETLANDS

Impacts to NWI wetlands and other aquatic habitats may be subject to regulation under Section 404 of the Clean Water Act, or other State/Federal statutes.

For more information please contact the Regulatory Program of the local U.S. Army Corps of Engineers District.

Please note that the NWI data being shown may be out of date. We are currently working to update our NWI data set. We recommend you verify these results with a site visit to determine the actual extent of wetlands on site.

FRESHWATER FORESTED/SHRUB WETLAND

- PFO1Ed
- PFO1Cd
- PFO1D
- PFO1C
- PSS1/EM1B
- PSS1/EM1E
- PSS1D
- PFO1/EM1A
- PFO1/SS1A
- PFO1/4C
- PFO1/SS1C
- PSS1E
- PFO1/EM1C
- PFO1E
- PFO1Ch
- PSS1/EM1A
- PFO5/SS1Fh
- PFO1/SS1Ch
- PSS1A
- PSS1/EM1Ex
- PSS1C
- PFO1A
- PFO1R

- PFO1B
- PFO1/SS1Cd

FRESHWATER EMERGENT WETLAND

- PEM1Ch
- PEM1Ax
- PEM1A
- PEM1B
- PEM1C
- PEM1F
- PEM1Ed
- PEM1/SS1B
- PEM1/FO1C
- PEM1Cd
- PEM1E
- PEM1/SS1E
- PEM1/SS1C
- PEM1Ad

RIVERINE

- R4SBCx
- R2UBH
- R3UBHx
- R5UBFx
- R3UBH
- R1UBV
- R2UBF
- R2UBHx
- R4SBC
- R2USA
- R5UBH

FRESHWATER POND

- PUBHx
- PUBHh
- PUBH

LAKE

- L1UBHh

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