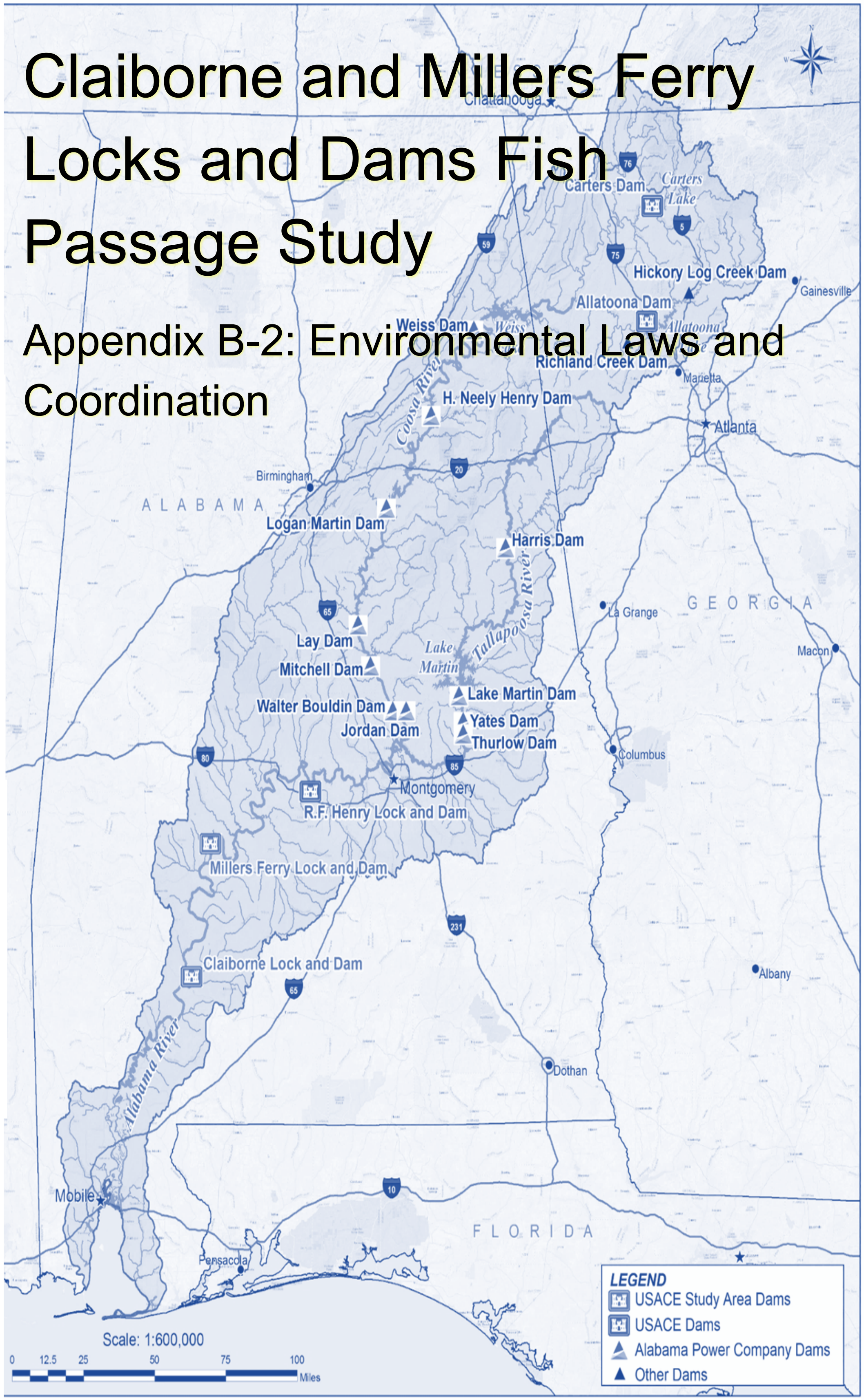
Claiborne and Millers Ferry Locks and Dams Fish Passage Study

Appendix B-2: Environmental Laws and Coordination



US Army Corps of Engineers

The Nature Conservancy

APPENDIX B-2: Environmental Laws and Coordination

B.2. Environmental Laws and Policies

B.2.1. *WRRDA 2014 Section 1005 Compliance*

In accordance with Section 1005 of the Water Resources Reform and Development Act of 2014, cooperating agency letters dated December 13, 2021, were mailed to the Federal and State agencies included in **Table B.2.1-1**. The template used for each letter is shown in **Figure B.2.1-1** and **Figure B.2.1-2**.

Table B.2.1-1: Distribution List of Cooperating Agency Agreement Letters

AGENCY	ADDRESSEE	ADDRESS
1. EPA Region 4	Mr. Trey Glenn Regional Administrator	Sam Nunn Federal Building 61 Forsyth Street South West Atlanta, Georgia 30303
2. FEMA Region 4	Ms. Gracia B. Szczech Regional Director	3003 Chamblee Tucker Road Atlanta, Georgia 30341
3. USGS SE Region	Ms. Holly Weyers Regional Director, Southeast Region	U.S. Geological Survey 1170 Corporate Drive, Suite 500 Atlanta, Georgia 30093
4. USFWS SE Region	Mr. Leopoldo Miranda-Castro Southeast Regional Director	1875 Century Boulevard Atlanta, Georgia 30345
5. USFWS DFO	Mr. Bill Pearson Field Supervisor	1208 Main Street Daphne, Alabama 36526
6. NOAA	Mr. Pace Wilbur Atlantic Branch Chief	
7. DOI	Ms. Michaela Noble Director, Office of Environmental Policy and Compliance	1849 C Street, Northwest Washington, DC 20240
8. DOI Atlanta Region	Ms. Joyce A. Stanley Regional Environmental Protection Specialist	Office of Environmental Policy and Compliance, Atlanta Region Suite 1144 75 Ted Turner Drive, S.W. Atlanta, GA 30303
9. AHC (SHPO)	Ms. Amanda McBride Alabama State Historical Preservation Officer	468 South Perry Street P.O. Box 300900 Montgomery, Alabama 36130-0900
10. NPS	Mr. Pedro M. Ramos Regional Director	100 Alabama Street, SW 1924 Building Atlanta, GA 30303
11. HUD	Ms. Patricia A. Hoban-Moore Director, Alabama Field Office	U.S. Department of Housing and Urban Development 950 22nd Street N Suite 900 Birmingham, Alabama 35203
12. NRCS	Mr. Ben Malone State Conservationist	3381 Skyway Drive Auburn, AL 33830
13. FHA Alabama Division	Mr. Mark D. Bartlett Division Administrator	9500 Wynlakes Place Montgomery, Alabama 36117
14. ADCNR **15. ADCNR, SLD**	Mr. Chris M. Blankenship Commissioner Ms. Patti Powell Director, State Lands Division	64 N. Union Street Montgomery, Alabama 36130

16. ADCNR WFFRD	Mr. Charles F. Sykes Director	64 N. Union Street, Suite 551 Montgomery, Alabama 36130
17. ADEM **18. ADEM, FOD**	Mr. Lance R. Lefleur Director Mr. Steven O. Jenkins Chief	P.O. Box 301463 Montgomery, Alabama 36130-1463
19. ASOS	The Honorable John H. Merrill Secretary of State	P.O. Box 5616 Montgomery, Alabama 36103-5616
20. AEMA	Mr. Brian Hastings Director	P.O. Drawer 2160 Clanton, Alabama 35046
21. ALDOT	Mr. John R. Cooper Transportation Director	P. O. Box 303050, Montgomery, Alabama 36130-3050
22. ALDOT Bridge Bureau	Mr. William Colquett, P.E. Bridge Engineer	P. O. Box 303050, Montgomery, Alabama 36130-3050
23. ADPH	Dr. Scott Harris State Health Officer	P.O. Box 303017 Montgomery, Alabama 36130-3017
24. Alabama Geological Society	Dr. Richard Esposito President	Postal Office Box 866184 Tuscaloosa, Alabama 35486-0055

DEPARTMENT OF THE ARMY
U.S. CORPS OF ENGINEERS, MOBILE DISTRICT
P.O. BOX 2288
MOBILE, AL 36628-0001

REPLY TO
ATTENTION OF

December 13, 2021

Inland Environment Team
Planning and Environmental Division

Ms. Michaela Noble
Director, Office of Environmental Policy and Compliance
Department of the Interior
1849 C Street, Northwest
Washington, DC 20240

Dear Ms. Noble:

The U.S. Army Corps of Engineers (USACE), Mobile District is conducting the Claiborne and Millers Ferry Locks and Dams Fish Passage Feasibility Study on the lower Alabama River. The study is a cost-shared agreement between USACE and the Alabama Chapter of The Nature Conservancy that was initiated on November 23, 2021. A Planning Charette occurred December 6-7, 2021 to determined area problems/needs and gather environmental data. An agency meeting and Conceptual Ecological Model development meeting will occur in early January. Invitations will be e-mailed before the end of December.

The Council on Environmental Quality (CEQ), Regulations on Implementing National Environmental Policy Act Procedures (NEPA) (40 CFR 1500-1508) emphasizes agency cooperation early in the NEPA process through the establishment of Cooperating Agency status. In essence any Federal or State agency which has jurisdiction over activities to be considered in the NEPA documentation has the opportunity to serve as a Cooperating Agency. Responsibilities of a Cooperating Agency include but are not limited to provision of data and/or information and development/review of the preliminary NEPA documentation for completeness.

Per the Water Resources Reform and Development Act (WRRDA) 2014, Section 1005, "Any federal agency that is invited to participate shall be designated as a cooperating agency unless the invited agency informs the lead agency in writing by the deadline specified in the invitation that the invited agency:

A) (i) (I) Has no jurisdiction or authority with respect to the project;
(II) Has no expertise or information relevant to the project; or
(III) Does not have adequate funds to participate in the project; and
(ii) Does not intend to submit comments on the project; or

B) Does not intend to submit comments on the project."

Figure B.2.1-1: Page 1 of Cooperating Agency Letter Template

Please know that "designation as a participating or cooperating agency does not imply that the participating or cooperating agency supports a proposed project or has any jurisdiction over, or special expertise with respect to evaluation of, the project." Please respond via letter with your agency's position. Should your agency wish to decline, please respond with a reasoning consistent with WRRDA 2014, quoted above. Failure to respond in either the affirmative or negative will be treated as confirmation of cooperating agency agreement.

As lead agency, USACE, Mobile District is requesting your involvement as a cooperating agency in this effort and would appreciate your response no later than 30 days after the date of this letter. We look forward to working with you on this project and if you should have any questions, please contact Ms. Heather Bulger at (251) 694-3889 or via email at heather.p.bulger@usace.army.mil.

Sincerely,

Jeremy M. LaDart
Chief, Planning and Environmental
Division

Figure B.2.1-2: Page 2 of Cooperating Agency Letter Template

B.2.2. *Section 106: National Historic Preservation Act of 1966*

B.2.2.1. *Programmatic Agreement*

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**PROGRAMMATIC AGREEMENT
AMONG
THE U.S. ARMY CORPS OF ENGINEERS,
THE ALABAMA STATE HISTORIC PRESERVATION OFFICER, AND THE ADVISORY COUNCIL ON HISTORIC PRESERVATION REGARDING THE CLAIBORNE AND MILLERS FERRY LOCKS AND DAMS FISH PASSAGE FEASBILITY STUDY**

WHEREAS, the U.S. Army Corps of Engineers, Mobile District (Corps), is proposing to install natural bypass channels at Millers Ferry and Claiborne Locks and Dams (Project) as a result of the Claiborne and Millers Ferry Locks and Dams Fish Passage Feasibility Study authorized in Section 216 of the Flood Control Act of 1970, Public Law 91-611 (33 U.S.C. 549a) ; and

WHEREAS, the Project is being developed to improve the quality of the environment, due to significantly changed physical conditions, by establishing fish passage through restoring connectivity in the Alabama and Cahaba Rivers; and

WHEREAS, the Corps proposes to construct natural bypass channels circumventing the dam to include either low gradient earthen or rocky channels which mimic natural stream structure and would include attraction flow and provide passage to aquatic species; and

WHEREAS, the Project alignment at Millers Ferry Lock and Dam will have a channel length of 8500 ft, bottom width of 100 ft, channel slope of 0.005 ft/ft, side slope of 1V:3H and be constructed of rock (Enclosure 1) and the Project alignment at Claiborne Lock and Dam will have a channel length of 2100 ft, bottom width of 75ft, channel slop of 0.013 ft/ft and side slope of 1V:3H (Enclosure 2); and

WHEREAS, the Project alignment at Claiborne calls for an extension of the right bank damming surface requiring approximately two feet of grading and driving a series of solder pile panels into the subsurface (Enclosure 3); and

WHEREAS, the Project comprises both the development and implementation of the Project, and the Corps will be the Lead Federal Agency for compliance with 54 U.S.C. § 306108 (National Historic Preservation Act (NHPA) Section 106); and

WHEREAS, the Corps has determined that the Project constitutes an Undertaking, as defined in 36 C.F.R. § 800.16(y), and therefore is subject to Section 106 of the NHPA, and will hereby be referred to as the Undertaking; and

WHEREAS, the Corps has determined that the Undertaking has the potential to affect properties that could be eligible for listing in the National Register of Historic Places (NRHP) and have consulted with the Alabama State Historic Preservation Officer (SHPO) pursuant to the NHPA; and

WHEREAS, the Corps has determined that the Area of Potential Effects (APE) for the Undertaking includes areas within the projected alignments of both natural bypass channels, any needed laydown area, access roads, and easements, and any disposal areas utilized during construction; and

WHEREAS, the Corps has identified, by means of desktop review, at least four potential Historic Properties in the APE at the Claiborne alignment and at least three potential Historic Properties in the APE at the Millers Ferry alignment, that may be affected by the undertaking and the cultural resources assessments conducted for these sites do not meet Alabama State guidelines for archaeological survey; and

WHEREAS, the Corps as lead federal agency, with the concurrence of SHPO, has decided to comply with Section 106 of the NHPA for the Undertaking through the execution and implementation of a Programmatic Agreement (Agreement), following 36 C.F.R. § 800.14(b); and

WHEREAS, the Nature Conservancy (TNC) is the non-Federal sponsor for the Project and has been invited to be a Concurring Party to this Agreement; and

WHEREAS, in accordance with 36 C.F.R. § 800.2(c)(2)(ii)(A), 800.3(f)(2), and 800.14(b)(2)(i), the Corps has contacted Federally Recognized Native American Tribes, via letter(s), phone call(s), email(s) and meetings, to invite them to consult on the Undertaking and this Agreement, including the Absentee-Shawnee Tribe of Oklahoma, the Alabama-Coushatta Tribes of Texas, the Alabama-Quassarte Tribal Town, the Caddo Nation of Oklahoma, the Catawba Indian Nation, the Cherokee Nation, the Chickasaw Nation, the Chitimacha Tribe of Louisiana, the Choctaw Nation of Oklahoma, The Coushatta Tribe of Louisiana, Eastern Band of the Cherokee Nation, the Eastern Shawnee Tribe of Oklahoma, the Jena Band of Choctaw Indians of Louisiana, the Kialegee Tribal Town of Oklahoma, the Miccosukee Tribe of Indians of Florida, the Mississippi Band of Choctaw Indians, Muscogee (Creek) Nation, the Poarch Band of Creek Indians, the Quapaw Tribe of Indians of Oklahoma, Shawnee Tribe of Oklahoma, the Seminole Nation of Oklahoma, the Seminole Tribe of Florida, the Thlopthlocco Tribal Town, Tunica-Biloxi Indian Tribe of Louisiana, and the United Keetoowah Band of Cherokee Indians in Oklahoma, and the Choctaw Nation of Oklahoma and the Mississippi Band of Choctaw Indians have chosen to participate in consultation; and

WHEREAS, in accordance with 36 C.F.R. § 800.2(c)(5), the Corps has contacted additional interested parties via letter(s), phone call(s), email(s), and meetings, to invite them to consult on the Undertaking and this Agreement, including environmentally disadvantaged communities, non-Federally listed tribes, historic societies, environmental interest groups, and other interested parties; and

WHEREAS, in accordance with 36 C.F.R. § 800.14(b)(3), the Corps invited the Advisory Council on Historic Preservation (ACHP) per 36 C.F.R. § 800.6(a)(1)(C) to participate in consultations to resolve potential adverse effects of the Undertaking, including development of this Agreement on DATE and CONCLUSION; and

WHEREAS, in accordance with 36 C.F.R. § 800.6(a)(4) and 36 C.F.R. § 800.14(b)(2)(ii), the Corps held a series of public meetings to notify the public of the Undertaking and provide an opportunity for members of the public to comment on the Project and the Section 106 process. These were conducted on DATES in LOCATIONS; and

NOW, THEREFORE, the signatories agree that the Undertaking shall be implemented in accordance with the following stipulations in order to take into account the effects of the undertaking on Historic Properties.

STIPULATIONS

The Corps shall ensure that the following measures are carried out:

I. TIME FRAMES AND REVIEW PROCEDURES

A. Document and Deliverable Review. For all documents and deliverables produced in compliance with this Agreement, the Corps will have thirty (30) calendar days to review. After completing its review, the Corps shall provide a hard copy draft document via mail or digital copies via email to the SHPO, Concurring Parties, and Federally Recognized Tribes, and other interested parties for review. Any written comments provided by the SHPO, Federally Recognized Tribes, and other interested parties within thirty (30) calendar days from the date of receipt shall be considered in the revision of the document or deliverable. The Corps shall document and report the written comments received for the document or deliverable and how comments were addressed. The Corps shall provide a revised final document or deliverable to the SHPO for concurrence. The SHPO shall have thirty (30) calendar days to respond. A copy of the final document shall be provided to the Signatories and to any consulting parties who request it, as appropriate per **Stipulation X (Confidentiality)**.

B. Disagreement. Should the SHPO, Federally Recognized Tribes, or an interested party object to the findings of NRHP eligibility and/or findings of effect within the final document or deliverable submitted for concurrence, the Corps, SHPO, Federally Recognized Tribes, and interested parties shall consult for a period not to exceed fifteen (15) calendar days following the receipt of SHPO's, a Federally Recognized Tribe's, or an interested party's written objection in an effort to come to agreement on the issues to which the SHPO, Federally Recognized tribe, or interested party has objected. Should the SHPO, a Federally Recognized Tribe, or interested party be unable to agree on the issues to which the SHPO, a Federally Recognized Tribe, or an interested party has objected, the SHPO, and the Corps shall proceed in accordance with **Stipulation XI (Dispute Resolution)**, below. The timeframe to consult to resolve a disagreement or objection may be extended by mutual consent of the Signatories.

II. AREA OF POTENTIAL EFFECTS

A. DETERMINATION OF THE AREA OF POTENTIAL EFFECTS. Currently the APE includes the Milers Ferry natural bypass channel alignment, the Claiborne natural bypass channel alignment including the west bank extension, associated laydown and access areas, and disposal sites that may be affected by proposed improvement measures. As the Project progresses and designs are finalized, the APE will become more refined and could expand or change. Because of these circumstances, the full extent of the APE for the Project has not been determined by the Corps as Lead Federal Agency. Maps of the existing APE are provided in Appendix A.

B. APE REVISIONS. As APE boundaries are revised during the course of the Project, the Corps will delineate the revised areas and consult on that revision in accordance with **Stipulation I (Timeframes and Review Procedures),** and the Corps shall determine the potential for Project activities in a revised APE to affect potential Historic Properties according to **Stipulation III A (Identification of Historic Properties)**.

III. IDENTIFICATION, EVALUATION, AND DETERMINATION OF EFFECT

The Corps shall complete any identification and evaluation of Historic Properties prior to proceeding with construction. Although, much of the existing APE has already been inventoried prior to the construction of the locks and dams, these assessments were conducted prior to 1983 and do not meet the current federal or state standards for archaeological survey and will require further investigation.

A. Identification of Historic Properties. Pursuant to 36 C.F.R. § 800.4 and in consultation with the Signatories and consulting parties of this agreement, the Corps shall conduct Phase I archaeological surveys to identify Historic Properties within the APE boundaries that have not been surveyed pursuant to 36 C.F.R. §296.21. Prior to surveying these areas, the Corps shall coordinate with the SHPO, Federally Recognized Tribes, and other interested parties according to **Stipulation II (Area of Potential Effect)** of this Agreement. The scope of the Phase I inventory and contents of the survey report are listed below:

1. Prepare a scope of work (SOW) for Phase I fieldwork
2. Conduct archival research to determine the known history and pre-Contact history of the area prior to fieldwork.
3. Conduct an archaeological survey to locate potentially NRHP eligible objects or sites within the APE.
4. Prepare a survey report that includes the nature of the project, methods, pre-Contact and historic contexts, and inventory of findings, an evaluation of all findings for significance and integrity, conclusions, and recommendations. A draft and draft final survey report will be submitted to the SHPO, Federally Recognized Tribes, and other interested parties for review and comment

following **Stipulation I (Timeframes and Review Procedures)** of this Agreement.

B. Evaluation and Determination of Effect. Findings determined to be cultural resources will be assessed by a qualified professional for their eligibility for listing in the NRHP consistent with the *Secretary of Interior's Standards for Evaluation*, 36 C.F.R. § 60.4. If during the Phase I archaeological survey of the APE, findings are made which could represent Historic Properties, these sites could be subjected to a Phase II evaluation to determine if they are NRHP eligible resources. The scope of Phase II evaluations along with a description of the contents of the evaluation report are listed below:

1. Submit a SOW for Phase II fieldwork for approval by the SHPO and for comment by Federally Recognized Tribes and other interested parties.

2. Phase II Objectives: The objective of the Phase II evaluation is to collect data regarding site significance and integrity from which determinations of NRHP eligibility can be made. Field methods for the Phase II investigation could include additional archaeological work to capture more detailed data on sites and objects and asses for NRHP eligibility.

3. A draft Phase II Survey, Evaluation, and Determination of Effects report will be prepared following the completion of the fieldwork. The draft report will include a description of project purposes, specific methods guiding the Phase II resource survey work including the results of fieldwork with site descriptions and locational data. The report will also contain evaluations of site significance using NRHP eligibility criteria and determinations of effects. Specific sites requiring mitigation measures will also be identified in this report. The Corps shall prepare and submit the draft and final Phase II Survey, Evaluation, and Determination of Effects Reports in accordance with **Stipulation I (Timeframes and Review Procedures)**. Confidentiality regarding the nature and location of archaeological sites and any other cultural resource discussed in any Phase II report under this agreement shall be maintained. Also, if any information provided to the Corps by Native American tribes or others who wish to control the dissemination of that information, the Corps will make a good faith effort to do so, to the extent permissible by law according to **Stipulation X (Confidentiality)** of this Agreement.

If SHPO, any Federally Recognized Tribes, or other interested parties disagree with the Corps' determinations of NRHP eligibility and effects, the Corps shall notify the SHPO, Federally Recognized Tribes, and other parties of the dispute and consult with the ACHP. If the dispute cannot be resolved, the Corps shall seek a formal determination of eligibility from the Keeper of the National Register. The Keeper's determination will be final in accordance with 36 C.F.R. 63.4.

Avoidance of adverse effects to Historic Properties is always the preferred treatment approach. However, it may not be possible to redesign the Project in order to avoid resources within the APE. The Corps will apply the criteria of adverse effect, pursuant to 36 C.F.R. § 800.5(a)(1), to all Historic Properties within the APE. If the Corps determines that Historic Properties will be adversely affected, **Stipulation IV (Historic Properties Treatment Plan)**, below, will be followed.

IV. HISTORIC PROPERTIES TREATMENT PLAN

If it is determined that project activities will result in adverse effects, the Corps, in consultation with the SHPO, Federally Recognized Tribes, and other interested parties shall develop a Historic Properties Treatment Plan (HPTP) to resolve all adverse effects resulting from the Project, which would be appended to this PA. The HPTP shall outline the minimization and mitigation measures necessary to resolve the adverse effects to Historic Properties. Proposed mitigation measures may include, but are not limited to, oral history, interpretive brochures, data recovery, or publications depending on their criterion for eligibility. Development of appropriate measures shall include consideration of Historic Property types and provisions for avoidance or protection of Historic Properties where possible.

If adverse effects are identified, the HPTP shall be in effect before construction commences. The HPTP may be amended and appended to this PA without amending the PA.

A. Review: The Corps shall submit the Draft HPTP to the SHPO, Federally Recognized Tribes, and other interested parties for review and comment pursuant to **Stipulation I (Timeframes and Review Procedures)**.

B. Reporting: Reports and other data pertaining to archaeological site locations and the treatment of effects to Historic Properties will be distributed to Federally Recognized Tribes and other interested parties, tribes, and other members of the public, consistent with **Stipulation X (Confidentiality)** of this PA, unless parties have indicated through consultation that they do not want to receive a report or data.

C. Amendments/Addendums/Revisions: If a Historic Property that is not covered by the existing HPTP is discovered within the APE subsequent to the initial inventory effort, or if there are previously unexpected effects to a Historic Property, or if the Corps and SHPO agree that a modification to the HPTP is necessary, the Corps shall prepare an addendum to the HPTP. The Corps shall then submit the addendum to the SHPO, Federally Recognized Tribes, and other interested and relevant parties for review and comment, and if necessary, shall follow the provisions of **Stipulation IX (New Discoveries)**. The HPTP may cover multiple discoveries for the same property type.

D. Data Recovery: When data recovery is proposed, the Corps, in consultation with the SHPO, Federally Recognized Tribes, and other interested parties shall ensure that specific Research Designs are developed consistent with the *Secretary of the Interior's Standards and Guidelines for Archaeology and Historic Preservation* and the ACHP's "Recommended Approach for Consultation on Recovery of Significant Information from Archaeological Sites" (ACHP, May 18, 1999).

V. QUALIFICATIONS

A. Professional Qualifications: All technical work required for historic preservation activities implemented pursuant to this Agreement shall be carried out by or under the direct supervision of a person or persons meeting, at a minimum, the *Secretary of Interior's Professional Qualifications Standards* for archeology or history, as appropriate (48 FR 44739) and relevant experience working in the surrounding region. For all technical work beyond identification level efforts, person(s) will have specialized experience related to the types of cultural resources identified (e.g., prehistory, historic archaeology, and/or underwater cultural resources). "Technical work" here means all efforts to inventory, evaluate, and perform subsequent treatment such as data recovery excavation or recordation of potential Historic Properties that is required under this Agreement. This stipulation shall not be construed to limit peer review, guidance, or editing of documents by SHPO and associated Project consultants.

B. Historic Preservation Standards: Historic preservation activities carried out pursuant to this Agreement shall meet the *Secretary of Interior's Standards and Guidelines for Archaeology and Historic Preservation* (48 FR 44716-44740), as well as standards and guidelines for historic preservation activities established by the SHPO. The Corps shall ensure that all reports prepared pursuant to this Agreement will be provided to the Signatories, Federally Recognized Tribes, and other interested parties, and are distributed in accordance with **Stipulation X (Confidentiality)**, and meet published standards of the Alabama Historical Commission, Administrative Code, Chapter 460-X-9.02(4) as updated in 2006 (Standards for Reports) and *Preservation Planning Bulletin* Number 4(a), "Archaeological Resources Management Reports (ARMR): Recommended Contents and Format" (December 1989).

VI. CONSULTATION WITH TRIBES AND INTERESTED PARTIES

A. In consultation with Federally Recognized Tribes and other interested Native American parties or individuals, the Corps will make a reasonable and good-faith effort to identify Historic Properties of traditional religious and cultural importance. As the Lead Federal Agency, the Corps shall ensure that consultation regarding site condition assessment, monitoring efforts, and determinations of eligibility and effects with other interested Native American parties and individuals continues throughout the implementation of the Agreement. The Corps shall be responsible for transmitting all relevant documents and deliverables to Federally Recognized Tribes and other interested Native American parties or individuals as part of their tribal consultation responsibility.

B. Federally Recognized Tribes and other interested Native American parties and individuals may choose not to sign this Agreement as a Concurring Party. However, the Corps will make a good faith effort to contact Federally Recognized Tribes and other interested Native American parties and individuals, not acting as Concurring Parties to the Agreement, with potential interest in consulting on site condition assessment efforts and on the proposed treatment of Historic Properties or potential Historic Properties. Efforts to identify these individuals or groups may include using online databases, consultations for previous projects, and using personal and professional knowledge. The Corps will then contact each identified organization and individual by phone, mail, or email inviting them to consult on additional Phase I efforts, Phase II investigations, site assessment efforts, and proposed treatments of Historic Properties or potential Historic Properties. Consultations may be carried out through either letters of notification, public meetings, environmental assessments/environmental impact statements, and/or other methods requested by a Federally Recognized Tribe or other interested Native American parties or individuals. Failure of any contacted group or individual to comment within thirty (30) calendar days shall not preclude the Corps from proceeding with the Project.

C. The Corps shall make a reasonable and good-faith effort to ensure that Native American Tribes or other interested parties, acting as either Concurring Parties or those expressing interest in the project, will be invited to participate in the implementation of the terms of this Agreement. Review periods shall be consistent with **Stipulation I (Timeframes and Review Procedures).** The Corps shall ensure that all reviewers from Federally Recognized Tribes and other interested parties shall receive copies of all reports.

VII. TREATMENT OF HUMAN REMAINS

A. In the event that Native American human remains, as well as Native American funerary objects, sacred objects, or objects of cultural patrimony are encountered within the APE during the Project, those remains and objects are subject to the Native American Graves Protection and Repatriation Act (NAGPRA) (25 U.S.C. 3001 *et seq.*) and treatment under NAGPRA's implementing regulations at 43 C.F.R. Part 10. When NAGPRA items are discovered inadvertently, an appropriate Corps official must be notified immediately upon the discovery. The Corps shall follow the requirements of 43 C.F.R. §10.3 for consultation; notification; development of excavation, treatment, and disposition plans as needed; and the requirements of 43 C.F.R. §10.6 for NAGPRA item disposition. The Corps will also notify the SHPO, Federally Recognized Tribes, other interested Native American parties, and individuals within 24 hours in the event that Native American human remains, Native American funerary objects, sacred objects, or objects of cultural patrimony are encountered. Confidentiality regarding the nature and locations of Native American remains, funerary objects, sacred objects, or objects of cultural patrimony under this agreement shall be maintained. Also, if any information provided to the Corps by Native American tribes or others who wish to control the dissemination of that information, the Corps will make a good faith effort to do so, to the extent permissible by law according to **Stipulation X (Confidentiality)** of this

Agreement.

B. In the event non-native human remains or unmarked human burials are encountered within the APE, those remains will be subject to the Alabama Historical Commission, Administrative Code, Chapter 460-X-10 (Burials) and Alabama's Burial Act, § 13A-7-23.1, as amended. When unmarked human burials or non-native human skeletal remains are inadvertently found, the appropriate Corps official must be notified immediately upon the discovery. The Corps will follow the requirements regarding notification, treatment, and jurisdiction under Chapter 460-X-10(f) (Notification).

VIII. PUBLIC CONSULTATION AND PUBLIC NOTICE

A. The interested public will be invited to provide input during the implementation of this document. The Corps shall carry this out through letters of notification, public meetings, and environmental assessment/environmental impact statements. The Corps shall ensure that any comments received from members of the public are taken under consideration and incorporated where appropriate. Review periods shall be consistent with **Stipulation I (Timeframes and Review Procedures)**. In seeking input from the interested public, locations of Historic Properties will be handled in accordance with **Stipulation X (Confidentiality)**. In cases where the release of location information may cause harm to the Historic Property, this information will be withheld from the public in accordance with Section 304 of the NHPA (54 U.S.C. § 307103).

IX. NEW DISCOVERIES

A. If new and unanticipated cultural materials are inadvertently discovered during implementation of the Undertaking, the Mobile District will cease all work in the vicinity of the discovery until it can be evaluated. If the property is determined to be NRHP eligible, the Corps shall consult with the SHPO, Federally Recognized Tribes, and other interested parties to develop a treatment plan according to **Stipulation IV (Historic Properties Treatment Plan)**.

B. The Corps will implement the HPTP once it has been reviewed by Federally Recognized Tribes and other interested parties according to **Stipulation I (Timeframes and Review Procedures)** and the HPTP has been approved by SHPO.

X. CONFIDENTIALITY

Confidentiality regarding the specific nature and location of the archaeological sites and any other cultural resource discussed in this Agreement shall be maintained to the extent allowable by law. Dissemination of such information shall be limited to appropriate Corps personnel, contractors, Federally Recognized Tribes, the SHPO, and other parties involved in planning, reviewing and implementing this Agreement and in accordance with Section 304 of the NHPA (54 U.S.C. § 307103). When information is provided to the Corps by Native American tribes or others who wish to control the dissemination of that information more than described above, the Corps will make a good faith effort to do so, to the extent permissible by law.

XI. DISPUTE RESOLUTION

A. Should any signatory or concurring party to this Agreement object at any time to any actions proposed or the manner in which the terms of this agreement are implemented, the Corps shall consult with such party to resolve the objection. If the Corps determines that such objection cannot be resolved, the Corps will:

1. Forward all documentation relevant to the dispute, including the District's proposed resolution, to the ACHP. The ACHP shall provide the Corps with its advice on the resolution of the objection within thirty (30) days of receiving adequate documentation. Prior to reaching a final decision on the dispute, the Corps shall prepare a written response that takes into account any timely advice or comments regarding the dispute from the ACHP, signatories and concurring parties, and provide them with a copy of this written response. The District will then proceed according to its final decision.

2. If the ACHP does not provide its advice regarding the dispute within the thirty (30) day time period, the Corps may make a final decision on the dispute and proceed accordingly. Prior to reaching such a final decision, the Corps shall prepare a written response that takes into account any timely comments regarding the dispute from the signatories and concurring parties to the Agreement, and provide them and the ACHP with a copy of such written response.

3. The Corps' responsibility to carry out all other actions subject to the terms of this Agreement that are not the subject of the dispute remain unchanged.

B. At any time during implementation of the measures stipulated in this Agreement should an objection pertaining to the Agreement be raised by a Native American Tribe, or a member of the public, the Corps shall notify the Signatory and Concurring Parties and take the objection under consideration, consulting with the objecting party and, should the objecting party request, any of the Signatory and Concurring Parties to this Agreement, for no longer than fifteen (15) calendar days. The Corps shall consider the objection, and in reaching its decision, will consider all comments provided by the other signatories and concurring parties. Within fifteen (15) calendar days following closure of the comment period, the Corps will render a decision regarding the objection and respond to the objecting party. The Corps will promptly notify the other signatories and concurring parties of its decision in writing, including a copy of the response to the objecting party. The Corps' decision regarding resolution of the objection will be final. Following issuance of its final decision, the Corps may authorize the action that was the subject of the dispute to proceed in accordance with the terms of that decision. The Corps' responsibility to carry out all other actions under this Agreement shall remain unchanged.

C. Should any Signatory Party to this Agreement object in writing to the determination of National Register eligibility, the objection will be addressed pursuant to 36 C.F.R. § 800.4(c)(2).

XII. NOTICES

A. All notices, demands, requests, consents, approvals or communications from all parties to this Agreement to other parties to this Agreement shall be either personally delivered, sent by United States Mail, or emailed, and all parties shall acknowledge receipt of correspondence within two business days..

B. If Signatory and Concurring Parties agree in advance in writing or by email, facsimiles, emails, or copies of signed documents may be used as if they bore original signatures.

C. If Signatory Parties agree, hard copies and/or electronic communications may be used for formal communication amongst themselves for activities in support of **Stipulation I (Time Frames and Review Procedures).**

XIII. AMENDMENTS, NONCOMPLIANCE, AND TERMINATION

A. Amendements: Any Signatory to this Agreement may propose that the Agreement be amended, whereupon the Corps shall consult with the SHPO to consider such amendment. This Agreement may be amended when such an amendment is agreed to in writing by both signatories. The amendment will be effective on the date a copy signed by both signatories is filed with the ACHP.

All attachments to this Agreement, and other instruments prepared pursuant to this agreement including, but not limited to, the maps of the APE may be individually revised or updated through consultation consistent with **Stipulation I (Timeframes and Review Procedures)** and agreement in writing of the Signatories without requiring amendment of this Agreement, unless the Signatories through such consultation decide otherwise. In accordance with **Stipulation VI (Consultations with Tribes and Other Interested Parties)** and **Stipulation VIII (Public Consultation and Public Notice)**, the Federally Recognized Tribes, and other interested parties, will receive amendments to the Project's description, any Phase I or Phase II survey reports and maps of the APE, and HPTPs, as appropriate, and copies of any amendment(s) to the Agreement.

B. Termination: Any signatory to this Agreement may terminate this Agreement. If this Agreement is not amended as provided for in **Stipulation XIII.A. (Amendments)** or if any Signatory proposes termination of this Agreement for other reasons, the Signatory proposing termination shall notify the other Signatories in writing, explain the reasons for proposing termination, and consult with the other Signatory to seek alternatives to termination, within thirty (30) calendar days of the notification.

1. Should such consultation result in an agreement on an alternative to termination, the Signatories shall proceed in accordance with that agreement and amend the Agreement as required.

2. Should such consultation fail, the Signatory proposing termination may terminate this Agreement by promptly notifying the other Signatories and Concurring Parties in writing.

3. Beginning with the date of termination, the Corps shall ensure that until and unless a new agreement is executed for the actions covered by this Agreement, such undertakings shall be reviewed individually in accordance with 36 C.F.R. § 800.4-800.6.

C. Duration: This Agreement shall remain in effect for a period of five (5) years after the date it takes effect and shall automatically expire and have no further force or effect at the end of this five-year period unless it is terminated prior to that time. No later than ninety (90) calendar days prior to the expiration date of the Agreement, the Corps shall initiate consultation to determine if the Agreement should be allowed to expire automatically or whether it should be extended, with or without amendments, as the Signatories may determine. Unless the Signatories unanimously agree through such consultation on an alternative to automatic expiration of this Agreement, this Agreement shall automatically expire and have no further force or effect in accordance with the timetable stipulated herein.

XIV. EFFECTIVE DATE

This Agreement shall take effect on the date that it has been fully executed by the Corps and SHPO.

EXECUTION of this Agreement by the Corps and SHPO and the implementation of its terms evidence that the Corps has taken into account the effects of this undertaking on Historic Properties and afforded the ACHP an opportunity to comment.

PROGRAMMATIC AGREEMENT
AMONG
THE U.S. ARMY CORPS OF ENGINEERS,
THE ALABAMA STATE HISTORIC PRESERVATION OFFICER, AND THE ADVISORY COUNCIL ON HISTORIC PRESERVATION REGARDING THE CLAIBORNE AND MILLERS FERRY LOCKS AND DAMS FISH PASSAGE FEASBILITY STUDY

SIGNATORIES TO THIS AGREEMENT:

U.S. ARMY CORPS OF ENGINEERS, MOBILE DISTRICT

BY:________ Digitally signed by CHAPMAN.JEREMY.JIGGS.1187181077 Date: 2024.01.04 09:42:07 -06'00' ________DATE : 4 Jan 2024
Jeremy Chapman, Colonel, U.S. Army Corps of Engineers, District Commander

ALABAMA STATE HISTORIC PRESERVATION OFFICER

BY:____DATE:____________
Lee Anne Wofford, Deputy State Historic Preservation Officer

PROGRAMMATIC AGREEMENT
BETWEEN THE U.S. ARMY CORPS OF ENGINEERS AND
THE ALABAMA STATE HISTORIC PRESERVATION OFFICER REGARDING THE
CLAIBORNE AND MILLERS FERRY LOCKS AND DAMS FISH PASSAGE
FEASBILITY STUDY

SIGNATORIES TO THIS AGREEMENT:

U.S. ARMY CORPS OF ENGINEERS, MOBILE DISTRICT

BY:____DATE :__________
Jeremy Chapman, Colonel, U.S. Army Corps of Engineers, District Commander

ALABAMA STATE HISTORIC PRESERVATION OFFICER

BY: Lisa D. Jones DATE: 2·20·24
Lisa Jones, Alabama State Historic Preservation Officer

Appendix A

Enclosure 1: Millers Ferry natural bypass channel proposed alignment

Enclosure 2: Claiborne natural bypass channel proposed alignment

B.2.3. *Clean Water Act*

B.2.3.1. *Water Quality Certification*

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B.2.3.2. ***404(b)(1) Evaluation***

SECTION 404(B)(1) EVALUATION FOR
CLAIBORNE AND MILLERS FERRY LOCKS AND DAMS FISH PASSAGE
WILCOX AND MONROE COUNTIES, AL

I. PROJECT DESCRIPTION:

A. Location. Millers Ferry Lock and Dam and Claiborne Lock and Dam, Wilcox, and, Monroe, Counties, Alabama. (**Figure B.2.3-1**.

B. General Description. As illustrated in Error! Reference source not found. through **Figure B.2.3-4**, the Recommended Plan would involve the construction of a natural bypass at both Claiborne and Millers Ferry Locks and Dams. The Millers Ferry bypass would have a gated structure and a vehicular bridge. Both bypass channels would use varying rock sizes to achieve pool complexes with a step-down approach.

Construction methods at Claiborne and Millers Ferry would include utilizing coffer dams to tie in the upstream and downstream ends of the bypass channel to the Alabama River. Both coffer dams would be approximately 500 linear feet with 100 foot buffer at the downstream and upstream ends and could be installed for the total duration of construction which is estimated for approximately 38 months. The coffer dams would be cellular and filled with material on-site. Following project completion, the material would be disposed at an approved upland site. The dry island at Claiborne would be armored using rock and sheet piles. **Table B.2.3-1** shows the conceptual design elements.

The design of both bypass structures are conceptual and subject to change during Preconstruction, Engineering, and Design (PED) phase.

C. Authority and Purpose.

This study is authorized by Section 216 of the Flood Control Act of 1970 (33 U.S.C. 549a). Section 216 “authorizes investigations for modification of completed projects or their operations when found advisable due to significantly changed physical or economic conditions and for improving the quality of the environment in overall public interest.”

D. General Description of Fill Material.

(1) General Characteristic of Material. Reference **Table B.2.3-2**.

(2) Quantity of Material. Reference **Table B.2.3-2** for materials to be dredged.

Figure B.2.3-1: Study Area

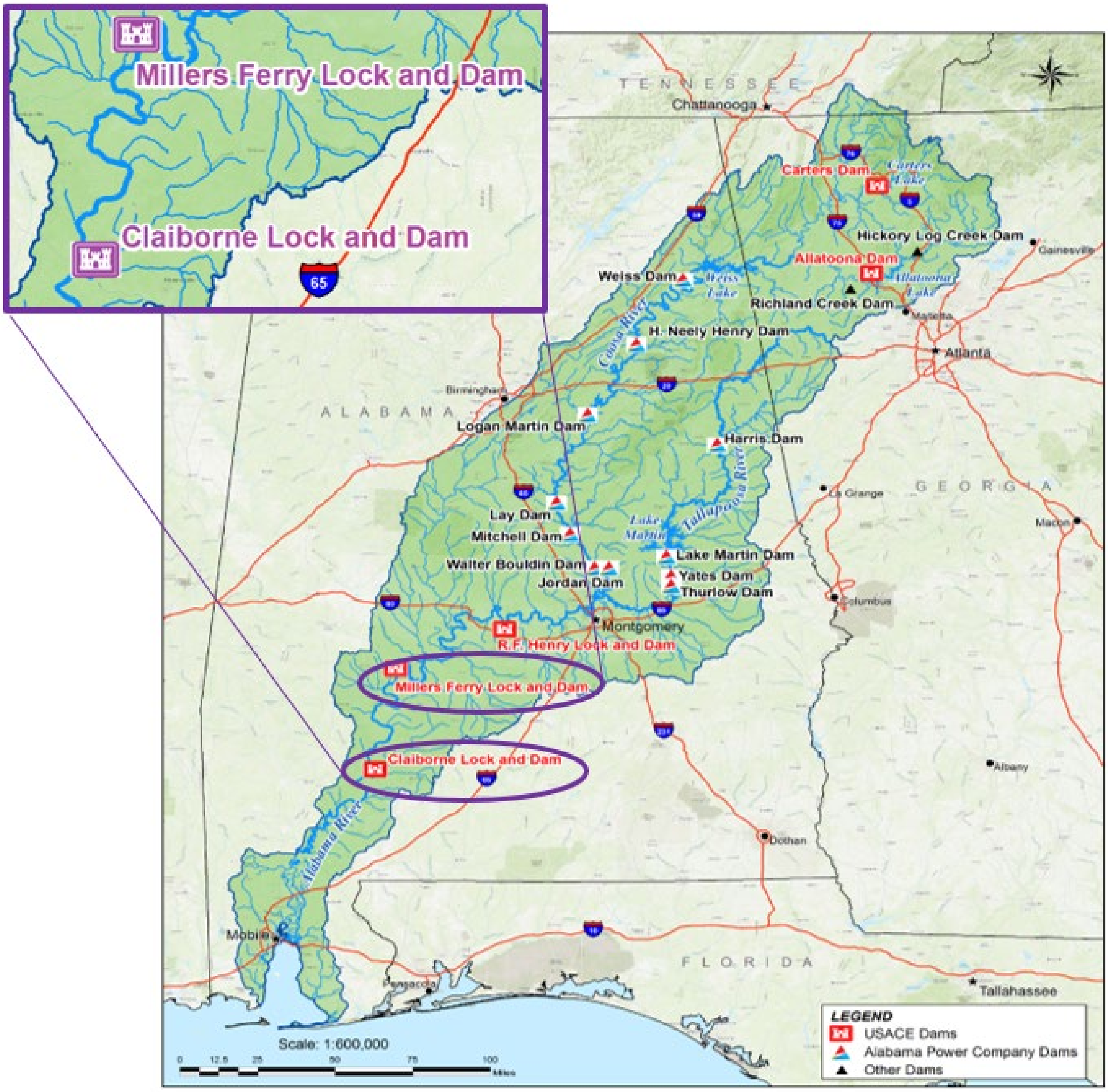

Figure B.2.3-2: Conceptual Design of Proposed Work at Millers Ferry Lock and Dam

Figure B.2.3-3: Conceptual Design – Millers Ferry Bridge and Control Gate Structure

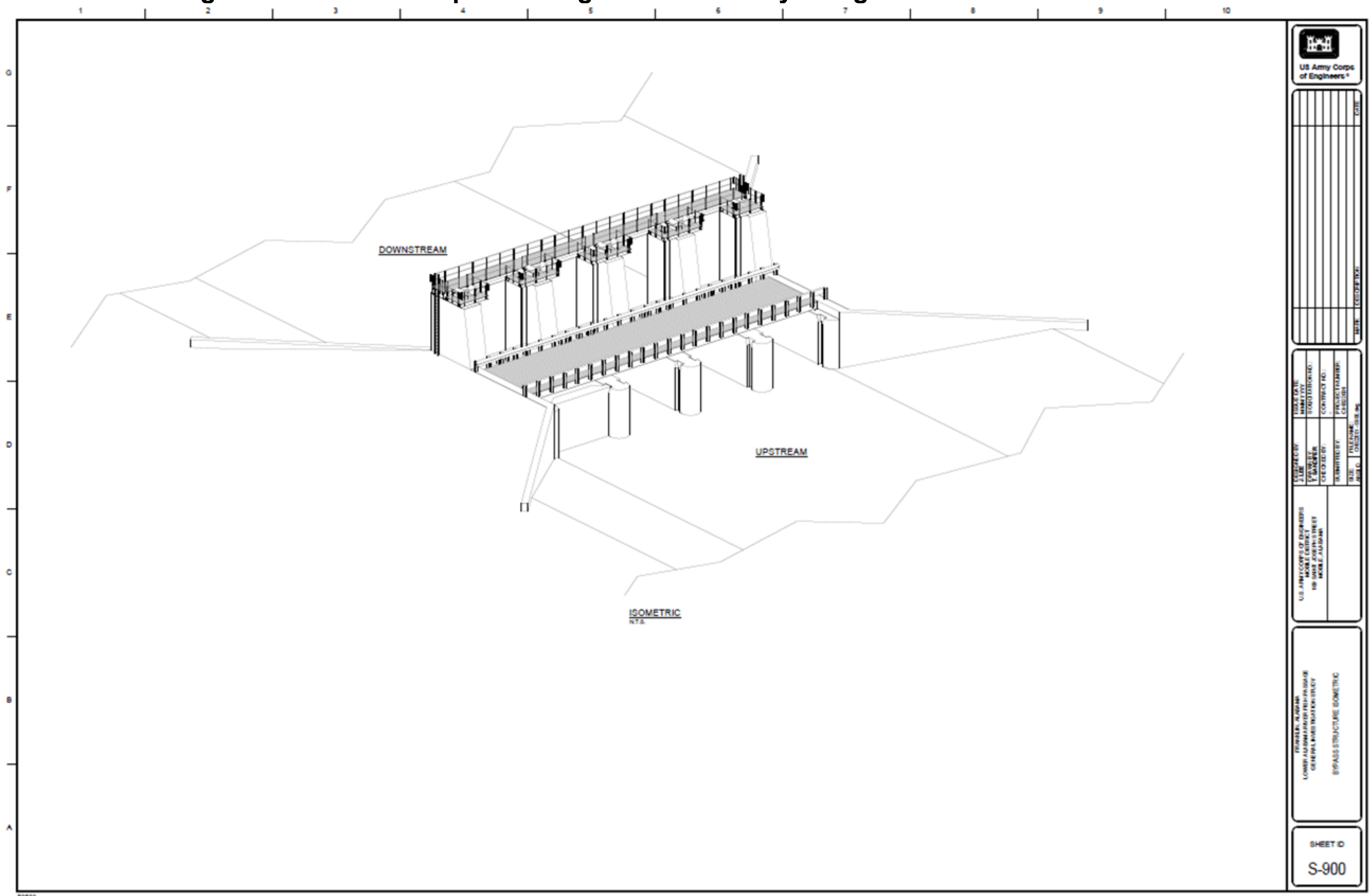

Table B.2.3-1: Conceptual Design and Quantities

Design Information	Bypass at Claiborne	Bypass at Millers Ferry
Starting Elevation (ft-NAVD88)	33.1	75
Ending Elevation (ft-NAVD88)	3.5	31
Bottom Width (ft)	75	100
Side Slopes	1V:3H	1V:3H
Channel Construction Materials	Rock	Rock
Slope of Channel (ft/ft)	0.014	0.005
Channel Length (ft)	2100	8500
Depth in Channel at Normal Pool (ft)	2.0	5.1
Approx. Number of Pools / Grade Control Structures	30	44
Approx. Pool Length (ft)	70 - 80	200 - 210
Maximum Velocity within Channel (ft/s)	7.4	6.6
Mean Velocity within Channel (ft/s)	4	4.2
Estimated Flow at Normal Pool (MF - 80.1 ft-NAVD88; CL - 35.1 ft-NAVD88; 50,000 CFS)	1200	1300

Figure B.2.3-4: Conceptual Design of Proposed Bypass at Claiborne Lock and Dam

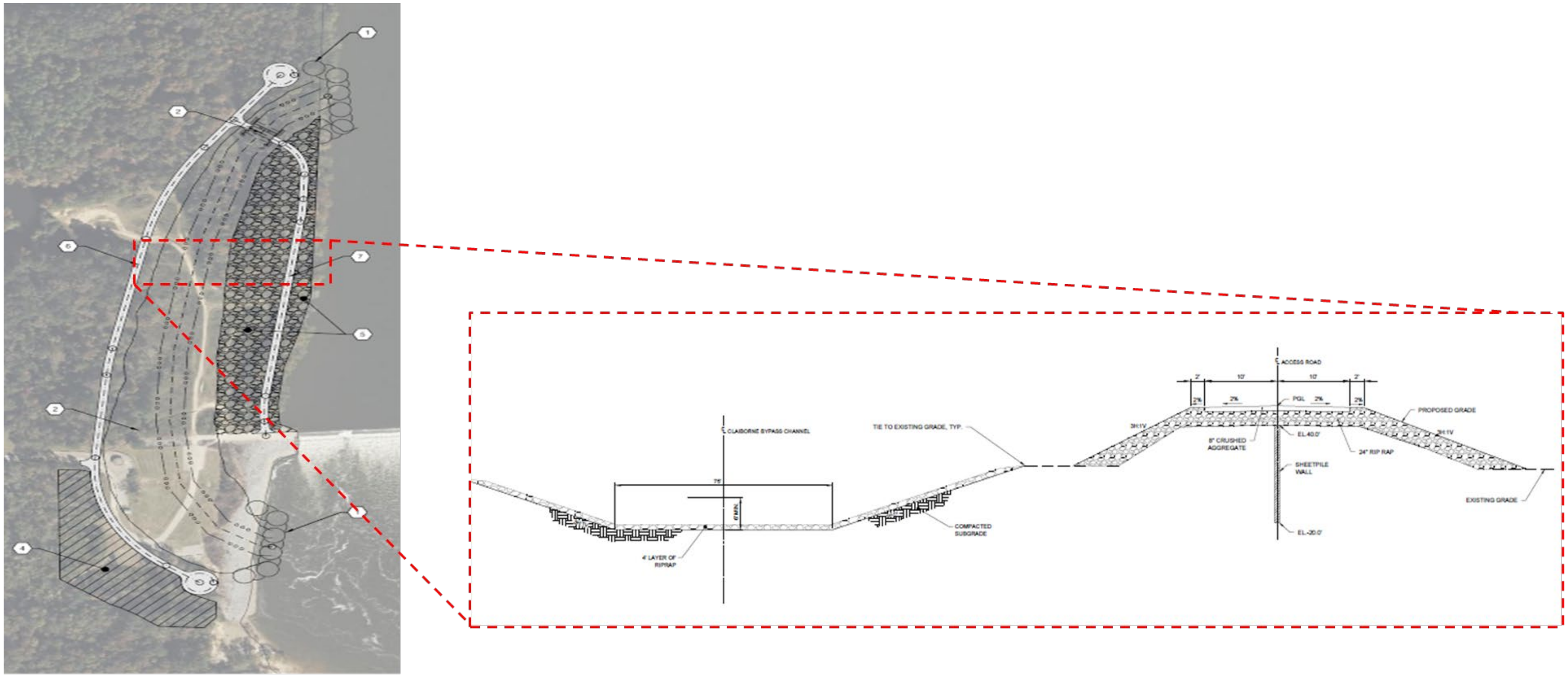

Table B.2.3-2: Quantities for Material

Location	Total Estimated Excavated Quantities (cubic yards)	Total Estimated Construction Materials
Claiborne	500,000	• **1,500 linear feet sheet pile** • **60,000 cubic yards (cy) of varying rock sizes**
Millers Ferry	2,000,000	• **175,000 cy rock** of varying sizes

(3) Source of Material. The source of material will be from an approved location at regional quarries.

E. Description of the Proposed Discharge Site.

(1) Location. The natural bypass channels will be constructed along the riverbank and riverbed with the Alabama River and near the existing facilities. Disposal will be at an upland site within the vicinity of the construction activities at each lock and dam.

(2) Size. Refer to **Table B.2.3-1** for project dimensions. Disposal would approximate either one 25 acre site at Millers Ferry and 10 acre site at Claiborne or multiple sites at smaller configurations.

(3) Type of Site. The proposed footprints are predominantly terrestrial along the right descending bank of the Alabama River with the tie-in portion of the bypass channels occurring in dry riverbed through the use of coffer dams. Disposal would be upland.

(4) Type of Habitat. The Alabama River within the Study Area consists of sediment heavy bottom either in the Millers Ferry and Claiborne pools or immediately downstream of the dams and subject to high flows and velocities. The footprints of each channel would span across terrestrial habitat, including potential wetlands, and tie into the Alabama River upstream and downstream of each project site.

(5) Timing and Duration of Discharge. Duration of construction would take approximately 38 months to complete and would begin following the Preconstruction, Engineering and Design (PED) phase of the study.

F. Description of Disposal Method. Material excavated from the natural bypass channels would be disposed of in approved upland placement sites to be identified during the pre-construction engineering and design phase. Disposal would be upland and approximate 25 acres total at Millers Ferry Lock and Dam and 10 acres total at Claiborne Lock and Dam. Best Management Practices would be used to minimize or avoid environmental impacts. Disposal placement would be identified during PED phase.

II. Factual Determinations (Section 230.11):

A. Physical Substrate Determinations.

(1) Substrate Elevation and Slope. Refer to **Table B.2.3-1**.

(2) Sediment Type. The predominant sediment of anticipated excavation for both locations is fine silt/clay materials.

(3) Dredged/Fill Material Movement. No movement of fill material is anticipated.

(4) Physical Effects on the Benthos. Benthos would be adversely impacted through direct disturbance to riverbed but this impact would be short-term during the construction phase. Indirect impacts to the immediate vicinity may occur due to increase local turbidity during construction.

(5) Physical Effects on Wetlands. The USACE determined that no wetland mitigation is required. Both wetlands and the Alabama River are considered Waters of the U.S which provides a nexus between the two habitats. The study's Aquatic Ecosystem Restoration benefits account for a minimum 206 river miles from Claiborne Lock and Dam to mouth of the Cahaba River and unaccounted benefits within the Cahaba River. The project would provide access to a significant amount of pristine spawning habitat for federally listed fish and would provide a significant number of ancillary benefits to several federally listed freshwater mussels. Conversely, the maximum potential for wetland impact would amount to an approximate total of 47 acres: 6 acres at Claiborne and 41 acres at Millers Ferry. These wetlands are low quality and contain neither bottomland hardwood nor habitat for federally listed species. The 47 acres of low-quality wetlands would be converted from palustrine to 77 acres open water habitat (20 acres at Claiborne and 57 acres at Millers Ferry) potentially including riffle-pool and/or riffle-pool-run sequences that would be utilized by federally listed species with potential to include riparian zone plantings. This would be an increase of aquatic habitat within the Study Area. Additional detail on riparian zone plantings would be determined in the preconstruction, engineering, and design phase.

(6) Actions Taken to Minimize Impacts (Subpart H). Construction Best Management Practices (BMPs) and an Erosion, Sediment, and Pollution Control Plan (ESPCP) would be implemented to contain potential increased turbidity resulting from the disposal and construction.

B. Water Column Determinations.

(1) Salinity. Not applicable.

(2) Water Chemistry. Water chemistry would not be significantly impacted.

(3) Clarity. Water clarity would be temporarily decreased in the vicinity of the construction activities. These impacts would subside once construction activities are completed. Therefore, no significant impacts are anticipated.

(4) Color. No effect.

(5) Odor. No effect.

(6) Taste. No effect.

(7) Dissolved Gas Levels. Dissolved gas levels would not be significantly affected.

(8) Nutrients. Nutrient levels would not be significantly impacted.

(9) Eutrophication. Eutrophication would not be significantly impacted.

C. Water Circulation, Fluctuation, and Salinity Gradient Determinations:

(1) Current Patterns and Circulation.

(a) Current Patterns and Flow. At normal pool levels, approximately 1,200 cfs would be diverted into the new natural bypass channels at each site. Overall current patterns and flow would not be significantly impacted.

(b) Velocity. Velocity would not be significantly impacted within the Alabama River. See **Table B.2.3-1** for velocity rates through each bypass channel.

(2) Stratification. There would be no impacts on water stratification.

(3) Hydrologic Regime. There would be no significant impacts on the hydrologic regime. The proposed action would not increase or decrease water quantity.

(4) Normal Water Level Fluctuations. There would be no significant impacts on water level fluctuations.

(5) Salinity Gradients. Not applicable.

D. Suspended Particulate/Turbidity Determinants.

(1) Expected Changes in Suspended Particulate and Turbidity Levels in Vicinity of Disposal Sites. A temporary increase in suspended particulates and turbidity levels would occur in the immediate vicinity of the construction zone. These impacts will subside when the activities are completed.

(2) Effects on Chemical and Physical Properties of the Water Column.

(a) Light Penetration. Increases in suspended solids concentrations will be nominal and temporary. No significant impacts to light penetration are anticipated.

(b) Dissolved Oxygen. Dissolved oxygen will not be significantly impacted.

(c) Toxic Metals and Organics. No significant increases in toxic metals and organics are expected to occur due to the construction activities.

(d) Pathogens. Pathogen levels will not be affected as a result of this project.

(e) Aesthetics. The area would be permanently altered from the construction of the natural bypass channels. Aesthetics would improve with enhanced connectivity of the Alabama River.

(3) Effects on biota.

(a) Primary Production, Photosynthesis. Temporary, localized impacts to primary production or photosynthesis levels may result from turbidity plumes generated by construction activities. These effects would be localized and would subside upon project completion.

(b) Suspension/Filter Feeders. Suspension/filter feeders in the immediate vicinity of the project footprint would be adversely impacted. Relocation would occur to minimize impacts. Species within the surrounding vicinity would not be significantly affected by this action. Increased turbidity will be contained using (BMPs and an ESCP.

(c) Sight Feeders. Sight feeders would vacate the vicinity and may be temporarily affected by increased turbidity. These effects would subside upon completion of the construction activities.

(4) Actions taken to Minimize Impacts (Subpart H). Construction BMPs and an ESPCP would be implemented in order to minimize impacts. Federal and State Agency coordination is ongoing to ensure adverse impacts to federally listed species are minimized.

E. Contaminant Determinations. See **Table B.2.3-2** for description of materials for each location. Fill materials would be obtained from sources removed of contamination. All material removed would be disposed at an approved upland site.

F. Aquatic Ecosystem and Organism Determinations.

(1) Effects on plankton. There may be temporary effects on plankton in the immediate vicinity of the construction zone due to increased turbidity; however, these effects would be localized and short-term.

(2) Effects on Benthos. Benthic organisms within the construction zone that are sessile would be lost. Benthic organisms would recolonize the area following construction. Adjacent benthic communities would be indirectly impacted from increased turbidity. No significant impacts would result from this project.

(3) Effects on Nekton. Nektonic species are expected to be temporarily affected during construction and may evacuate the immediate vicinity; however, they are expected to return once turbidity levels return to pre-project conditions. No significant impacts are anticipated.

(4) Effects on Aquatic Food Web. This project would pose no significant impacts to the aquatic food web.

(5) Effects on Special Aquatic Sites.

(a) Sanctuaries and Refuges. No sanctuaries or refuges occur within the proposed project area; therefore, there would be no impacts resulting from this project.

(b) Wetlands. Approximately 47 acres of poor quality palustrine wetlands not supporting of federally listed species would be converted to 77 acres of open water habitat supporting of federally listed species with the potential for added riparian zone plantings.

(c) Mud Flats. No mud flats exist within the project vicinity; therefore, there would be no impacts as a result of the project.

(d) Vegetated Shallows. No vegetated shallows would be affected by this project.

(e) Coral Reefs. Not applicable.

(f) Riffle and Pool Complexes. Riffle-pool and/or riffle-pool-run sequences may be designed within each bypass channel. Construction of each bypass would not impact existing complexes; therefore, the proposed action would be an increase in these complexes in the Study Area.

(6) Threatened and Endangered Species. The USACE determined the proposed alternative would have No Effect on the Alabama pearlshell and orangenacre mucket and May Affect but is not Likely to Adversely Affect the Georgia Rockcress, Southern Clubshell, Inflated Heelsplitter, Alabama sturgeon, and Gulf sturgeon. The USACE also determined the proposed alternative may affect, but is not likely to adversely affect critical habitat for the Alabama Sturgeon. The U.S. Fish and Wildlife Service concurred with the determinations via letter dated September 5, 2023. Significant beneficial impacts would occur to federally listed freshwater mussel species through increased connectivity for the associated host fish species.

(7) Other Wildlife. Significant beneficial impacts would occur to migratory fish species through increased connectivity of aquatic habitat and spawning sites from the Cahaba River confluence with the Alabama River to Claiborne Lock and Dam. Temporary and minor impacts may occur during construction due

to localized increased turbidity and noise disturbances; however, these impacts would revert to preconstruction conditions upon project completion.

(8) Actions to Minimize Impacts. Aquatic Ecosystem Restoration benefits to the wetlands and federally listed species would offset the minimal adverse impacts to the resources.

G. Proposed Fill Site Determination.

(1) Mixing Zone Determination. This activity does not require a mixing zone determination. The nature of the construction activities and constituent concentrations preclude the need for a mixing zone determination.

(2) Determination of Compliance with Applicable Water Quality Standards. The proposed action will comply with applicable water quality standards as established by the Alabama Department of Environmental Management (ADEM).

(3) Potential Effects on Human Use Characteristics.

(a) Municipal and Private Water Supply. This project would not significantly impact municipal or private water supplies.

(b) Recreation and Commercial Fisheries. Fishing activities at the sites would be altered by construction of this project but ample other sites exist for anglers.

(c) Water Related Recreation. The proposed action would temporarily disrupt water-related recreation at each construction site; however, no negative long-term effects are anticipated from the action. Recreationers would be able to access surrounding areas for enjoyment.

(d) Aesthetics. Aesthetics would be permanently impacted as a result of the proposed action. The proposed alternative would divert a portion of the natural river into a man-made structure designed to pass fish. These structures would be designed to mimic natural features using pool complexes to create a step-down approach.

(e) Parks, National and Historic Monuments, National Seashores, Wilderness Areas, Research Sites, and Similar Preserves. No parks, national historic monuments, national seashores, wilderness areas, research sites and similar preserves in the vicinity will be adversely impacted as a result of this project.

(f) Other Effects. Not applicable.

H. Determination of Cumulative Effects on the Aquatic Ecosystem. Significant benefits to aquatic species, including Federally listed fish and mussels, would occur.

I. Determination of Secondary Effects on the Aquatic Ecosystem. Temporary and localized impacts may occur downstream of the construction activities.

III. Findings of Compliance or Noncompliance with the Restrictions on Discharge.

A. No significant adaptations of the guidelines were made relative to this evaluation.

B. The proposed discharge represents the least environmentally damaging practicable alternative that would accomplish the project objectives.

C. Based on the nature of the fill material, construction activities would be in compliance with applicable state Water Quality Standards. Furthermore, Water Quality Certification will be obtained from the State of Alabama prior to construction activities.

D. The fill material would not violate the Toxic Effluent Standard of Section 307 of the Clean Water Act.

E. The placement of fill material would not jeopardize the continued existence of any Federally listed endangered or threatened species or their critical habitat.

F. The proposed discharge of fill material would not contribute to significant degradation of waters of the United States. Nor would it result in significant adverse effects on human health and welfare, including municipal and private water supplies, recreation and commercial fishing; life stages of organisms dependent upon the aquatic ecosystem; ecosystem diversity, productivity and stability; or recreational, aesthetic or economic values.

G. Appropriate and practicable steps to minimize potential adverse impacts of the discharge on the aquatic ecosystem include:

(1) Locations, times and duration of the project have been selected to minimize potential adverse impacts to the aquatic ecosystem.

(2) An interdisciplinary team has evaluated sites, and project designs have been altered per their recommendations.

DATE:________________________________ ________________________________

JEREMY J CHAPMAN
Colonel, U.S. Army
District Commander

B.2.4. *Endangered Species Act*

B.2.4.1. *U.S. Fish and Wildlife Concurrence*

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United States Department of the Interior

FISH AND WILDLIFE SERVICE
1208-B Main Street
Daphne, Alabama 36526

SEP 05 2023

IN REPLY REFER TO:
2023-0041208

Ms. Heather P. Bulger, Inland Environment Team Biologist
U.S. Army Corps of Engineers, Mobile District
109 St. Joseph St
Mobile, AL 36602

Dear Ms. Bulger:

Thank you for your project submission on March 29, 2023, which requests Endangered Species Act (ESA) Section 7 concurrence on the U.S. Army Corps of Engineers (Corps) effects determination for the proposed construction of fish passage structures at Claiborne and Millers Ferry Locks and Dams on the Alabama River. We understand that the Tentatively Selected Plan includes construction of a natural bypass channel along the right descending bank at both dams. We also understand that natural materials such as soil, riprap embankment protection, and stone weirs will be used to create alternating riffle and pool habitats to achieve a step-pool nature-like fishway design throughout each structure. We have reviewed the information and provide the following comments in accordance with the Endangered Species Act of 1973 (87 Stat. 884, as amended; 16 U.S.C. 1531 et seq.).

Millers Ferry

The Millers Ferry natural bypass channel structure will include control gate structures and two vehicular bridges. Prior to construction, aquatic, terrestrial, topographic, and cultural resource surveys will be conducted in addition to a geotechnical investigation and sediment transport and hydrologic analyses.

Freshwater biological surveys will provide baseline information for the adaptive management and monitoring plan, which will be completed during future planning efforts. Terrestrial biological surveys will be completed for timber sales, planting replacement analysis, and other project functions. A topographical survey will be performed after real estate acquisition, if applicable, and post-construction. Cultural resources surveys will be completed along the project footprint. Geotechnical and hydrological field work may include geotechnical core sampling, stream gauging, and further field studies. A geotechnical investigation within the project footprints is planned to determine soil types and if rock will be encountered. The timeframe of this investigation is currently unknown.

Construction of the natural bypass structure will include the following activities:

- Construction of abutment walls, piles, and bridge parapets
- Construction of staging area with barge support
- Installation and removal of temporary cofferdams

PHONE: 251-441-5181 FAX: 251-441-6222

- Debris and vegetation removal
- Excavation of soils and sediments and associated grading
- Installation of a slide gate
- Channelization of the stream section of the structure
- Installation and anchoring of bank protection

At Millers Ferry Lock and Dam, two vehicular bridges will be constructed. One bridge will provide project personnel access to the west side of the dam, and the other bridge will provide public access to the Alabama River or to property between the fish passage structure and the river. The crossing to the spillway at Millers Ferry will consist of a three-span bridge, with a total bridge length of approximately 76 feet. The superstructure of the bridges will consist of steel girders and beams to support steel grating. Bridge girders will be fixed at one end and free at the other to allow for expansion and contraction. The substructure will consist of pier walls and concrete abutments and will likely be supported by two to three piles constructed in the natural bypass channel. Bridge parapets will be constructed for both bridges. Abutment walls will be constructed prior to stream flow in the Millers Ferry natural bypass channel as a structural base for the bridging and slide gate structure.

A staging area for materials and equipment will be constructed for the duration of the project. Depending on materials needed, at least one lockable storage unit will be placed in the area. Barges will be staged in water around the construction area for additional support.

Cofferdams will be constructed to separate water bodies from the construction area. Any installed cofferdams will be removed after construction.

All vegetation, timber, and debris will be removed from the bypass channel footprint and properly disposed of. Vegetation will be removed from approximately 165 acres at Millers Ferry. Once excavation and rock placement are completed, the project area will be reseeded with native flora to restore natural biodiversity and to stabilize new structures.

At Millers Ferry, two million cubic yards of material will be excavated. The current topography of the site will be altered and replaced by a stream channel of varying depths with an approximate width of 100 feet. The area will be graded to create a channel with a 3:1 horizontal to vertical slope. No unstable soils will be left after the construction of the project.

Steel slide gates able to withstand maximum hydrostatic pressures at flood stage and debris impact will be constructed and used to control the flow of water in the bypass channel at Millers Ferry. The gates will be mechanically operated from an offsite location. Remote operation design details will be developed during the preconstruction, engineering, and design phase of the project.

The natural bypass channel will be excavated to a depth that will be determined in more detailed design. At Millers Ferry, the channel will start above the dam at an elevation of 75 feet and end below the dam at an elevation of 31 feet and will descend at a 0.005 foot/foot slope for 8,500 feet. Currently, the average channel velocity at Millers Ferry is 4.2 feet per second (ft/s). Approximately 5,000 cubic feet per second (cfs) of flow will travel through the natural bypass channel instead of through the current spillway structure or the Millers Ferry Powerhouse. Natural bypass channel construction will create a new stream. After construction, streamflow through the bypass channel will be moderated with the slide gate to minimize increases in water velocity. Excavated materials will be used as appropriate to create the needed geometry for the project.

The natural bypass channel will have riprap or another type of protective measure installed on its banks to anchor and prevent erosion of the channel. After project construction, the bypass channels will likely be lit for safety at night.

Claiborne

At Claiborne Lock and Dam, one bridge will be needed for project personnel to access the west side of the dam. At this time, it is unknown if the bridge at Claiborne will be a pedestrian or vehicular bridge. All survey and construction activities discussed in the previous section for the Millers Ferry natural bypass structure also apply to the structure at Claiborne. The following paragraphs highlight any differences in project area or scope.

Vegetation will be removed from 30 acres at Claiborne, and this area will be reseeded after construction. At Claiborne, approximately 482,000 cubic yards of material will be excavated.

The Claiborne natural bypass channel will start above the dam at an elevation of 33 feet and end below the dam at an elevation of 3 feet and will descend at a 0.013 foot/foot slope over 2,100 feet. Currently, the average channel velocity at Claiborne is 4.0 feet per second (ft/s). Approximately 5,000 cubic feet per second (cfs) of flow will travel through the natural bypass channel instead of through the current spillway structure.

Effects Determination

The Corps has indicated that streamflow and riverine habitat below the current Millers Ferry and Claiborne Lock and Dam structures will be maintained and not affected throughout construction of the bypass structures. Overall bathymetry and depth profile of the area will not dramatically change. Minor changes in water depth are predicted. No major changes in substrate composition or water temperature are predicted as a result of this project. During high flows, the natural bypass structure gate at Millers Ferry may be closed to regulate flow through the structure. At Claiborne, average flows are not expected to exceed 6.6 feet per second (ft/s).

We understand that the Corps has determined this project may affect, but is not likely to adversely affect the following federally listed species:

- Alabama sturgeon (*Scaphirhynchus suttkusi*)—Endangered
- Georgia rockcress (*Arabis georgiana*)—Threatened
- Gulf sturgeon (*Acipenser oxyrinchus desotoi*)—Threatened
- Inflated heelsplitter (*Potamilus inflatus*)—Threatened
- Southern clubshell (*Pleurobema decisum*)—Endangered
- Tulotoma snail (*Tulotoma magnifica*)—Threatened

We understand that the Corps based this determination for the aquatic species listed above based on their potential presence in the project area.

An extant population of Georgia rockcress has been identified near the project area. A preliminary habitat assessment of the project area did not find suitable habitat present at the site. Corps personnel noted a high volume of leaf litter and heavy understory growth throughout the site. Bare ground with little to no leaf litter and rock ledges, which consist of shallow soils over rocky bluffs, are needed for Georgia rockcress and were not present at the site. A terrestrial survey of the project area prior to construction will be completed to confirm presence or absence of Georgia rockcress at the site.

We also understand that the Corps will incorporate the following conservation measures:

- Riprap or other protective measures will be used to armor and to protect streambanks from erosion.
- Matting or blankets will be placed on exposed soils to control erosion.
- Mulch from a biological source will be placed at the site to prevent erosion and reduce exposed soils.
- Downed woody debris and cleared timber will be removed from the site to reduce fuel sources.
- Seeding of grasses will be used for erosion control purposes.
- Care will be taken to reduce the number of "spud drops" during selective spudding by the barges in and around the project area. Barges and other boats will operate at low speeds in the project area to reduce the likelihood of vessel strikes of both Alabama and Gulf sturgeon.
- Aquatic and terrestrial preconstruction surveys will be conducted.

Based upon a review of our records and on the information provided in your project submission, we concur with your determination that the project actions may affect, but are not likely to adversely affect the above species.

The Corps also determined that proposed construction of two natural bypass channels may affect, but is not likely to adversely affect critical habitat for the Alabama sturgeon. We concur with this determination.

We understand that the Corps has determined this project will have no effect on the following federally listed species:

- Alabama pearlshell (*Margaritifera marrianae*)—Endangered
- Orangenacre mucket (*Hamiota perovalis*)—Threatened

While the ESA gives federal action agencies the authority to make a no effect determination without additional concurrence from the Service, we appreciate you notifying us of your decision. We understand that Alabama pearlshell was excluded from further environmental review and analysis since the most recent 5-year review indicated that it is extirpated from the Alabama River drainage, and orangenacre mucket was excluded since it is believed extirpated from the main stem Alabama River.

We also understand that the Corps did not make an effects determination for the following species, and that they were excluded from further review and analysis since they are not listed species under ESA:

- Alligator snapping turtle (*Macrochelys temminckii*)—Proposed Threatened
- Monarch butterfly (*Danaus plexippus*)—Candidate

The Service understands that this project is currently in the feasibility study of the planning process and that the Corps has estimated the project is at about 30% completed design. The Service also understands that aquatic and terrestrial species surveys will be conducted at both sites. Survey plans and results will be provided to the Service for further project evaluation in addition to more design details, which includes but is not limited to, an adaptive management and monitoring plan and planned operations and maintenance of the passage structures. The Service looks forward to receiving this information and to continuing to coordinate with the Corps on this fish passage project.

In accordance with 50 CFR 402.16, reinitiation of consultation is required and shall be requested by the Corps, where discretionary Federal involvement or control over the action has been retained or is authorized by law and:

- If the amount or extent of taking specified in the incidental take statement is exceeded;
- If new information reveals effects of the action that may affect listed species or critical habitat in a manner or to an extent not previously considered;
- If the identified action is subsequently modified in a manner that causes an effect to the listed species or critical habitat that was not considered in the biological opinion or written concurrence; or
- If a new species is listed or critical habitat designated that may be affected by the identified action.

If you have any questions or need additional information, please contact Ms. Morgan Brizendine of my staff at (251) 441-5839 or at morgan_brizendine@fws.gov. Please refer to the reference number located at the top of this letter in future phone calls or written correspondence.

Sincerely,

William J Pearson
Field Supervisor
Alabama Ecological Services Field Office

B.2.5. *Fish and Wildlife Coordination Act*

B.2.5.1. *Planning Aid Letter*

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United States Department of the Interior

FISH AND WILDLIFE SERVICE
1208-B Main Street
Daphne, Alabama 36526

IN REPLY REFER TO:
2023-0009362

Colonel Jeremy J. Chapman, District Commander
U.S. Army Corps of Engineers, Mobile District
P.O. Box 2288
Mobile, AL 36628

Dear Colonel Chapman:

The U.S. Fish and Wildlife Service (Service) has prepared this Planning Aid Letter (PAL) to provide information that will help inform a feasibility study on fish passage in the Alabama River at Claiborne and Millers Ferry locks and dams. This PAL is provided in accordance with the Fish and Wildlife Coordination Act of 1958 (FWCA) (48 Stat. 401, as amended; 16 U.S.C. § 661 *et seq.*) and section 7 of the Endangered Species Act of 1973 (ESA) (87 Stat. 884, as amended; 16 U.S.C. § 1531 *et seq.*). This PAL does not constitute the report of the Secretary of the Interior as required by section 2(b) of the FWCA, nor does it constitute a biological opinion under section 7 of the ESA. The purpose of this PAL is to provide the U.S. Army Corps of Engineers (Corps) with information that identifies fish and wildlife resource values and issues, including endangered species issues. These comments are based on previous studies and government documents as well as new datasets and information provided by state and federal agencies and other partners. Continued efforts will be made to provide additional information and expertise in the form of another PAL and/or the draft FWCA report. A separate consultation will occur regarding the potential impacts of the Corps' proposal on federally threatened and endangered species protected under the ESA.

Fish Passage

Dams can contribute to declines in aquatic species populations, but migratory fishes in particular are affected when these structures prevent access to habitat for spawning (Hershey et al. 2022). Fish ladders were first designed and implemented in North America around 200 years ago (Matica 2020). Different types of fish passage structures have been developed over time; however, they are usually designed for a target species and do not consider the needs of the native fish community (Matica 2020). These structures are also designed to facilitate upstream migration and do not fully consider the importance of downstream movements of fishes post-spawn (Larinier 2001). Mortality from interaction with hydraulic turbines or over spillways can negatively affect population numbers and stability (Larinier 2001). Downstream passage can involve the use of screens to prevent fish from interacting with turbines, of surface bypasses, or of behavioral guidance devices, although the latter devices are considered experimental (Larinier 2001). Downstream fish passage success is dependent on understanding how fishes respond to

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accelerating flows at different times of their life cycles and how they respond to different screens or attractants at passage structures (Enders et al. 2009).

In addition to adult fish migrating downstream post-spawn, downstream dispersal of juvenile fishes is also important for population stability and survival (Pavlov and Mikheev 2017). Larval drift of broadcast spawners like sturgeon is also affected by restricted flows at dams (Marotz and Lorang 2018), which can prevent successful reproduction. Complicated life histories of aquatic species and the challenges associated with the barriers and effects of restricted flows from dams has created the need for managers to develop a toolkit for successful mitigation strategies (Katopodis 2005). This toolkit should include methods that analyze the relationship between fish migration and hydrographs, fish attraction to passage structures, passage structure hydraulics and fish passibility, fish screen hydraulics and fish responses, and development of natural structures that contain fish habitat (Katopodis 2005).

The goal of this feasibility study is to evaluate fish passage structures on the Alabama River at Claiborne Lock and Dam and at Millers Ferry Lock and Dam (L&D). The following sections discuss the study area and its aquatic resources, proposed alternatives the Corps have identified, and recommendations from the Service to consider moving forward.

Study Area

The Alabama River is part of the Alabama-Coosa-Tallapoosa River System, which has five Corps operated dams, 11 private dams, and 16 reservoirs and comprises the eastern part of the Mobile River drainage (Freeman et al. 2005). This study will focus on the reach of the Alabama River immediately below Claiborne L&D upstream to Millers Ferry L&D pool (60.5 river miles). However, if fish passage structures are constructed at both Claiborne and Millers Ferry L&D and fish passage is successful, then habitat for aquatic species, especially migratory fishes and some species of freshwater mussels, from the Mobile Delta to R.F. Henry L&D on the Alabama River would be connected for the first time since 1970. In addition, these species would also be able to access the free-flowing waters of the Cahaba River, a major tributary of the Alabama River.

Millers Ferry L&D is located in Wilcox County about 133 miles upstream of the mouth of the Alabama River, 10 miles northwest of Camden, and 30 miles southwest of Selma, Alabama (Corps 2015). Construction began in 1964 and was completed in 1970. This structure includes a concrete gravity-type dam, a gated spillway, earth dikes, a navigation lock and control station, and a 90-megawatt power plant. Millers Ferry L&D is primarily used for hydropower and navigation. It is also authorized for public recreation, water quality, and fish and wildlife conservation and mitigation purposes (Corps 2015). William "Bill" Dannelly Lake extends approximately 105 miles upstream with the lower 25 miles located in Wilcox County and the upper 80 miles located in Dallas County. It has a volume of 346,254 acre-feet at full capacity (Corps 2015).

Claiborne L&D is located downstream of Millers Ferry L&D in Monroe County, Alabama, approximately 72.5 miles upstream of the mouth of the Alabama River (Corps 2014). Construction began on this structure in 1966 and was completed in 1970. This structure includes a concrete gravity-type dam, a gated spillway, an un-gated free overflow spillway, earth dikes, and a navigation lock and control station. Claiborne L&D is primarily used as a navigation structure and regulates hydropower releases from Millers Ferry L&D. Other authorized purposes include water quality, public recreation, and fish and wildlife conservation and mitigation; however, the Corps does not consider recreation when making water control decisions (Corps 2014). This structure is also not used for flood risk management storage. Claiborne Lake extends about 60 miles upstream with the lower 28 miles located in Monroe and Clarke counties and the upper 32 miles located in Wilcox County. It has a volume of 102,480 acre-feet at full capacity (Corps 2014).

Fish and Wildlife Resources

Alabama River

Today, 44% of the Alabama River is inundated by reservoirs created by dams that were built from 1914 through the 1980s for hydropower generation and navigation (Freeman et al. 2005). As a result, altered flow regimes have negatively affected the diversity of the aquatic community. Dams create deep pool habitats with slow flows that collect silt and sediment that can favor non-native or invasive species (Boschung, Jr. and Mayden 2004). Natural flow regimes help keep sand, gravel, and cobble substrates well oxygenated and free of silt and sediment, which provides essential habitat for many native species of fish, mussels, crayfish, snails, and other macroinvertebrates (Boschung, Jr. and Mayden 2004). Free-flowing riverine habitat is still found in the main stem of the Alabama River below dams and in major tributaries free from impoundments (Freeman et al. 2005); however, these sections of riverine habitat are fragmented which has caused declines in populations and genetic diversity of fishes, freshwater mussels, and other aquatic species. Surveys of sand and gravel bar habitat in the Alabama River have documented the importance of preserving this habitat to prevent further loss of fish biodiversity (Haley and Johnston 2014). Dredging and other anthropogenic activities continue to damage and destroy this bar habitat (Haley and Johnston 2014).

Degraded water quality in the Alabama River has also negatively affected the diversity of the aquatic community. Flow control at dams can lead to low dissolved oxygen events during periods of elevated water temperatures (Hartline et al. 2020). Although flow management strategies attempt to avoid these events, little is known about how nongame fishes cope with these conditions; additionally, lack of research and data on these species' reactions to adverse conditions means they are likely underrepresented when water quality criteria for dissolved oxygen levels are developed (Hartline et al. 2020).

The Alabama Department of Environmental Management (ADEM) is required by Section 303(d) of the Clean Water Act to identify impaired waters in the state (ADEM 2022). In 2022, ADEM listed 13 tributaries of the Alabama River that were impaired because of high levels of nutrients, pesticides, siltation, pathogens (*E. coli*), and/or metals (mercury) (ADEM 2022). Claiborne Lake, including Claiborne L&D, is listed for high levels of metals (mercury) due to atmospheric deposition (ADEM 2022).

Bioaccumulation of mercury in fishes can inhibit reproduction, growth, and survival; furthermore, age, fish size, and life history characteristics all determine the severity of these effects in different species (Crump and Trudeau 2009; Zillioux 2015; Zheng et al. 2019). Sediment-bound pollutants or toxicants can be introduced into streams along with extrinsic sediments (Niraula et al. 2016). Toxicants, which include pesticides, ammonia, metals, and ions such as potassium, chloride, and sulfate, can disrupt growth, feeding, and reproduction in freshwater mussels, and prolonged exposure to toxicants can lead to death (Naimo 1995; Newton et al. 2003; Bringolf et al. 2007; Wang et al. 2016; Ciparis et al. 2019). Wang et al. (2016) also found that the few species of freshwater mussels that have been tested in toxicological studies are often common species that may be less sensitive to toxicants than species with a narrow endemic range. Freshwater gastropods, especially listed species, are more underrepresented in these studies even though they may be more sensitive to some toxicants than freshwater mussels (Gibson et al. 2016). Maintaining and improving water quality will be essential for long-term conservation of the diverse aquatic community in the Alabama River and for the recovery of its threatened and endangered species.

At-risk and federally listed species
There are several at-risk and federally listed species in or near the study area (Table 1) that could be affected by the addition of fish passage at Claiborne and Millers Ferry L&D. The following paragraphs briefly summarize life history information for each species.

Table 1. A list of at-risk and listed species that may be present in the study area or affected by fish passage at Claiborne and Millers Ferry L&D. Listed species are classified as threatened or endangered and are protected under ESA. At-risk species are those that are petitioned for listing, proposed threatened, proposed endangered, under discretionary review, or a candidate for listing. This table should not be used for Section 7 consultation, and additional species may be added in future PALs and/or in the draft FWCA report.

COMMON NAME	SCIENTIFIC NAME	TYPE	FEDERAL STATUS
Georgia rockcress	*Arabis georgiana*	Plant	Threatened
Spotted rocksnail	*Leptoxis picta*	Snail	At-risk
Tulotoma snail	*Tulotoma magnifica*	Snail	Threatened
Inflated heelsplitter	*Potamilus inflatus*	Clam	Threatened
Southern clubshell	*Pleurobema decisum*	Clam	Endangered
Alabama sturgeon	*Scaphirhynchus suttkusi*	Fish	Endangered
Gulf sturgeon	*Acipenser oxyrinchus* (=*oxyrhynchus*) *desotoi*	Fish	Threatened

Georgia rockcress is a perennial herb in the mustard family (Brassicaceae) that grows up to 90 cm (35.4 in) tall (Service 2021). It grows in a variety of dry conditions, including shallow soil accumulations on rocky bluffs, ecotones of gently sloping rock outcrops, and in sandy loam along eroding riverbanks. It is occasionally found in adjacent mesic woods, but it will not persist in heavily shaded conditions. This species is adapted to high or moderately high light intensities and occurs on soils which are circumneutral to slightly basic. It is thought that seed dispersal mainly occurs by gravity and wind; however, surface runoff or flowing rivers likely facilitate long-distance dispersal (Service 2021).

The spotted rocksnail has a shell that is globose in shape with an ovate and broadly rounded aperture (Garner et al. 2022). Juveniles have interrupted color bands that disappear in adults (Whelan et al. 2014). Females lay clutches of eggs that are coated with mucus in a spiral pattern (Whelan et al. 2014). Historically, this species was found in the Alabama River from Claiborne upstream to the Coosa River below Wetumpka, which is below the Fall Line, and from the confluence of the Alabama and Cahaba rivers upstream to Lily Shoals in Bibb County (Whelan et al. 2017). Currently, this species can be found in the Alabama River from river miles 46.0 to 231.5 and at one reintroduction site in the Cahaba River near Centreville (Whelan et al. 2017).

Tulotoma snails have dark brown or black globosely conic shells with irregularly convex to straight whorls (Garner et al. 2022). Most shells have spiral bands of tubercles and are up to 35 mm in length (Garner et al. 2022). This species can be found in localized areas of the main stem Alabama and Coosa rivers and in the free-flowing lower reaches of several tributaries (Garner et al. 2016; Garner et al. 2022). Although this species has been found under large rocks and in bedrock crevices, side-scan sonar has been successfully used to target the boulder habitat that tulotoma snails are more commonly found in (Garner et al. 2016).

The inflated heelsplitter is a unionid mussel endemic to the Mobile Basin that has a thin, moderately inflated shell (Williams et al. 2008). Generally, males are larger than females, and this species is considered a long-term brooder. Females release glochidia in the summer, and freshwater drum (*Aplodinotus grunniens*) are the only known host fish for this species. (Williams et al. 2008). Inflated heelsplitters grow rapidly, mature after one year of growth, and live for approximately eight years (Brown and Daniel 2014). These mussels inhabit large rivers and are found in slow to moderate current with sandy and muddy substrates (Williams et al. 2008).

The southern clubshell is a freshwater mussel that grows up to 93 mm in length and has a thick shell with an elliptical outline (Williams et al. 2008). This species is found in large creeks and rivers throughout the Mobile Basin in flow with gravel and sand substrates. Southern clubshell are short-term brooders and gravid females release orange or white conglutinates filled with glochidia in June and July. Blacktail shiner (*Cyprinella venusta*) and striped shiner (*Luxilus chrysocephalus*) have been identified as primary and secondary fish hosts (Williams et al. 2008).

The Alabama sturgeon is a benthic fish that eats macroinvertebrates and grows to lengths of 0.7 to 0.8m (2.3 to 2.6 ft) (Mettee et al. 1996). Most of its fins are brownish orange, and the body near the lateral scutes is yellow to tan while its belly and anal fin are white. Alabama sturgeon are endemic to the Mobile River basin, and several specimens have been collected from the Alabama River, including three adults downstream of Claiborne L&D (Mettee et al. 1996). Gravid females were collected in late March 1969 at the mouth of the Cahaba River; however, females collected in April and May 1985 from the Alabama River were not gravid (Mettee et al. 1996). Although specific spawning areas and larval drift have not been documented in Alabama sturgeon, it is likely that they spawn on hard bottom substrates in deep water and that successful larval development is dependent on long stretches of highly oxygenated, free-flowing water (Service 2009; Kuhajda and Rider 2016).

Alabama sturgeon critical habitat was designated in 2009 and encompasses 524 km (326 mi) of river channel in the Alabama and Cahaba rivers (Service 2009). The designated area in the Alabama River extends a total of 394 km (245 mi) from its confluence with Tombigbee River upstream to R.F. Henry L&D. In the Cahaba River, a total of 130 km (81 mi) of critical habitat is designated from its confluence with the Alabama River upstream to its cross with U.S. Highway

82 (Service 2009). Critical habitat is defined as areas that are occupied by the species and areas that are essential to its conservation, including those that are not occupied at the time of listing (Service 2009).

Similar to the Alabama sturgeon, Gulf sturgeon are benthic and feed on organisms that live in sediment, including bivalves, snails, crustaceans, and other macroinvertebrates (Service 2022). Gulf sturgeon are a considered a subspecies of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*), grow up to lengths of 2.7 m (9 ft), and live for up to 50 years (NOAA 2022). Gulf sturgeon are anadromous and migrate from freshwater rivers to marine foraging habitat in the Gulf of Mexico in the winter (Service 2022). These habitats are usually less than 7 m deep and well oxygenated with low turbidity and coarse or find sand substrates (Service 2022). Although these fish begin migrating to freshwater rivers in February and spawn in the spring (Mettee et al. 1996), fall spawning has also been documented in the Suwanee and Choctawhatchee rivers in Florida (Service 2022).

Fishes

At least 184 fishes are native to the Alabama River, with 33 of these species considered endemic (Freeman et al. 2005; Haley and Johnston 2014). In 2005, ten fishes, including seven endemic species, were federally listed, and at least 28 fish species were considered vulnerable by experts (Freeman et al. 2005). From 2010-2011, fish assemblage surveys on the Alabama River from Dixie Landing at river mile 22 upstream to Claiborne L&D only documented 48 species (Haley and Johnston 2014). These samples were not similar to historical samples and indicate a temporal shift in the fish community and a loss of diversity (Haley and Johnston 2014). Of the known fishes that inhabit the Alabama and/or Cahaba rivers, five are federally listed, including Alabama sturgeon, Gulf sturgeon, blue shiner, Cahaba shiner, and goldline darter (Table 2). Frecklebelly madtom and coal darter are currently under review for federal protection (Table 2).

Table 2. A list of fishes that are present in the Alabama and/or Cahaba rivers and their state and federal status (ADCNR and GSA unpublished dataset). Note that blue shiners (*Cyprinella caerulea)* are currently extirpated from both river systems. SP denotes a species that is state protected under the Alabama State Invertebrate Species Regulation 220-2-.98. The state ranking system abbreviations are defined as follows: S1 = critically imperiled, S2 = imperiled, S3 = vulnerable, S4 = apparently secure, S5 = secure, SX = presumed extirpated, and SE = exotic (ADCNR 2017).

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Chestnut lamprey	*Ichthyomyzon castaneus*	S5	-
Southern brook lamprey	*Ichthyomyzon gagei*	S5	-
Least brook lamprey	*Lampetra aepyptera*	S5	-
Gulf sturgeon	*Acipenser oxyrinchus desotoi*	S2, SP	Threatened
Alabama sturgeon	*Scaphirhynchus suttkusi*	S1, SP	Endangered
Paddlefish	*Polyodon spathula*	S3	-

Alligator gar	*Atractosteus spatula*	S3	-
Spotted gar	*Lepisosteus oculatus*	S5	-
Longnose gar	*Lepisosteus osseus*	S5	-
Bowfin	*Amia calva*	S5	-
Mooneye	*Hiodon tergisus*	S3	-
American eel	*Anguilla rostrata*	S4	-
Bay anchovy	*Anchoa mitchilli*	S5	-
Alabama shad	*Alosa alabamae*	S1	-
Skipjack Herring	*Alosa chrysochloris*	S3	-
Gulf Menhaden	*Brevoortia patronus*	S5	-
Gizzard Shad	*Dorosoma cepedianum*	S5	-
Threadfin Shad	*Dorosoma petenense*	S5	-
Largescale Stoneroller	*Campostoma oligolepis*	S5	-
Goldfish	*Carassius auratus*	-	-
Grass carp	*Ctenopharyngodon idella*	-	-
Blue shiner	*Cyprinella caerulea*	S1, SP	Threatened
Alabama shiner	*Cyprinella callistia*	S5	-
Tricolor shiner	*Cyprinella trichroistia*	S5	-
Blacktail shiner	*Cyprinella venusta*	S5	-
Common carp	*Cyprinus carpio*	-	-
Cypress minnow	*Hybognathus hayi*	S3	-
Mississippi silvery minnow	*Hybognathus nuchalis*	S4	-
Clear chub	*Hybopsis winchelli*	S5	-
Bighead carp	*Hypopthalmichthys nobilis*	-	-
Striped shiner	*Luxilus chrysocephalus*	S5	-
Pretty shiner	*Lythrurus bellus*	S5	-
Mountain shiner	*Lythrurus lirus*	S4	-
Cherryfin shiner	*Lythrurus roseipinnis*	S5	-
Mobile chub	*Macrhybopsis boschungi*	S3	-
Coosa chub	*Macrhybopsis etnieri*	S4	-
Silver chub	*Macrhybopsis storeriana*	S5	-
Bluehead chub	*Nocomis bellicus*	S5	-
Golden shiner	*Notemigonus crysoleucas*	S5	-
Orangefin shiner	*Notropis ammophilus*	S5	-
Longjaw minnow	*Notropis amplamala*	S5	-
Burrhead shiner	*Notropis asperifrons*	S5	-
Emerald shiner	*Notropis atherinoides*	S5	-
Rough shiner	*Notropis baileyi*	S5	-

Cahaba shiner	*Notropis cahabae*	S1, SP	Endangered
Silverside shiner	*Notropis candidus*	S5	-
Ironcolor shiner	*Notropis chalybaeus*	S1, SP	-
Rainbow shiner	*Notropis chrosomus*	S5	-
Fluvial shiner	*Notropis edwardraneyi*	S4	-
Longnose shiner	*Notropis longirostris*	S5	-
Taillight shiner	*Notropis maculatus*	S4	-
Coastal shiner	*Notropis petersoni*	S5	-
Silverstripe shiner	*Notropis stilbius*	S5	-
Weed shiner	*Notropis texanus*	S5	-
Skygazer shiner	*Notropis uranoscopus*	S3	-
Mimic shiner	*Notropis volucellus*	S5	-
Pugnose minnow	*Opsopoeodus emiliae*	S5	-
Riffle minnow	*Phenacobius catostomus*	S5	-
Bluntnose minnow	*Pimephales notatus*	S5	-
Fathead minnow	*Pimephales promelas*	S5	-
Bullhead minnow	*Pimephales vigilax*	S5	-
Sailfin shiner	*Pteronotropis hypselopterus*	S5	-
Flagfin shiner	*Pteronotropis signipinnis*	S5	-
Bluenose shiner	*Pteronotropis welaka*	S2	-
Creek chub	*Semotilus atromaculatus*	S5	-
Dixie chub	*Semotilus thoreauianus*	S5	-
Quillback	*Carpiodes cyprinus*	S5	-
Highfin carpsucker	*Carpiodes velifer*	S5	-
Southeastern blue sucker	*Cycleptus meridionalis*	S4	-
Creek chubsucker	*Erimyzon oblongus*	S5	-
Lake chubsucker	*Erimyzon sucetta*	S5	-
Sharpfin chubsucker	*Erimyzon tenuis*	S5	-
Alabama hog sucker	*Hypentelium etowanum*	S5	-
Smallmouth buffalo	*Ictiobus bubalus*	S5	-
Spotted sucker	*Minytrema melanops*	S5	-
River redhorse	*Moxostoma carinatum*	S5	-
Black redhorse	*Moxostoma duquesnei*	S5	-
Golden redhorse	*Moxostoma erythrurum*	S5	-
Blacktail redhorse	*Moxostoma poecilurum*	S5	-
Black bullhead	*Ameiurus melas*	S5	-
Yellow bullhead	*Ameiurus natalis*	S5	-
Brown bullhead	*Ameiurus nebulosus*	S5	-
Blue catfish	*Ictalurus furcatus*	S5	-
Channel catfish	*Ictalurus punctatus*	S5	-

Black madtom	*Noturus funebris*	S5	-
Tadpole madtom	*Noturus gyrinus*	S5	-
Speckled madtom	*Noturus leptacanthus*	S5	-
Frecklebelly madtom	*Notutus munitus*	S1, SP	Under Review
Freckled madtom	*Noturus nocturnus*	S5	-
Flathead catfish	*Pylodictis olivaris*	S5	-
Redfin pickerel	*Esox americanus*	S5	-
Chain pickerel	*Esox niger*	S5	-
Pirate perch	*Aphredoderus sayanus*	S5	-
Striped mullet	*Mugil cephalus*	S5	-
Stout silverside	*Labidesthes vanhyningi*	S5	-
Inland silverside	*Menidia beryllina*	S5	-
Atlantic needlefish	*Strongylura marina*	S5	-
Western starhead topminnow	*Fundulus blairae*	S4	-
Blackstripe topminnow	*Fundulus notatus*	S5	-
Bayou topminnow	*Fundulus notti*	S5	-
Blackspotted topminnow	*Fundulus olivaceus*	S5	-
Southern studfish	*Fundulus stellifer*	S5	-
Rainwater killifish	*Lucania parva*	S4	-
Western mosquitofish	*Gambusia affinis*	S5	-
Eastern mosquitofish	*Gambusia holbrooki*	S5	-
Least killifish	*Heterandria formosa*	S4	-
Banded sculpin	*Cottus carolinae*	S5	-
White bass	*Morone chrysops*	S5	-
Yellow bass	*Morone mississippiensis*	S5	-
Striped bass	*Morone saxatilis*	S3	-
Shadow bass	*Ambloplites ariommus*	S5	-
Flier	*Centrarchus macropterus*	S5	-
Bluespotted sunfish	*Enneacanthus gloriosus*	S4	-
Redbreast sunfish	*Lepomis auritus*	S5	-
Green sunfish	*Lepomis cyanellus*	S5	-
Warmouth	*Lepomis gulosus*	S5	-
Orangespotted sunfish	*Lepomis humilis*	S5	-
Bluegill	*Lepomis macrochirus*	S5	-
Dollar sunfish	*Lepomis marginatus*	S5	-
Longear sunfish	*Lepomis megalotis*	S5	-
Redear sunfish	*Lepomis microlophus*	S5	-
Redspotted sunfish	*Lepomis miniatus*	S5	-

Cahaba bass	*Micropterus cahabae*	S5	-
Alabama bass	*Micropterus henshalli*	S5	-
Largemouth bass	*Micropterus salmoides*	S5	-
White crappie	*Pomoxis annularis*	S5	-
Black crappie	*Pomoxis nigromaculatus*	S5	-
Naked sand darter	*Ammocrypta beanii*	S5	-
Southern sand darter	*Ammocrypta meridiana*	S5	-
Crystal darter	*Crystallaria asprella*	S3, SP	-
Redspot darter	*Etheostoma artesiae*	S5	-
Bluntnose darter	*Etheostoma chlorosoma*	S5	-
Swamp darter	*Etheostoma fusiforme*	S5	-
Harlequin darter	*Etheostoma histrio*	S5	-
Greenbreast darter	*Etheostoma jordani*	S5	-
Johnny darter	*Etheostoma nigrum*	S5	-
Goldstripe darter	*Etheostoma parvipinne*	S5	-
Cypress darter	*Etheostoma proeliare*	S5	-
Alabama darter	*Etheostoma ramseyi*	S5	-
Rock darter	*Etheostoma rupestre*	S5	-
Speckled darter	*Etheostoma stigmaeum*	S5	-
Gulf darter	*Etheostoma swaini*	S5	-
Backwater darter	*Etheostoma zonifer*	S5	-
Goldline darter	*Percina aurolineata*	S2, SP	Threatened
Coal darter	*Percina brevicauda*	S2	Under Review
Mobile logperch	*Percina kathae*	S5	-
Freckled darter	*Percina lenticula*	S3	-
Blackside darter	*Percina maculata*	S5	-
Blackbanded darter	*Percina nigrofasciata*	S5	-
Dusky darter	*Percina sciera*	S5	-
River darter	*Percina shumardi*	S5	-
Gulf logperch	*Percina suttkusi*	S5	-
Saddleback darter	*Percina vigil*	S5	-
Walleye	*Sander vitreus*	S4	-
Freshwater drum	*Aplodinotus grunniens*	S5	-
Everglades pygmy sunfish	*Elassoma evergladei*	S3	-
Banded pygmy sunfish	*Elassoma zonatum*	S5	-
Southern flounder	*Paralichthys lethostigma*	-	-
Hogchoker	*Trinectes maculatus*	S5	-

Freshwater mussels
Alabama has more freshwater mussels than any other state at approximately 173 species that represent 43 genera and both Margaritiferidae and Unionidae families (Williams et al. 2008). The Mobile River basin has roughly 73 species of mussels with 34 of these species considered endemic. The eastern part of this drainage, which includes the Alabama River, has about 67 species with 30 considered endemic (Williams et al. 2008). Of the known mussel species that inhabit the Alabama and/or Cahaba rivers, 13 are federally listed and seven are under review for federal protection (Table 3).

Table 3. A list of freshwater mussels and their host fishes that are present in the Alabama and/or Cahaba rivers and their state and federal status (ADCNR and GSA unpublished dataset). Known host fishes are also noted. SP denotes a species that is state protected under the Alabama State Invertebrate Species Regulation 220-2-.98. The state ranking system abbreviations are defined as follows: S1 = critically imperiled, S2 = imperiled, S3 = vulnerable, S4 = apparently secure, S5 = secure, SX = presumed extirpated, and SE = exotic (ADCNR 2017).

COMMON NAME	SCIENTIFIC NAME	HOST FISH(ES)	STATE STATUS	FEDERAL STATUS
Alabama pearlshell	*Margaritifera marrianae*	Redfin pickerel, Chain pickerel	S1, SP	Endangered
Amblema	*Amblema* sp.		S4	-
Rock pocketbook	*Arcidens confragosus*	American eel, Rock bass, White crappie, Skipjack herring, Channel catfish	S3	-
Alabama rainbow	*Cambraunio nebulosa*	Cahaba bass, Largemouth bass	S2, SP	Under Review
Coosa orb	*Cyclonaias kieneriana*	-	S5	-
Butterfly	*Ellipsaria lineolata*	-	S4	-
Alabama spike	*Elliptio arca*	Southern sand darter, Redspot darter, Blackbanded darter	S1, SP	Under Review
Delicate spike	*Elliptio arctata*	-	S2, SP	Under Review
Elephantear	*Elliptio crassidens*	-	S4	-
Upland combshell	*Epioblasma metastriata*	-	SX	Endangered
Southern combshell	*Epioblasma penita*	Mobile logperch, Blackbanded darter	SX, SP	Endangered
Gulf pigtoe	*Fusconaia cerina*	Alabama shiner, Blacktail shiner, Pretty shiner, Orangefin shiner, Emerald shiner, Silverstripe	S4	-

		shiner, Bluntnose minnow		
Round pearlshell	*Glebula rotundata*	Hogchoker, Green sunfish, Bluegill, Bay anchovy, Spotted gar	S4	-
Finelined pocketbook	*Hamiota altilis*	Cahaba bass, Alabama bass, Largemouth bass	S2, SP	Threatened
Orangenacre mucket	*Hamiota perovalis*	Cahaba bass, Alabama bass, Largemouth bass	S2, SP	Threatened
Little spectaclecase	*Leaunio lienosa*	Green sunfish, Bluegill, Largemouth bass, Brown bullhead	S5	-
Southern pocketbook	*Lampsilis ornata*	Alabama bass, Largemouth bass	S5	-
Southern fatmucket	*Lampsilis straminea*	Bluegill, Alabama bass, Largemouth bass	S4	-
Yellow sandshell	*Lampsilis teres*	Green sunfish, Largemouth bass, White crappie, Black crappie, Spotted gar, Longnose gar	S5	-
Alabama heelsplitter	*Lasmigona alabamensis*	Skipjack herring	S3	-
Etowah heelsplitter	*Lasmigona etowaensis*	Banded sculpin	S2, SP	Under Review
Black sandshell	*Ligumia recta*	Largemouth bass, White crappie, Walleye	S2, SP	-
Alabama moccasinshell	*Medionidus acutissimus*	Naked sand darter, Southern sand darter, Johnny darter, Speckled darter, Gulf darter, Mobile logperch, Blackbanded darter, Saddleback darter	S1, SP	Threatened

Coosa moccasinshell	*Medionidus parvulus*	Mobile logperch, Blackbanded darter	SX, SP	Endangered
Washboard	*Megalonaias nervosa*	Bluegill, Longear sunfish, Alabama bass, Largemouth bass, White crappie, Black crappie, Mooneye, Brown bullhead, Longnose gar	S5	-
Threehorn wartyback	*Obliquaria reflexa*	Gizzard shad, Blacktail shiner, Bluntnose minnow, Mooneye, Walleye, Freshwater drum	S5	-
Southern hickorynut	*Obovaria arkansasensis*	-	S1, SP	-
Alabama hickorynut	*Obovaria unicolor*	Naked sand darter, Southern sand darter, Redspot darter, Johnny darter, Gulf darter, Blackbanded darter, Dusky darter	S2, SP	Under Review
Bankclimber	*Plectomerus dombeyanus*	-	S5	-
Southern clubshell	*Pleurobema decisum*	Alabama shiner, Blacktail shiner, Striped shiner, Clear chub	S2, SP	Endangered
Ovate clubshell	*Pleurobema perovatum*	Striped shiner	S1, SP	Endangered
Warrior pigtoe	*Pleurobema rubellum*	Alabama shiner, Blacktail shiner, Creek chub	S1, SP	Endangered
Heavy pigtoe	*Pleurobema taitianum*	-	S1, SP	Endangered
True pigtoe	*Pleurobema verum*	-	SX	-
Fragile papershell	*Potamilus fragilis*	Freshwater drum	S5	-
Inflated heelsplitter	*Potamilus inflatus*	Freshwater drum	S2, SP	Threatened
Bleufer	*Potamilus purpuratus*	Freshwater drum	S5	-
Alabama creekmussel	*Pseudodontiodeus connasaugaensis*	Banded sculpin, Yellow bullhead	S2, SP	-

Triangular kidneyshell	*Ptychobranchus foremanianus*	Mobile logperch, Blackbanded darter	S1, SP	Endangered
Giant floater	*Pyganodon grandis*	Largemouth bass, White crappie, Black crappie, Yellow bullhead, Brown bullhead	S5	-
Southern mapleleaf	*Quadrula apiculata*	Channel catfish	S4	-
Ridged mapleleaf	*Quadrula rumphiana*	Channel catfish	S5	-
Ebonyshell	*Reginaia ebena*	-	S5	-
Pondmussel	*Sagittunio subrostrata*	Bowfin, Largemouth bass, Tadpole madtom	S4	-
Rayed creekshell	*Strophitus radiatus*	-	S2, SP	Under Review
Southern monkeyface	*Theliderma johnsoni*	-	S2, SP	-
Stirrupshell	*Theliderma stapes*	-	SX	Endangered
Southern purple lilliput	*Toxolasma corvunculus*	-	S1, SP	Under Review
Lilliput	*Toxolasma parvum*	-	S4	-
Pistolgrip	*Tritogonia verrucosa*	Weed shiner, Black bullhead, Yellow bullhead, Brown bullhead, Channel catfish	S4	-
Gulf mapleleaf	*Tritogonia nobilis*	Channel catfish	S3	-
Fawnsfoot	*Truncilla donaciformis*	Freshwater drum	S3	-
Pondhorn	*Uniomerus tetralasmus*	-	S4	-
Paper pondshell	*Utterbackia imbecillis*	Largemouth bass, Black crappie	S5	-
Southern rainbow	Villosa vibex	Longear sunfish, Largemouth bass	S5	Endangered

Crayfish, gastropods, and other macroinvertebrates

Similar to fishes and freshwater mussels, dam construction also negatively impacts populations of native crayfishes, gastropods, and other macroinvertebrates (Tiemann 2013; Krajenbrink et al. 2019; Barnett and Adams 2021). There are currently records of 31 different species of crayfish from the Alabama and Cahaba rivers, including one under review for federal status and 11 that are state protected (Schuster et al. 2022; Table 4).

Table 4. The 11 species listed in this table are crayfish found in the Alabama and/or Cahaba rivers that are state protected and/or under review for federal protection (ADCNR and GSA unpublished dataset). SP denotes a species that is state protected under the Alabama State Invertebrate Species Regulation 220-2-.98. The state ranking system abbreviations are defined

as follows: S1 = critically imperiled, S2 = imperiled, S3 = vulnerable, S4 = apparently secure, S5 = secure, SX = presumed extirpated, and SE = exotic (ADCNR 2017).

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Angular dwarf crayfish	*Cambarellus lesliei*	S1, SP	-
Speckled burrowing crayfish	*Creaserinus danielae*	S2, SP	Under Review
Shrimp crayfish	*Faxonius lancifer*	S2, SP	-
Prominence riverlet crayfish	*Hobbseus prominens*	S2, SP	-
Cockscomb crayfish	*Procambarus clemmeri*	S2, SP	-
Panhandle crayfish	*Procambarus evermanni*	S2, SP	-
Southern prairie crayfish	*Procambarus h. hagenianus*	S2, SP	-
Celestial crayfish	*Procambarus holifieldi*	S2, SP	-
Smoothnose crayfish	*Procambarus hybus*	S2, SP	-
Spur crayfish	*Procambarus lewisi*	S2, SP	-
Criscross crayfish	*Procambarus marthae*	S2, SP	-

There are currently records of 53 unique species of gastropods in the Alabama and Cahaba rivers which represent 10 families, including Lymnaeidae, Physidae, Planorbidae, Viviparidae, Amnicolidae, Emmericidae, Hydrobiidae, Lithoglyphidae, Pleuroceridae, and Pomatiopsidae (ADCNR and GSA unpublished dataset). Twenty of these species are state and/or federally protected or under review (Table 5).

Table 5. The 20 species listed in this table are gastropods found in the Alabama and/or Cahaba rivers that are state protected and/or have federal status or are under review (ADCNR and GSA unpublished dataset). SP denotes a species that is state protected under the Alabama State Invertebrate Species Regulation 220-2-.98. The state ranking system abbreviations are defined as follows: S1 = critically imperiled, S2 = imperiled, S3 = vulnerable, S4 = apparently secure, S5 = secure, SX = presumed extirpated, and SE = exotic (ADCNR 2017).

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Cahaba ancylid	*Rhodacmea cahawbensis*	S1, SP	-
Cylindrical lioplax	*Lioplax cyclostomatiformis*	S1, SP	Endangered
Tulotoma	*Tulotoma magnifica*	S2, SP	Threatened
Watercress snail	*Fontigens nickliniana*	S1, SP	-
Coosa pyrg	*Marstonia hershleri*	S1, SP	-
Cahaba pebblesnail	*Clappia cahabensis*	S2, SP	-
Flat pebblesnail	*Lepyrium showalteri*	S1, SP	Endangered
Mud elimia	*Elimia alabamensis*	S3	Under Review
Ample elimia	*Elimia ampla*	S2, SP	Under Review
Lilyshoals elimia	*Elimia annettae*	S2, SP	Under Review
Princess elimia	*Elimia bellacrenata*	S1, SP	Under Review
Cockle elimia	*Elimia cochliaris*	S1, SP	Under Review
Teardrop elimia	*Elimia lachryma*	S1, SP	Under Review

Caper elimia	*Elimia olivula*	S3	Under Review
Compact elimia	*Elimia showalterii*	S3	Under Review
Puzzle elimia	*Elimia varians*	S2, SP	-
Squat elimia	*Elimia variata*	S2, SP	-
Round rocksnail	*Leptoxis ampla*	S2, SP	Threatened
Oblong rocksnail	*Leptoxis compacta*	S1	Under Review
Spotted rocksnail	*Leptoxis picta*	S2, SP	Under Review

Effects on crayfishes, gastropods, and other macroinvertebrates will be further explored in a future PAL and/or in the draft FWCA report.

Proposed Alternatives

The Corps began this feasibility study with an initial array of 17 alternatives, which included partial and/or full structure removal at one or both dam locations. The following alternatives have been selected for consideration for habitat modelling and economic analysis:

- Alternative 1: No action
- Alternative 3: Fixed weir rock arch both dams
- Alternative 5d: Natural bypass channel both dams
- Alternative 12b: Fixed weir rock arch at Claiborne L&D and natural bypass channel at Millers Ferry L&D
- Alternative 13b: Natural bypass channel at Claiborne L&D and fixed weir rock arch at Miller's Ferry L&D

The Corps has noted that additives for attraction to fish passage structures will be added to these alternatives and evaluated in the future. Currently, 19 priority fishes are being modelled to evaluate habitat availability and fish passibility of the different passage structures (Table 6).

Table 6. The priority species listed in this table are being used as a representative subset of the fish community to evaluate the fish passibility of each alternative (ADCNR and GSA unpublished dataset). SP denotes a species that is state protected under the Alabama State Invertebrate Species Regulation 220-2-.98. The state ranking system abbreviations are defined as follows: S1 = critically imperiled, S2 = imperiled, S3 = vulnerable, S4 = apparently secure, S5 = secure, SX = presumed extirpated, and SE = exotic (ADCNR 2017).

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Mobile logperch	*Percina kathae*	S5	-
Gulf logperch	*Percina suttkusi*	S5	-
Blacktail shiner	*Cyprinella venusta*	S5	-
Freshwater drum	*Aplodinotus grunniens*	S5	-
Chain pickerel	*Esox niger*	S5	-
Largemouth bass	*Micropterus salmoides*	S5	-
Skipjack herring	*Alosa chrysochloris*	S3	-
Alabama shad	*Alosa alabamae*	S1	-
Striped bass	*Morone saxatilis*	S3	-

Crystal darter	*Crystallaria asprella*	S3, SP	-
River redhorse	*Moxostoma carinatum*	S5	-
Southeastern blue sucker	*Cycleptus meridionalis*	S4	-
Alabama sturgeon	*Scaphirhynchus suttkusi*	S1, SP	Endangered
Gulf sturgeon	*Acipenser oxyrinchus* (=*oxyrhynchus*) *desotoi*	S2, SP	Threatened
Mississippi silvery minnow	*Hybognathus nuchalis*	S4	-
Southern walleye	*Sander* sp. cf. *vitreus*	S4	-
American eel	*Anguilla rostrata*	S4	-
Smallmouth buffalo	*Ictiobus bubalus*	S5	-
Paddlefish	*Polyodon spathula*	S3	-

Recommendations

In addition to additives for fish attraction to proposed passage structures, which could include changes to the regulation of flow, we also recommend the Corps consider mitigation measures that will facilitate downstream migration of fishes and restore natural flow regimes as much as possible. As discussed, downstream migration is an essential component of many migratory fishes' life cycles, and mortality from interaction with hydraulic turbines or over spillways can negatively affect population numbers and stability (Larinier 2001). Downstream passage can involve the use of screens to prevent fish from interacting with turbines, of surface bypasses, or of behavioral guidance devices, although the latter devices are considered experimental (Larinier 2001). Restoration of natural flows would also benefit native aquatic species, including several listed and at-risk fishes, freshwater mussels, crayfish, and gastropods, by re-connecting populations and improving water quality and habitat.

Our recommendations in this PAL are preliminary. We look forward to receiving the results of the habitat modelling and economic analyses of different fish passage alternatives that the Corps is currently conducting and the selection of the final alternative. If you have any questions about this PAL, please contact Morgan Brizendine of my staff at (251) 441-5839 or at morgan_brizendine@fws.gov. Please refer to the reference number located at the top of this letter in future phone calls or written correspondence.

Sincerely,

WILLIAM PEARSON

Digitally signed by WILLIAM PEARSON
Date: 2022.10.31 15:59:38 -05'00'

William J Pearson
Field Supervisor
Alabama Ecological Services Field Office

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B.2.5.2. *Coordination Act Report*

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Fish and Wildlife Coordination Act Report

On

Claiborne and Millers Ferry Locks and Dams Fish Passage Study
(Alabama River, Alabama)

Prepared by:
Alabama Ecological Services Field Office
Daphne, Alabama

U.S. Fish and Wildlife Service
Southeast Region
Daphne, Alabama
February 26, 2024

2023-0009362

Colonel Jeremy J. Chapman, District Commander
U.S. Army Corps of Engineers, Mobile District
P.O. Box 2288
Mobile, AL 36628

Dear Colonel Chapman:

The U.S. Fish and Wildlife Service (Service) has prepared this Fish and Wildlife Coordination Act Report (FWCAR) to provide comments and recommendations on the Claiborne and Millers Ferry Locks and Dams (L&D) Fish Passage Study (Alabama River, Alabama). This FWCAR is provided in fulfillment and accordance with the Fish and Wildlife Coordination Act of 1958 (FWCA; 48 Stat. 401, as amended, 16 U.S.C. §661 et seq.). In addition, our comments are submitted pursuant to our authorities under the Endangered Species Act of 1973 (ESA; 87 Stat. 884, as amended, 16 U.S.C. §1531 et seq.), Migratory Bird Treaty Act of 1918 (MBTA; as amended, 16 U.S.C. §703 et seq.), and Executive Order 13186 for the Conservation of Migratory Birds, Bald and Golden Eagle Protection Act (BGEPA; as amended, 16 U.S.C. §668 et seq.). This FWCAR constitutes the final report of the Secretary of the Interior as required by section 2(b) of the FWCA; however, it does not constitute a biological opinion under section 7 of the ESA. A separate consultation will occur regarding the potential impacts of the Corps' proposal on federally threatened and endangered species protected under the ESA.

The purpose of this FWCAR is to provide the U.S. Army Corps of Engineers (Corps) with information that identifies fish and wildlife resource values and issues, including endangered species concerns. These comments are based on previous studies and government documents as well as new datasets and information provided by state and federal agencies and other partners. Continued efforts will be made to provide additional information and expertise to the Corps as needed. The draft FWCAR was concurrently distributed to the National Oceanic Atmospheric Administration and the Alabama Department of Conservation and Natural Resources. We have incorporated their comments and information provided into this report in addition to comments and information provided by the Corps.

After comparing the No Action Alternative and the Recommended Plan of constructing natural bypass structures at both Claiborne and Millers Ferry L&D (Alternative 5d), the Service prefers the Recommended Plan. However, more information on design, particularly on details that will address downstream migration, additives for fish attraction to passage structures, and other factors that will affect the passability of the structures, have not been addressed at the time of this report. In addition, the Service recommends that the Corps consider wetland mitigation, migratory bird conservation measures, and recreational area preservation or improvement to conserve all habitats potentially affected by the project and to benefit all resources. The Service understands that this project is currently in the feasibility study phase of the planning process and that the Corps has estimated the project is at about 30% completed design. We recommend reviewing some design parameters based on information provided in this document and continuing to involve partners and stakeholders when establishing monitoring and adaptive management goals and objectives. If more design details become available during future phases of the planning process that reveal effects not considered by this FWCAR, the Service may need to update this document to ensure the best scientific and commercial information available continues to be considered throughout development of the project.

We look forward to continuing to work with the Corps as they begin the next phase of this study and finalize the design of their selected alternative. In addition to the FWCAR, we have enclosed copies of *Fish Passage Engineering Design Criteria* (Service 2019b) and *Federal Interagency Nature-like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes* (Turek et al. 2016).

If you have any questions about this FWCAR, please contact Morgan Brizendine of my staff by phone at 251-441-5839 or by e-mail at morgan_brizendine@fws.gov.

Sincerely,

WILLIAM PEARSON
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William J. Pearson
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Enclosures

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EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (Corps), under Section 216 of the Flood Control Act of 1970, has recognized that Claiborne and Millers Ferry Locks and Dams (L&D) on the lower Alabama River have impeded the historical migration of numerous fish species, including listed species like the Alabama sturgeon, and have led to loss of habitat connectivity that also affects other native aquatic species. The Claiborne and Millers Ferry Locks and Dams Fish Passage Study will address ecosystem restoration of the Alabama River in a feasibility report that will be finalized in 2024. Objectives of the study include increasing spatial distribution of aquatic species while encouraging balanced native populations in the Alabama River system; increasing habitat connectivity for migration, spawning, foraging, and nurseries for native fish and mussel species in the Alabama River system; and restoring a more natural flow regime to improve migration and post-spawning life cycle requirements. This Fish and Wildlife Coordination Act Report (FWCAR) describes the status of fish and wildlife resources in the study area, including endangered species concerns, describes the proposed alternatives, evaluates the Tentatively Selected Plan (TSP) and Recommended Plan, and provides U.S. Fish and Wildlife Service (Service) conservation measures and recommendations.

Based on the analyses presented by the Corps at the TSP Milestone Meeting on March 1, 2023, and at the Agency Decision Milestone (ADM) Meeting on September 28, 2023, the Service tentatively supports the Recommended Plan (Alternative 5d) of construction of natural bypass structures at both Claiborne and Millers Ferry L&D and currently prefers this option over the No Action Alternative. However, additional information on design, particularly on details that will address downstream migration, additives for fish attraction to passage structures, and other factors that will affect the passability of the structures, including but not limited to the timing and duration of flows through the bypass channel, channel dimensions, and channel depth, will be needed in order for the Service to fully evaluate this plan. In addition, the Service recommends that the Corps consider wetland mitigation, migratory bird conservation measures, and recreational area preservation or improvement to conserve all habitats potentially affected by the project and to benefit all resources. We also recommend implementing criteria from the Service's *Fish Passage Engineering Design Criteria* (2019b) guidelines and conservation measures from the East Gulf Coastal Plain Joint Venture Implementation Plan when feasible. The Service understands that this project is currently in the feasibility study phase of the planning process and that the Corps has estimated the project is at about 30% completed design. We recommend reviewing some design parameters based on information provided in this document and continuing to involve partners and stakeholders when establishing monitoring and adaptive management goals and objectives. If more design details become available during future phases of the planning process that reveal effects not considered by this final FWCAR, the Service will either amend this document or provide a supplementary report to ensure the best scientific and commercial information available continues to be considered throughout development of the project.

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INTRODUCTION

Authority

The Claiborne and Millers Ferry Locks and Dams Fish Passage Study (Alabama River, Alabama) is authorized by Section 216 of the Flood Control Act of 1970 (33 U.S.C. 549a) for "investigations for modification of completed projects or their operations when found advisable due to significantly changed physical or economic conditions and for improving the quality of the environment in the overall public interest" (Corps 2022). The Service's involvement in this study is authorized by the Fish and Wildlife Coordination Act (FWCA; 48 Stat. 401, as amended; 16 U.S.C. § 661 et seq.). Under the National Letter of Agreement, the Corps transferred funds to the Service for completion of this report.

Purpose and Scope

The Corps, under Section 216 of the Flood Control Act of 1970 (33 U.S.C. 549a), has recognized that Claiborne and Millers Ferry Locks and Dams (L&D) on the lower Alabama River have impeded the historical migration of numerous fish species, including listed species like the Alabama sturgeon (Corps 2022), and have led to loss of habitat connectivity that also affects other native aquatic species. This study will address ecosystem restoration of the Alabama River in a feasibility report that will be finalized in 2024, and the following planning objectives have been identified (Corps 2022):

- Increase spatial distribution of aquatic species while encouraging balanced native populations in the Alabama River system.
- Increase habitat connectivity for migration, spawning, foraging, and nurseries for native fish and mussel species in the Alabama River system.
- Restore a more natural flow regime to improve migration and post-spawning life cycle requirements.

During the Tentatively Selected Plan (TSP) milestone meeting on March 1, 2023, the Corps also identified the following constraints for the study:

- Avoid/minimize adverse impacts to threatened and endangered species.
- Avoid impacts to dam head limits and access to Corps facilities.
- Minimize impacts to authorized purposes of navigation and hydropower.

During the Agency Decision Milestone (ADM) meeting on September 28, 2023, the Corps updated the project and study purpose to "restore connectivity for fish and other species from the Alabama upstream to the Cahaba River."

Prior Studies and Reports

The following studies and/or reports are pertinent documents used to produce the FWCAR:

U.S. Army Corps of Engineers (Corps). 2022. Approval of Review Plan for the Claiborne and Millers Ferry Locks and Dams Fish Passage Study, Alabama River, Alabama. Memorandum for Commander, Mobile District, Mobile, Alabama. 18 pp.

U.S. Army Corps of Engineers (Corps). 2015. Millers Ferry Lock and Dam and William "Bill" Dannelly Lake, Alabama River, Alabama. Alabama-Coosa-Tallapoosa River Basin Water Control Manual Appendix E. 154 pp.

U.S. Army Corps of Engineers (Corps). 2014. Update of the water control manual for the Alabama-Coosa-Tallapoosa River basin in Georgia and Alabama. Final Environmental Impact Statement Volume 2: Appendix A(F). 170 pp.

U.S. Fish and Wildlife Service (Service). 2017. Fish passage engineering design criteria. U.S. Fish and Wildlife Service, Hadley, Massachusetts. 224 pp.

Alabama Department of Conservation and Natural Resources (ADCNR) and Geological Survey of Alabama (GSA). Unpublished dataset. Received via electronic mail correspondence. September 16, 2022.

Mettee, M.F., P.E. O'Neil, T.E. Shepard, and S.W. McGregor. 2005. A study of fish movements and fish passage at Claiborne and Millers Ferry Locks and Dams on the Alabama River, Alabama. Open-File Report 0507, Geological Survey of Alabama, Tuscaloosa. 32 pp.

Hershey, H., D.R. DeVries, R.A. Wright, and D. McKee. 2022. Evaluating fish passage and tailrace space use at a low-use low-head lock and dam. *Transactions of the American Fisheries Society* 151: 50-71.

Katopodis, C. 2005. Developing a toolkit for fish passage, ecological flow management, and fish habitat works. *Journal of Hydraulic Research* 43(5): 451-467.

Katopodis, C., J.A. Kells, and M. Acharya. 2001. Nature-like and conventional fishways: alternative concepts?. *Canadian Water Resources Journal* 26:211-232.

McGregor S.W. and J.T. Garner. 2008. Results of analysis of the freshwater mussel fauna in the Alabama River downstream of Claiborne, Millers Ferry, and Robert F. Henry Locks and Dams, 2006-2008. Open-file report 0812, Geological Survey of Alabama, Tuscaloosa. 35 pp.

Turek, J., A. Haro, and B. Towler. 2016. Federal Interagency Nature- like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes. Interagency Technical Memorandum. 47 pp.

DESCRIPTION OF STUDY AREA

<u>Lower Alabama River Dams</u>

The Alabama River is part of the Alabama-Coosa-Tallapoosa River System, which has five Corps operated dams, 11 private dams, and 16 reservoirs and comprises the eastern part of the Mobile River drainage (Freeman et al. 2005; Figure 1). This study will focus on the reach of the Alabama River immediately below Claiborne L&D upstream to Millers Ferry L&D pool (60.5 river miles). However, if fish passage structures are constructed at both Claiborne and Millers Ferry L&D and fish passage is successful, then habitat for aquatic species, especially migratory fishes and some species of freshwater mussels, from the Mobile Delta to R.F. Henry L&D on the Alabama River would be connected for the first time since 1970. In addition, these species would also be able to access the free-flowing waters of the Cahaba River, a major tributary of the Alabama River.

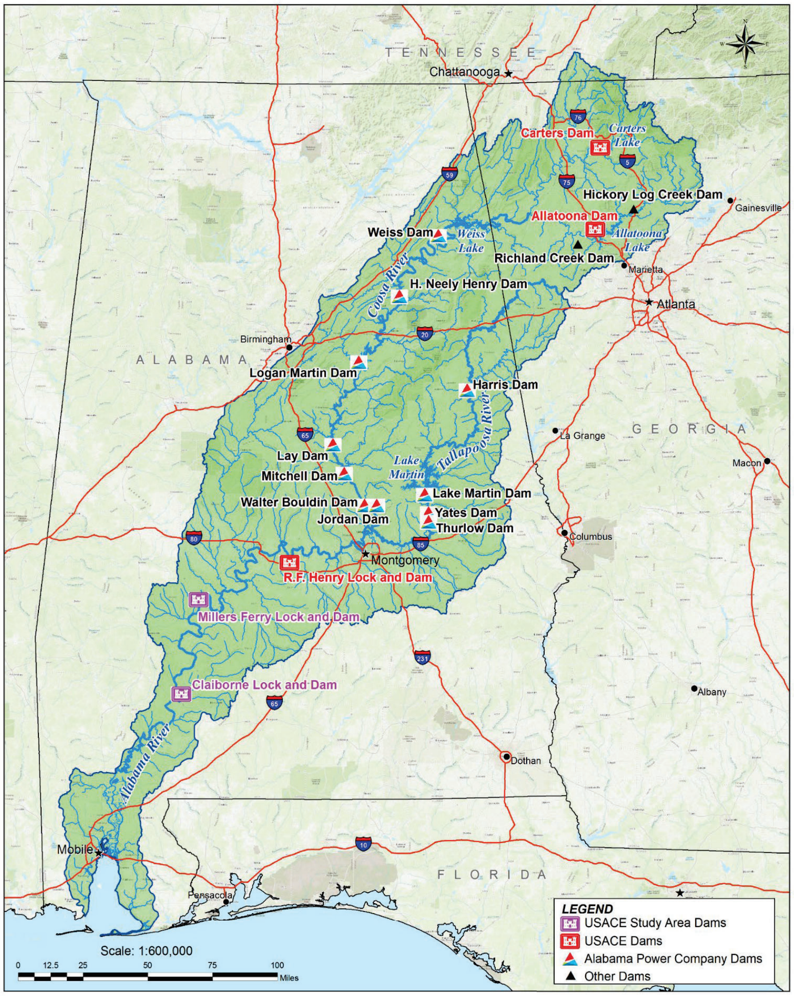


Figure 1. Map of the Alabama-Coosa-Tallapoosa River system that shows both public and private dam facilities. Claiborne and Millers Ferry L&D are the two lowermost dams and are part of the Corps' fish passage study. Map provided by the Corps during the TSP milestone meeting on March 1, 2023.

Millers Ferry L&D is located in Wilcox County about 133 miles upstream of the mouth of the Alabama River, 10 miles northwest of Camden, and 30 miles southwest of Selma, Alabama (Corps 2015). Construction began in 1964 and was completed in 1970. This structure includes a concrete gravity-type dam, a gated spillway, earth dikes, a navigation lock and control station, and a 90-megawatt power plant. Millers Ferry L&D is primarily used for hydropower and navigation. It is also authorized for public recreation, water quality, and fish and wildlife conservation and mitigation purposes (Corps 2015). William "Bill" Dannelly Reservoir extends approximately 105 miles upstream with the lower 25 miles located in Wilcox County and the upper 80 miles located in Dallas County. It has a volume of 346,254 acre-feet at full capacity (Corps 2015).

Claiborne L&D is located downstream of Millers Ferry L&D in Monroe County, Alabama, approximately 72.5 miles upstream of the mouth of the Alabama River (Corps 2014).

Construction began on this structure in 1966 and was completed in 1970. This structure includes a concrete gravity-type dam, a gated spillway, an un-gated free overflow spillway, earth dikes, and a navigation lock and control station. Claiborne L&D is primarily used as a navigation structure and regulates hydropower releases from Millers Ferry L&D. Other authorized purposes include water quality, public recreation, and fish and wildlife conservation and mitigation; however, the Corps does not consider recreation when making water control decisions (Corps 2014). This structure is also not used for flood risk management storage. Claiborne Reservoir extends about 60 miles upstream with the lower 28 miles located in Monroe and Clarke counties and the upper 32 miles located in Wilcox County. It has a volume of 102,480 acre-feet at full capacity (Corps 2014).

Alabama River Water Quality

Today, 44% of the Alabama River is inundated by reservoirs created by dams that were built from 1914 through the 1980s for hydropower generation and navigation (Freeman et al. 2005). As a result, altered flow regimes have negatively affected the diversity of the aquatic community. Dams create deep pool habitats with slow flows that collect silt and sediment that can favor non-native or invasive species (Boschung and Mayden 2004). Natural flow regimes help keep sand, gravel, and cobble substrates well oxygenated and free of silt and sediment, which provides essential habitat for many native species of fish, mussels, crayfish, snails, and other macroinvertebrates (Boschung. and Mayden 2004). Free-flowing riverine habitat is still found in the main stem of the Alabama River below dams and in major tributaries free from impoundments (Freeman et al. 2005); however, these sections of riverine habitat are fragmented which has caused declines in populations and genetic diversity of fishes, freshwater mussels, and other aquatic species. Surveys of sand and gravel bar habitat in the Alabama River have documented the importance of preserving this habitat to prevent further loss of fish biodiversity (Haley and Johnston 2014). Dredging and other anthropogenic activities continue to damage and destroy this bar habitat (Haley and Johnston 2014).

Degraded water quality in the Alabama River has also negatively affected the diversity of the aquatic community. Flow control at dams can lead to low dissolved oxygen events during periods of elevated water temperatures (Hartline et al. 2020). Although flow management strategies attempt to avoid these events, little is known about how nongame fishes cope with these conditions; additionally, lack of research and data on these species' reactions to adverse conditions means they are likely underrepresented when water quality criteria for dissolved oxygen levels are developed (Hartline et al. 2020).

The Alabama Department of Environmental Management (ADEM) is required by Section 303(d) of the Clean Water Act to identify impaired waters in the state (ADEM 2022). In 2022, ADEM listed 13 tributaries of the Alabama River that were impaired because of high levels of nutrients, pesticides, siltation, pathogens (*E. coli*), and/or metals (mercury) (ADEM 2022). Claiborne Lake, including Claiborne L&D, is listed for high levels of metals (mercury) due to atmospheric deposition (ADEM 2022).

Bioaccumulation of mercury in fishes can inhibit reproduction, growth, and survival; furthermore, age, fish size, and life history characteristics all determine the severity of these effects in different species (Crump and Trudeau 2009; Zillioux 2015; Zheng et al. 2019).

Sediment-bound pollutants or toxicants can be introduced into streams along with extrinsic sediments (Niraula et al. 2016). Toxicants, which include pesticides, ammonia, metals, and ions such as potassium, chloride, and sulfate, can disrupt growth, feeding, and reproduction in freshwater mussels, and prolonged exposure to toxicants can lead to death (Naimo 1995; Newton et al. 2003; Bringolf et al. 2007; Wang et al. 2016; Ciparis et al. 2019). Wang et al. (2016) also found that the few species of freshwater mussels that have been tested in toxicological studies are often common species that may be less sensitive to toxicants than species with a narrow endemic range. Freshwater gastropods, especially listed species, are more underrepresented in these studies even though they may be more sensitive to some toxicants than freshwater mussels (Gibson et al. 2016). Maintaining and improving water quality will be essential for long-term conservation of the diverse aquatic community in the Alabama River and for the recovery of its threatened and endangered species.

FISH AND WILDLIFE RESOURCES

Federally Listed and At-risk Species

There are several at-risk and federally listed species potentially present in or near the study area (Table 1) that could be affected by the addition of fish passage at Claiborne and Millers Ferry L&D. The following paragraphs briefly summarize life history information for each species.

Table 1. A list of at-risk and listed species that may be present in the study area or affected by fish passage at Claiborne and Millers Ferry L&D. Listed species are classified as threatened or endangered and are protected under ESA. At-risk species are those that are petitioned for listing, proposed threatened, proposed endangered, under discretionary review, or a candidate for listing. This table should not be used for Section 7 consultation.

COMMON NAME	SCIENTIFIC NAME	TYPE	FEDERAL STATUS
Alabama sturgeon	*Scaphirhynchus suttkusi*	Fish	Endangered
Gulf sturgeon	*Acipenser oxyrinchus (=oxyrhynchus) desotoi*	Fish	Threatened
Inflated heelsplitter	*Potamilus inflatus*	Clam	Threatened
Southern clubshell	*Pleurobema decisum*	Clam	Endangered
Spotted rocksnail	*Leptoxis picta*	Snail	Under review
Tulotoma snail	*Tulotoma magnifica*	Snail	Threatened
Tricolored bat	*Perimyotis subflavus*	Mammal	Proposed endangered
Alligator snapping turtle	*Macrochelys temminckii*	Reptile	Proposed threatened
Georgia rockcress	*Arabis georgiana*	Plant	Threatened

Georgia rockcress

Georgia rockcress is a perennial herb in the mustard family (Brassicaceae) that grows up to 90 cm (35.4 in) tall (Service 2021c). It grows in a variety of dry conditions, including shallow soil accumulations on rocky bluffs, ecotones of gently sloping rock outcrops, and in sandy loam along eroding riverbanks. It is occasionally found in adjacent mesic woods, but it will not persist in heavily shaded conditions. This species is adapted to high or moderately high light intensities and occurs on soils which are circumneutral to slightly basic. It is thought that seed dispersal mainly occurs by gravity and wind; however, surface runoff or flowing rivers likely facilitate long-distance dispersal. Georgia rockcress was historically distributed within the Ridge and Valley, Piedmont, and Southeastern Plains ecoregions of Alabama and Georgia, and it is currently considered extant in Dallas and Wilcox counties in Alabama (Service 2021c). Seventeen units of critical habitat have been designated for this species, including four units in Monroe, Wilcox, and Dallas counties (Service 2014 and 2021c)

Alligator snapping turtle
The alligator snapping turtle is the largest species of freshwater turtle in North America and can be found throughout river basins that drain into the Gulf of Mexico (Service 2021b). Most nesting occurs from April to May in the southern portion of the range, and nests have been observed from approximately 8 to 656 ft (2.5 to 200 m) landward from the nearest water body (Service 2021b). This species is associated with deep water habitats like large rivers, major tributaries, bayous, canals, swamps, lakes, ponds, and oxbows. Shallow water is occupied by adults in the summer and by hatchlings and juveniles, while deeper depths are occupied in late summer and mid-winter (Service 2021b).

Tricolored bat
The tricolor bat is a small bat that often appears yellowish to nearly orange (Service 2021d). This species' range includes the eastern and central United States and portions of southern Canada, Mexico and Central America. Suitable habitat consists of a wide variety of forested/wooded habitats where they roost, forage, and travel and may include some adjacent and interspersed non-forested habitats such as emergent wetlands and adjacent edges of agricultural fields, old fields, and pastures. This species occupies similar forest habitats in the spring, summer, and fall (i.e., non-hibernating seasons). However, in the southern portion of the range, where tricolored bats exhibit shorter torpor bouts and remain active and feed year-round, individuals may roost in culverts, bridges, cavities in live trees, live and dead leaf clusters, and/or Spanish moss during the winter (Service 2021d). Tricolored bats seem to prefer foraging along forested edges of larger forest openings, along edges of riparian areas, and over water and avoid foraging in dense, unbroken forests, and narrow road cuts through forests. Tricolored bats 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); therefore, these structures should also be considered potential summer habitat. This species faces extinction due to several threats, including the impacts of white-nose syndrome, a deadly disease that affects cave-dwelling bats across the continent (Service 2021d).

Spotted rocksnail
The spotted rocksnail has a shell that is globose in shape with an ovate and broadly rounded aperture (Garner et al. 2022). Juveniles have interrupted color bands that disappear in adults (Whelan et al. 2014). Females lay clutches of eggs that are coated with mucus in a spiral pattern (Whelan et al. 2014). Historically, this species was found in the Alabama River from Claiborne upstream to the Coosa River below Wetumpka, which is below the Fall Line, and from the confluence of the Alabama and Cahaba rivers upstream to Lily Shoals in Bibb County (Whelan et al. 2017). Currently, this species can be found in the Alabama River from river miles 46.0 to 233 and at one reintroduction site in the Cahaba River near Centreville (Whelan et al. 2017; Garner et al. 2022). Spotted rocksnail populations appear to be declining in the tailwaters of R.F.

Henry, Millers Ferry, and Claiborne L&D (Garner et al. 2023) and small numbers have been observed at the reintroduction site in the Cahaba River (Garner et al. 2022).

Tulotoma snail
Tulotoma snails have dark brown or black globosely conic shells with irregularly convex to straight whorls (Garner et al. 2022). Most shells have spiral bands of tubercles and are up to 35 mm in length (Garner et al. 2022). This species is endemic to the Alabama and Coosa River drainages and can be found in localized areas of the main stem Alabama and Coosa rivers and in the free-flowing lower reaches of several tributaries (Garner et al. 2016; Garner et al. 2022). Although this species has been found under large rocks and in bedrock crevices, side-scan sonar has been successfully used to target the boulder habitat that tulotoma snails are more commonly found in (Garner et al. 2016). During targeted surveys that used side scan sonar, live Tulotoma were documented at five sites on the Alabama River from river miles 198 to 269.2 (Garner et al. 2016). Live Tulotoma have also been found in tributaries of the Coosa River, including Hatchet Creek and Kelly Creek, and relic shells have been found at multiple sites in the Alabama and Coosa rivers (Garner et al. 2022). Recent observations of declines of spotted rocksnail and of overall aquatic snail density in the Alabama River may indicate similar population trends for Tulotoma snail, and ADCNR is currently assessing known populations of Tulotoma snail in the Alabama and Coosa rivers (Garner et al. 2023).

Inflated heelsplitter
The inflated heelsplitter is a unionid mussel endemic to the Mobile Basin that has a thin, moderately inflated shell (Williams et al. 2008). Generally, males are larger than females, and this species is considered a long-term brooder. Females release glochidia in the summer, and freshwater drum (*Aplodinotus grunniens*) are the only known host fish for this species (Table 10; Williams et al. 2008). Inflated heelsplitters grow rapidly, mature after one year of growth, and live for approximately eight years (Brown and Daniel 2014). These mussels inhabit large rivers and are found in slow to moderate current with sandy and muddy substrates. Inflated heelsplitter has been collected in the Alabama, Black Warrior, and Tombigbee rivers and from the lower reaches of large tributaries, including the Cahaba, Sipsey, and Noxubee rivers. The most recent record from the Alabama River drainage is one fresh dead shell collected in 1998 near the confluence of the Alabama and Tombigbee rivers (Williams et al. 2008).

Southern clubshell
The southern clubshell is a freshwater mussel that grows up to 93 mm in length and has a thick shell with an elliptical outline (Williams et al. 2008). This species is considered a short-term brooder, and gravid females release orange or white conglutinates filled with glochidia in June and July. Blacktail shiner (*Cyprinella venusta*) and striped shiner (*Luxilus chrysocephalus*) have been identified as primary and secondary fish hosts (Williams et al. 2008), and Alabama shiner (*Cyprinella callistia*) and clear chub (*Hybopsis winchelli*) have also been identified as fish hosts (Table 10). Historically, southern clubshell was found in large creeks and rivers throughout the Mobile Basin, including the Alabama, Coosa, Tallapoosa, and Tombigbee River drainages, in flow with gravel and sand substrates (Williams et al. 2008). Currently, this species is found in several drainages, including the Tombigbee River, the Conasauga River, the Coosa River, Big Canoe Creek, the Cahaba River, Bogue Chitto Creek, Bull Mountain Creek, the Buttahatchee River, and Sipsey River (Service 2008 and 2019a).

Although this species' status is considered improving since it is more widespread and has higher densities since its listing in 1993, southern clubshell distribution in the Alabama River drainage is limited to one reach in the main stem and several tributaries, including Sturdivant Creek, McCall Creek, the Cahaba River, and Bogue Chitto Creek (Service 2004, 2008, and 2019a). Two units of critical habitat in the Alabama River drainage have been designated for this species, including a reach of the Alabama River upstream of its confluence with the Cahaba River from river miles 189 to 234 and a reach of Bogue Chitto Creek from its confluence of the Alabama River upstream to Highway 80, both of which were occupied at the time of designation (Service 2004). No live or fresh dead southern clubshell were collected during dive surveys below Claiborne L&D in 2006, Millers Ferry L&D in 2007, and R.F. Henry L&D in 2008 (McGregor and Garner 2008) and below Claiborne L&D in 2023 (J. Garner pers. comm. 2024).

Alabama sturgeon

The Alabama sturgeon is a benthic fish that eats macroinvertebrates and grows to lengths of 0.7 to 0.8 m (2.3 to 2.6 ft) (Mettee et al. 1996). Most of its fins are brownish orange, and the body near the lateral scutes is yellow to tan while its belly and anal fin are white. Alabama sturgeon are endemic to the Mobile River basin, and were historically known from the Tombigbee, Alabama, Mobile, Tensaw, Black Warrior, Cahaba, Coosa, and Tallapoosa rivers (Kuhajda and Rider 2016). Several specimens have been collected from the Alabama River, including three adults downstream of Claiborne L&D (Mettee et al. 1996). Gravid females were collected in late March 1969 at the mouth of the Cahaba River; however, females collected in April and May 1985 from the Alabama River were not gravid (Mettee et al. 1996). Although specific spawning areas and larval drift have not been documented in Alabama sturgeon, it is likely that they spawn on hard bottom substrates in deep water and that successful larval development is dependent on long stretches of highly oxygenated, free-flowing water (Service 2009; Kuhajda and Rider 2016).

From 1997 to 2007, biologists used intensive, conventional efforts to sample Alabama sturgeon and only collected seven specimens, including one fish in the lower Cahaba River in 2000 and one fish that was sonic tagged and released below Claiborne L&D in 2007 (Rider and Hartfield 2007; Rider et al. 2011; Pfleger et al. 2016). The last specimen from the Alabama River was observed below Robert F. Henry L&D in 2009 (Rider et al. 2010; Pfleger et al. 2016). One environmental DNA (eDNA) sample collected in December 2014 detected Alabama sturgeon below Millers Ferry L&D, while samples collected in April, May, and July of 2015 detected the species at multiple sites, including Claiborne and Millers Ferry L&D (Pfleger et al. 2016). Precipitated eDNA sampling methodology has been used to detect Alabama sturgeon in both surface and benthic samples (Janosik et al. 2021). Benthic samples showed the first detections of the species in the Tombigbee River, which may provide overwintering habitat. Positive detections for Alabama sturgeon were also noted in the Alabama, Cahaba, and Mobile rivers in August and in the Alabama River in April (Janosik et al. 2021).

Alabama sturgeon critical habitat was designated in 2009 and encompasses 524 km (326 mi) of river channel in the Alabama and Cahaba rivers (Service 2009). The designated area in the Alabama River extends a total of 394 km (245 mi) from its confluence with Tombigbee River upstream to R.F. Henry L&D. In the Cahaba River, a total of 130 km (81 mi) of critical habitat is designated from its confluence with the Alabama River upstream to its cross with U.S. Highway 82 (Service 2009). Critical habitat is defined as areas that are occupied by the species and areas that are essential to its conservation, including those that are not occupied at the time of listing (Service 2009).

Gulf sturgeon
Similar to the Alabama sturgeon, Gulf sturgeon are benthic and feed on organisms that live in sediment, including bivalves, snails, crustaceans, and other macroinvertebrates (Service 2022a). Gulf sturgeon are usually considered a subspecies of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*); however, Robins et al. has recognized Gulf sturgeon as a separate species (2018). Gulf sturgeon grow up to lengths of 2.7 m (9 ft) and live for up to 50 years (NOAA 2022). Gulf sturgeon are anadromous and migrate from freshwater rivers to marine foraging habitat in the Gulf of Mexico in the winter (Service 2022a). These habitats are usually less than 7 m deep and well oxygenated with low turbidity and coarse or fine sand substrates (Service 2022a). Although these fish begin migrating to freshwater rivers in February and spawn in the spring (Mettee et al. 1996), fall spawning has also been documented in the Suwanee and Choctawhatchee rivers in Florida (Service 2022a). Gulf sturgeon have been detected during spring months using eDNA sampling in the Alabama, Cahaba, and Tombigbee rivers and below Claiborne, Millers Ferry, and R.F. Henry L&D (Rider et al. 2016; Pfleger et al. 2016). Gulf sturgeon with sonic tags have also been detected in the Alabama River below Claiborne L&D (Rider et al. 2016; Pfleger et al. 2016).

Priority State Protected Species

The species discussed in this section are considered priority state protected species by ADCNR and believed to occur in Clarke, Monroe, and Wilcox counties based on a combination of data from USFWS county and state lists and the Alabama State Lands Division's Natural Heritage Section Database of species occurrence data. Tables 2 (fishes), 3 (freshwater mussels and gastropods), 4 (crayfishes), 5 (salamanders), 6 (reptiles), and 7 (mammals) list these priority species by taxa. The following paragraphs briefly summarize life history information for priority state protected species, which include fishes, mollusks, crustaceans, amphibians, mammals, reptiles, and plants, that are known to occur within a 3-mile radius of the proposed fish passage projects at Claiborne and Millers Ferry L&D.

Table 2. A list of ADCNR priority state protected fishes that may be present in the project area(s) at Claiborne and/or Millers Ferry L&D. Priority ranked state protected species are categorized as follows: S1 = critically imperiled, S2 = imperiled, and S3 = vulnerable. In addition to State Wildlife Action Plan (SWAP) state species ranks, ADCNR has state protections, including species protected by Regulation 220-2-.92 (Nongame Species Regulation), 220-2-.98 (Invertebrate Species Regulation), 220-2-.26(4) (Protection of Sturgeon), 220-2-.94 (Prohibition of Taking or Possessing Paddlefish), and 220-2-.97 (Alligator Protection Regulation). Species with an asterisk (*) are known to occur within a 3-mile radius of the project area(s). This table is provided for informational purposes and should not be used for Section 7 consultation.

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
*Alabama shad	*Alosa alabamae*	S1	-

*Alabama sturgeon	*Scaphirhynchus suttkusi*	S1	Endangered
Alligator gar	*Atractosteus spatula*	S2	-
*Crystal darter	*Crystallaria asprella*	S3	-
Frecklebelly madtom	*Noturus munitus*	S1	-
*Gulf sturgeon	*Acipenser oxyrinchus (=oxyrhynchus) desotoi*	S2	Threatened
Ironcolor shiner	*Alburnops chalybaeus*	S1	-
Scaly sand darter	*Ammocrypta vivax*	S1	-

Alabama shad, Alabama sturgeon, crystal darter, and Gulf sturgeon are known to occur within a 3-mile radius of the proposed fish passage projects at Claiborne and Millers Ferry L&D. Alabama sturgeon and Gulf sturgeon are discussed in the previous section on pages 15 and 16. Alabama shad and crystal darter are discussed on pages 32 and 33. ADCNR believes that alligator gar, frecklebelly madtom, ironcolor shiner, and scaly sand darter occur within the county of the project area and could potentially occur at the project sites. These species are further discussed in the following paragraphs.

Alligator gar
The alligator gar is one of the largest freshwater fish in North America, and adults can reach lengths of greater than two meters (Boschung and Mayden 2004). Although this species is not usually found in inland waters in Alabama, it can be found in the Mississippi Sound, brackish waters of the Gulf Coast, and the Mobile-Tensaw Delta. Alligator gar typically inhabit slow flowing sections of large rivers, reservoirs, and bays in fresh, brackish, and occasionally salt water (Boschung and Mayden 2004). Little is known about reproduction for this species; however, reproductive hormone analyses indicate spawning likely occurs in late spring. Females mature at around 11 years of age and live up to 50 years, while males mature at six years and live up to 26 years (Boschung and Mayden 2004). Adults occupy 2.73-12.25 kilometer linear home ranges and are considered highly mobile, while juveniles exhibit site fidelity (Sakaris et al. 2003). Alligator gar abundance has declined in Alabama, and it is classified as a nongame species of moderate conservation concern (Armstrong and Purcell 2020). Recent ADCNR stockings and reported angler catches suggest alligator gar are present in the Alabama River upstream to Claiborne Lake (T. Fobian pers. comm. 2023).

Frecklebelly madtom
Frecklebelly madtoms are small ictalurids that consume aquatic invertebrates and likely live for up to three years (Boschung and Mayden 2004). In Alabama, this species is known from the upper Tombigbee, upper Alabama, and Cahaba rivers. These fish inhabit flowing, stable gravel riffles and river rapids with relatively low siltation and sedimentation and are associated with riverweed in the Cahaba River (Boschung and Mayden 2004). Ripe females have been collected from the Cahaba River in June and from the upper Tombigbee River in July and August. Frecklebelly madtoms have not been collected in the lower Alabama River since shortly after the construction of Claiborne and Millers Ferry L&D (Boschung and Mayden 2004; Bennett et al. 2008); however, positive eDNA samples collected in June 2018 in the Alabama River indicate potential species presence approximately 30-40 river miles downstream from Claiborne L&D (Janosik and Whitaker 2018). Seven historical sites in the Cahaba River were sampled in 2018,

and frecklebelly madtoms were recorded at six of those sites (Rider et al. 2018). The Service recently conducted a species status assessment (SSA) for frecklebelly madtom and determined that the Upper Coosa River distinct population segment (DPS) warrants protection as threatened with designated critical habitat and a 4(d) rule to provide for conservation of the species (Service 2020 and 2023).

Ironcolor shiner
The ironcolor shiner is a minnow that is distributed in the Atlantic and Gulf seaboards from New York south to Florida and west to Texas (Boschung and Mayden 2004). This species is also found in some inland Mississippi River Valley streams; however, it is considered uncommon in Alabama. In Alabama, ironcolor shiners occupy small, clear creeks with slow flow and likely breed in nuptial pairs from March to September in pools where fertilized eggs are broadcast and settle in the substrate (Boschung and Mayden 2004). In 2006, this species was found at one site in Franklin Creek in Mobile County (O'Neil et al. 2006). Surveys of historically occupied sites in 2023 did not yield any collections of ironcolor shiner, which indicates potential extirpation of this species from Alabama streams (T. Fobian pers. comm. 2024).

Scaly sand darter
Scaly sand darters are small percids found in sandy, shallow creeks and small rivers in the Pascagoula River, San Jacinto River drainage, lower Tennessee River drainage, Mississippi River basin, and several coastal drainages west of the Mississippi River (Boschung and Mayden 2004). In Alabama, this species has been collected in Franklin Creek in the Escatawpa River system. Scaly sand darters eat midge larvae and spawn from mid-April to mid-August (Boschung and Mayden 2004).

Table 3. A list of ADCNR priority state protected mollusks that may be present in the project area(s) at Claiborne and/or Millers Ferry L&D. Priority ranked state protected species are categorized as follows: S1 = critically imperiled, S2 = imperiled, and S3 = vulnerable. In addition to State Wildlife Action Plan (SWAP) state species ranks, ADCNR has state protections, including species protected by Regulation 220-2-.92 (Nongame Species Regulation), 220-2-.98 (Invertebrate Species Regulation), 220-2-.26(4) (Protection of Sturgeon), 220-2-.94 (Prohibition of Taking or Possessing Paddlefish), and 220-2-.97 (Alligator Protection Regulation). Species with an asterisk (*) are known to occur within a 3-mile radius of the project area(s). This table is provided for informational purposes and should not be used for Section 7 consultation.

COMMON NAME	SCIENTIFIC NAME	TYPE	STATE STATUS	FEDERAL STATUS
Alabama creekmussel	*Psuedodontoideus connasaugaensis*	Clam	S2	-
Alabama hickorynut	*Obovaria unicolor*	Clam	S2	Under review
*Alabama spike	*Elliptio arca*	Clam	S1	Under review
Black sandshell	*Ligumia recta*	Clam	S2	
*Delicate spike	*Elliptio arctata*	Clam	S2	Under review
Finelined pocketbook	*Hamiota altilis*	Clam	S2	

*Heavy pigtoe	*Pleurobema taitianum*	Clam	S1	Endangered
Inflated heelsplitter	*Potamilus inflatus*	Clam	S2	Threatened
*Orangenacre mucket	*Hamiota perovalis*	Clam	S2	Threatened
Ovate clubshell	*Pleurobema perovatum*	Clam	S1	Endangered
*Rayed creekshell	*Strophitus radiatus*	Clam	S2	Not listed
Southern clubshell	*Pleurobema decisum*	Clam	S2	Endangered
Southern hickorynut	*Obovaria jacksoniana*	Clam	S1	
*Southern monkeyface	*Theliderma metanevra*	Clam	S2	
Southern purple lilliput	*Toxolasma corvunculus*	Clam	S1	
Salt Spring hydrobe	*Pseudotryonia grahamae*	Snail	S1	
*Spotted rocksnail	*Leptoxis picta*	Snail	S2	Under review
Teardrop elimia	*Elimia lachryma*	Snail	S1	Under review
*Tulotoma snail	*Tulotoma magnifica*	Snail	S2	Threatened

Spotted rocksnail and tulotoma snail are discussed in the previous section on pages 13 and 14. Alabama spike, delicate spike, heavy pigtoe, southern monkeyface, orangenacre mucket, and rayed creekshell are known to occur within a 3-mile radius of the proposed fish passage projects at Claiborne and Millers Ferry L&D. These species are further discussed in the following paragraphs.

Alabama spike

The Alabama spike is a moderately inflated freshwater mussel that has an elongate elliptical outline with a straight ventral margin and lower, smaller pseudocardinal teeth than other similar species (Williams et al. 2008). This species is sexually mature at two years of age and is a short-term brooder that is gravid from late May through Late July. Redspot darter and blackbanded darter are considered primary hosts, and southern sand darter is a secondary host (Table 10; Williams et al. 2008). The Alabama spike is found in sand and gravel substrates in medium creeks to large rivers. This species is known from the Mobile River basin in Alabama, the Pascagoula and Pearl River drainages in Mississippi, and the Amite River in Louisiana (Williams et al. 2008). The Alabama spike was most recently collected from river mile 209.2 of the Alabama River in 1997 (one relic shell), the Cahaba River in 2004, and Claiborne L&D tailwaters in 2014 (T. Fobian pers. comm. 2024).

Delicate spike

The delicate spike is a compressed to slightly inflated mussel that has an elongate elliptical outline with a straight to slightly concave ventral margin and a thinner, more arcuate shell than similar species (Williams et al. 2008). This species is likely a short-term brooder that's gravid in spring and summer. Its fish host is unknown (Table 10; Williams et al. 2008). This species is found in moderate currents of creeks and rivers and under rocks in silt. The delicate spike is found in coastal drainages from the Apalachicola Basin west to the Pearl River drainage, which includes the Mobile Basin (Williams et al. 2008). Several live individuals of this species were collected below Claiborne L&D in 2006 (McGregor and Garner 2008).

Heavy pigtoe
The heavy pigtoe is a thick, anteriorly inflated mussel that has a bluntly pointed posterior margin and a shallow sulcus anterior of the posterior ridge (Williams et al. 2008). This species is a short-term brooder that is gravid in spring and summer. Although its fish host is unknown, similar species use cyprinids (Table 10; Williams et al. 2008). This species is endemic to the Mobile Basin and was historically found throughout the Tombigbee and Alabama rivers (Williams et al. 2008). In 2008, an individual was collected downstream of Robert F. Henry L&D (McGregor and Garner 2008), and currently, a single extant population of heavy pigtoe is known from the Alabama River, Dallas County, Alabama (Garner and Buntin 2011; Service 2021). No evidence of recruitment of heavy pigtoe within this population has been documented since its discovery in 2011, and propagation attempts have been unsuccessful (Service 2015).

Orangenacre mucket
The orangenacre mucket is a moderately inflated oval to elliptical mussel that has a narrowly rounded posterior margin, moderately inflated umbo, and brown to black rays (Williams et al. 2008). This species is a long-term brooder that is gravid from late summer or autumn until the spring. Females display superconglutinates that are creamy white with a broad black stripe and eyespot to attract their fish hosts, which include Cahaba bass, Alabama bass, and largemouth bass (Table 10; Williams et al. 2008). This species is extirpated from most of its historical large river habitat and is typically found in medium creeks in areas with slow to moderate current and sand and gravel substrates (Williams et al. 2008).

The orangenacre mucket was originally described from the Alabama River at Claiborne and occurs in the Alabama, Black Warrior, and Tombigbee River drainages; however, its exact distribution is uncertain because of its resemblance to finelined pocketbook (*Hamiota altilis*) (Williams et al. 2008). The orangenacre mucket is thought to be restricted to the western and southern reaches of the Mobile Basin (Williams et al. 2008). This species is currently found in numerous tributaries of the Tombigbee, Black Warrior, and Alabama rivers (Service 2019a). In the Alabama River drainage, the orangenacre mucket is found in the Cahaba River, Little Cahaba River, Big Flat Creek, Limestone Creek, and Bogue Chitto Creek (Service 2019a). Although populations of this species are small and localized, no known populations have been lost since it was listed in 1993 (Service 2019a).

Rayed creekshell
Mussels in the genus *Strophitus* exhibit elliptical to rhomboidal shells that are thin to moderately thick and inflated with a broadly rounded posterior ridge and have rudimentary pseudocardinal teeth (Williams et al. 2008). Rayed creekshell are typically collected in small to medium-sized creeks from slow to medium currents and from a variety of substrates, including mud, sand, or gravel (NatureServe Explorer 2023). This species is likely a long-term brooder, and its glochidial host(s) are currently unknown (Table 10; NatureServe Explorer 2023).

Historically, three species of *Strophitus* were thought to occur in Alabama; however, sympatric distribution between *Strophitus connasaugaensis* and *Strophitus subvexus* in the Mobile Basin, especially downstream of the Fall Line, highlighted the need for additional surveys (Williams et al. 2008). In 2018, a taxonomic review of molecular and morphological data identified polyphyly in the *Strophitus* genus (Smith et al. 2018). Smith et al. (2018) determined that *Anodontoides radiatus* should be included under *Strophitus radiatus* (rayed creekshell) to reflect shared ancestry and that the genus *Pseudodontoideus* should be resurrected to represent *Strophitus connasaugaensis* and *Strophitus subvexus*. In addition, Smith et al. (2018) identified and described two new species within the *Strophitus radiatus* complex, including *Strophitus williamsi* and *Strophitus pascagoulaensis*, and identified a third potential species. Although rayed creekshell was petitioned for listing in 2011, the Center for Biological Diversity withdrew the petition in 2023 based on new survey information, and the species was not listed under the Endangered Species Act.

Southern monkeyface
The monkeyface (*Theliderma metanevra*) is a moderately inflated mussel with a rounded anterior margin and an elevated posterior ridge that typically exhibits large knobs (Williams et al. 2008). The monkeyface is a short-term brooder, and females are gravid from May through July. In laboratory trials, spotfin shiner, bluntnose minnow, eastern blacknose dace, and creek chub have been used as fish hosts, while green sunfish, bluegill, and sauger have been observed with glochidia in the wild (Williams et al. 2008). This species can be found in sand and gravel substrates in the flowing waters of medium to large rivers. The monkeyface is distributed throughout the Mississippi, Ouachita, and Ohio river basins, downstream of Cumberland Falls in the Cumberland River drainage, and in the Tennessee River drainage (Williams et al. 2008). The monkeyface was thought to be found in the Mobile Basin below the Fall Line and in the upstream reaches of the Coosa River (Williams et al. 2008); however, recent genetic analyses have identified specimens from the Mobile Basin as a separate species known as southern monkeyface (*Theliderma johnsoni*) (Lopes-Lima et al. 2019). Although the southern monkeyface is considered extant in select river reaches of the Alabama, Cahaba, and Tombigbee rivers, little to no recruitment has been documented in these populations since the late 1990s (Williams et al. 2008).

Table 4. A list of ADCNR priority state protected crustaceans that may be present in the project area(s) at Claiborne and/or Millers Ferry L&D. Priority ranked state protected species are categorized as follows: S1 = critically imperiled, S2 = imperiled, and S3 = vulnerable. In addition to State Wildlife Action Plan (SWAP) state species ranks, ADCNR has state protections, including species protected by Regulation 220-2-.92 (Nongame Species Regulation), 220-2-.98 (Invertebrate Species Regulation), 220-2-.26(4) (Protection of Sturgeon), 220-2-.94 (Prohibition of Taking or Possessing Paddlefish), and 220-2-.97 (Alligator Protection Regulation). Species with an asterisk (*) are known to occur within a 3-mile radius of the project area(s). This table is provided for informational purposes and should not be used for Section 7 consultation.

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Capillaceous crayfish	*Procambarus capillatus*	S2	-
Cockscomb crayfish	*Procambarus clemmeri*	S2	-

*Crisscross crayfish	*Procambarus marthae*	S2	-
Lavender burrowing crayfish	*Fallicambarus byersi*	S2	-
Mobile crayfish	*Procambarus lecontei*	S2	-
Prominence riverlet crayfish	*Hobbseus prominens*	S2	-
Shrimp crayfish	*Faxonius lancifer*	S2	-

Crisscross crayfish
Crisscross crayfish have flat to slightly excavated rostrums with smooth floors, acumens shorter than their rostrums, and laterally compressed carapaces that are arched dorsoventrally (Schuster et al. 2022). Crisscross crayfish are endemic to Alabama and have been collected in the lower Alabama, Cahaba, and Tombigbee River drainages. This species is found around vegetation and plant debris in slow to moderate current in clay-bottomed streams and in ephemerally flooded ditches and fields. Little is known about the life history of this species, but it likely breeds in late fall or early winter and lays eggs in late winter or early spring since juveniles have been collected in April (Schuster et al. 2022).

Table 5. A list of ADCNR priority state protected amphibians that may be present in the project area(s) at Claiborne and/or Millers Ferry L&D. Priority ranked state protected species are categorized as follows: S1 = critically imperiled, S2 = imperiled, and S3 = vulnerable. In addition to State Wildlife Action Plan (SWAP) state species ranks, ADCNR has state protections, including species protected by Regulation 220-2-.92 (Nongame Species Regulation), 220-2-.98 (Invertebrate Species Regulation), 220-2-.26(4) (Protection of Sturgeon), 220-2-.94 (Prohibition of Taking or Possessing Paddlefish), and 220-2-.97 (Alligator Protection Regulation). Species with an asterisk (*) are known to occur within a 3-mile radius of the project area(s). This table is provided for informational purposes and should not be used for Section 7 consultation.

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Eastern tiger salamander	*Ambystoma tigrinum*	S2	-
Holbrook's southern dusky salamander	*Desmognathus auriculatus*	S1	-
*Red hills salamander	*Phaeognathus hubrichti*	S1	Threatened

Red Hills salamander
The Red Hills salamander is the official state amphibian of Alabama (Service 1983). It is a large, lungless salamander and was first collected in 1960 in Butler County, Alabama (Service 2013). The Red Hills salamander grows to a total length of about 11 inches, its body color is dark brown with no distinct markings, and it breathes through its moist skin (Service 1983). Red Hills salamanders likely complete their life cycle within burrows and occasionally leave their burrows to prey on invertebrates and land snails (Service 2013). This species is restricted to steep slopes in forested habitat within the Red Hills physiographic province in Alabama from the

Alabama River east to the Conecuh River (Service 2013). This species has been documented on bluffs adjacent to the Alabama River near Haines Island, Monroe County, Alabama (T. Fobian pers. comm. 2024).

Table 6. A list of ADCNR priority state protected reptiles that may be present in the project area(s) at Claiborne and/or Millers Ferry L&D. Priority ranked state protected species are categorized as follows: S1 = critically imperiled, S2 = imperiled, and S3 = vulnerable. In addition to State Wildlife Action Plan (SWAP) state species ranks, ADCNR has state protections, including species protected by Regulation 220-2-.92 (Nongame Species Regulation), 220-2-.98 (Invertebrate Species Regulation), 220-2-.26(4) (Protection of Sturgeon), 220-2-.94 (Prohibition of Taking or Possessing Paddlefish), and 220-2-.97 (Alligator Protection Regulation). Species with an asterisk (*) are known to occur within a 3-mile radius of the project area(s). This table is provided for informational purposes and should not be used for Section 7 consultation.

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Alligator snapping turtle	*Macrochelys temminckii*	S3	Proposed threatened
Black pinesnake	*Pituophis melanoleucus*	S1	Threatened
Black-knobbed map turtle	*Graptemys nigrinoda*	S3	-
Coal skink	*Plestiodon anthracinus*	S2	-
Gopher tortoise	*Gopherus polyphemus*	S2	Threatened
Harlequin coralsnake	*Micrurus fulvius*	S1	-
Southeastern five-lined skink	*Plestiodon inexpectatus*	S2	-
Speckled kingsnake	*Lampropeltis getula*	S2	-

Although none of the reptile state priority species listed in Table 6 are known to occur within a 3-mile radius of the proposed fish passage projects at Claiborne and Millers Ferry L&D, ADCNR believes that alligator snapping turtle, black pinesnake, black-knobbed map turtle, coal skink, gopher tortoise, harlequin coralsnake, southeastern five-lined skink, and speckled kingsnake occur within the counties of the project area and could potentially occur at the project sites.

Table 7. A list of ADCNR priority state protected mammals that may be present in the project area(s) at Claiborne and/or Millers Ferry L&D. Priority ranked state protected species are categorized as follows: S1 = critically imperiled, S2 = imperiled, and S3 = vulnerable. In addition to State Wildlife Action Plan (SWAP) state species ranks, ADCNR has state protections, including species protected by Regulation 220-2-.92 (Nongame Species Regulation), 220-2-.98 (Invertebrate Species Regulation), 220-2-.26(4) (Protection of Sturgeon), 220-2-.94 (Prohibition of Taking or Possessing Paddlefish), and 220-2-.97 (Alligator Protection Regulation). Species with an asterisk (*) are known to occur within a 3-mile radius of the project area(s). This table is provided for informational purposes and should not be used for Section 7 consultation.

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Brazilian free-tailed bat	*Tadarida brasiliensis*	S2	-
Eastern spotted skunk	*Spilogale putorius*	S2	-
Long-tailed weasel	*Mustela frenata*	S2	-
Rafinesque's big-eared bat	*Corynorhinus rafinesquii*	S1	-
Southeastern myotis	*Myotis austroriparius*	S1	-
Southeastern pocket gopher	*Geomys pinetis*	S2	-
Tricolored bat	*Perimyotis subflavus*	S2	Proposed endangered
*West Indian manatee	*Trichechus manatus*	S1	Threatened

West Indian manatee
West Indian manatees are mammals that eat vegetation and live in freshwater, brackish, and marine habitats (Service 2001). This species was downlisted from endangered to threatened in 2017 (Service 2017). During winter months, this species is concentrated in peninsular Florida or near warm water from natural springs and power plant outfalls. The Service primarily focuses on manatees in Florida and Puerto Rico for recovery activities; however, the species is managed and protected throughout its range which during the summer can extend north to Rhode Island and west to Texas on the Gulf coast (Service 2001). This species was observed below Claiborne L&D in June 2012 (T. Fobian pers. comm. 2024).

Traveler's delight (*Price's potato bean*)
Traveler's delight (*Apios priceana*), also known as Price's potato bean, is a member of the pea family Fabaceae and is a perennial vine that grows from a tuber. Individual plants are considered reproductive adults when their stem diameters are greater than two millimeters, and medium to large bees are efficient pollinators (Service 2016). This species is found in forest gaps or along forest edges, in open areas near or along the banks of streams, and in rights-of way (Service 1993). In Alabama, a total of 20 extant populations are found in Autauga, Butler, Dallas, Jackson, Lawrence, Madison, Marshall, Monroe, and Wilcox counties (Service 2022b).

<u>Fishes</u>

At least 184 fishes are native to the Alabama River, with 33 of these species considered endemic (Freeman et al. 2005; Haley and Johnston 2014). In 2005, ten fishes, including seven endemic species, were federally listed, and at least 28 fish species were considered vulnerable by experts (Freeman et al. 2005). From 2010-2011, fish assemblage surveys on the Alabama River from Dixie Landing at river mile 22 upstream to Claiborne L&D only documented 48 species (Haley and Johnston 2014). These samples were not similar to historical samples and indicate a temporal shift in the fish community and a loss of diversity (Haley and Johnston 2014). Of the known fishes that inhabit the Alabama and/or Cahaba rivers, five are federally listed, including Alabama sturgeon, Gulf sturgeon, blue shiner, Cahaba shiner, and goldline darter (Table 8). The frecklebelly madtom Upper Coosa River Distinct Population Segment (DPS) was listed as threatened in 2023, and coal darter is currently under review for federal protection (Table 8).

Table 8. A list of fishes that are present in the Alabama and/or Cahaba River drainages and their state and federal status (ADCNR and GSA unpublished dataset). Note that blue shiner (*Cyprinella caerulea)* is currently extirpated from both river systems. An asterisk (*) denotes species collected during Sustainable Rivers Project (SRP) sampling efforts in 2023 upstream of Millers Ferry L&D to downstream of Claiborne L&D (TNC unpublished data). SP denotes a species that is state protected under the Alabama State Nongame Species Regulation 220-2-.92, Protection of Sturgeon 220-2-.26(4), or Prohibition of Taking or Possessing Paddlefish 220-2-.94. The state ranking system abbreviations are defined as follows: S1 = critically imperiled, S2 = imperiled, S3 = vulnerable, S4 = apparently secure, S5 = secure, SX = presumed extirpated, and SE = exotic (ADCNR 2017).

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Alabama bass*	*Micropterus henshalli*	S5	-
Alabama darter	*Etheostoma ramseyi*	S5	-
Alabama hog sucker	*Hypentelium etowanum*	S5	-
Alabama shad	*Alosa alabamae*	S1	Under review
Alabama shiner	*Cyprinella callistia*	S5	-
Alabama sturgeon	*Scaphirhynchus suttkusi*	S1, SP	Endangered
Alligator gar	*Atractosteus spatula*	S3	-
American eel*	*Anguilla rostrata*	S4	-
Atlantic needlefish*	*Strongylura marina*	S5	-
Backwater darter	*Etheostoma zonifer*	S5	-
Banded pygmy sunfish	*Elassoma zonatum*	S5	-
Banded sculpin	*Cottus carolinae*	S5	-
Bay anchovy*	*Anchoa mitchilli*	S5	-
Bayou topminnow	*Fundulus notti*	S5	-
Bighead carp	*Hypopthalmichthys nobilis*	-	-
Black bullhead	*Ameiurus melas*	S5	-
Black crappie*	*Pomoxis nigromaculatus*	S5	-
Black madtom	*Noturus funebris*	S5	-
Black redhorse	*Moxostoma duquesnei*	S5	-
Blackbanded darter*	*Percina nigrofasciata*	S5	-
Blackside darter	*Percina maculata*	S5	-
Blackspotted topminnow*	*Fundulus olivaceus*	S5	-
Blackstripe topminnow	*Fundulus notatus*	S5	-
Blacktail redhorse*	*Moxostoma poecilurum*	S5	-
Blacktail shiner*	*Cyprinella venusta*	S5	-

Blue catfish*	*Ictalurus furcatus*	S5	-
Blue shiner	*Cyprinella caerulea*	S1, SP	Threatened
Bluegill*	*Lepomis macrochirus*	S5	-
Bluehead chub	*Nocomis bellicus*	S5	-
Bluenose shiner	*Pteronotropis welaka*	S2	-
Bluespotted sunfish	*Enneacanthus gloriosus*	S4	-
Bluntnose darter	*Etheostoma chlorosoma*	S5	-
Bluntnose minnow	*Pimephales notatus*	S5	-
Bowfin*	*Amia calva*	S5	-
Brown bullhead	*Ameiurus nebulosus*	S5	-
Bullhead minnow*	*Pimephales vigilax*	S5	-
Burrhead shiner	*Notropis asperifrons*	S5	-
Cahaba bass	*Micropterus cahabae*	S5	-
Cahaba shiner	*Notropis cahabae*	S1, SP	Endangered
Chain pickerel	*Esox niger*	S5	-
Channel catfish*	*Ictalurus punctatus*	S5	-
Cherryfin shiner	*Lythrurus roseipinnis*	S5	-
Chestnut lamprey	*Ichthyomyzon castaneus*	S5	-
Clear chub*	*Hybopsis winchelli*	S5	-
Coal darter	*Percina brevicauda*	S2	Under Review
Coastal shiner	*Notropis petersoni*	S5	-
Common carp*	*Cyprinus carpio*	-	-
Coosa chub	*Macrhybopsis etnieri*	S4	-
Creek chub	*Semotilus atromaculatus*	S5	-
Creek chubsucker	*Erimyzon oblongus*	S5	-
Crystal darter*	*Crystallaria asprella*	S3, SP	-
Cypress darter	*Etheostoma proeliare*	S5	-
Cypress minnow	*Hybognathus hayi*	S3	-
Dixie chub	*Semotilus thoreauianus*	S5	-
Dollar sunfish	*Lepomis marginatus*	S5	-
Dusky darter	*Percina sciera*	S5	-
Eastern mosquitofish	*Gambusia holbrooki*	S5	-
Emerald shiner*	*Notropis atherinoides*	S5	-
Everglades pygmy sunfish	*Elassoma evergladei*	S3	-
Fathead minnow	*Pimephales promelas*	S5	-
Flagfin shiner	*Pteronotropis signipinnis*	S5	-
Flathead catfish*	*Pylodictis olivaris*	S5	-
Flier	*Centrarchus macropterus*	S5	-
Fluvial shiner*	*Notropis edwardraneyi*	S4	-
Frecklebelly madtom	*Notutus munitus*	S1, SP	Threatened DPS
Freckled darter	*Percina lenticula*	S3	-

Freckled madtom	*Noturus nocturnus*	S5	-
Freshwater drum*	*Aplodinotus grunniens*	S5	-
Gizzard shad*	*Dorosoma cepedianum*	S5	-
Golden redhorse	*Moxostoma erythrurum*	S5	-
Golden shiner	*Notemigonus crysoleucas*	S5	-
Goldfish	*Carassius auratus*	-	-
Goldline darter	*Percina aurolineata*	S2, SP	Threatened
Goldstripe darter	*Etheostoma parvipinne*	S5	-
Grass carp	*Ctenopharyngodon idella*	-	-
Green sunfish*	*Lepomis cyanellus*	S5	-
Greenbreast darter	*Etheostoma jordani*	S5	-
Gulf darter	*Etheostoma swaini*	S5	-
Gulf logperch	*Percina suttkusi*	S5	-
Gulf menhaden	*Brevoortia patronus*	S5	-
Gulf sturgeon	*Acipenser oxyrinchus (=oxyrhynchus) desotoi*	S2, SP	Threatened
Harlequin darter	*Etheostoma histrio*	S5	-
Highfin carpsucker*	*Carpiodes velifer*	S5	-
Hogchoker*	*Trinectes maculatus*	S5	-
Inland silverside	*Menidia beryllina*	S5	-
Ironcolor shiner	*Notropis chalybaeus*	S1, SP	-
Johnny darter	*Etheostoma nigrum*	S5	-
Lake chubsucker	*Erimyzon sucetta*	S5	-
Largemouth bass*	*Micropterus salmoides*	S5	-
Largescale stoneroller	*Campostoma oligolepis*	S5	-
Least brook lamprey	*Lampetra aepyptera*	S5	-
Least killifish	*Heterandria formosa*	S4	-
Longear sunfish*	*Lepomis megalotis*	S5	-
Longjaw minnow	*Notropis amplamala*	S5	-
Longnose gar*	*Lepisosteus osseus*	S5	-
Longnose shiner	*Notropis longirostris*	S5	-
Mimic shiner*	*Notropis volucellus*	S5	-
Mississippi silvery minnow*	*Hybognathus nuchalis*	S4	-
Mobile chub*	*Macrhybopsis boschungi*	S3	-
Mobile logperch	*Percina kathae*	S5	-
Mooneye	*Hiodon tergisus*	S3	-
Mountain shiner	*Lythrurus lirus*	S4	-
Naked sand darter*	*Ammocrypta beanii*	S5	-
Orangefin shiner	*Notropis ammophilus*	S5	-

Orangespotted sunfish	*Lepomis humilis*	S5	-
Paddlefish*	*Polyodon spathula*	S3	-
Pirate perch	*Aphredoderus sayanus*	S5	-
Pretty shiner	*Lythrurus bellus*	S5	-
Pugnose minnow	*Opsopoeodus emiliae*	S5	-
Quillback*	*Carpiodes cyprinus*	S5	-
Rainbow shiner	*Notropis chrosomus*	S5	-
Rainwater killifish	*Lucania parva*	S4	-
Redbreast sunfish	*Lepomis auritus*	S5	-
Redear sunfish*	*Lepomis microlophus*	S5	-
Redfin pickerel	*Esox americanus*	S5	-
Redspot darter	*Etheostoma artesiae*	S5	-
Redspotted sunfish*	*Lepomis miniatus*	S5	-
Riffle minnow	*Phenacobius catostomus*	S5	-
River darter*	*Percina shumardi*	S5	-
River redhorse	*Moxostoma carinatum*	S5	-
Rock darter*	*Etheostoma rupestre*	S5	-
Rough shiner	*Notropis baileyi*	S5	-
Saddleback darter	*Percina vigil*	S5	-
Sailfin shiner	*Pteronotropis hypselopterus*	S5	-
Shadow bass	*Ambloplites ariommus*	S5	-
Sharpfin chubsucker	*Erimyzon tenuis*	S5	-
Silver chub*	*Macrhybopsis storeriana*	S5	-
Silverside shiner*	*Notropis candidus*	S5	-
Silverstripe shiner	*Notropis stilbius*	S5	-
Skipjack herring*	*Alosa chrysochloris*	S3	-
Skygazer shiner	*Notropis uranoscopus*	S3	-
Smallmouth buffalo*	*Ictiobus bubalus*	S5	-
Southeastern blue sucker*	*Cycleptus meridionalis*	S4	-
Southern brook lamprey	*Ichthyomyzon gagei*	S5	-
Southern flounder	*Paralichthys lethostigma*	-	-
Southern sand darter*	*Ammocrypta meridiana*	S5	-
Southern studfish	*Fundulus stellifer*	S5	-
Southern walleye	*Sander* sp. cf. *vitreus*	S4	-
Speckled darter*	*Etheostoma stigmaeum*	S5	-
Speckled madtom	*Noturus leptacanthus*	S5	-
Spotted bass	*Micropterus punctulatus*	S5	
Spotted gar*	*Lepisosteus oculatus*	S5	-
Spotted sucker	*Minytrema melanops*	S5	-

Stout silverside*	*Labidesthes vanhyningi*	S5	-
Striped bass	*Morone saxatilis*	S3	-
Striped mullet*	*Mugil cephalus*	S5	-
Striped shiner	*Luxilus chrysocephalus*	S5	-
Swamp darter	*Etheostoma fusiforme*	S5	-
Tadpole madtom	*Noturus gyrinus*	S5	-
Taillight shiner	*Notropis maculatus*	S4	-
Threadfin shad*	*Dorosoma petenense*	S5	-
Tricolor shiner	*Cyprinella trichroistia*	S5	-
Warmouth*	*Lepomis gulosus*	S5	-
Weed shiner*	*Notropis texanus*	S5	-
Western mosquitofish*	*Gambusia affinis*	S5	-
Western starhead topminnow	*Fundulus blairae*	S4	-
White bass*	*Morone chrysops*	S5	-
White crappie*	*Pomoxis annularis*	S5	-
Yellow bass	*Morone mississippiensis*	S5	-
Yellow bullhead	*Ameiurus natalis*	S5	-

In 2023, multi-agency sampling efforts funded by the Sustainable Rivers Project (SRP), a national partnership between the Corps and The Nature Conservancy (TNC), were conducted in the Alabama River upstream of Millers Ferry L&D, between Claiborne and Millers Ferry L&D, and downstream of Claiborne L&D (TNC unpublished dataset). A total of 24 sites were selected based on historical data and were sampled with a combination of sampling gears, including boat electrofishing shoreline habitats, seining gravel bar habitats, and trawling deep gravel bar habitats (TNC unpublished dataset; O'Neil et al. 2014). Preliminary results indicate that between all gears and sites, 54 total species were collected with 41 species collected during boat electrofishing, 21 species collected during seining, and 28 species collected during trawling (TNC unpublished dataset). Additional trawling will be conducted in spring 2024. Species collected during the 2023 sampling efforts are denoted with an asterisk in Table 8.

Alabama sturgeon and Gulf sturgeon have been discussed in the previous section on pages 15 and 16. In addition to these species, the Corps and other partners have identified priority fishes for passage that reflect community diversity of the Alabama River, including Mobile logperch, Gulf logperch, blacktail shiner, freshwater drum, chain pickerel, largemouth bass, skipjack herring, Alabama shad, striped bass, crystal darter, river redhorse, southeastern blue sucker, Mississippi silvery minnow, southern walleye, American eel, smallmouth buffalo, and paddlefish (Table 9; Corps 2023b). A number of these species have been tagged and monitored at Claiborne and Millers Ferry L&D and have been noted as species that would benefit from fish passage efforts (Mettee et al. 2005). The following paragraphs provide a brief summary of each species.

Table 9. A list of priority fishes for passage that reflect community diversity (ADCNR and GSA unpublished dataset; Corps 2023b). Migratory fishes are freshwater fish that exhibit significant linear migrations, and diadromous fishes are fish that migrate significant distances between

freshwater and saltwater. Game species refers to fishes that are pursued by anglers for recreational purposes. Spawning season encompasses the time of year that the species begins moving to spawning sites, time for spawning, and time for outmigration after the end of spawning.

COMMON NAME	SCIENTIFIC NAME	TYPE	SPAWNING SEASON
Alabama shad	*Alosa alabamae*	Migratory	Unknown[1]
Alabama sturgeon	*Scaphirhynchus suttkusi*	Diadromous	Unknown[2]
American eel	*Anguilla rostrata*	Diadromous	Late February-April-
Blacktail shiner	*Cyprinella venusta*	-	April-September
Chain pickerel	*Esox niger*	Game species	Late February-April
Crystal darter	*Crystallaria asprella*	-	Late February-April
Freshwater drum	*Aplodinotus grunniens*	Migratory	Late April-June
Gulf logperch	*Percina suttkusi*	-	Late January-March
Gulf sturgeon	*Acipenser oxyrinchus (=oxyrhynchus) desotoi*	Diadromous	Late February-May
Largemouth bass	*Micropterus salmoides*	Game species	Mid-April-June
Mississippi silvery minnow	*Hybognathus nuchalis*	-	Late February-April-
Mobile logperch	*Percina kathae*	-	Late January-March
Paddlefish	*Polyodon spathula*	Migratory	March-April-
River redhorse	*Moxostoma carinatum*	Migratory	Late March-May
Skipjack herring	*Alosa chrysochloris*	Diadromous	March-May
Smallmouth buffalo	*Ictiobus bubalus*	Migratory	Late March-June-
Southeastern blue sucker	*Cycleptus meridionalis*	Migratory	March-April-
Southern walleye	*Sander* sp. cf. *vitreus*	Game species	Late February-April
Striped bass	*Morone saxatilis*	Diadromous	March-June

[1]Spawning season is unknown, but Alabama shad are known to spawn in freshwater habitats with moderate current and sand substrates when water temperatures are 19-23˚C (Rider et al. 2021).

[2]Spawning season is unknown, but upstream movement of a sonic tagged male to Claiborne L&D tailwaters was documented in spring 2008 when water temperatures were 16-21˚C (Kuhajda and Rider 2016). Additionally, several gravid female Alabama sturgeon were captured in the mouth of the Cahaba River in late March 1969 (Kuhajda and Rider 2016). Experts estimate that spawning for this species likely occurs from late April until June (ADCNR and GSA unpublished dataset).

Mobile and Gulf logperch

The Mobile logperch is a slender bodied percid that reaches lengths of about six inches. This species likely spawns from midspring to early summer in gravel substrates with moderate currents in creeks and rivers (Boschung and Mayden 2004). Mobile logperch are endemic throughout the Mobile Basin, except in headwater streams, and are more frequently found above the Fall Line (Boschung and Mayden 2004). This species is the known fish host for several state protected and federally protected freshwater mussels, including southern combshell (endangered), Alabama moccasinshell (threatened), Coosa moccasinshell (endangered), and triangular kidneyshell (endangered) (Table 10).

Gulf logperch likely have a similar biology when compared to Mobile logperch. This species is often found in gravel-bottomed runs of large creeks and rivers and distributed throughout Gulf Coast drainages below the Fall Line in the Tombigbee and Alabama rivers west to Lake Pontchartrain tributaries (Boschung and Mayden 2004).

Blacktail shiner

Blacktail shiner and their subspecies can be found in schools from the Suwannee River drainage in Florida west to the Rio Grande in Texas and north in the Mississippi Basin to central Missouri and southern Illinois (Boschung and Mayden 2004). Blacktail shiner occupy moderately large, clear streams with sandy substrate and spawn from March to October (Boschung and Mayden 2004). Shiners are common fish hosts for freshwater mussels, and blacktail shiner are the known fish host for Gulf pigtoe, threehorn wartyback, southern clubshell (endangered), and warrior pigtoe (endangered) (Table 10).

Freshwater drum

Freshwater drum are silver, deep bodied fishes that are found in a variety of habitats and range throughout much of mid-America from the Rock Mountains to the Appalachians and from Hudson Bay south to Guatemala (Boschung and Mayden 2004). This species is not found in Gulf Coast streams east of Mobile Basin. Adults spawn in May when the temperature is 20˚C (Boschung and Mayden 2004). Freshwater drum are the known fish hosts for Amblema, butterfly, threehorn wartyback, fragile papershell, bluefer, and inflated heelsplitter (threatened) (Table 10).

Chain pickerel

Chain pickerel are widely ranging esocids that are adapted to live in a variety of habitats from lakes and impoundments with vegetation to large streams (Boschung and Mayden 2004). These fish can tolerate warmer water temperatures and higher levels of salinity than other esocids. In Alabama, adults spawn from fall to spring when temperatures range from 6˚ to 16˚C and broadcast eggs over vegetation and detritus in swampy streams and flooded lowlands (Boschung and Mayden 2004). Chain pickerel are known fish hosts for Alabama pearlshell (Table 10; Fobian et al. 2019).

Largemouth bass

The largemouth bass is a centrarchid whose native range includes Alabama and can be found in lakes, ponds, reservoirs, and pools of rivers (Boschung and Mayden 2004). This species is a popular sport fish and is the fish host for a variety of freshwater mussels, including Amblema, little spectaclecase, southern pocketbook, southern fatmucket, yellow sandshell, black sandshell, washboard, giant floater, pondmussel, paper pondshell, and southern rainbow (Table 10). Largemouth bass are also fish hosts for state protected and federally protected species, including Alabama rainbow (under review), finelined pocketbook (threatened), and orangenacre mucket (threatened) (Table 10).

Skipjack herring
Skipjack herring are alosines that have premaxilla that meet at an obtuse angle and 18 to 24 gill rakers on the lower limb of the first gill arch (Boschung and Mayden 2004). Although considered anadromous, skipjack herring can survive and reproduce in landlocked populations where silt-free sand and gravel substrates are available for spawning. This species typically spawns from March to April in the main channels of large rivers and has a lifespan of approximately 4 years (Boschung and Mayden 2004).

Historically, this species was found in the Missouri-Mississippi and Ohio River basins (Boschung and Mayden 2004). Today, it is known from the Gulf Coast in Florida to Texas, from freshwater rivers in Florida to Texas, and throughout the Mobile Basin below the Fall Line. Its populations in Alabama are considered stable (Boschung and Mayden 2004). Skipjack herring are fish hosts for several species of freshwater mussels, including rock pocketbook, elephantear, Alabama heelsplitter, and ebonyshell (Table 10).

Alabama shad
The Alabama shad is an anadromous species that differs from other alosines with premaxillaries that meet at an acute angle and 42 to 48 gill rakers on the lower limb of the first gill arch (Boschung and Mayden 2004). Adult 3-year-old males and 4-year-old females migrate up rivers from February to April to spawn in areas with coarse sand and gravel substrate and moderate current (Boschung and Mayden 2004). Fertilized eggs need clean, silt-free substrate in order to develop and hatch. Construction of dams and impoundments has fragmented and altered suitable habitat, which has contributed to the decline of this species (Smith et al. 2011).

Alabama shad were historically found throughout the Mississippi and Ohio River basins and their tributaries from Arkansas to West Virginia and in Gulf Coast tributaries from the Suwannee River in Florida to Mississippi (Boschung and Mayden 2004). In Alabama, it was found throughout the Mobile Basin below the Fall Line and in coastal rivers (Boschung and Mayden 2004). Although it has been petitioned for listing, the Alabama shad is not federally protected; however, ADCNR considers this species critically imperiled (S1), and it is rarely encountered during routine sampling efforts (Smith et al. 2011). Since 1994, five Alabama shad have been collected in the Alabama River (Rider et al. 2021). One specimen was collected below Claiborne L&D in 1994 and 2001 and below Millers Ferry L&D in 1995 and 1997. Biologists spent 129.5 hours conducting electrofishing surveys targeting Alabama shad from 2009-2018 and did not collect any of these fish (Rider et al. 2021).

Striped bass
Striped bass are anadromous fish that migrate to free-flowing rivers with sand, gravel, and rocky substrate to spawn (Boschung and Mayden 2004). In Alabama, this species was known to migrate up the Alabama River to the Coosa and Tallapoosa rivers before the construction of dams and may have been potamodromous or able to complete its life cycle within freshwater Gulf Coast streams (Boschung and Mayden 2004). Although the Alabama Marine Resources Division has attempted to restore Gulf Coast striped bass in the Alabama River by stocking, it is unlikely that the population is self-sustaining (Boschung and Mayden 2004).

Crystal darter
Crystal darters have long, slender bodies with enlarged pectoral fins and can be differentiated from other darters because they have a combination of 4 dark saddles and a forked caudal fin (Boschung and Mayden 2004). Historically, this species ranged from the upper Mississippi and Ohio river basins south to Arkansas and the Gulf Slope. In Alabama, this species was found in the Mobile Basin below the Fall Line and in the Conecuh-Escambia River system (Boschung and Mayden 2004). Crystal darters likely occur in the lower Cahaba, lower Tallapoosa, and Conecuh River systems (Boschung and Mayden 2004) and were collected from the Alabama River in 2016 (T. Fobian pers. comm. 2024). They begin spawning in February when water temperatures are 12˚C in moderate to swift currents of side-channel riffles with gravel substrate (Boschung and Mayden 2004). Although crystal darters are not known fish hosts, other species of darters are known fish hosts of multiple species of freshwater mussels in Alabama (Table 10).

River redhorse
River redhorse are one of the largest species of *Moxostoma* and have large molariform teeth that they use to crush mollusk shells (Boschung and Mayden 2004). River redhorse are distributed in Gulf Slope drainages from the Escambia River to Pearl River and the Mobile Basin, as well as in the upper Mississippi and Ohio basins. This species' stronghold in Alabama is the Cahaba River, where adults spawn over a 10-day period in mid-April when water temperatures range from 22.2˚ to 24.4˚C. River redhorse have been collected in the Alabama River below Millers Ferry L&D (Boschung and Mayden 2004) and Claiborne L&D as well as in the Cahaba River system (T. Fobian pers. comm. 2024).

Southeastern blue sucker
Southeastern blue sucker are large catostomids that have small heads and long dorsal fins (Boschung and Mayden 2004). This species was historically distributed throughout large rivers in the Mobile Basin and the Pascagoula and Pearl River drainages. During spawning runs, males turn an unusual deep blue color (Boschung and Mayden 2004), and in the Alabama River below Millers Ferry L&D, adults spawn in late March with water temperatures ranging from 15-17˚C (Mettee et al. 2004b). Surveys from 1995-2004 documented adults who spawned annually below Millers Ferry L&D for 10 years and two males that moved upstream and downstream past Claiborne L&D. One sonic and anchor tagged male was captured and recaptured for a total of 1,288 days and was detected 100 miles downstream of its original release site at Millers Ferry in 1999 and 93 miles upstream of its last detection in 2002 (Mettee et al. 2004b). Although the southeastern blue sucker is not a known host fish for freshwater mussels in Alabama, amblema have been documented using other catostomid species (Table 10).

Mississippi silvery minnow
Mississippi silvery minnows reach a maximum standard length of about 130 mm (5.12 in) (Boschung and Mayden 2004). This species is usually found in the eddy currents of pools and backwaters of moderately large streams where they feed on algae and organic detritus. These minnows are distributed throughout the Mississippi Basin from Minnesota to Louisiana, the Mobile Basin below the Fall Line, and west to the Brazos River in Texas and are likely extirpated from the Tennessee River. Although Mississippi silvery minnows are not known host fish, other species of minnows are host fishes for freshwater mussels in Alabama, including Gulf pigtoe (Table 10).

Southern walleye
Walleye are percids with large, glassy eyes that are native east of the Continental Divide in North America (Boschung and Mayden 2004). Southern walleye, also called Gulf Coast walleye, are genetically unique when compared to northern walleye and are native to the Mobile Basin (MDWFP 2023). ADCNR has documented a spawning population in Hatchet Creek, a tributary of Lake Mitchell, and a population in the Mulberry Fork, a tributary of the Black Warrior River (DeWitt 2017). ADCNR has also received reports from the public indicating these fish are present in the Cahaba, Tombigbee, and Alabama rivers (DeWitt 2017). Walleye are known host fish for black sandshell (Table 10).

American eel
American eels have elongated bodies with no pelvic fins and olive-green backs that fade to yellowish or white bellies (Boschung and Mayden 2004). This species is widely distributed and can be found in freshwater streams from Iceland to Colombia, which includes the Tennessee River drainage, Mobile Basin, and coastal streams from the Apalachicola to the Escatawpa rivers. American eels are catadromous, and juvenile eels, also called elvers, migrate from marine to fresh waters to feed and grow for several years before returning to the sea to spawn. These migrations are inhibited by dams (Boschung and Mayden 2004). ADCNR biologists have collected American eels in rocky shoals in the Coosa and Tallapoosa rivers below Jordan and Thurlow dams (ADCNR 2023b), and in the Cahaba River as far upstream as Shoal Creek in Shelby County, Alabama (Moss 2006). In 1992 and 1993, ADCNR also collected this species in beds of aquatic vegetation and by undercut mud banks in the Mobile Delta (ADCNR 2023b). This species has also been collected below Millers Ferry and Claiborne L&D, but it has not been collected below R.F. Henry L&D or in the Cahaba River system over the last 25 years (T. Fobian pers. comm. 2024). American eels are known host fish for rock pocketbook (Table 10).

Smallmouth buffalo
Smallmouth buffalo have deep bodies, relatively small and conical heads, and small inferior mouths (Boschung and Mayden 2004). This species is found in large rivers throughout the Mississippi River drainage and from the Mobile Basin to the Rio Grande. In Alabama, smallmouth buffalo are common in the Tennessee River and its large tributaries and in large rivers of the Mobile Basin (Boschung and Mayden 2004). Smallmouth buffalo were tracked in the Alabama River from its confluence with the Tombigbee River upstream to Millers Ferry L&D (RKM 225) from 2017-2020, and acoustic telemetry receiver arrays were positioned in the tailrace of Claiborne L&D to monitor fish movement (Hershey et al. 2022). During the study, 35 of 157 tagged smallmouth buffalo, including 16 females, 14 males, and 5 unknown sex fish, successfully passed Claiborne L&D. Passage for smallmouth buffalo was mainly limited to periods of high flow, and ripe male and female fish were noted in the Claiborne L&D tailrace (Hershey et al. 2022).

Paddlefish
Paddlefish are known for their unique spatula-like snout and heterocercal tail, which has unequal upper and lower lobes (Boschung and Mayden 2004). Historically, this species was widely distributed from the Des Moines and Platte rivers in the Midwest south to large streams of the Mississippi River drainage and Gulf Slope drainages from the Mobile Basin to the San Jacinto River in Texas. In Alabama, paddlefish are currently limited to the Mobile Basin below the Fall

Line, and numbers are declining in the Alabama River, especially above Millers Ferry L&D (Boschung and Mayden 2004). From 2002-2004, 33 paddlefish below Millers Ferry L&D and five below Claiborne L&D were sonic tagged and tracked (Mettee et al. 2004a). Of these fish, one individual moved through the lock chamber at Millers Ferry to Dannelly Reservoir, 31 fish inhabited the Alabama River between Claiborne and Millers Ferry L&D, and 20 fish moved downstream of Claiborne L&D. Six of the fish that moved downstream of Claiborne L&D travelled 180 miles to the Tensaw River below the I-65 bridge, which may indicate this area provides summer habitat for paddlefish that spawn in the Alabama River (Mettee et al. 2004a). Hershey et al. (2022) also tracked paddlefish in addition to smallmouth buffalo in the Alabama River from 2017-2020, and noted that 49 of 163 tagged paddlefish successfully passed Claiborne L&D. The paddlefish that passed were generally longer, and eight were female, 17 were male, and the remaining fish were of unknown sex (Hershey et al. 2022).

Freshwater Mussels

Freshwater mussels are filter feeders that influence ecosystem processes, including community respiration, algal clearance rates, and concentrations of ammonia, nitrate, and phosphorus in the water column (Williams et al. 2008). Presence of mussels usually indicates clean, flowing water and a lack of pollution, contaminants, and pesticides in an aquatic environment. Freshwater mussels provide food for some fishes, crayfish, salamanders, turtles, and other wildlife (Williams et al. 2008). Female freshwater mussels produce glochidia, which are larval parasites that must attach to host fish gills for the first few weeks of life in order to survive; furthermore, some species have evolved different host fish attraction strategies, including active mantle lures and conglutinates that both mimic host fish food. Hosts fishes, particularly those who migrate long distances, can transfer glochidia to new areas or between populations before they drop to the substrate as juveniles (Williams et al. 2008).

Alabama has more freshwater mussels than any other state at approximately 186 species that represent 43 genera and both Margaritiferidae and Unionidae (Williams et al. 2008 and 2017). The Mobile River basin has roughly 73 species of mussels with 34 of these species considered endemic. The eastern part of this drainage, which includes the Alabama River, has about 67 species with 30 considered endemic (Williams et al. 2008). Of the known mussel species that inhabit the Alabama and/or Cahaba rivers, 13 are federally listed and seven are under review for federal protection (Table 10).

Table 10. A list of freshwater mussels and their host fishes that are present in the Alabama and/or Cahaba River drainages and their state and federal status (ADCNR and GSA unpublished dataset; Williams et al. 2008). Known host fishes are also noted. SP denotes a species that is state protected under the Alabama State Invertebrate Species Regulation 220-2-.98. The state ranking system abbreviations are defined as follows: S1 = critically imperiled, S2 = imperiled, S3 = vulnerable, S4 = apparently secure, S5 = secure, SX = presumed extirpated, and SE = exotic (ADCNR 2017).

COMMON NAME	SCIENTIFIC NAME	HOST FISH(ES)	STATE STATUS	FEDERAL STATUS
Alabama creekmussel	*Pseudodontiodeus connasaugaensis*	Banded sculpin, Yellow bullhead	S2, SP	-

Alabama heelsplitter	*Lasmigona alabamensis*	Skipjack herring	S3	-
Alabama hickorynut	*Obovaria unicolor*	Naked sand darter, Southern sand darter, Redspot darter, Johnny darter, Gulf darter, Blackbanded darter, Dusky darter	S2, SP	Under Review
Alabama moccasinshell	*Medionidus acutissimus*	Naked sand darter, Southern sand darter, Johnny darter, Speckled darter, Gulf darter, Mobile logperch, Blackbanded darter, Saddleback darter	S1, SP	Threatened
Alabama pearlshell	*Margaritifera marrianae*	Redfin pickerel, Chain pickerel	S1, SP	Endangered
Alabama rainbow	*Cambraunio nebulosa*	Cahaba bass, Largemouth bass	S2, SP	Under Review
Alabama spike	*Elliptio arca*	Southern sand darter, Redspot darter, Blackbanded darter	S1, SP	Under Review
Coosa fiveridge	*Amblema elliottii*	-		
Threeridge	*Amblema plicata*	Centrarchids, Catostomids, Perch, Shiners, Freshwater drum, Channel catfish	S4	-
Bankclimber	*Plectomerus dombeyanus*	-	S5	-
Black sandshell	*Ligumia recta*	Largemouth bass, White crappie, Walleye	S2, SP	-
Bleufer	*Potamilus purpuratus*	Freshwater drum	S5	-
Butterfly	*Ellipsaria lineolata*	Freshwater drum	S4	-
Coosa moccasinshell	*Medionidus parvulus*	Mobile logperch, Blackbanded darter	SX, SP	Endangered
Coosa orb	*Pustulosa kieneriana*	-	S5	-
Delicate spike	*Elliptio arctata*	-	S2, SP	Under Review

Ebonyshell	*Reginaia ebenus*	Skipjack herring	S5	-
Elephantear	*Elliptio crassidens*	Skipjack herring	S4	-
Etowah heelsplitter	*Lasmigona etowaensis*	Banded sculpin	S2, SP	Under Review
Fawnsfoot	*Truncilla donaciformis*	Freshwater drum	S3	-
Finelined pocketbook	*Hamiota altilis*	Cahaba bass, Alabama bass, Largemouth bass	S2, SP	Threatened
Fragile papershell	*Potamilus fragilis*	Freshwater drum	S5	-
Giant floater	*Pyganodon grandis*	Largemouth bass, White crappie, Black crappie, Yellow bullhead, Brown bullhead	S5	-
Gulf mapleleaf	*Tritogonia nobilis*	Channel catfish	S3	-
Gulf pigtoe	*Fusconaia cerina*	Alabama shiner, Blacktail shiner, Pretty shiner, Orangefin shiner, Emerald shiner, Silverstripe shiner, Bluntnose minnow	S4	-
Heavy pigtoe	*Pleurobema taitianum*	-	S1, SP	Endangered
Inflated heelsplitter	*Potamilus inflatus*	Freshwater drum	S2, SP	Threatened
Lilliput	*Toxolasma parvum*	Green sunfish, Johnny darter, Warmouth, Orangespotted sunfish, Bluegill, White crappie	S4	-
Little spectaclecase	*Leaunio lienosa*	Green sunfish, Bluegill, Largemouth bass, Brown bullhead	S5	-
Orangenacre mucket	*Hamiota perovalis*	Cahaba bass, Alabama bass, Largemouth bass	S2, SP	Threatened
Ovate clubshell	*Pleurobema perovatum*	Striped shiner	S1, SP	Endangered
Paper pondshell	*Utterbackia imbecillis*	Largemouth bass, Black crappie	S5	-
Pistolgrip	*Tritogonia verrucosa*	Weed shiner, Black bullhead, Yellow bullhead, Brown bullhead, Channel catfish	S4	-
Pondhorn	*Uniomerus tetralasmus*	Golden shiner	S4	-

Pondmussel	*Sagittunio subrostrata*	Bowfin, Largemouth bass, Tadpole madtom	S4	-
Rayed creekshell	*Strophitus radiatus*	-	S2, SP	Not Listed
Ridged mapleleaf	*Quadrula rumphiana*	Channel catfish	S5	-
Rock pocketbook	*Arcidens confragosus*	American eel, Rock bass, White crappie, Skipjack herring, Channel catfish	S3	-
Round pearlshell	*Glebula rotundata*	Hogchoker, Green sunfish, Bluegill, Bay anchovy, Spotted gar	S4	-
Southern clubshell	*Pleurobema decisum*	Alabama shiner, Blacktail shiner, Striped shiner, Clear chub	S2, SP	Endangered
Southern combshell	*Epioblasma penita*	Mobile logperch, Blackbanded darter	SX, SP	Endangered
Southern creekmussel	*Pseudodontiodeus subvexus*	Alabama hogsucker, Tuskaloosa darter, Blackbanded darter, Creek chub, Longear sunfish		
Southern fatmucket	*Lampsilis straminea*	Bluegill, Alabama bass, Largemouth bass	S4	-
Southern hickorynut	*Obovaria arkansasensis*	-	S1, SP	-
Southern mapleleaf	*Quadrula apiculata*	Channel catfish	S4	-
Southern monkeyface	*Theliderma johnsoni*	-	S2, SP	-
Southern pocketbook	*Lampsilis ornata*	Alabama bass, Largemouth bass	S5	-
Southern purple lilliput	*Toxolasma corvunculus*	-	S1, SP	Under Review
Southern rainbow	*Villosa vibex*	Longear sunfish, Largemouth bass	S5	-
Stirrupshell	*Theliderma stapes*	-	SX	Endangered
Threehorn wartyback	*Obliquaria reflexa*	Gizzard shad, Blacktail shiner,	S5	-

		Bluntnose minnow, Mooneye, Walleye, Freshwater drum		
Triangular kidneyshell	*Ptychobranchus foremanianus*	Mobile logperch, Blackbanded darter	S1, SP	Endangered
True pigtoe	*Pleurobema verum*	-	SX	-
Upland combshell	*Epioblasma metastriata*	-	SX	Endangered
Warrior pigtoe	*Pleurobema rubellum*	Alabama shiner, Blacktail shiner, Creek chub	S1, SP	Endangered
Washboard	*Megalonaias nervosa*	Bluegill, Longear sunfish, Alabama bass, Largemouth bass, White crappie, Black crappie, Mooneye, Brown bullhead, Longnose gar	S5	-
Yellow sandshell	*Lampsilis teres*	Green sunfish, Largemouth bass, White crappie, Black crappie, Spotted gar, Longnose gar	S5	-

From 2006-2008, ADCNR and GSA sampled the riverine reaches by river mile (RM) below Claiborne (RM 38 – 71), Millers Ferry (RM 105.4 – 131.7), and Robert F. Henry (RM 203.9 – 237) L&D to determine the status of listed mussels, including southern clubshell (*Pleurobema decisum*), inflated heelsplitter (*Potamilus inflatus*), and heavy pigtoe (*Pleurobema taitianum*) (McGregor and Garner 2008). No southern clubshell or inflated heelsplitter were collected during the study. The following species were collected in all riverine reaches:

- Butterfly (*Ellipsaria lineolata*)
- Elephant-ear (*Elliptio crassidens*)
- Gulf pigtoe (*Fusconaia cerina*)
- Ebonyshell (*Fusconaia ebena*)
- Yellow sandshell (*Lampsilis teres*)
- Fragile papershell (*Potamilis fragilis*)
- Washboard (*Megalonaias nervosa*)
- Threehorn wartyback (*Obliquaria reflexa*)
- Bankclimber (*Plectomerus dombeyanus*)
- Bluefer (*Potamilus purpuratus*)

- Southern mapleleaf (*Quadrula apiculata*)
- Alabama orb (*Pustulosa asperata*)
- Monkeyface (*Quadrula metanevra*)
- Gulf mapleleaf (*Tritogonia nobilis*)
- Ridged mapleleaf (*Quadrula rumphiana*)
- Fawnsfoot (*Truncilla donaciformis*)

Delicate spike (*Elliptio arctata*) were only collected below Claiborne L&D, and an individual heavy pigtoe, southern pocketbook (*Lampsilis ornata*), and little spectaclecase (*Villosa lienosa*) were only collected below Robert F. Henry L&D. Rough fatmucket (*Lampsilis straminea*) and paper pondshell (*Utterbackia imbecillis*) were collected below Claiborne and Millers Ferry L&D (McGregor and Garner 2008).

Crayfish, Gastropods, and Benthic Macroinvertebrates

Crayfish are important in aquatic ecosystems because they are often the largest invertebrates with the largest biomass represented in these systems (Schuster et al. 2022). They are predators that eat other invertebrates, small fishes, amphibians, snails, and vegetation, and they provide food for some fishes and other wildlife. Crayfish live in nearly all freshwater aquatic habitats and some species build burrows (Schuster et al. 2022).

Fifty-eight species of crayfish, including 20 endemics, are found in the Mobile River basin (Schuster et al. 2022). There are currently records of 31 different species of crayfish from the Alabama and Cahaba rivers, including one under review for federal status and 11 that are state protected (Table 11; Schuster et al. 2022).

Table 11. The 11 species listed in this table are crayfish found in the Alabama and/or Cahaba River drainages that are state protected and/or under review for federal protection (ADCNR and GSA unpublished dataset). SP denotes a species that is state protected under the Alabama State Invertebrate Species Regulation 220-2-.98. The state ranking system abbreviations are defined as follows: S1 = critically imperiled, S2 = imperiled, S3 = vulnerable, S4 = apparently secure, S5 = secure, SX = presumed extirpated, and SE = exotic (ADCNR 2017).

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Angular dwarf crayfish	*Cambarellus lesliei*	S1, SP	-
Celestial crayfish	*Procambarus holifieldi*	S2, SP	-
Cockscomb crayfish	*Procambarus clemmeri*	S2, SP	-
Criscross crayfish	*Procambarus marthae*	S2, SP	-
Panhandle crayfish	*Procambarus evermanni*	S2, SP	-
Prominence riverlet crayfish	*Hobbseus prominens*	S2, SP	-
Shrimp crayfish	*Faxonius lancifer*	S2, SP	-
Smoothnose crayfish	*Procambarus hybus*	S2, SP	-
Southern prairie crayfish	*Procambarus h. hagenianus*	S2, SP	-
Speckled burrowing crayfish	*Creaserinus danielae*	S2, SP	Under Review

Spur crayfish	*Procambarus lewisi*	S2, SP	-

Freshwater snails, also called gastropods, scrape algae and feed on organic debris in streams and provide a food source for some fishes, turtles, and other wildlife (Johnson 2019). They are used as indicators of good water quality because of their sensitivity to pollution and contaminants. North America has the highest species richness of freshwater snails in the world, and 120 species were once found in the Mobile River basin; unfortunately, 38 of those species are now considered extinct (Johnson 2019). There are currently records of 53 unique species of gastropods in the Alabama and Cahaba rivers which represent 10 families, including Lymnaeidae, Physidae, Planorbidae, Viviparidae, Amnicolidae, Emmericidae, Hydrobiidae, Lithoglyphidae, Pleuroceridae, and Pomatiopsidae (ADCNR and GSA unpublished dataset). Twenty of these species are state and/or federally protected or under review (Table 12).

Table 12. The 20 species listed in this table are gastropods found in the Alabama and/or Cahaba River drainages that are state protected and/or have federal status or are under review (ADCNR and GSA unpublished dataset). SP denotes a species that is state protected under the Alabama State Invertebrate Species Regulation 220-2-.98. The state ranking system abbreviations are defined as follows: S1 = critically imperiled, S2 = imperiled, S3 = vulnerable, S4 = apparently secure, S5 = secure, SX = presumed extirpated, and SE = exotic (ADCNR 2017).

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	FEDERAL STATUS
Ample elimia	*Elimia ampla*	S2, SP	Under Review
Cahaba ancylid	*Rhodacmea cahawbensis*	S1, SP	-
Cahaba pebblesnail	*Clappia cahabensis*	S2, SP	-
Caper elimia	*Elimia olivula*	S3	Under Review
Cockle elimia	*Elimia cochliaris*	S1, SP	Under Review
Compact elimia	*Elimia showalterii*	S3	Under Review
Coosa pyrg	*Marstonia hershleri*	S1, SP	-
Cylindrical lioplax	*Lioplax cyclostomatiformis*	S1, SP	Endangered
Flat pebblesnail	*Lepyrium showalteri*	S1, SP	Endangered
Lilyshoals elimia	*Elimia annettae*	S2, SP	Under Review
Mud elimia	*Elimia alabamensis*	S3	Under Review
Oblong rocksnail	*Leptoxis compacta*	S1	Under Review
Princess elimia	*Elimia bellacrenata*	S1, SP	Under Review
Puzzle elimia	*Elimia varians*	S2, SP	-
Round rocksnail	*Leptoxis ampla*	S2, SP	Threatened
Spotted rocksnail	*Leptoxis picta*	S2, SP	Under Review
Squat elimia	*Elimia variata*	S2, SP	-
Teardrop elimia	*Elimia lachryma*	S1, SP	Under Review
Tulotoma	*Tulotoma magnifica*	S2, SP	Threatened
Watercress snail	*Fontigens nickliniana*	S1, SP	-

Benthic macroinvertebrates are important in aquatic food webs because they convert energy from aquatic plants, algae, and detritus to fishes. Caddisfly fauna were unknown in Alabama until statewide collections were evaluated in 1986, and three new species were identified (Harris

1986). In 1991, caddisflies were assessed again throughout Alabama, and 342 species representing 58 genera and 19 families were identified (Harris et al. 1991). Specimens from four families represented 71% of caddisfly fauna collected, which included Hydroptilidae (103 species), Leptoceridae (58 species), Hydropsychidae (48 species), and Polycentropodidae (34 species). In the Alabama River basin, 142 unique species of caddisflies were collected (Harris et al. 1991).

Benthic macroinvertebrates, including larval mayflies (*Ephemeroptera*), stoneflies (*Plecoptera*), and caddisflies (*Trichoptera*), are also used as biological indicators to monitor stream water quality and can be used to measure stream restoration success (Kenney et al. 2009). The Alabama Department of Environmental Management routinely collects macroinvertebrate samples to evaluate water quality of streams across the state (ADEM 2020).

<u>Invasive Species</u>

Non-native species that are introduced outside of their native ranges and that are harmful to the ecological environment, also called invasive species, have the potential to alter, damage, or destroy aquatic resources in Alabama (ADCNR 2021; U.S. Department of Interior 2021). ADCNR has defined these species as aquatic nuisance species (ANS) and developed a management plan to prevent, control, and manage the introduction of new and existing ANS in Alabama to minimize impacts on native species, environmental quality, human health, and economics. Of the 90 species evaluated, 22 were ranked, and ADCNR has identified bighead carp, blueback herring, common carp, grass carp, *Corbicula* clam, nutria, and several invasive plants, including, alligatorweed, brittle waternymph, dotted duckweed, *Lyngbya*, parrotfeather, and water hyacinthas present in the Alabama River drainage (Table 13; ADCNR 2021). The following paragraphs provide more information about these species.

Table 13. The species listed in this table are considered aquatic nuisance animals and plants of concern by the Alabama Aquatic Nuisance Species Task Force (ALANSTF) that are known to occur in the Alabama River drainage. Each species was ranked based on criteria within the following categories: ecological impact, current distribution and status, trend in distribution and abundance, management difficulty, and economic impact. Ranks of 3 are considered high threats, 2 are considered medium threats, and 1 are considered low threats (ADCNR 2021). The state ranking system abbreviations are defined as follows: SE = exotic (ADCNR 2017).

COMMON NAME	SCIENTIFIC NAME	STATE STATUS	ALANSTF RANK
Bighead carp	*Hypophthlmichthys nobilis*	SE	3.0
Blueback herring	*Alosa aestivalis*	SE	2.6
Common carp	*Cyprinus carpio*	SE	3.0
Grass carp	*Ctenopharyngodon idella*	SE	2.4
Corbicula clam	*Corbicula fluminea*	SE	3.0
Nutria	*Myocastor coypus*	SE	3.0
Alligatorweed	*Alternanthera philoxeroides*	SE	2.6
Brittle waternymph	*Najas minor*	SE	2.1
Dotted duckweed	*Landoltia punctata*	SE	2.3
Lyngbya	*Lyngbya wollei*	SE	2.4

Parrotfeather	*Myriophyllum aquaticum*	SE	2.3
Water hyacinth	*Eichhornia crassipes*	SE	2.8

Bighead carp
Bighead carp are dark gray in color with dark blotches along the body and off-white undersides (Boshchung and Mayden 2004; ADCNR 2021). This species has small cycloid scales, small eyes, wide mouths, and well-developed ventral keels (Boshchung and Mayden 2004; ADCNR 2021). Bighead carp are native to drainages of eastern China and found in large rivers (Boschung and Mayden 2004). This species' diet consists of zooplankton, algae, macroinvertebrate larvae, phytoplankton, and detritus. Bighead carp are pelagic spawners that reproduce from April to June during flood events in their native range. Females can produce up to one million eggs, and males headbutt females during spawning (Boschung and Mayden 2004). In Alabama, bighead carp have been collected in reservoirs in several systems, including the Tennessee River basin, Tallapoosa River, Alabama River, and Tombigbee River, and in several rivers of the Mobile River basin, including the Mobile and Tensaw rivers (ADCNR 2021). In the Alabama River, this species has been collected in Jones Bluff and Millers Ferry reservoirs, Claiborne Pool, and the Alabama River below Claiborne L&D. Small specimens of bighead carp have been collected below Millers Ferry powerhouse and in the Alabama River, which could indicate reproduction and recruitment. This species competes with sportfish and native fishes for habitat and forage and could reduce food availability for native freshwater mussels (ADCNR 2021).

Blueback herring
Blueback herring are silver fish with blueish green to gray backs that have larger eyes and greater body depth than alewife (ADCNR 2021). Blueback herring are anadromous and native to the Atlantic coast and ascend lower reaches of coastal rivers to spawn in the spring. In Alabama, this species has been documented in the Black Warrior, Tallapoosa, Chattahoochee, and Alabama River drainages. In 2017, a single specimen was collected from the Jones Bluff Reservoir on the Alabama River. Blueback herring consume fish eggs and larvae, which can impact sportfish populations, and they compete with other forage fishes like shad and sunfish for resources (ADCNR 2021).

Common carp
Common carp are large, deep bodied fish that have two pairs of barbels present on their upper jaws (Boschung and Mayden 2004; ADCNR 2021). Common carp are native to several drainages in Asia and are found in a variety of habitats, including low gradient streams, lakes, and reservoirs with organic matter and rooted vegetation (Boschung and Mayden 2004). This species' diet consists of aquatic plants, macroinvertebrates, crustaceans, mollusks, and detritus. Spawning begins in the spring and can occur when water temperatures range from 17˚C to 28˚C. Females can produce up to two million eggs and select shallow areas with aquatic plants to spawn with several males. Eggs are sticky and adhere to plants and rocks before hatching in 3-6 days (Boschung and Mayden 2004). Common carp are found in all major rivers of the Mobile Basin, in the Tennessee River basin, and in the Chattahoochee, Conecuh, and Choctawhatchee drainages (ADCNR 2021). This species may compete with native species that occupy the same ecological niche, such as carpsuckers (*Carpiodes* sp.) and buffalos (*Ictiobus* sp.) and can cause decreased habitat quality for native species (ADCNR 2021).

Grass carp
Grass carp are silvery to olive in color with long, slender bodies, subterminal mouths, and no barbels (Boschung and Mayden 2004; ADCNR 2021). This species is native to rivers and lakes of drainages in eastern Asia and spawns in moderate currents in rivers when water temperatures and water levels simultaneously rise (Boschung and Mayden 2004). Eggs are semipelagic and hatch after several days of drift. After hatching, larvae settle in backwater, lake, or reservoir habitats to feed and develop. Adult grass carp can eat their weight in vegetation each day and can grow to be one of the largest members of *Cyprinidae* (Boschung and Mayden 2004; ADCNR 2021). Grass carp are found in several river drainages of the Tennessee River basin and the Mobile Basin, including the Alabama River (ADCNR 2021).

Corbicula clam
Corbicula clams are yellowish to dark brown or black with moderately thick shells that are round in young individuals and triangular in older individuals (Williams et al. 2008). This species is native to eastern Asia, found in a variety of natural and man-made habitats, and is differentiated from similar species by its serrated lateral teeth (Williams et al. 2008). *Corbicula* clams are found throughout the state except in Baldwin and Lamar counties and in all drainages except the Perdido and Blackwater rivers (ADCNR 2021). This species can outcompete native freshwater mussels and clams for habitat and food and can clog water intake pipes (ADCNR 2021).

Nutria
Nutria are large rodents that have long, thin round tails and resemble beavers and muskrats (ADCNR 2021). This species is abundant in states along the Gulf of Mexico and has a viable, increasing population in the Alabama and Tombigbee River drainages. Nutria decimate native vegetation in wetlands and marshes, undermine water control structures when digging burrows, and feed on agricultural crops. They can also carry parasites that affect both humans and livestock, destroy waterbird nests, and are known to outcompete native muskrats for resources (ADCNR 2021).

Invasive aquatic plants
Alligatorweed, brittle waternymph, dotted duckweed, *Lyngbya*, parrotfeather, and water hyacinth are all invasive plants that have been observed in the Alabama River drainage (ADCNR 2021). Alligatorweed reproduces from stem fragments and can outcompete native vegetation by forming dense mats of vegetation along shorelines. If the mats are large enough, this species can alter water quality and the composition of the aquatic community. Brittle waternymph is a fragile submersed aquatic plant that can form dense stands in shallow water that hinders water recreation and inhibits forage efficiency of predatory fish (ADCNR 2021). This species can also outcompete native *Najas* species because it is more tolerant of turbid and eutrophic water conditions. Dotted duckweed is a tiny plant that floats and reproduces by vegetative budding to rapidly colonize still waterways. This species can impact the aquatic community by limiting sunlight penetration (ADCNR 2021).

Lyngbya is a blue-green algae that grows on the bottom of streams but can detach and form dense mats on the water's surface (ADCNR 2021). This species is found throughout Alabama, especially in small impoundments. *Lyngbya* can impede water navigation and angling activities, displace native vegetation, reduce fish spawning habitat, and cause fish kills. Parrotfeather is a rooted aquatic plant that reproduces asexually and is found in shallow areas of lakes, ponds, reservoirs, and slow-moving rivers and streams (ADCNR 2021). Parrotfeather can form dense mats that alter water quality, outcompete native shoreline vegetation, and impede water navigation. Water hyacinth is a large, floating aquatic plant that is mainly found in coves of reservoirs and backwater areas across Alabama. This species can reproduce asexually by forming daughter plants or sexually and can disperse individually across bodies of water or form dense mats. Water hyacinth can form large, floating mats that can outcompete native aquatic plants, degrade fish spawning areas and waterfowl habitat, and impact water quality (ADCNR 2021).

Migratory Birds

The study area at Claiborne and Millers Ferry L&D is located within the Mississippi Flyway. Several species of migratory birds from the Service's Birds of Conservation Concern (BCC) list (2021a) could be present in this area, including:

- American kestrel (*Falco sparverius paulus*)
- Bachman's sparrow (*Aimophila aestivalis*)
- Bald eagle (*Haliaeetus leucocephalus*)
- Brown-headed nuthatch (*Sitta pusilla*)
- Cerulean warbler (*Dendroica cerulea*)
- Chimney swift (*Chaetura pelagica*)
- Kentucky warbler (*Oporonis formosus*)
- Prairie warbler (*Dendroica discolor*)
- Prothonotary warbler (*Protonotaria citrea*)
- Red-headed woodpecker (*Melanerpes erythrocephalus*)
- Ruddy turnstone (*Arenaria interpres morinella*)
- Swallow-tailed kite (*Elanoides forficatus*)
- Wood thrush (*Hylocichla mustelina*)

Stressors like vegetation removal, invasive species introduction, artificial lighting, collision, entrapment, noise, chemical contamination, and fire can negatively affect migratory birds.

Wetlands

Wetlands are important in freshwater and marine ecosystems because they improve water quality, stabilize banks, reduce flood stages, and provide habitat for fish, birds, and other wildlife (McPherson 1996). In 2009, a national study estimated that the U.S. had approximately 110.1 million acres of wetlands, which was a decline of 62,300 acres from 2004 estimates (Dahl 2011). Of all wetlands, about 95% were classified as freshwater with four types identified, including forested wetlands (49.5%), freshwater emergent (26.3%), shrub wetlands (17.8%), and freshwater ponds (6.4%) (Dahl 2011). In 1992, the Service estimated that there were approximately 2.3 million to 3.1 million acres of wetlands in Alabama (McPherson 1996). Forested wetlands were mostly identified as bottom-land forests in alluvial flood plains, and a 50-mile conservation tract is protected within the Mobile-Tensaw River Delta. Scrub-shrub wetlands and emergent wetlands were identified as small and isolated, while riverine wetlands were identified as common in slow-flowing rivers in the Coastal Plain, which is the region south of the Fall Line (McPherson 1996). Water from river flooding and groundwater have supplied extensive areas of wetlands in the Coastal Plain. Over the past 200 years, as much as 50% of the estimated 7.6 million acres of wetlands in Alabama have been converted to other land uses, and 10% of interior wetlands were lost from 1956-1979 (McPherson 1996). Wetland restoration targets for the Upper Mississippi and Missouri basins have been estimated at 7% of the watershed to achieve water quality improvement and flood control on a landscape scale (Mitch and Gosselink 2000).

Recreational Features

The Alabama River in addition to Claiborne and William "Bill" Dannelly (Millers Ferry) reservoirs provide fishing and boating opportunities for the public. Millers Ferry Reservoir is known for its high-quality largemouth bass and spotted bass fisheries, and anglers also target white crappie, black crappie, channel catfish, and blue catfish in the reservoir and striped bass in its tailwaters (ADCNR 2023c). Millers Ferry Reservoir generated an estimated $2,528,141 in revenue in 2015 from associated angler expenses, including fuel, lodging, food, tournament fees, equipment, and bait (Gratz 2017). In Claiborne Reservoir, anglers target the same species except for spotted bass (ADCNR 2023a). ADCNR manages several recreational facilities along the Alabama River, including Portland Landing and Dallas Wildlife Management Area upstream of Millers Ferry L&D and Claiborne Landing downstream of Claiborne L&D. USACE also provides camping facilities near both reservoirs and manages approximately 5,600 acres of publicly accessible land for hunting along the Alabama River (Corps 2023c).

DESCRIPTION OF NO ACTION ALTERNATIVE

No Action Alternative

Dams prevent upstream and downstream migrations of fish as they search for food, shelter, and suitable spawning areas (Katopodis et al. 2001). Dams also alter the condition of upstream and downstream habitats, which can contribute to declines in all riverine fishes, but migratory fishes in particular are affected when these structures prevent access to habitat for spawning (Hershey et al. 2022). Freshwater mussels depend on fish hosts to complete their life cycles and fish host migrations to facilitate gene flow between populations (Vaughn 2012). Additionally, dams alter downstream habitats, which can cause a mussel extinction gradient until flowing, riverine habitat is recovered (Vaughn and Taylor 1999). Altered distribution and declining abundance of migratory fishes and freshwater mussels can lead to ecosystem-level effects, including loss of nutrient and energy inputs, reduced primary production and detrital processing, and reduced stream productivity, nutrient retention, and benthic stability (Freeman et al. 2003). In addition to localized effects, multiple dams in a river basin can result in cumulative effects that need to be further evaluated for effective conservation and management of riverine species (Cooper et al. 2016).

Similar to fishes and freshwater mussels, loss of suitable riverine habitat and population fragmentation from dam construction also negatively impacts populations of native crayfishes (Barnett and Adams 2021), gastropods (Tiemann 2013), and benthic macroinvertebrates (Krajenbrink et al. 2019). Downstream populations of round rocksnail are more genetically diverse than upstream populations, which indicates the conservation importance of uninterrupted gene flow between populations of gastropods (Whelan et al. 2019).

The Mobile River Basin supports a diverse aquatic community, which includes an endemic fauna of 40 fish, 33 freshwater mussel, and 110 gastropod species (Service 2000). These species have been negatively affected by channelization and impoundment of rivers, mining and dredging operations, and point and nonpoint pollution. At least 17 species of mussels and 37 gastropods are now considered extinct in the Mobile River Basin (Service 2000; Foighil et al. 2011; Whelan et al. 2012), and more than 20 fishes and mollusks are currently protected under the Endangered Species Act with nearly as many species under review for federal protection (Tables 8, 10, and 12). Continued degradation of riverine habitat and loss of aquatic species will persist without restoration of natural flow regimes to rivers in this ecosystem.

<u>Fish Passage</u>

Fish ladders were first designed and implemented in North America around 200 years ago (Katopodis and Williams 2011; Matica 2020). Different types of fish passage structures have been developed over time; however, they are usually designed for a target species and do not consider the needs of the native fish community (Matica 2020). These structures are also designed to facilitate upstream migration and do not fully consider the importance of downstream movements of fishes post-spawn (Larinier 2001). Mortality from interaction with hydraulic turbines or over spillways can negatively affect population numbers and stability (Larinier 2001). Downstream passage can involve the use of screens to prevent fish from interacting with turbines, of surface bypasses, or of behavioral guidance devices, although the latter devices are considered experimental (Larinier 2001). Downstream fish passage success is dependent on understanding how fishes respond to accelerating flows at different times of their life cycles and how they respond to different screens or attractants at passage structures (Enders et al. 2009). In addition to adult fish migrating downstream post-spawn, downstream dispersal of juvenile fishes is also important for population stability and survival (Pavlov and Mikheev 2017). Larval drift of broadcast spawners like sturgeon is also affected by restricted flows at dams (Marotz and Lorang 2018), which can prevent successful reproduction.

Conventional fish passage structures use materials like concrete for construction, while nature-like fishways, also called bypass channels, use ecological materials like rock to mimic natural conditions (Katopodis et al. 2001). Bypass channels were developed in the 1990s to create habitat and facilitate movement for diverse aquatic communities and migratory fishes (Katopodis and Williams 2012). Often, these channels are the preferred passage solution for low-head barriers, provided there is ample space for construction. Several variations of bypass channels are used worldwide, but pool and riffle and rocky ramp are the most commonly used types (Katopodis and Williams 2012). Pool and riffle bypass channels are built in stair-step configurations that connect short, steep sections called riffles to flat, long reaches called pools, while rocky ramps are typically long, sloping channels with refugia designed to provide resting areas for fishes. Efficiency and passability of bypass channels are dependent on similar factors to other fish passage structures, including entrance location (Katopodis and Williams 2012).

PROPOSED ALTERNATIVES AND RECOMMENDED PLAN

The Corps began this study with an initial array of 17 alternatives, which was focused into 10 alternatives that included partial and/or full dam removal at one or both locations. Alternatives that included full and/or partial dam removal were screened from further consideration because of impacts to navigation, hydropower, and water supply and the estimated cost of removal. The following alternatives were selected by the Corps for final consideration for habitat modelling and economic analysis:

- Alternative 1: No action
- Alternative 3: Fixed weir rock arch both dams
- Alternative 5d: Natural bypass channel both dams
- Alternative 12b: Fixed weir rock arch at Claiborne L&D and natural bypass channel at Millers Ferry L&D
- Alternative 13b: Natural bypass channel at Claiborne L&D and fixed weir rock arch at Miller's Ferry L&D

The Corps used two planning suite models, including the cost effectiveness/incremental cost analysis (CE/ICA) model and the multi-criteria decision analysis (MCDA) model, to rank each alternative. Table 14 describes the criteria and metrics used for these analyses. Alternative 5d, which includes natural bypass channels at both Claiborne and Millers Ferry L&D, was announced by the Corps as the tentatively selected plan (TSP) on March 1, 2023. The following paragraphs detail the criteria and metrics used to evaluate the final array of alternatives and how Alternative 5d was scored.

Table 14. Criteria and metrics used for analysis of final array. This table was presented by the Corps during the TSP milestone meeting on March 1, 2023.

Criteria	Metric	Description
Cost	Dollars—real estate and construction	Class four cost estimates for final array
Ecological Lift	Habitat Units	Fish Passage Connectivity Index x Habitat
Named Entity Recognition (NER) Benefits	Habitat Benefit Analysis	Determined using CE/ICA (Habitat Units and Cost)
National Economic Development (NED) Benefits	Impact to Hydropower—MWH/Dollars	Determine lost or gained hydropower in MWH and convert to dollars
Environmental Quality (EQ) Benefits	Habitat Units	Fish Passage Connectivity Index x Habitat
Regional Economic Development (RED) Benefits	Employment and Value Added	Use RECONS to compare final array
Other Social Effects (OSE) Benefits	Habitat Units	Actions to halt biodiversity loss generally benefit the climate
Sponsor Support	Yes/No	Does the sponsor support the alternative?

A group of 19 priority fishes selected by experts to represent the diversity of the fish community was modelled to evaluate habitat availability and fish passability of the different alternatives (Table 9; Corps 2023b). These fishes were incorporated into a fish passage connectivity index (FPCI) model to obtain a connectivity value for each alternative by assessing passability, encounterability, passage location, and time of passage available. Alternative 5d, which includes natural bypass channels at both dams, scored the highest of all alternatives with an FPCI value of 0.523. The Nature Conservancy (TNC) assessed and quantified available habitat for each species within the study area. These habitat units were calculated by multiplying the connectivity values by the available habitat on a per species basis and then averaged. Alternative 5d had the highest average habitat units available at 1,005,661 units and the highest environmental quality (EQ) score.

Total project cost estimates were calculated by evaluating several factors, including construction and construction management, real estate, PED, contingencies, and escalation estimates. An abbreviated risk analysis method was used to estimate contingencies. The total project cost for Alternative 5d was the lowest at $188 million, and it was also the most cost effective (CE) at $8.45 average cost per habitat unit.

Impact to hydropower (MWH/dollar), impact to navigation (tonnage/dollar), and impact to recreation (unit-day) values were calculated and combined to provide a national economic development (NED) account score for each alternative for 2023. Alternative 1 (no action) had the highest value at $18,621,994 while Alternative 5d had a lower value at $17,315,220.

The Corps used a certified regional economic model called Regional Economic System (RECONS) to determine MCDA scores for each alternative. Alternative 5d was ranked among the lowest with $347,992,000 gross regional product for Alabama and 3,211 full-time equivalent jobs created. The Corps used an other social effects (OSE) analysis to evaluate benefits to disadvantaged communities and focused on increased ecosystem resiliency metrics. Alternative 5d was ranked the highest with a score of 1.000.

Finally, a comprehensive plan determination multi-criteria decision analysis (MCDA), which incorporated EQ, RED, NED, and OSE values, was used to rank all alternatives. Alternative 5d had the highest comprehensive score at 3.538. The Corps also noted that natural bypass structures at both dams is the preferred alternative of The Nature Conservancy, the non-federal sponsor.

Channel design for Millers Ferry natural bypass includes rock channel construction, 100 ft bottom width, 1V:3H side slopes, 0.005 channel slope, 8,500 ft channel length, 1200 cfs flow rate at normal pool elevation, 4.2 ft/s mean velocity within channel, and 6.6 ft/s maximum velocity within channel (Figures 2 and 3). Channel design for Claiborne natural bypass includes rock channel construction, 75 ft bottom width, 1V:3H side slopes, 0.013 channel slope, 2,100 ft channel length, 600 cfs flow rate at normal pool elevation, 4.0 ft/s mean velocity within channel, and 5.5 ft/s maximum velocity within channel (Figures 2 and 3). The Corps has noted that additives for attraction to fish passage structures will be added to each structure; however, those additives have not been added to the overall structure design at the time of this report.

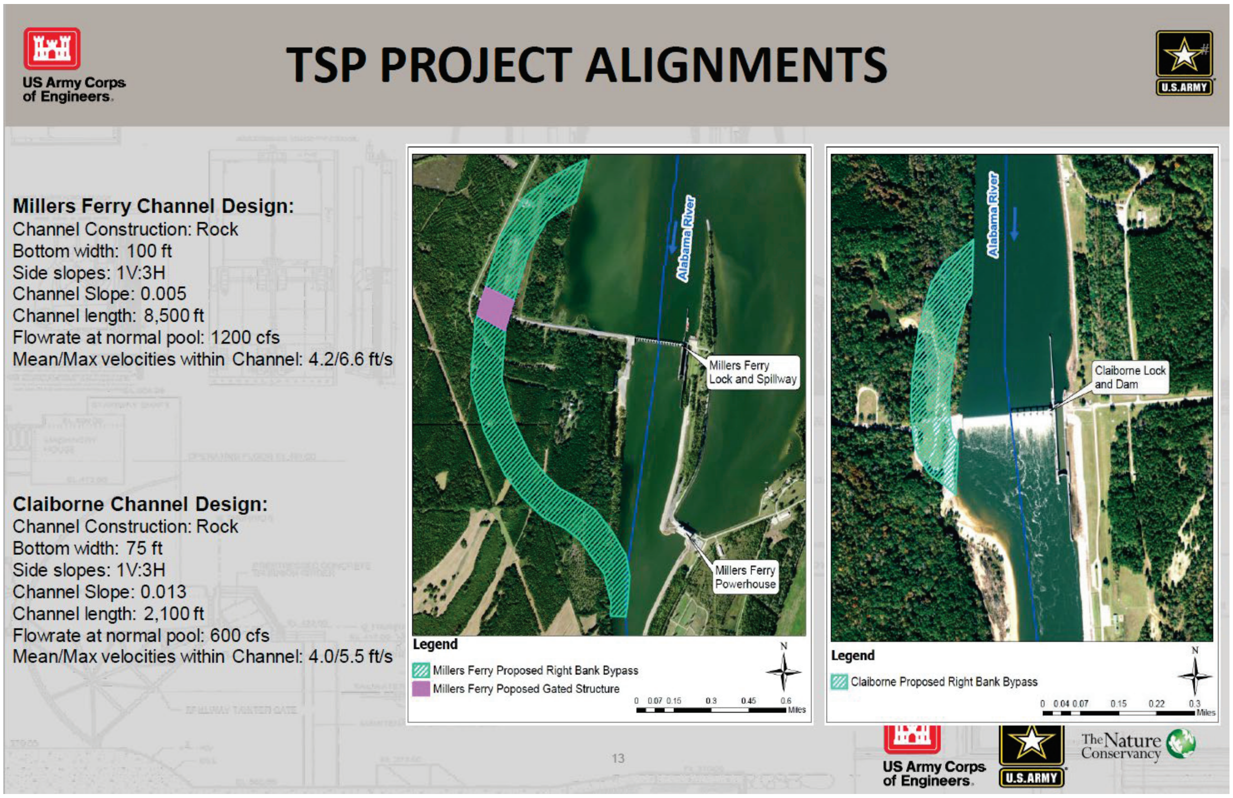
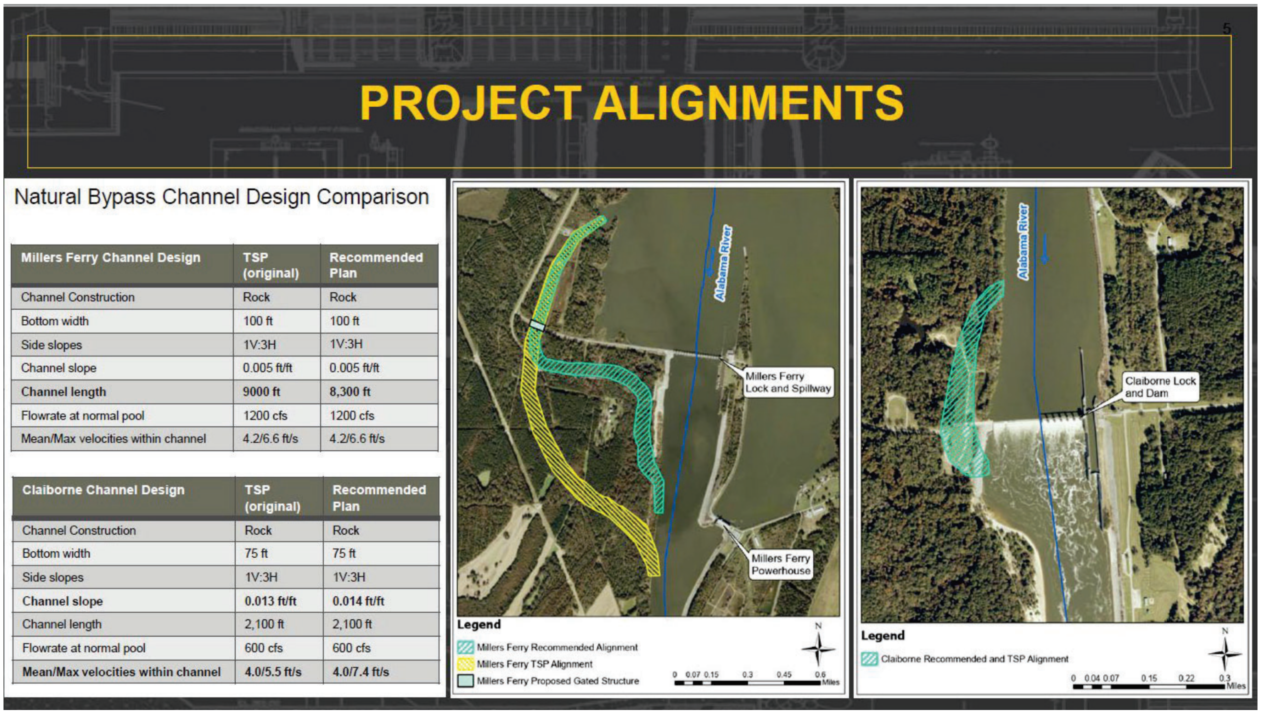


Figure 2. Initial design of natural bypass structures at Claiborne and Millers Ferry L&D (USACE, TSP Milestone Meeting, March 1, 2023).

On September 28, 2023, the selected TSP was approved as the recommended plan at the Agency Decision Milestone meeting (Corps 2023b). The estimated cost for the Recommended Plan was initially $161.2 million but has been updated to approximately $184.3 million (Corps 2024b). The channel alignment at Claiborne L&D did not change; however, its design was altered to include stop logs to control flows during maintenance activities, additional erosion protection, and a sheet-pile cutoff wall between the bypass channel and the river (Figures 2, 3, and 4). The channel alignment at Millers Ferry L&D was altered to avoid private lands and is now fully on federally owned property (Figures 2, 3, and 5). In addition, the gate structure design now includes four slots that will be opened and closed as needed to maintain pool level during high and low flows (Corps 2023b).



Millers Ferry Channel Design	TSP (original)	Recommended Plan
Channel Construction	Rock	Rock
Bottom width	100 ft	100 ft
Side slopes	1V:3H	1V:3H
Channel slope	0.005 ft/ft	0.005 ft/ft
Channel length	**9000 ft**	**8,300 ft**
Flowrate at normal pool	1200 cfs	1200 cfs
Mean/Max velocities within channel	4.2/6.6 ft/s	4.2/6.6 ft/s

Claiborne Channel Design	TSP (original)	Recommended Plan
Channel Construction	Rock	Rock
Bottom width	75 ft	75 ft
Side slopes	1V:3H	1V:3H
Channel slope	**0.013 ft/ft**	**0.014 ft/ft**
Channel length	2,100 ft	2,100 ft
Flowrate at normal pool	600 cfs	600 cfs
Mean/Max velocities within channel	**4.0/5.5 ft/s**	**4.0/7.4 ft/s**

Figure 3. Updated design of natural bypass structures at Claiborne and Millers Ferry L&D (USACE, Agency Decision Milestone Meeting, September 28, 2023).

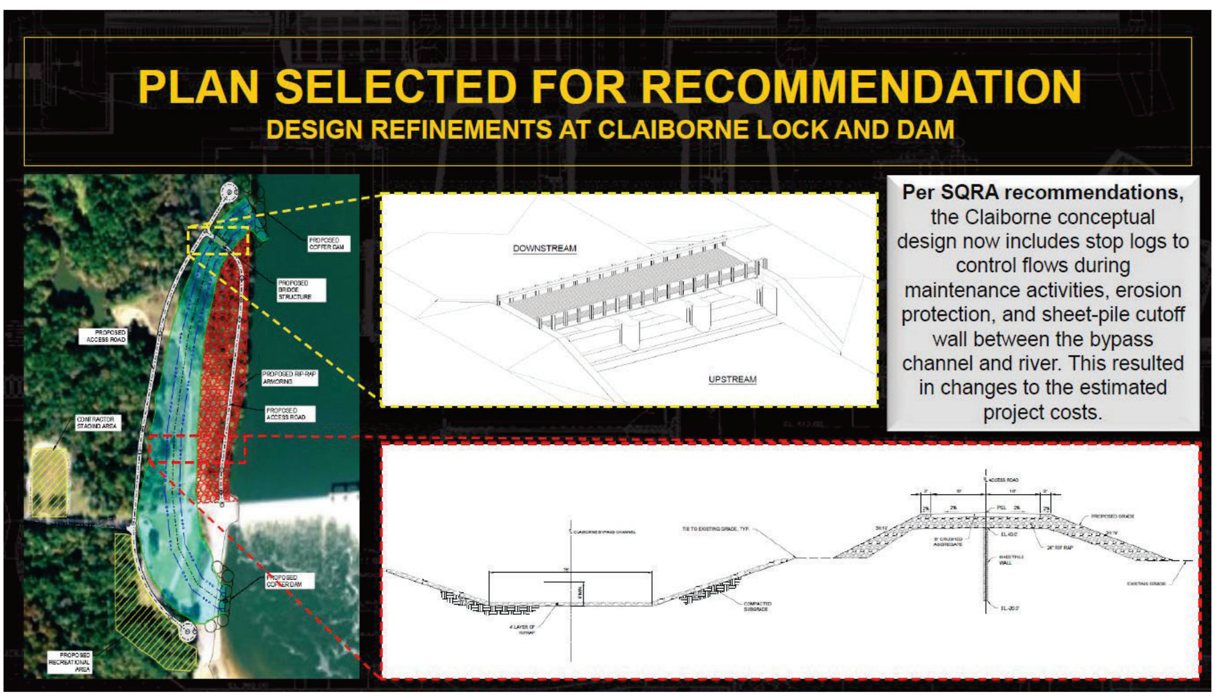


Figure 4. The updated design of the fish bypass structure at Claiborne L&D includes stop logs to control flows during maintenance activities (yellow box), increased erosion protection by armoring with riprap (shaded red area), and a sheet-pile cutoff wall between the bypass channel and the river (red box).

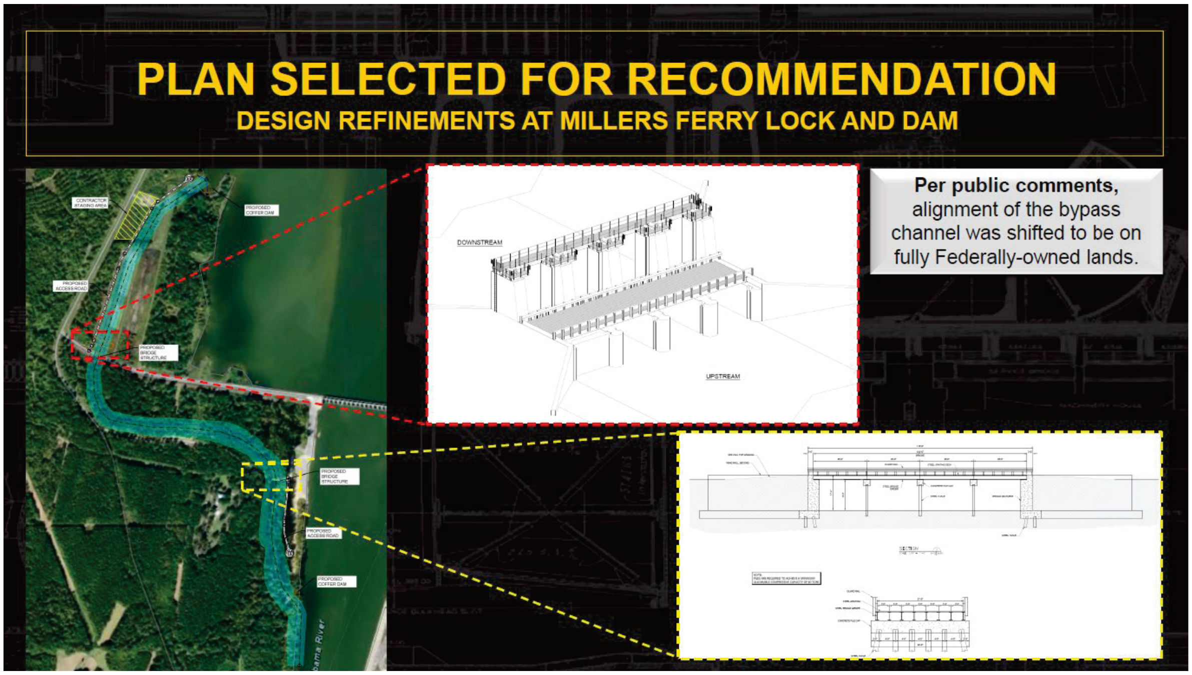


Figure 5. The updated design of the fish bypass structure at Millers Ferry L&D includes an alignment change so the structure would occupy only federal property. In addition, the gate structure includes four slots that will be opened and closed as needed to maintain pool level during high and low flows.

FISH AND WILDLIFE CONSERVATION MEASURES AND RECOMMENDATIONS

The following conservation measures and recommendations are provided to minimize loss of or damage to fish and wildlife resources and to provide for the improvement of such resources. The Service recommends the Corps consider these recommendations and implement these conservation measures when feasible to reduce impacts and to benefit fish and wildlife. The Corps has requested section 7 consultation on Alternative 5d regarding the construction of natural bypass structures at Claiborne and Millers Ferry L&D, which will be addressed in a separate document.

Fish Passage

Complicated life histories of aquatic species and the challenges associated with the barriers and effects of restricted flows from dams have created the need for managers to develop a toolkit for successful mitigation strategies (Katopodis 2005). This toolkit should include methods that analyze the relationship between fish migration and hydrographs, fish attraction to passage structures, passage structure hydraulics and fish passability, fish screen hydraulics and fish responses, and development of natural structures that contain instream fish habitat (Katopodis 2005). Analysis of seasonal fish migrations is essential during the design of fish passage structures, and unique considerations for each priority fish species should include the timing of spawning runs, body shape and size, swimming and leaping capabilities, and behavioral responses to physical and hydraulic environments (Turek et al. 2016). Spawning seasons for the priority fishes identified for this study, which include the time of year that the species begins moving to spawning sites, time for spawning, and time for outmigration after the end of spawning, begin in late January and end in late June except for blacktail shiner (Table 9). In addition to additives for fish attraction to proposed passage structures, which could include changes to the regulation of flow, we also highly recommend the Corps consider mitigation measures that will facilitate downstream migration of fishes and restoration of natural flow regimes as much as possible. Downstream migration is an essential component of migratory fishes' life cycles, and mortality from interaction with hydraulic turbines or over spillways can negatively affect population numbers and stability (Larinier 2001). Downstream passage can be improved by utilizing screens to prevent fish from interacting with turbines or of behavioral guidance devices, although the latter devices are considered experimental (Larinier 2001). Restoration of natural flows would also benefit other native aquatic species, including several listed and at-risk fishes, freshwater mussels, crayfish, and gastropods, by restoring connectivity and improving water quality and habitat.

The Service understands that this project is currently in the feasibility study phase of the planning process and that the Corps has estimated the project is at about 30% completed design. We also understand that additional design details will likely be determined during the preconstruction engineering and design (PED) phase. During this phase, we recommend implementing criteria from the *Fish Passage Engineering Design Criteria* (Service 2019b) guidelines and design parameters from the *Federal Interagency Nature-like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes* (Turek et al. 2016) technical memorandum when feasible.

In addition to considering implementation of the toolkit and downstream passage discussed in the previous paragraphs, the Service recommends determining and reviewing predicted flows, the depth and width of upstream connections to the river, and channel pool depth for each bypass structure. We also recommend determining and reviewing schedules for maintenance and dredging activities for both bypass channels and for control gate operations for the Millers Ferry bypass channel. Specifically, we recommend the Corps review some preliminary design parameters, including the minimum pool depths of both bypass structures, which is currently at greater than 5.0 feet during Gulf sturgeon migration and greater than 2.0 feet during normal flow conditions at Claiborne and greater than 5.0 feet at Millers Ferry at the upstream end of the bypass (Corps 2024a). For passage of shortnose sturgeon (*Acipenser brevirostrum*), a smaller-bodied sturgeon, the recommended minimum pool/channel depth is 4.0 feet and for Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*), a larger-bodied sturgeon, the recommended minimum depth is 7.0 feet (Turek et al. 2016). The recommended minimum pool/channel depth is 5.25 feet for striped bass, and for alosines like alewife and shad, the recommended minimum depth ranges from 2.0-4.0 feet (Turek et al. 2016).

The Corps has drafted an environmental modeling, monitoring, and adaptive management plan to evaluate success of the fish passage projects (Corps 2023a and 2024a). During the PED phase, the Service recommends refining this document to include a comprehensive study plan that includes which species and life stages will be selected for additional study and which sampling methodologies will be used for pre-construction, during construction, and post construction monitoring. Example performance standards can include passage efficiency, attraction efficiency, and maximum migration delays for each priority species and all of its life stages and for both upstream and downstream passage (Service 2019b). Generally, partner expertise is used to consider unique life history and population requirements in addition to identifying management plan objectives and goals (Service 2019b). Currently, the monitoring plan is limited to three priority species, including skipjack, logperch, and freshwater drum, and the objective is to pass more than 15% of these species for the first two years of monitoring and then add species as needed (Corps 2024a). We recommend reviewing previous monitoring studies (Mettee et al. 2005; Raabe et al. 2019; Hershey et al. 2022) and reviewing the monitoring and adaptive management plan with partners and technical species' experts to ensure all goals and objectives are being achieved. Based on the draft monitoring plan, the Service understood that more than 51% of passage attempts of staged species would need to be successful in order to meet the performance standard (Corps 2023a). The Service strongly recommends that the Corps revisit this performance measure and the process used to select the staged species for the updated monitoring plan (Corps 2024a) and share this information with involved partners and stakeholders. The Service was not represented at the October 16, 2023, meeting with cooperating agencies and was not informed of changes to the passage attempts performance standard or the selection of staged species (Corps 2024a).

Wetland Mitigation

The Service recommends the Corps conserve all habitats potentially affected by construction of fish passage structures in order to achieve conservation of all species. Avoidance and minimization of modification of wetland habitat is recommended. If impacts to wetlands cannot be avoided, then the Service recommends that, at minimum, the current status of the affected resource is maintained, if not improved. The Corps discussed a potential wetland mitigation plan during the TSP milestone meeting on March 1, 2023, which analyzed a ratio of 2.5 mitigation bank credits per acre of affected wetland (Figure 6).

TSP WETLAND MITIGATION

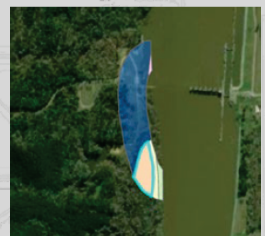
US Army Corps of Engineers

Millers Ferry			
Type	Acreage	Credits*	Cost
PF01A	3.11	7.775	$326,550.00
PFO1A	6.53	16.325	$685,650.00
PFO6Fh	1.16	2.9	$121,800.00
PSS1/4A	25.02	62.55	$2,627,100.00
PSS4/1A	0.2	0.5	$21,000.00
PFO1A	19.11	47.775	$2,006,550.00
Total	**55.13**	**137.825**	**$ 5,788,650.00**

Claiborne			
Type	Acreage	Credits*	Cost
PFO1C	1.36	3.4	$142,800.00
PF05/6Fh	3.06	7.65	$321,300.00
Total	**4.42**	**11.05**	**$ 464,100.00**

* Cost of $42,000 per credit

PFOA1- **Palustrine (P), Forested (FO), Broad-leaved Deciduous (1), Temporarily Flooded (A)**
PF06Fh- PALUSTRINE, Forested, Deciduous, Semipermanently Flooded, Dike Impounded
PSS1/4A- Paulstrine, Scrub-Shrub, Broad leaf Deciduous, Needle Leaved Evergreen, Temporarily Flooded
PSS1/4A- Paulstrine, Scrub-Shrub, Needle Leaved Evergreen, Broad leaf Deciduous,, Temporarily Flooded
PFO1C- **PALUSTRINE, Forested, Broad Leaf, Deciduous, Seasonally Flooded**
PFO5/6Fh-**PALUSTRINE, Forested, Dead, Deciduous, Semipermanently Flooded, Dike Impounded**



- Coordination with U.S. Fish & Wildlife Service (USFWS) suggests project may require mitigation.
- Wetland credits in a mitigation bank would mitigate for loss of ecological function (riverine bottomland hardwoods).
- A desktop analysis using the National Wetland Inventory was performed.
- Ratio of 2.5 credits in wetland mitigation bank for each acre of required mitigation.
- A wetlands functional assessment will be performed based upon a refined project alignment to determine final cost of mitigation wetlands, if any.
- Further consultation with USFWS and Alabama Department of Environmental Management may reduce or eliminate wetland mitigation need based upon ecological lift gained from restoration project.

US Army Corps of Engineers
U.S. ARMY
The Nature Conservancy

Figure 6. Potential wetland mitigation plan for the Corps' selected alternative. Presented at the TSP milestone meeting on March 1, 2023.

When the DFWCAR was provided to the Corps, the Service was operating under the 1981 mitigation policy, which recognizes that the goal of avoiding or minimizing losses can include physical modification of replacement habitat to convert it to the same type lost, restoration or rehabilitation of previously altered habitat, increased management of similar replacement habitat so that the in-kind value of the lost habitat is replaced, or a combination of these measures (46 FR 15, January 23, 1981).

In May 2023, the Service approved a revised mitigation policy for recommendations on mitigating adverse impacts of land and water developments on fish and wildlife (88 FR 31000, May 15, 2023). The revised mitigation policy also provides guidance to avoid, minimize, and compensate for action-caused impacts to species and their habitats. For this project, the Corps determined that both wetlands within the project area and the Alabama River are considered waters of the U.S., which provides a nexus between the habitats. The Corps has also determined that aquatic ecosystem benefits for this fish passage project will connect a minimum of 206 river miles from Claiborne L&D to the Cahaba River.

Since the TSP milestone meeting, the Corps has conducted further analyses to determine the quantity and quality of wetlands that could be potentially impacted by construction of the fish passage bypass structures. The Corps determined that a maximum of two miles of wetlands could be impacted, and these wetlands are low quality habitat that do not contain bottomland hardwoods or habitat for federally listed species. The Corps has also determined that any potentially impacted wetlands would be converted from palustrine to open water habitat. The

Corps will consider the feasibility of the potential use of riparian zone plantings to incorporate the addition of wetland plants during the preconstruction, engineering, and design (PED) phase of the project.

Migratory Birds

Multiple species of migratory birds from the Service's Birds of Conservation Concern (BCC) list (2021a) could be present in the study area around Claiborne and Millers Ferry L&D. The Service recommends the Corps follow the nationwide conservation standards to conserve these species and implement conservation measures from the East Gulf Coastal Plain Joint Venture Implementation Plan (Greene et al. 2021), which identifies long-term goals and objectives that will improve sustainability of priority bird populations, if feasible.

The Corps has agreed to use Best Management Practices (BMPs) to minimize adverse impacts to migratory species within the project construction areas. In addition, The Corps has determined that conversion of habitat from low quality wetlands to open water habitat may serve as a benefit to migratory species due to increased open water surface area and potential riparian zones.

Recreational Areas

The Service recommends that the Corps maintain, replace, or create recreational features in the vicinity of the study area around Claiborne and Millers Ferry L&D. These features can allow access to the river in different ways and allow the public to appreciate fish and wildlife resources. Any recreational features incorporated into this project should achieve these objectives.

The Corps has determined that access to existing recreational areas would continue but would be rerouted at the dams. In addition, conversion of the existing duck ponds at Millers Ferry to a natural bypass channel would not significantly reduce recreation within the project area due to the continued access to the reservoir and surrounding fishing and hunting locations. A vehicular bridge at Millers Ferry L&D will provide public viewing and fishing access, and all public use amenities currently maintained at Claiborne L&D will be relocated and maintained after construction is completed (Figures 7 and 8).

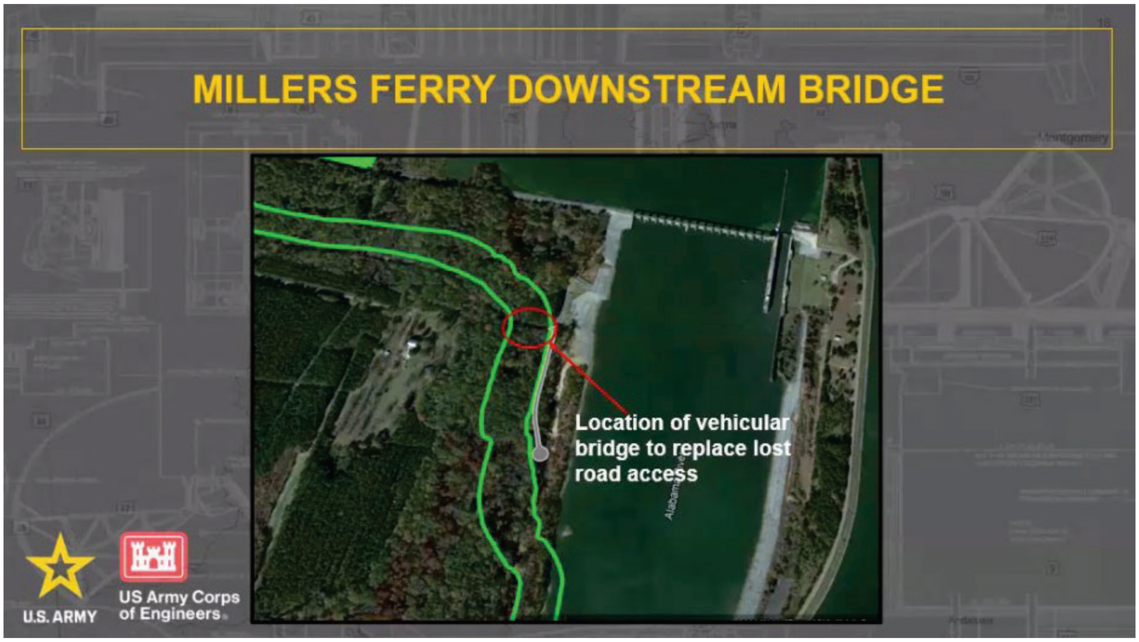


Figure 7. A vehicular bridge will be included in construction of the natural bypass channel at Millers Ferry L&D. This bridge will provide public access to park and walk or fish from the shore of the Alabama River.

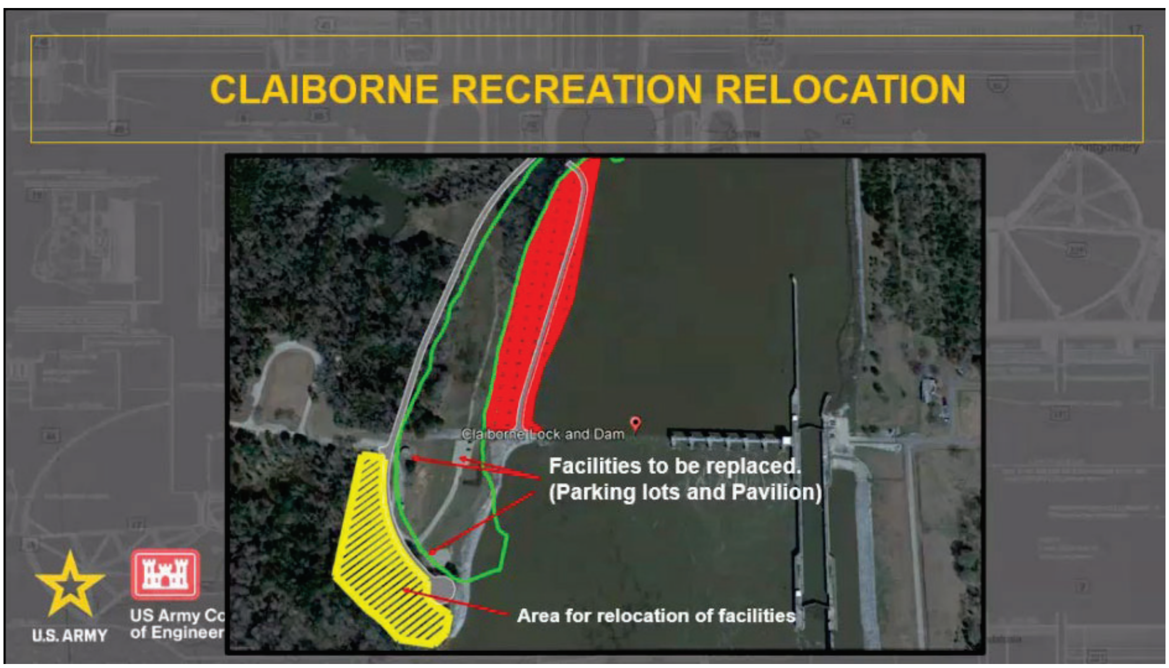


Figure 8. Construction of a natural bypass channel at Claiborne L&D will require relocation two parking lots, one pavilion, and one outhouse. The Corps will continue to maintain these facilities for public use after construction is completed.

USFWS POSITION

Based on the analyses presented by the Corps on March 1, 2023, and on September 28, 2023, the Service supports the Recommended Plan (Alternative 5d) of construction of natural bypass channels at both Claiborne and Millers Ferry L&D and currently prefers this option over the No Action Alternative. However, more information on design is needed, particularly on details that will address downstream migration, additives for fish attraction to passage structures, and other factors that will affect the passability of the structures, including but not limited to the timing and duration of flows through the bypass channels. In addition, the Service recommends that the Corps consider wetland mitigation, migratory bird conservation measures, and recreational area preservation or improvement to conserve all habitats potentially affected by the project and to benefit all resources. The Service understands that this project is currently in the feasibility study phase of the planning process and that the Corps has estimated the project is at about 30% completed design. We recommend reviewing some design parameters based on information provided in this document and continuing to involve partners and stakeholders when establishing monitoring and adaptive management goals and objectives. If more design details become available during future phases of the planning process that reveal effects not considered by this final FWCAR, the Service will either amend this document or provide a supplementary report to ensure the best scientific and commercial information available continues to be considered throughout development of the project. We look forward to continuing to work with the Corps and other partners and stakeholders during the next phase of the study to finalize the design of the selected alternative and to conserve fish and wildlife resources.

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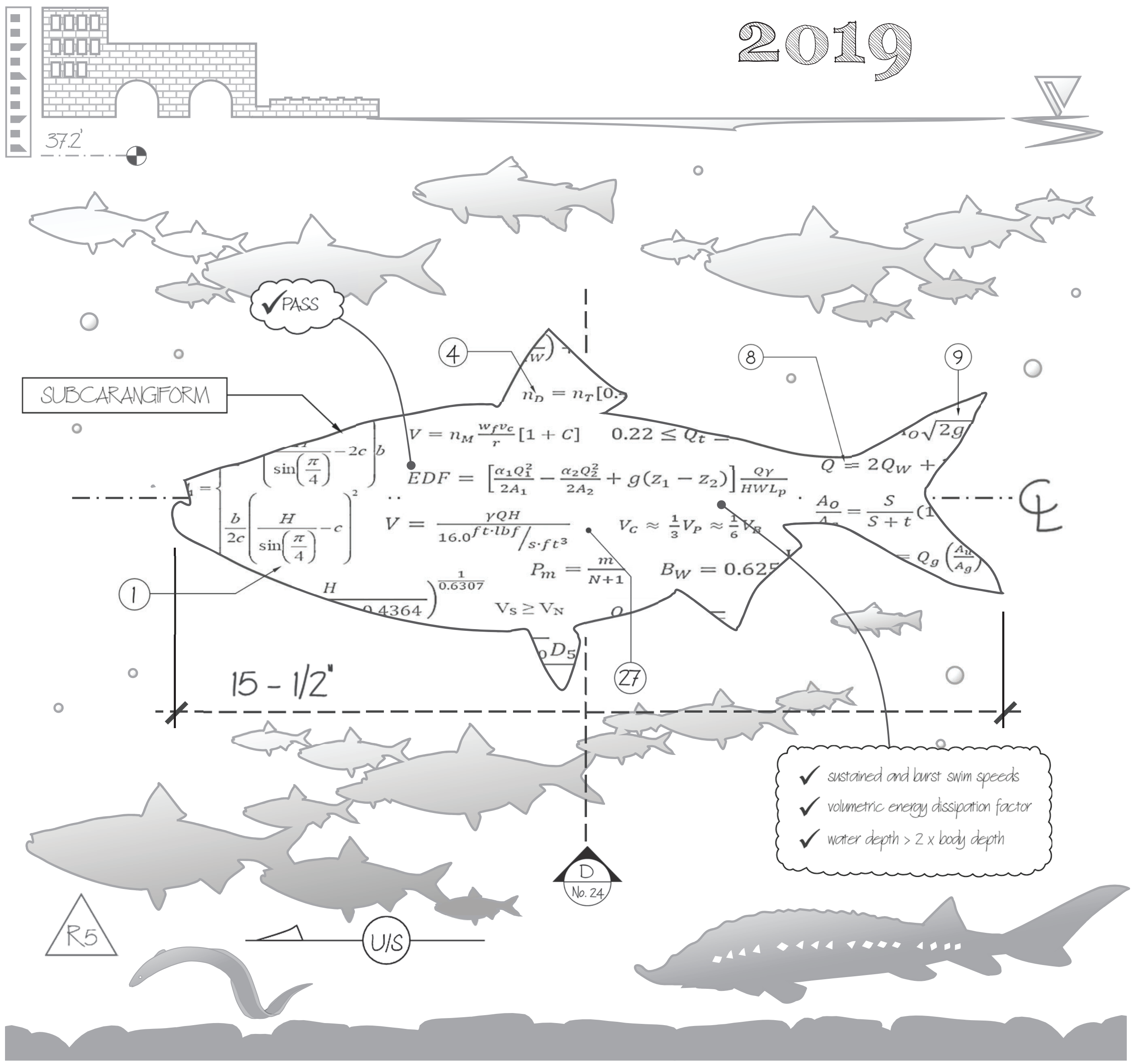
FISH PASSAGE ENGINEERING DESIGN CRITERIA

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

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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

This 2019 edition of "Fish Passage Engineering Design Criteria" was written by subject matter experts from the Fish and Aquatic Conservation program of the U.S. Fish and Wildlife Service's Northeast Region. The editor and lead author of this manual is Brett Towler, Ph.D., P.E., P.H. Co-authors are Bryan Sojkowski, P.E, Jesus Morales, P.E., and Jessica Pica, P.E.

This edition was finalized after thorough review by personnel from the Fish and Aquatic Conservation and Ecological Services programs. Substantive contributions were provided by Michael Bailey, Antonio Bentivoglio, Steven Shepard, and Douglas Smithwood.

Previous Editions:

The editor and lead author of the 2017 edition was Brett Towler. Co-author was Bryan Sojkowski. Contributors included Kevin Mulligan, Curt Orvis, Jesus Morales, and Jessica Pica. Reviews and input were provided by Steven Shepard, Ken Sprankle, Lauren Bennett, and Cathy Bozek.

The 2016 edition was authored by Brett Towler, Kevin Mulligan, and Curt Orvis. Contributors included Bryan Sojkowski, Jesus Morales, Ben Rizzo, and Richard Quinn. Reviews and input were provided by Michael Bailey, Antonio Bentivoglio, Scott Craig, Sheila Eyler, Melissa Grader, Richard McCorkle, Stephen Patch, Steven Shepard, Ken Sprankle, John Sweka, and John Warner.

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:

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

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:

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

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 <u>Low Design Flow</u>

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:

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

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:

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

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.

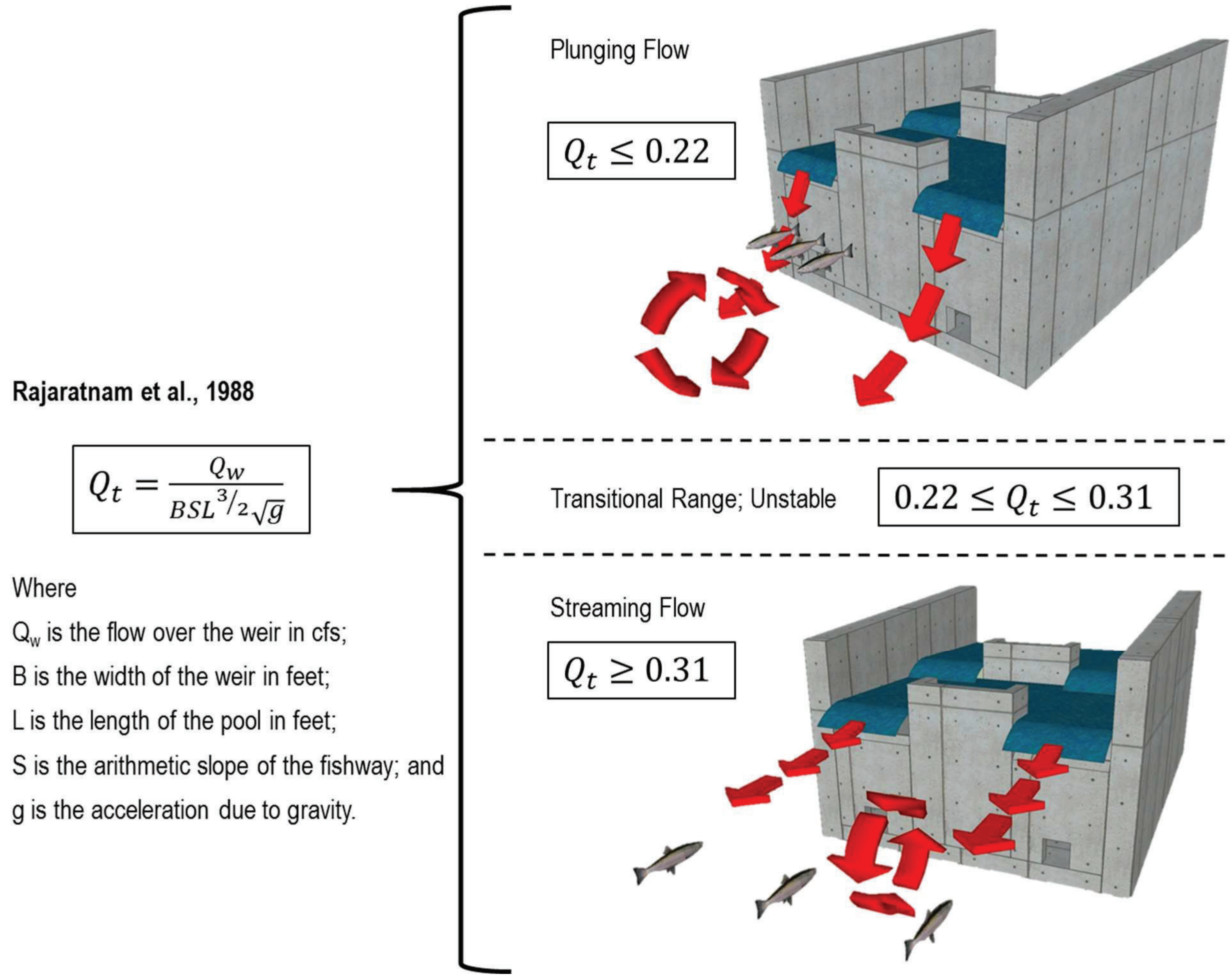


Figure 1: Plunging versus streaming flow conditions.

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.

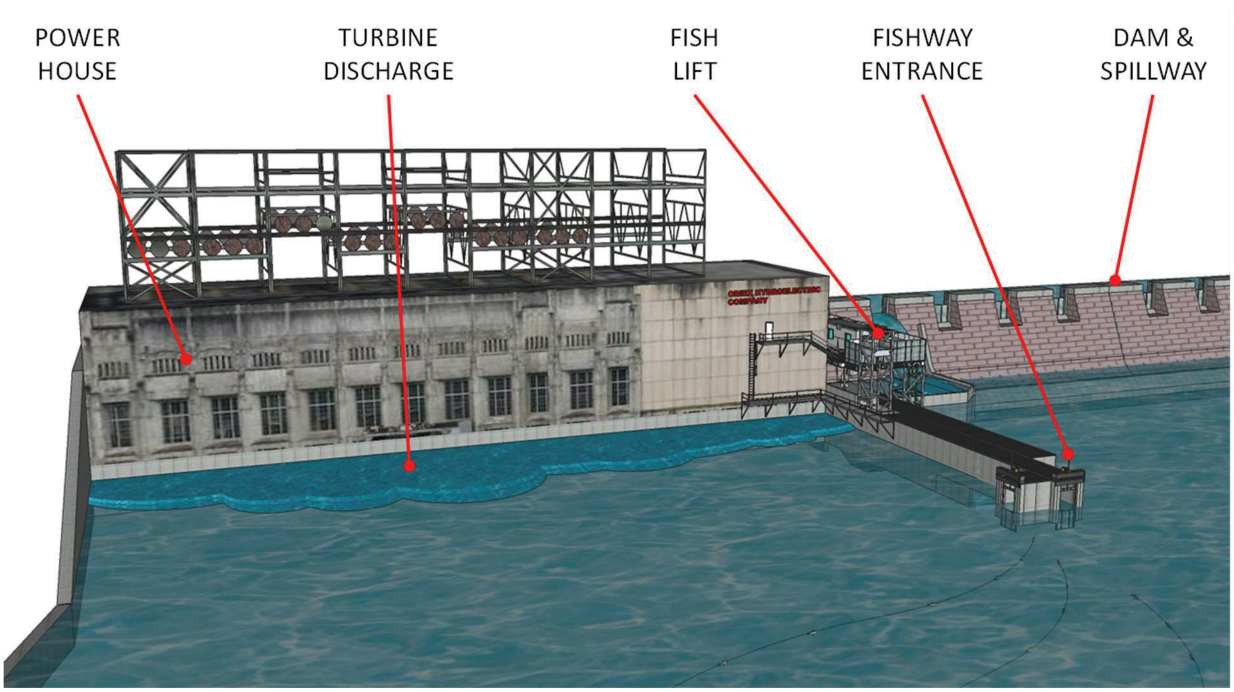


Figure 2: An example of competing flow fields at a hydroelectric facility.

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.

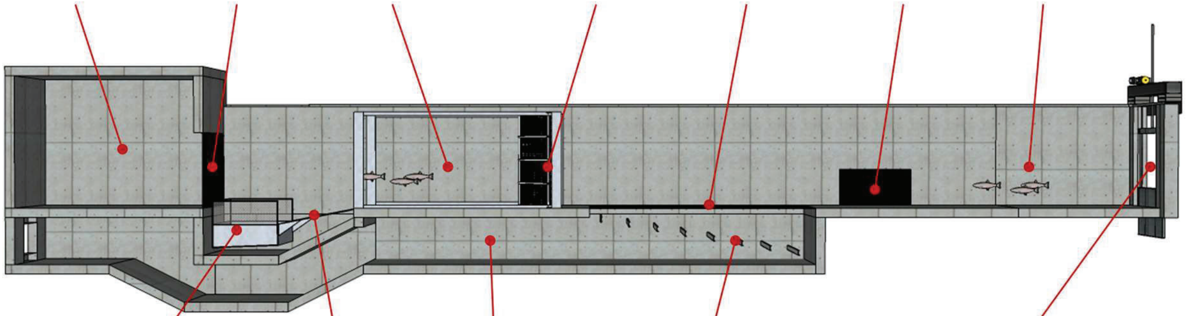


Figure 3: Cross-sectional view of the lower section of a fish lift.

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 Location

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 <u>Entrance Jet Velocity</u>

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.

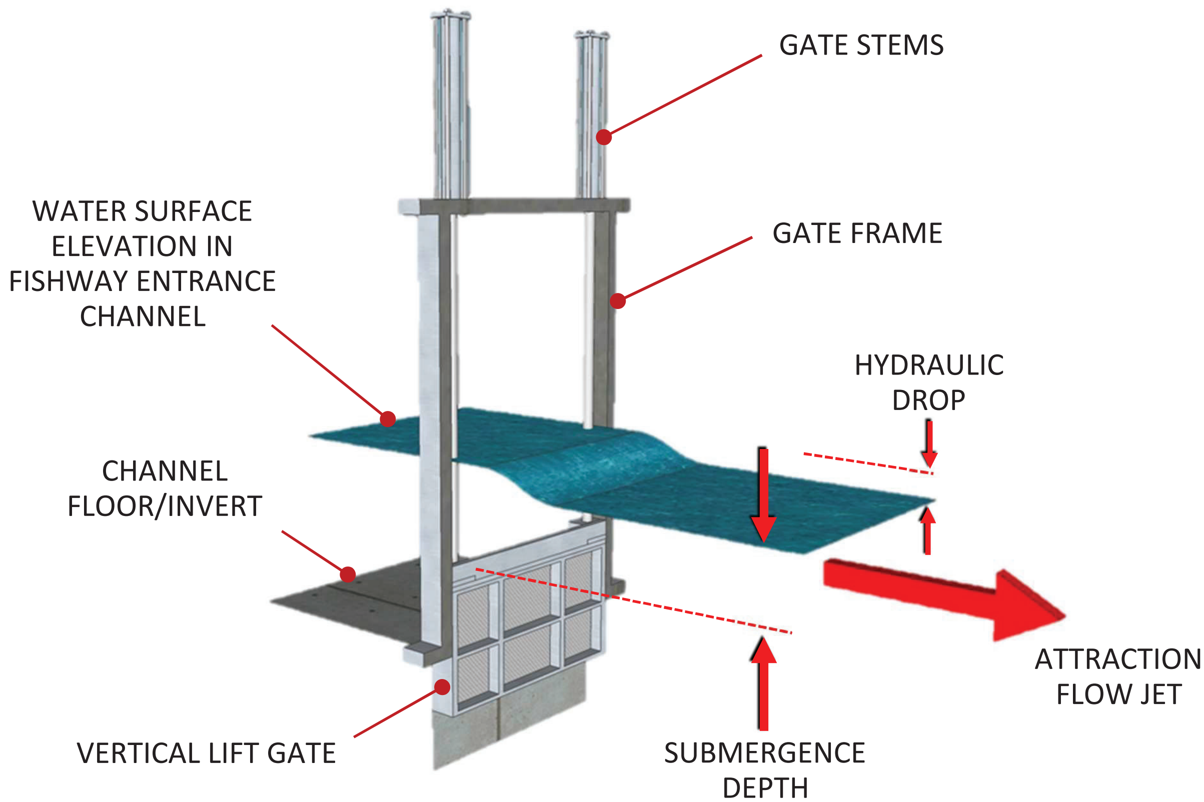


Figure 4: A typical entrance gate at a large technical fishway.

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.

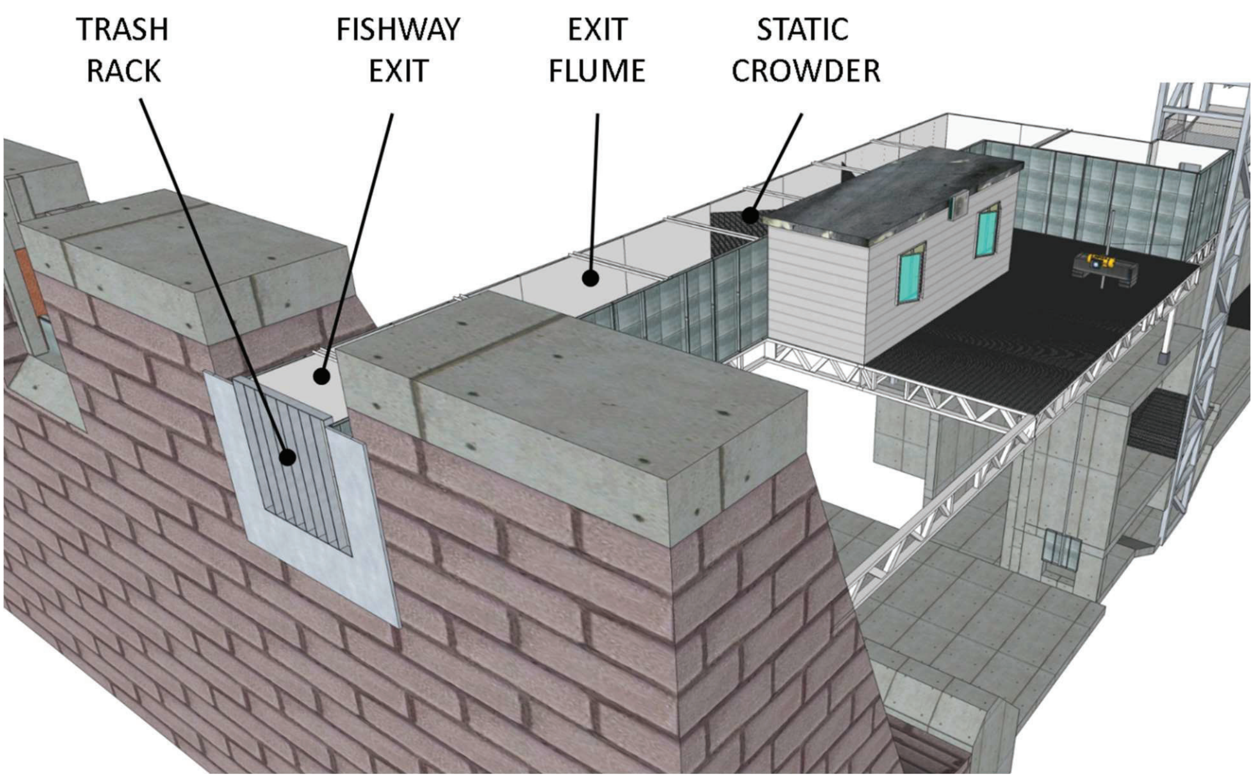


Figure 5: Example of a fish lift exit.

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:

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

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/dℓ is equivalent to the (hydraulic) drop per pool over the length of the pool.

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

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-lbf/s-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."

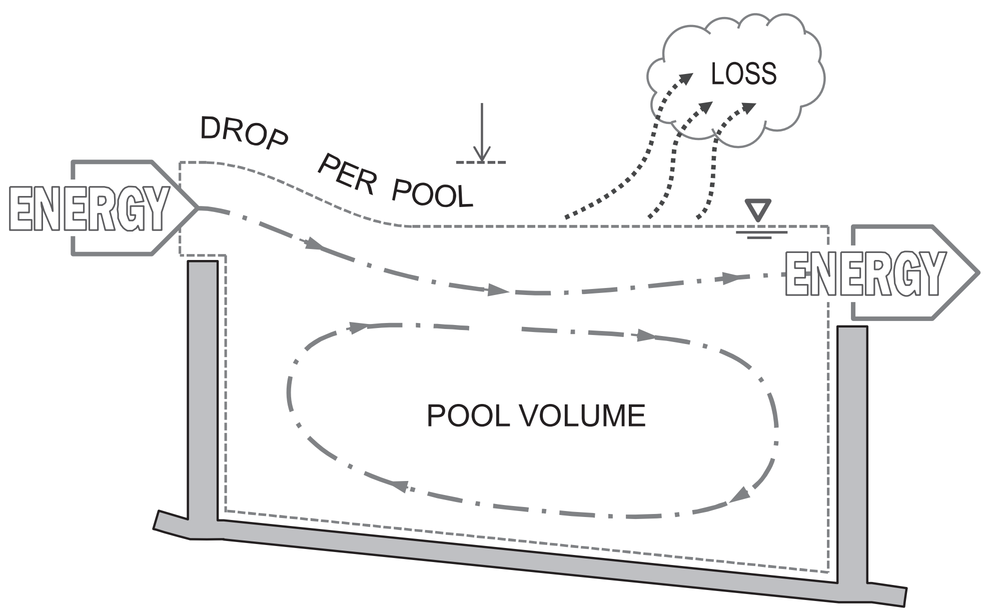


Figure 6: Sizing step pools in a ladder type fishway based on the EDF.

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-lbf/s-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:

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

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:

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

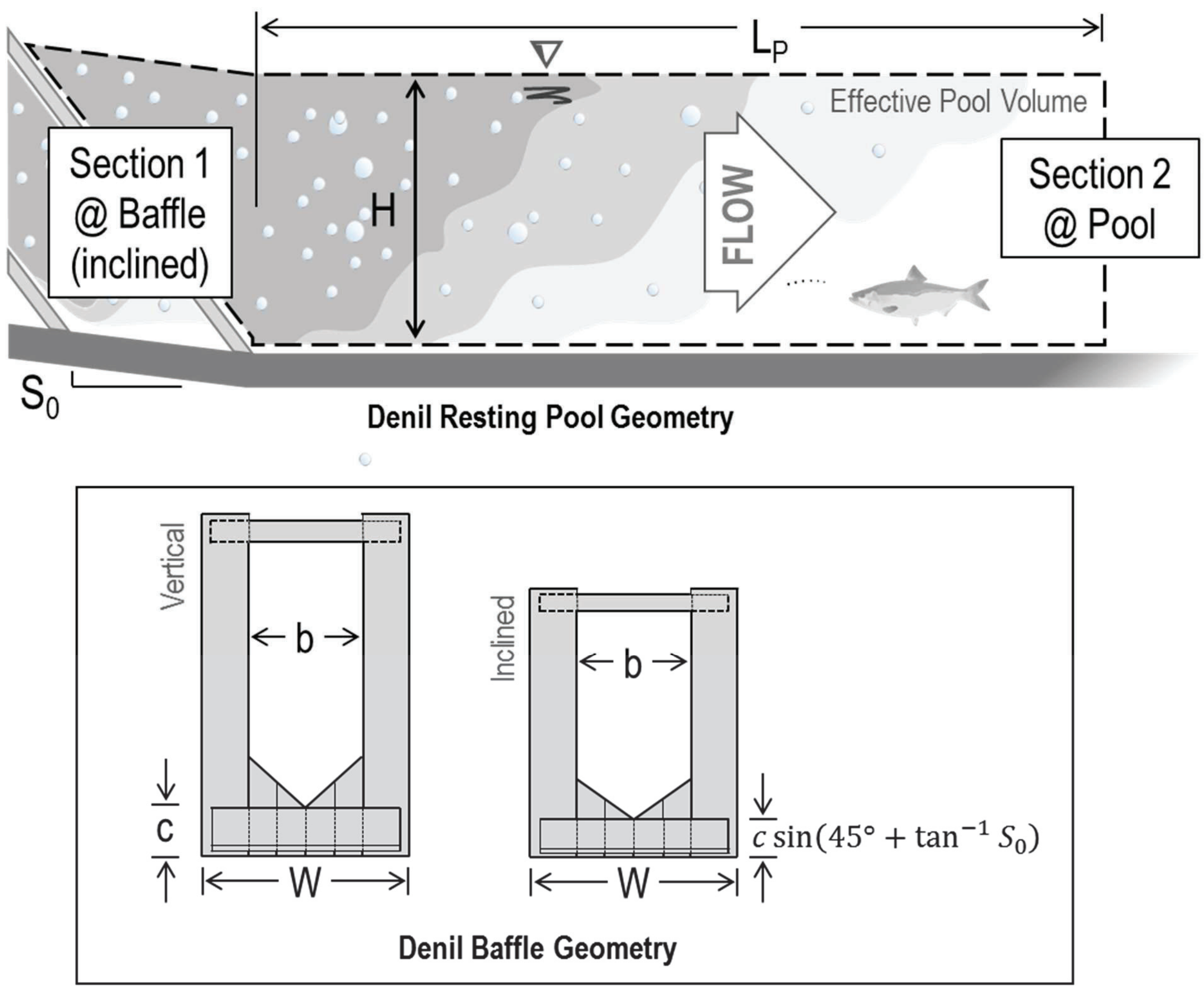


Figure 7: A cross-sectional view of a Denil fishway resting pool and baffle.

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:

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

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.

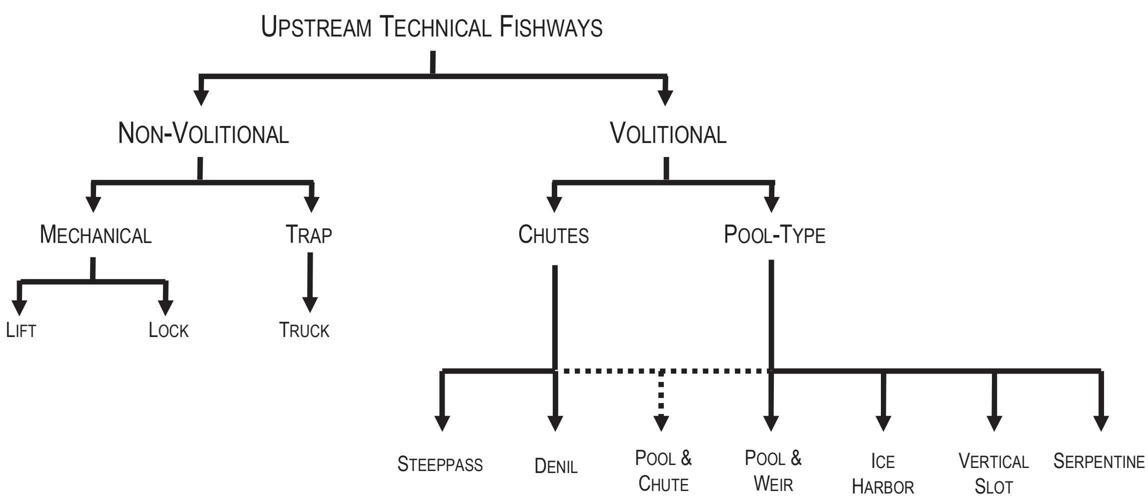


Figure 8: Technical upstream fishway types

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

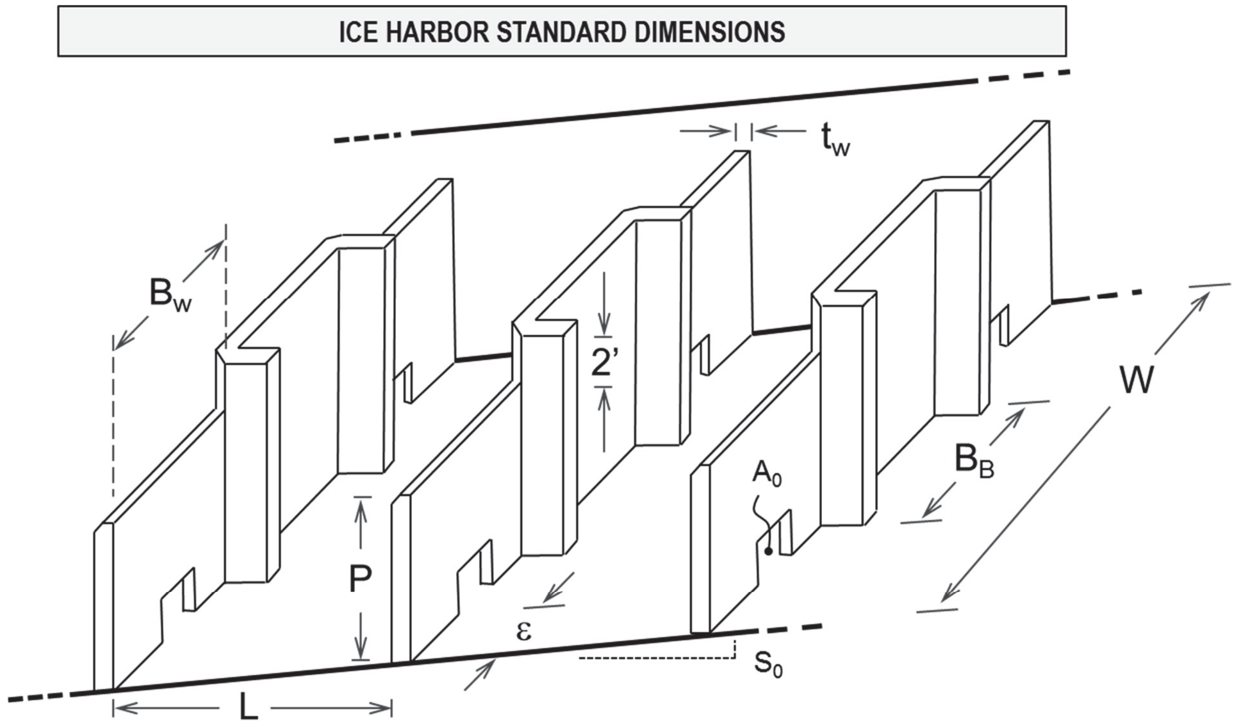
Turning pools are locations within the fishway where bends are required. These pools are often curved in shape or rectangular with chamfered walls. This shape differs from linear resting pools and, consequently, can create much more complex hydraulic conditions. Turning pools often also act as a resting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

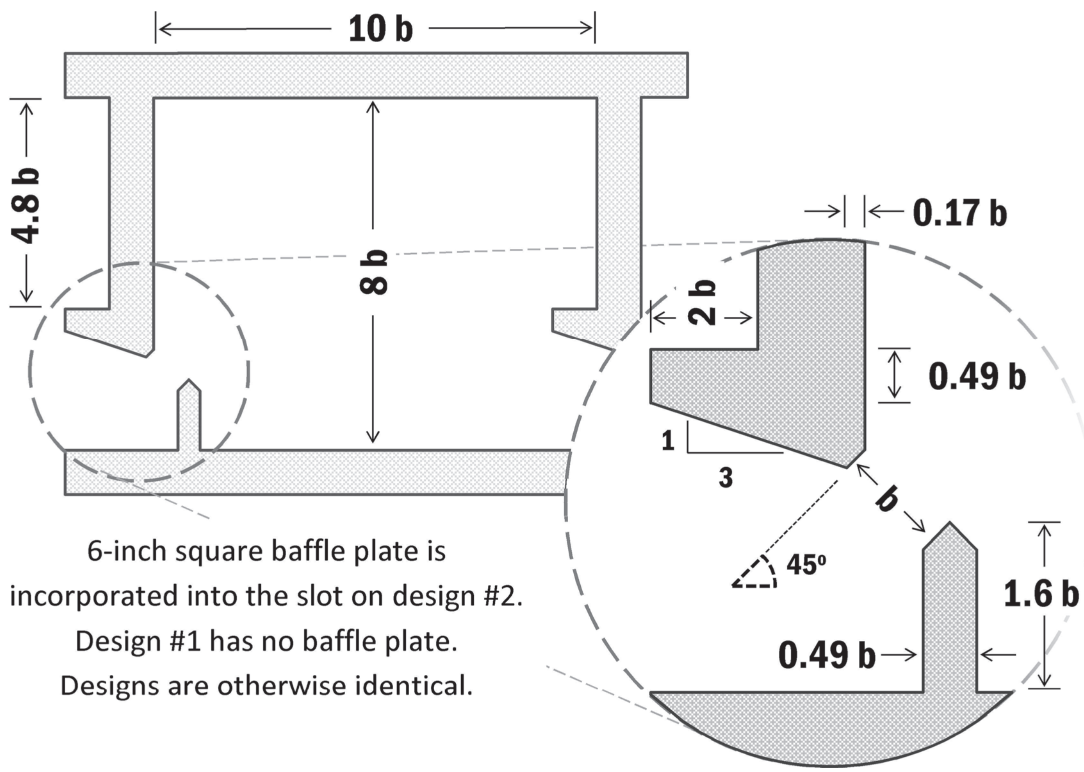


Figure 10: Geometric ratios for the vertical slot fishway designs #1 and #2.

(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.

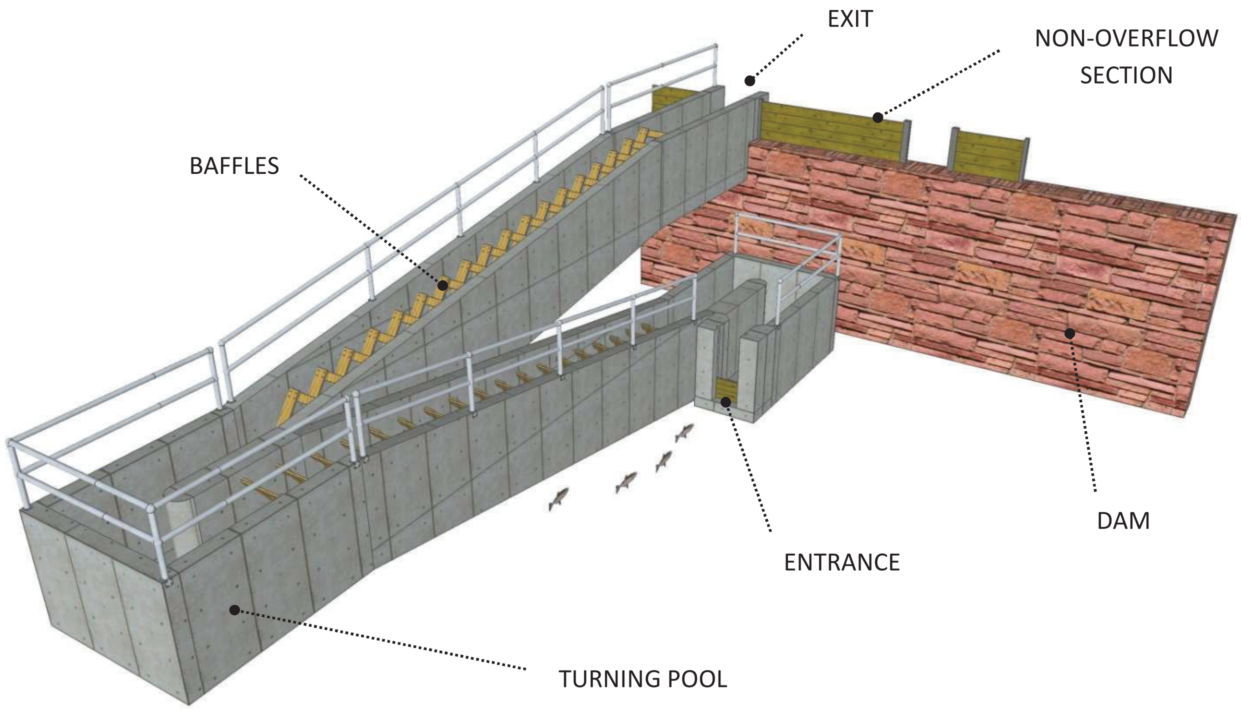


Figure 11: A Standard Denil fishway illustration.

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

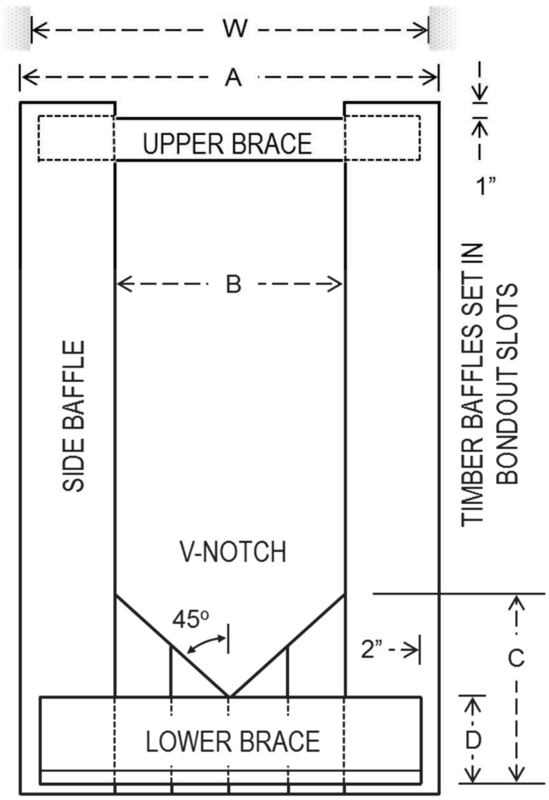
Similar to the fishway slope, recommended widths for Denils vary by target species.

- 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.

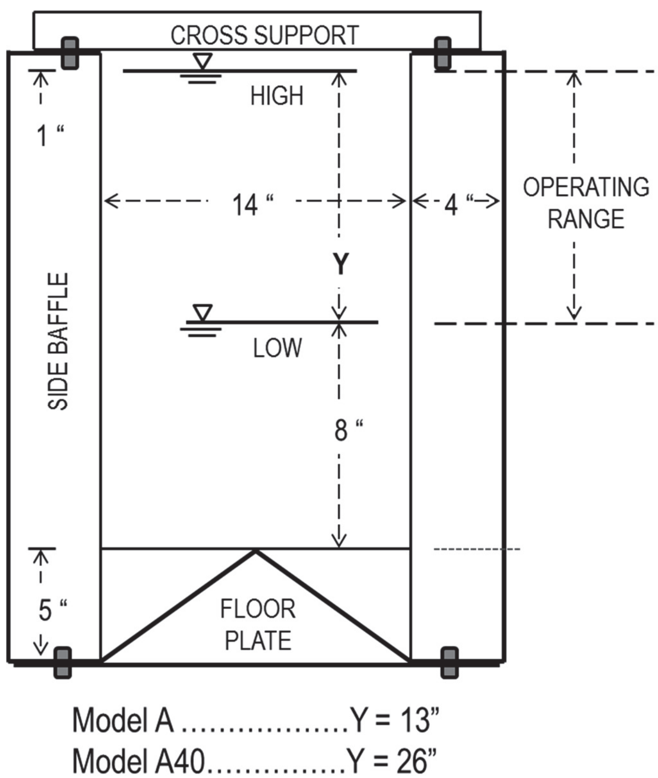


Figure 13: Steeppass fishway baffle geometry.

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 Other Considerations

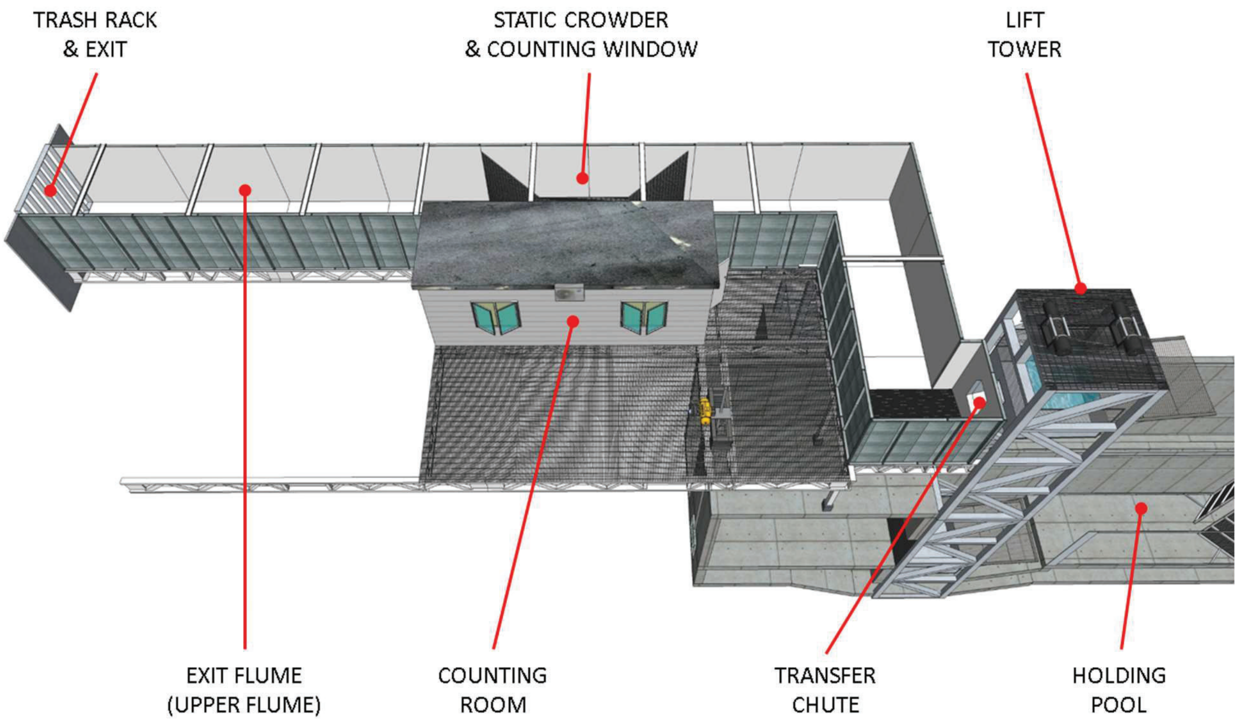
- A steeppass fishway is limited by its low flow capacity. As a result, steeppasses are only applicable to small (coastal) watersheds; the Model A is limited to locations with a drainage area of 20 square miles or less, whereas the Model A40 is limited to locations with a drainage area of 30 square miles 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.”



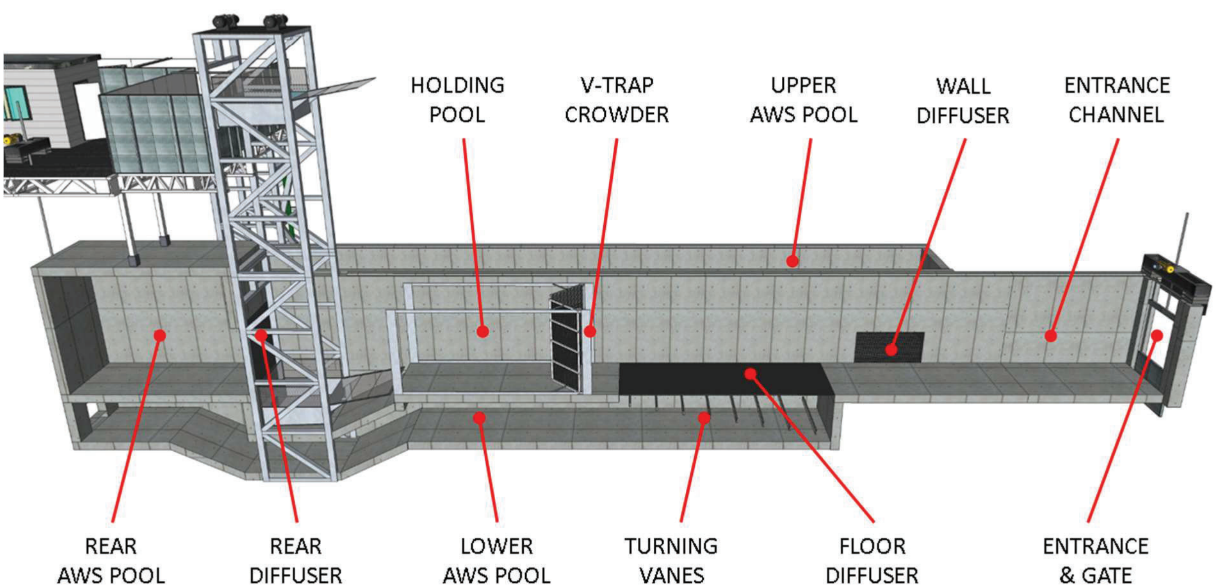


Figure 14: Multiple cross-sectional views of a fish lift.

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.

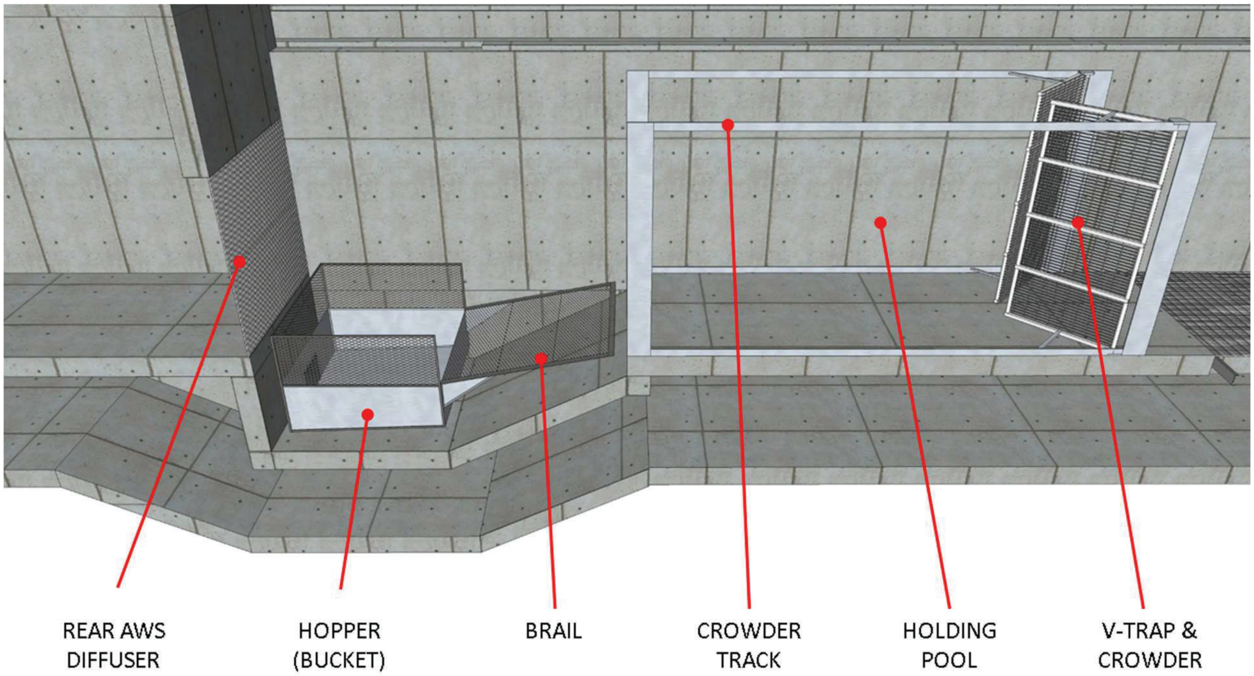


Figure 15: Illustration of fish lift components.

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.

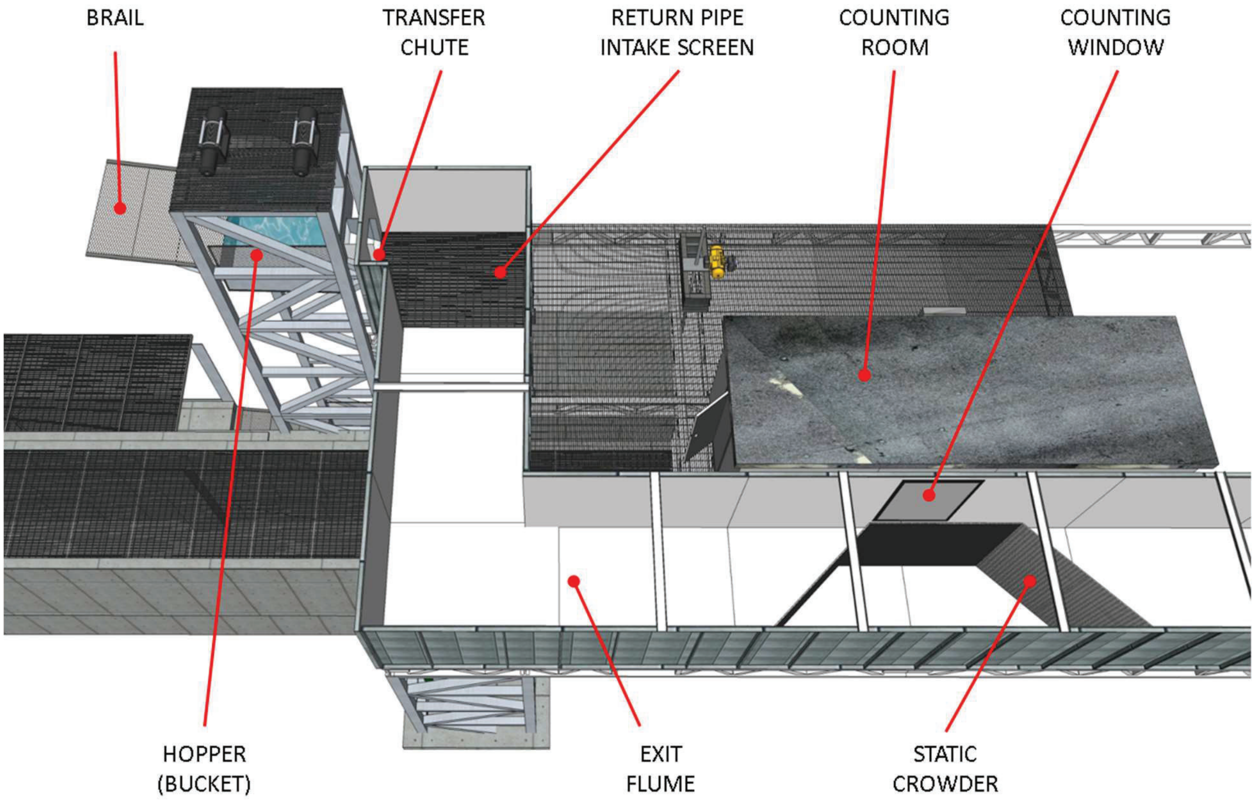


Figure 16: An illustration of fish lift transfer of fish components.

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.

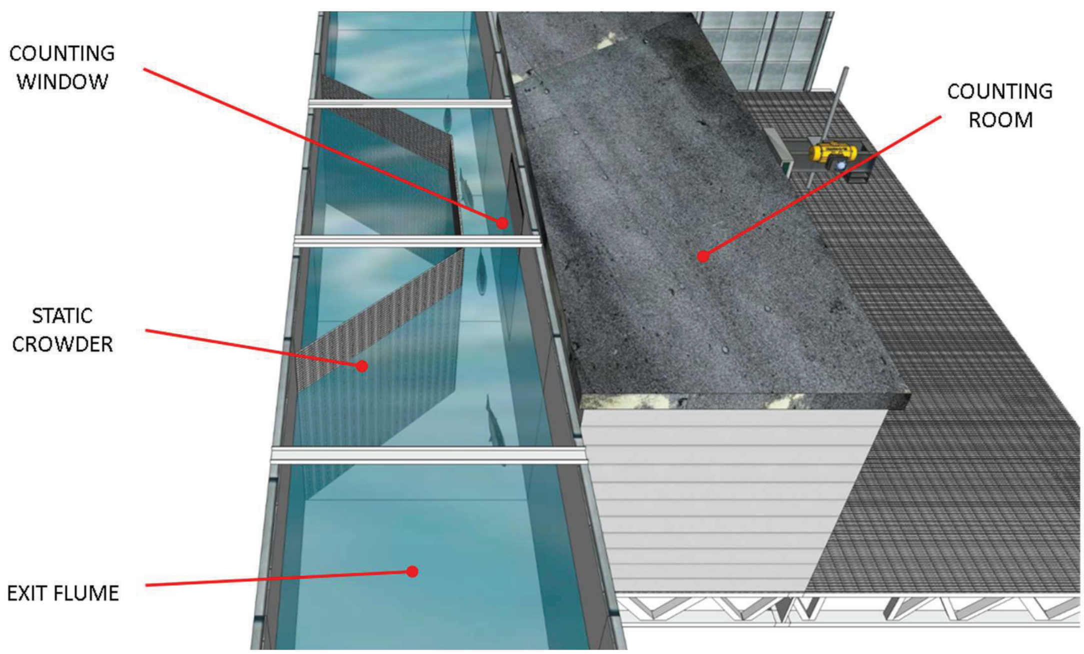


Figure 17: Illustration of fish lift counting facilities.

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.

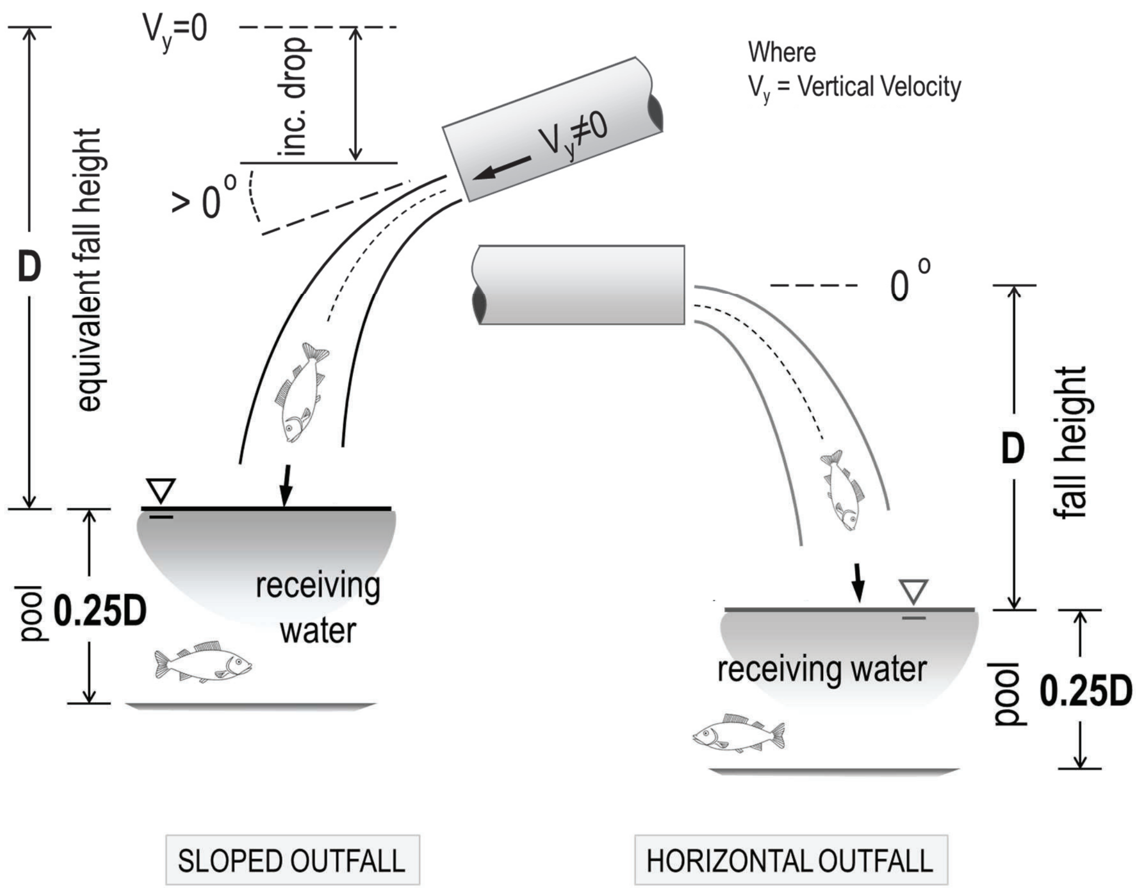


Figure 18: Fall height and plunge pool requirements

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

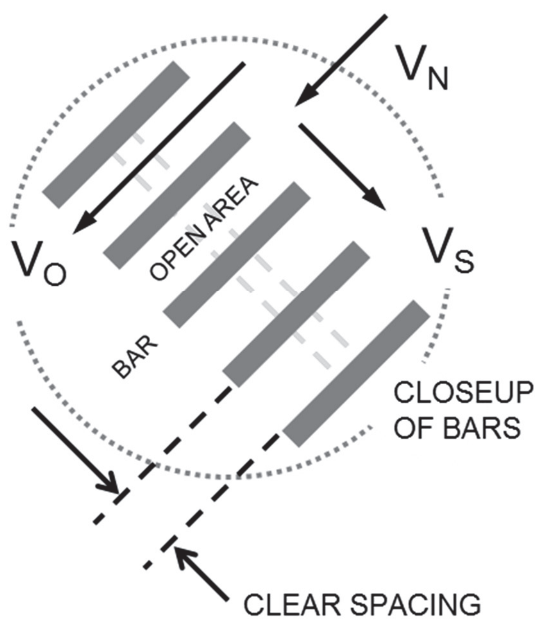
In the case of a full-depth guidance structure (e.g., louvers and angled bar screen), a 2-dimensional velocity vector is often used to inform the design. These two velocity components, displayed in Figure 19, are referred to as the sweeping velocity (velocity component parallel to the guidance structure 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).



Velocity components at the screen:

- 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 Louvers

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 Inclined Bar Screen

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 Floating Guidance Systems and Booms

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 <u>Behavioral Barriers</u>

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.

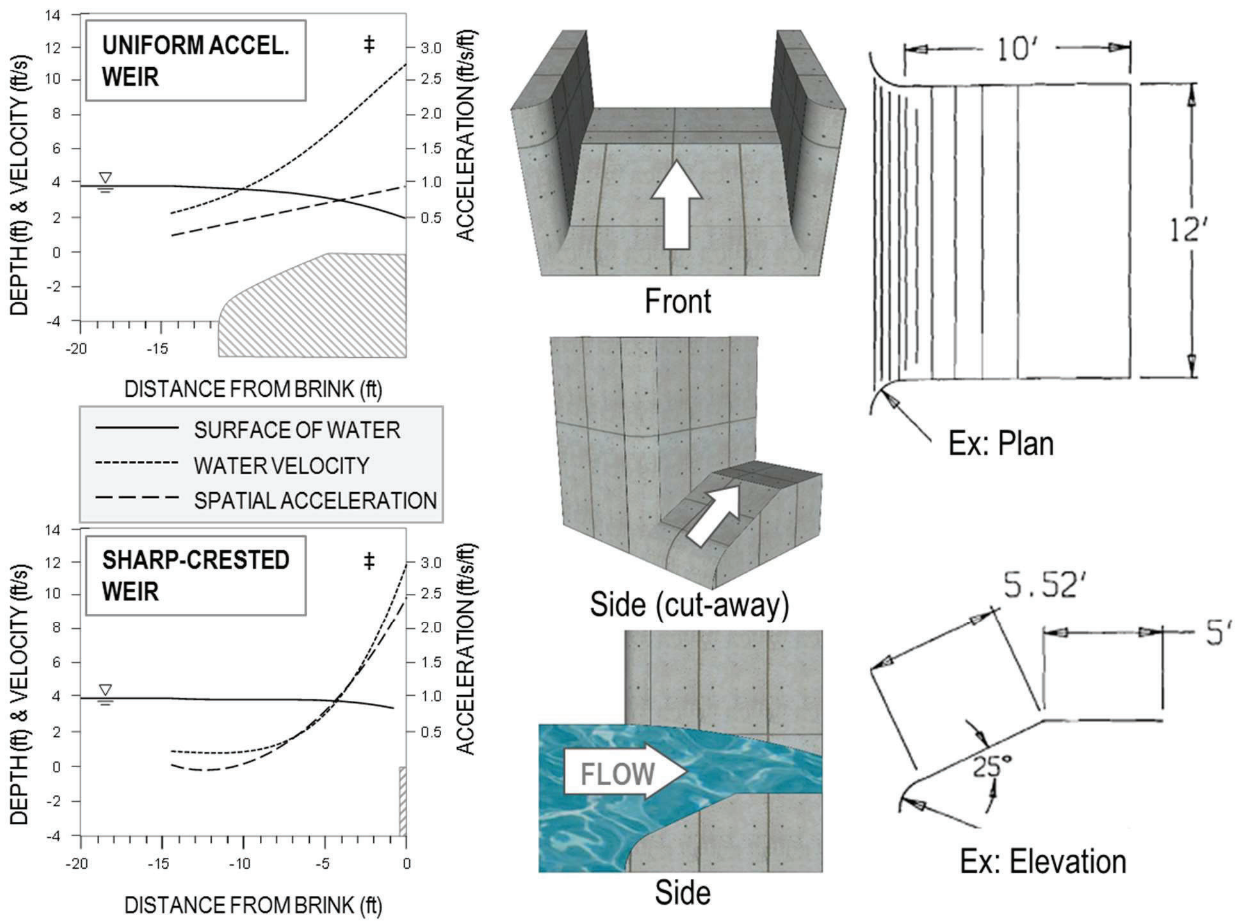


Figure 20: Comparison of uniform acceleration and sharp-crested weirs.

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.

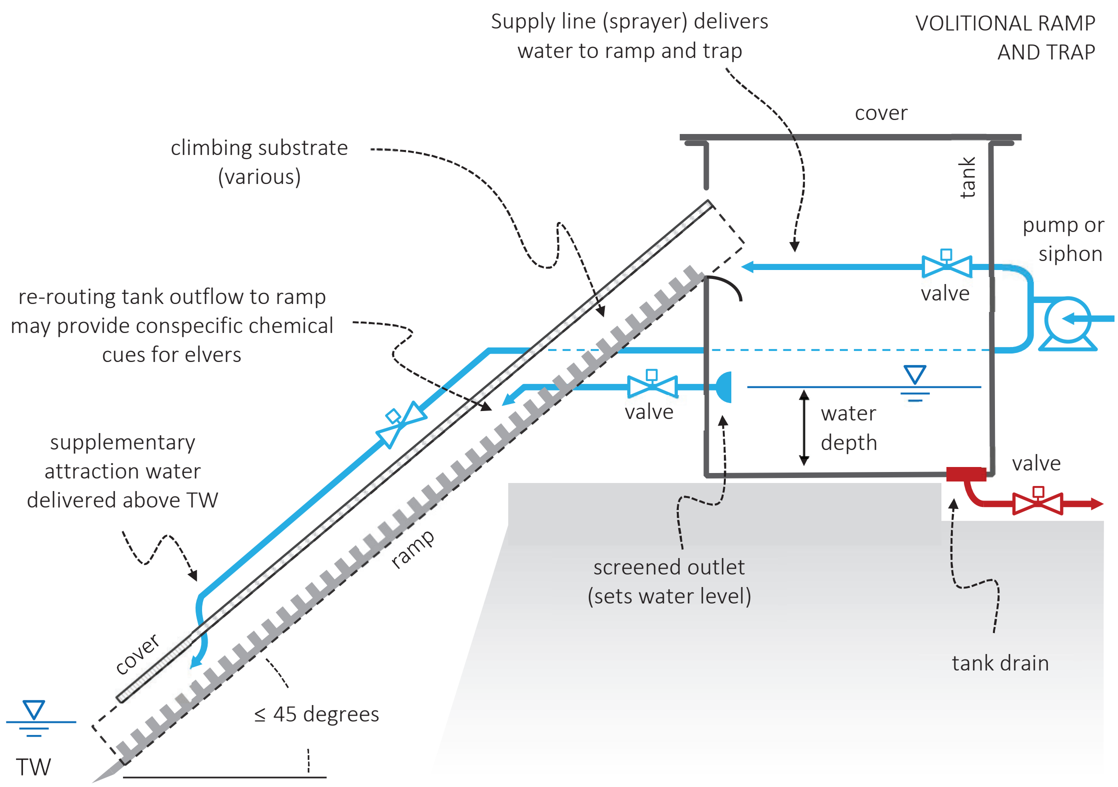


Figure 21: Conventional arrangement of an eel ramp and trap assembly

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.

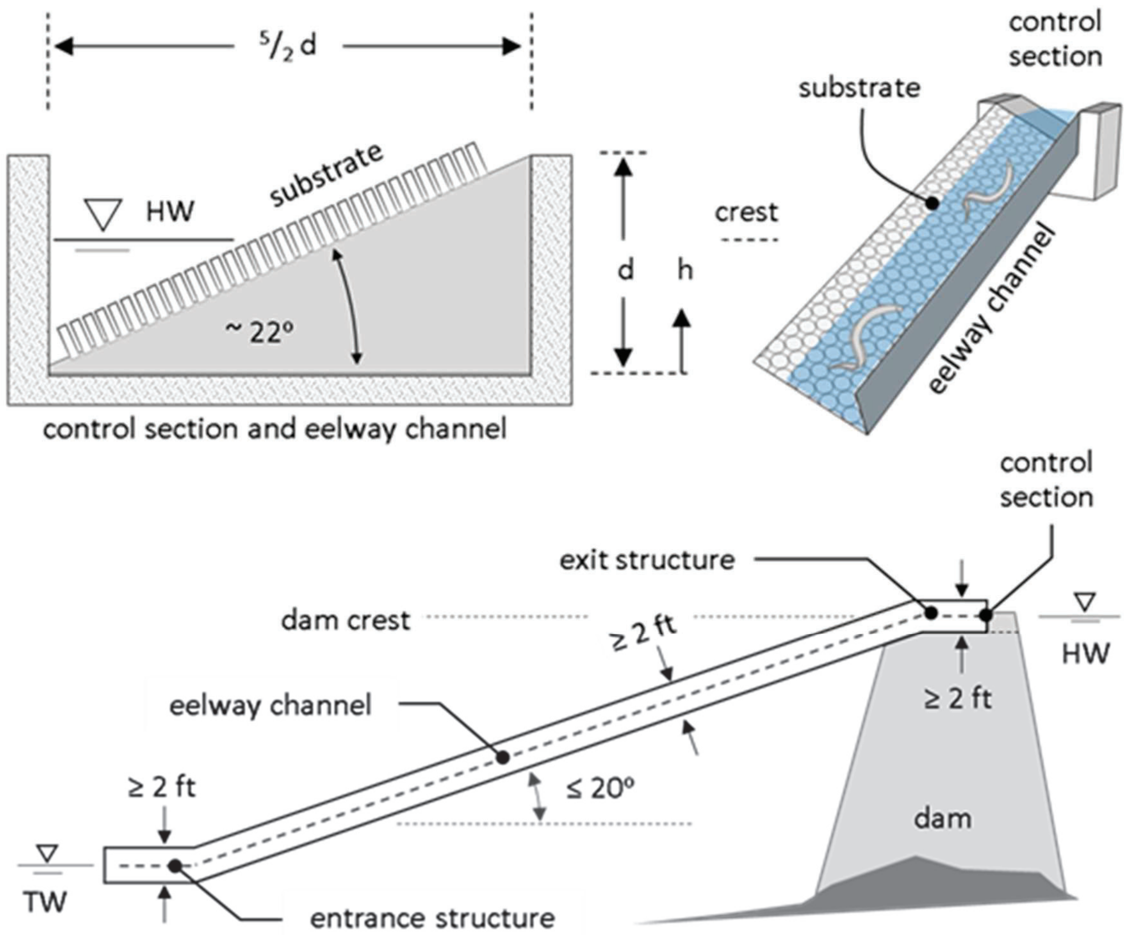


Figure 22: Design parameters for a laterally sloped eel ramp

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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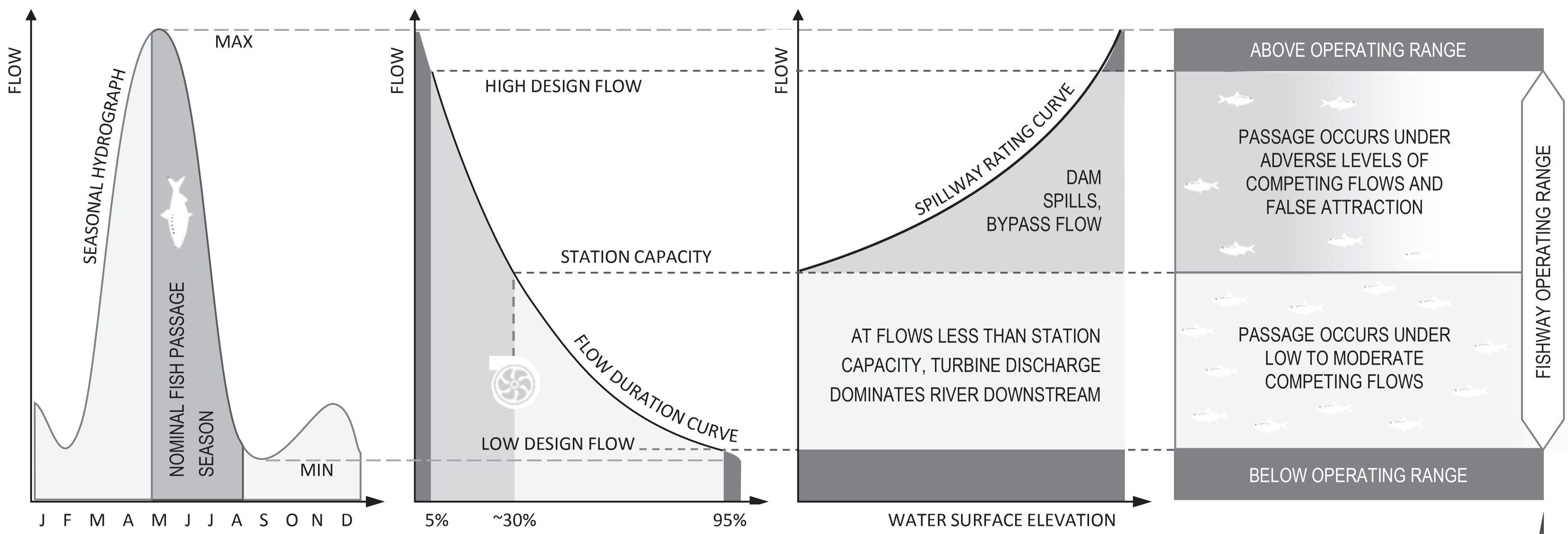
Appendix A
Reference Plates



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

SWIM SPEED CATEGORIES

REFERENCE PLATE 5-1

BURST

V_B

Burst or Dart or Sprint Speed is the swim speed that a fish can maintain for mere seconds

- 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

V_P

Prolonged (or Sustained Speed *) is the swim speed that a fish can maintain for minutes;

- 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

V_C

Cruising or Sustained Speed is the swim speed that a fish can maintain for hours;

- 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"
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USFWS Northeast Region (R5), FAC
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Issued 1/6/2017; replaces "Swim Speeds" 7/23/2014

POWER DISSIPATION RATES

REFERENCE PLATE 5-2

FT-LB/S/FT³ — RECOMMENDATIONS & REQUIREMENTS

ENERGY DISSIPATION FACTOR (EDF)

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)

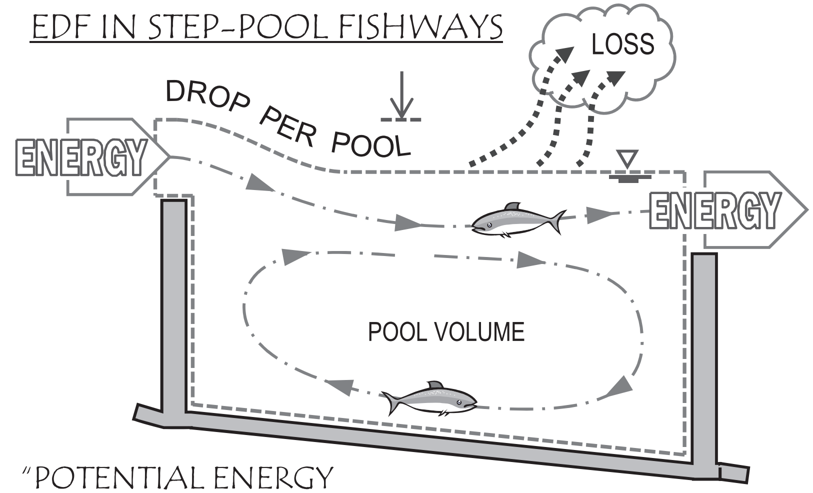
salmonids, juvenile (2.0 ft-lb/s/ft^3); NOAA (2011)

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"

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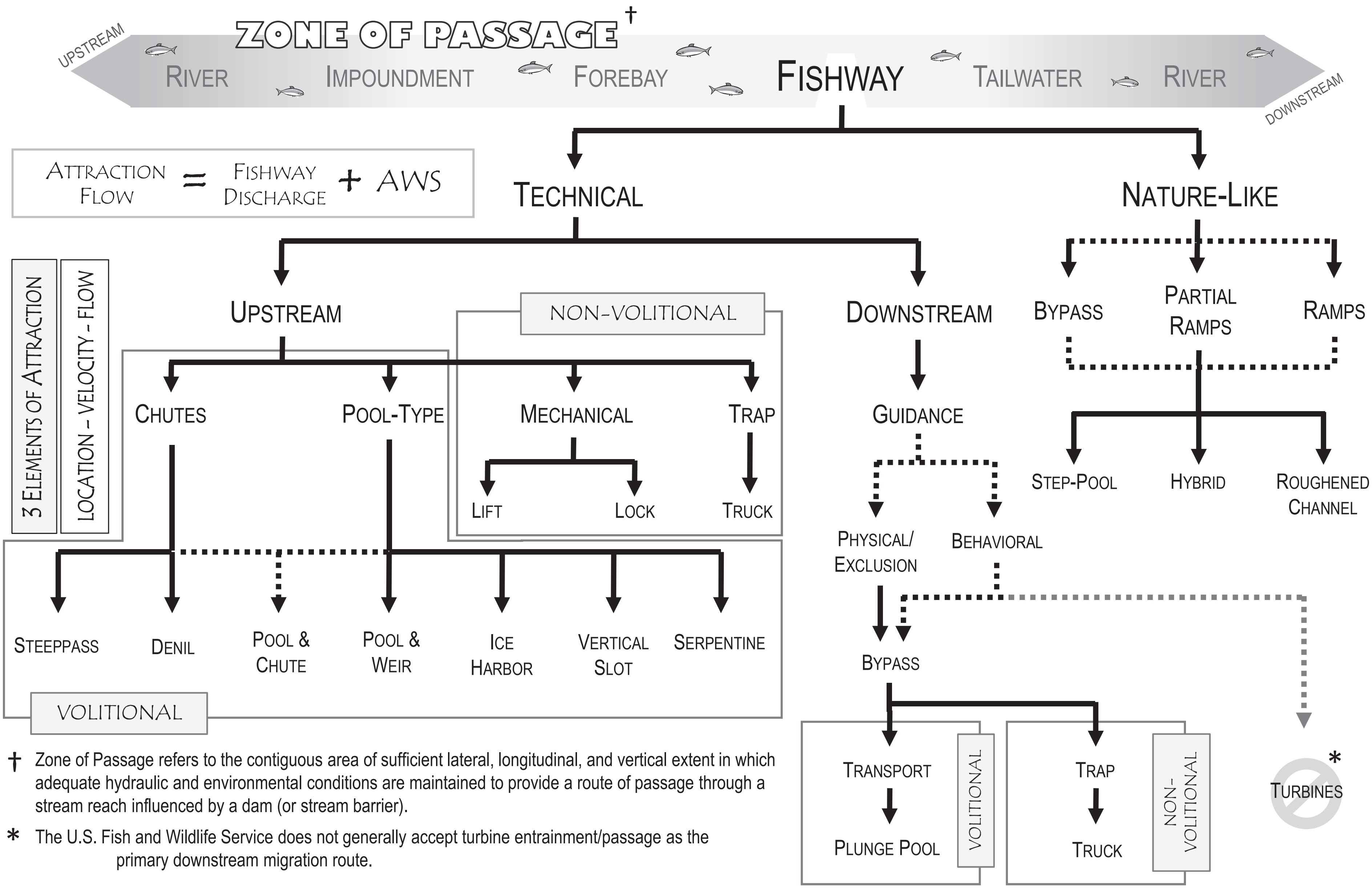
Fish Passage Engineering, B. Towler

Issued 1/6/2017; replaces "Power Dissipation Rates" 7/26/2014



† 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.

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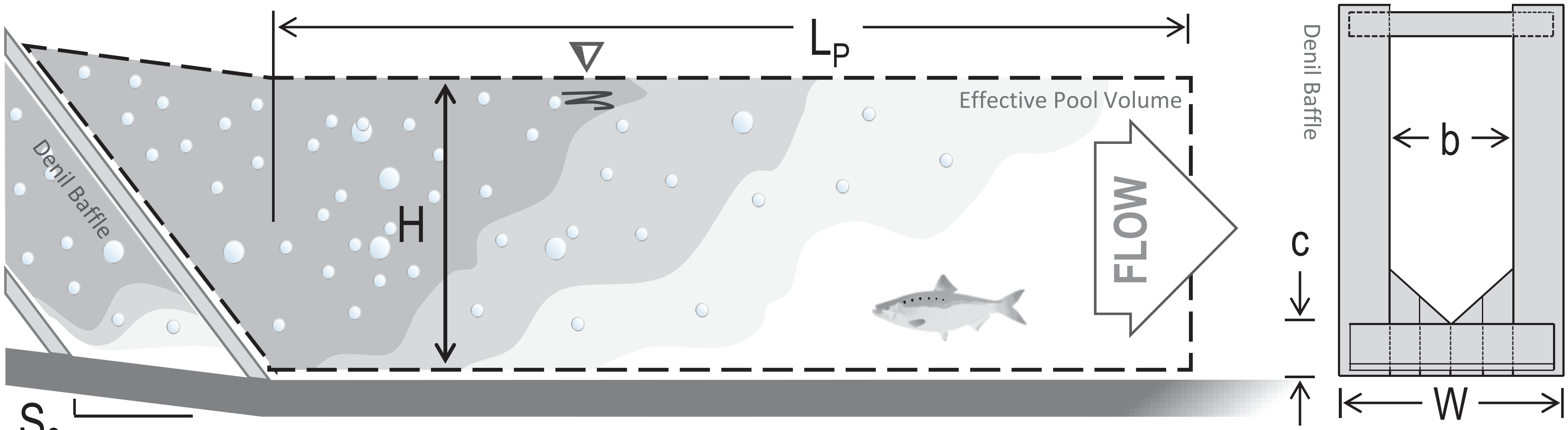
FISHWAY TYPES
REFERENCE PLATE 6-1



Denil Fishway Resting Pool Geometry

Generalized Power Dissipation in Denil Resting Pools

$$EDF = \left[\frac{Q}{2}\left(\frac{1}{A_1} - \frac{1}{HW}\right) + gH\left(\sqrt{2}\,\cos\frac{-\pi + 4\tan^{-1} S_0}{4} - 1\right)\right]\frac{Q\gamma}{HWL_P}$$

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

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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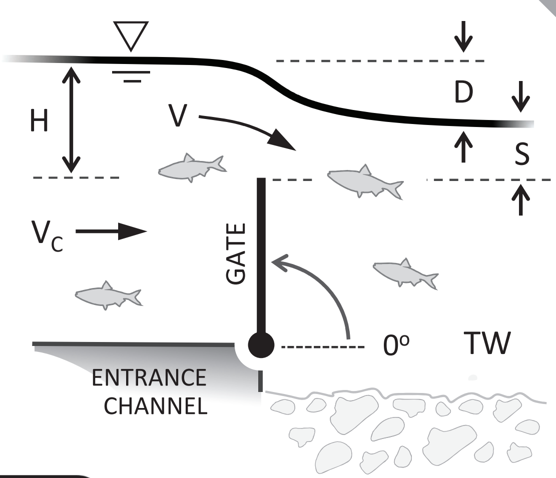
Issued 1/6/2017; replaces "Denil Resting Pools" 10/27/2015

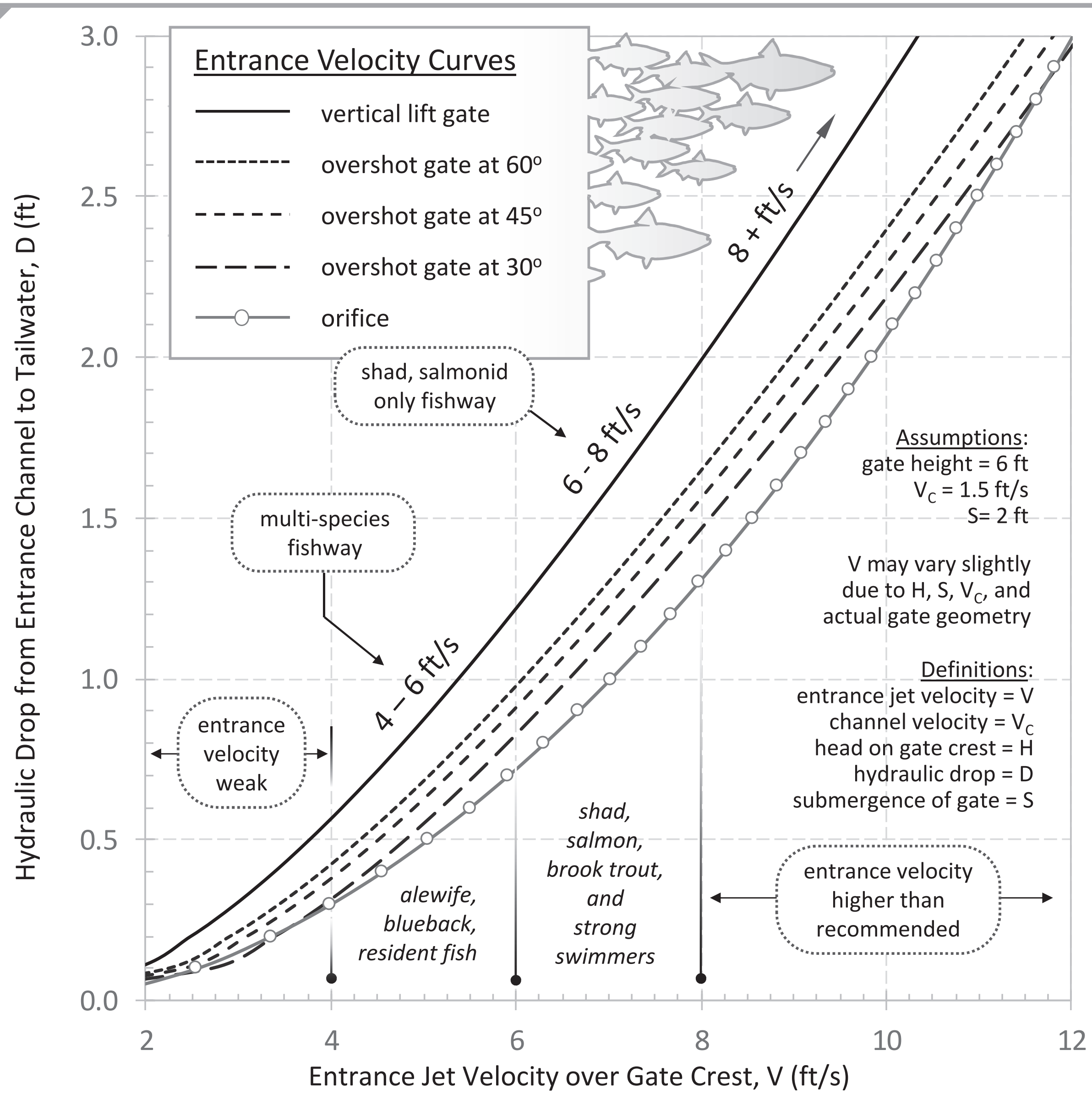
DENIL RESTING POOLS

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
60º Overshot	5	4
	12	6
	20	8
45º Overshot	5	4
	11	6
	19	8
30º Overshot	4	4
	10	6
	18	8





*estimated curves based on Rehbock eqn. and Wahlin & Replogle (1994);

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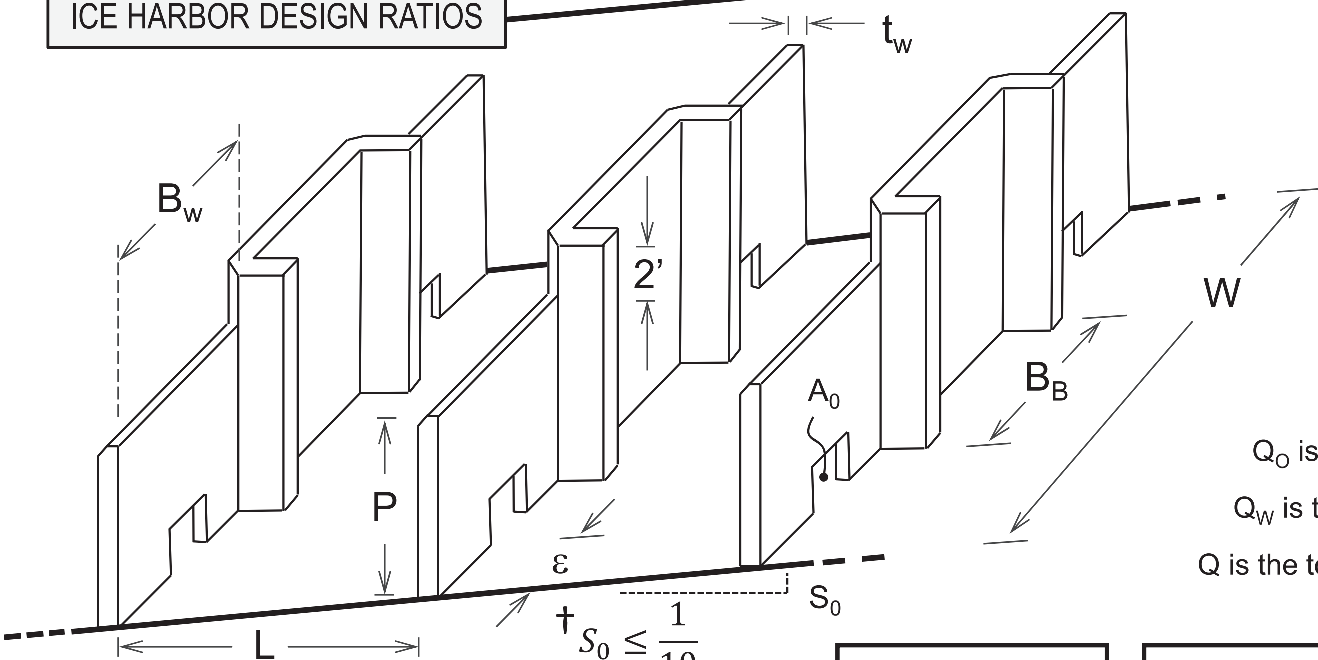
Issued 6/05/2019

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



† $L \geq 9\,ft$

† $S_0 \leq \frac{1}{10}$

† U.S. Fish and Wildlife Service criteria

$$Q_W = CB_W H_W^{\ 1.5}$$

$$Q_O = C_O A_O \sqrt{2gH_O}$$

$$Q = 2Q_W + 2Q_O$$

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

$C_O = 0.86$

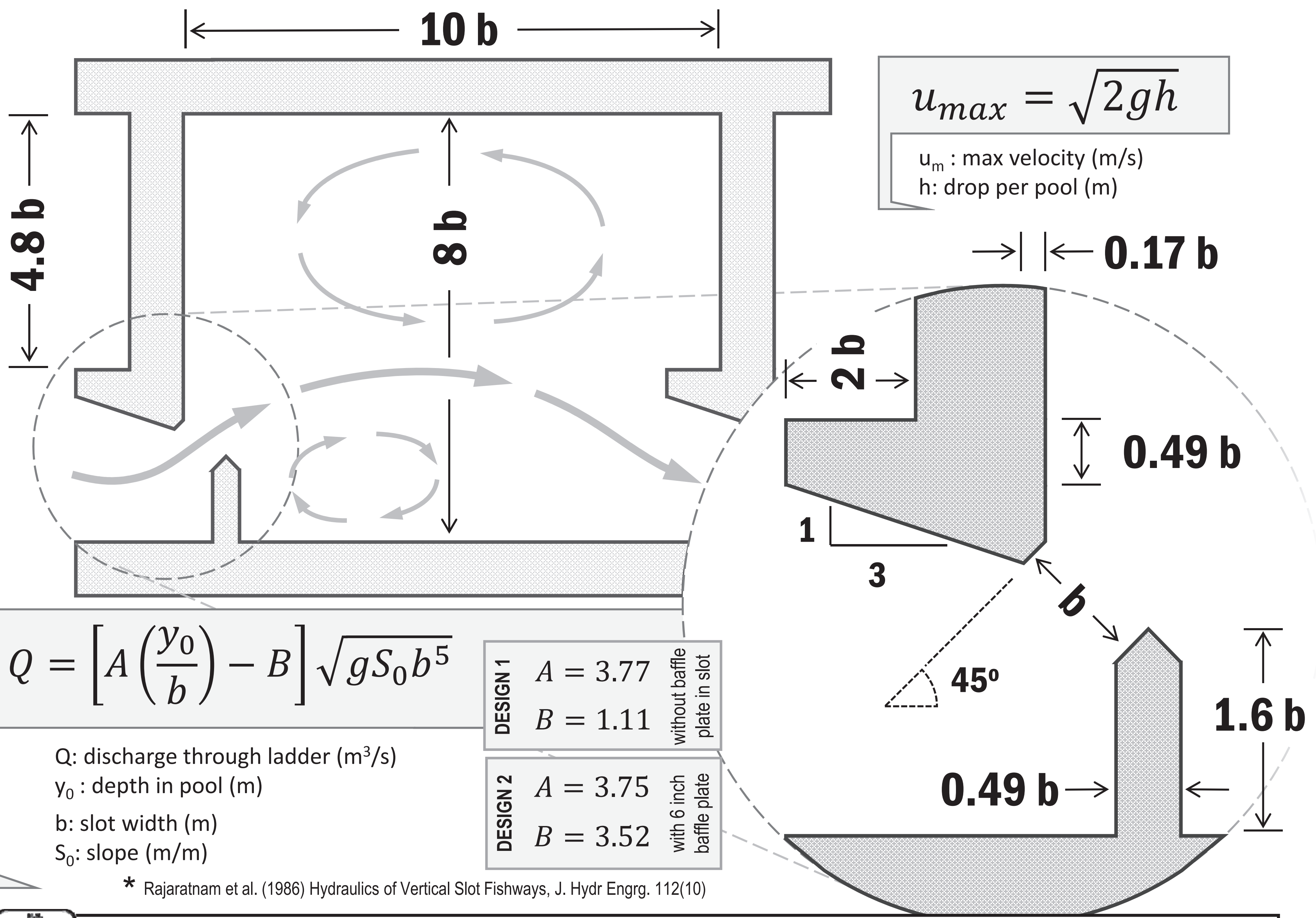
$C_d = 0.68$

$C = \frac{2}{3}\sqrt{2g}\,C_d$

USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler
Issued 1/6/2017; replaces “Ice Harbor Fishway” 7/24/2014

ICE HARBOR FISHWAY

REFERENCE PLATE 7-1



$$u_{max} = \sqrt{2gh}$$

u_m : max velocity (m/s)
h: drop per pool (m)

*
$$Q = \left[A\left(\frac{y_0}{b}\right) - B\right]\sqrt{gS_0 b^5}$$

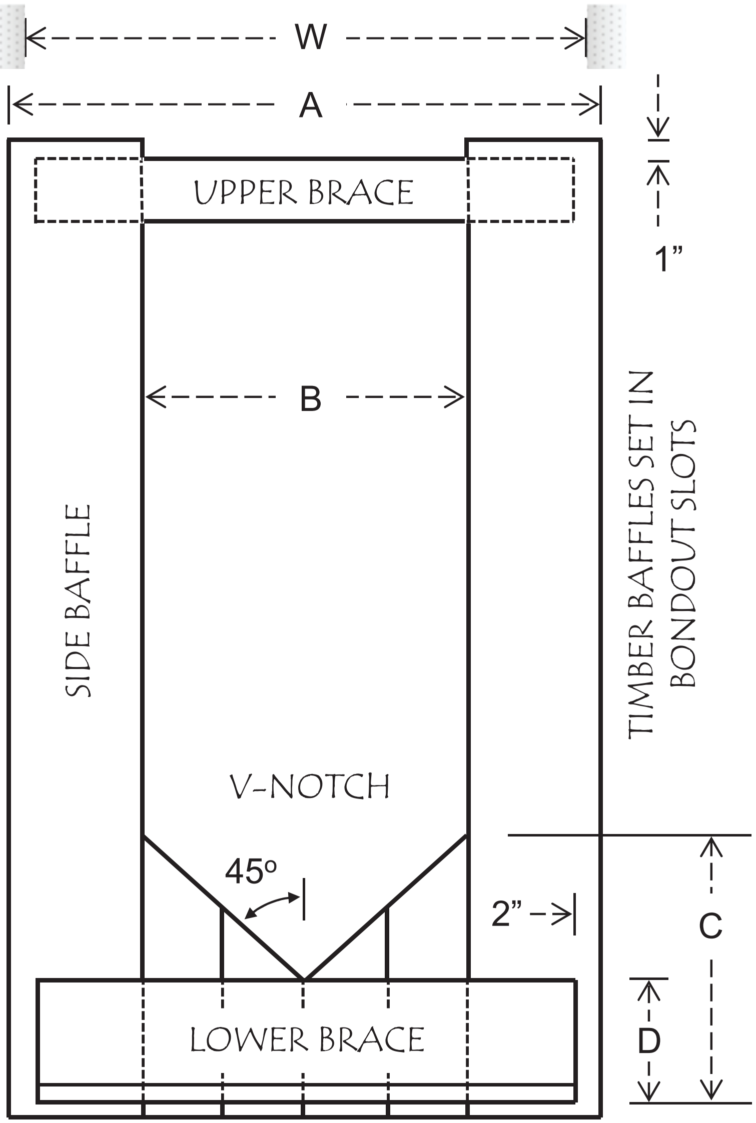
DESIGN 1	$A = 3.77$ $B = 1.11$	without baffle plate in slot
DESIGN 2	$A = 3.75$ $B = 3.52$	with 6 inch baffle plate

Q: discharge through ladder (m^3/s)
y_0 : depth in pool (m)
b: slot width (m)
S_0: slope (m/m)

* Rajaratnam et al. (1986) Hydraulics of Vertical Slot Fishways, J. Hydr Engrg. 112(10)

VERTICAL SLOT FISHWAY
REFERENCE PLATE 7-2

USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler
Issued 1/6/2017; replaces "Vertical Slot Fishway" 10/27/2015



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

$$Q = (1.34 - 1.84S_0)h_u^{1.75}B^{0.75}\sqrt{g\,S_0}$$

$$h_u = H - Dsin[45^o + tan^{-1}(S_0)]$$ †

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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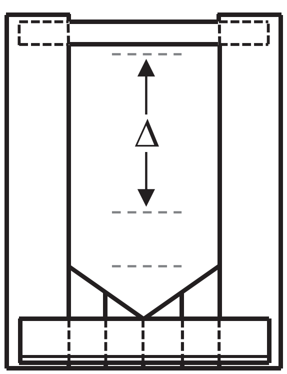
Fish Passage Engineering, B. Towler
Issued 1/6/2017; replaces “Standard Denil Ladder” 7/23/2014

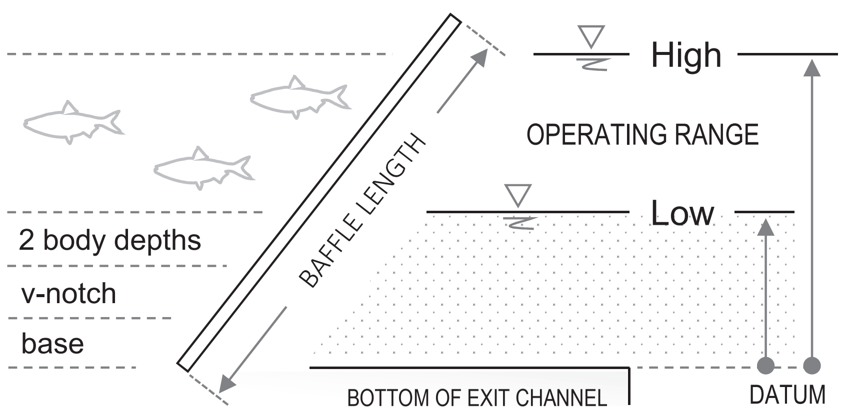
STANDARD DENIL GEOMETRY

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.

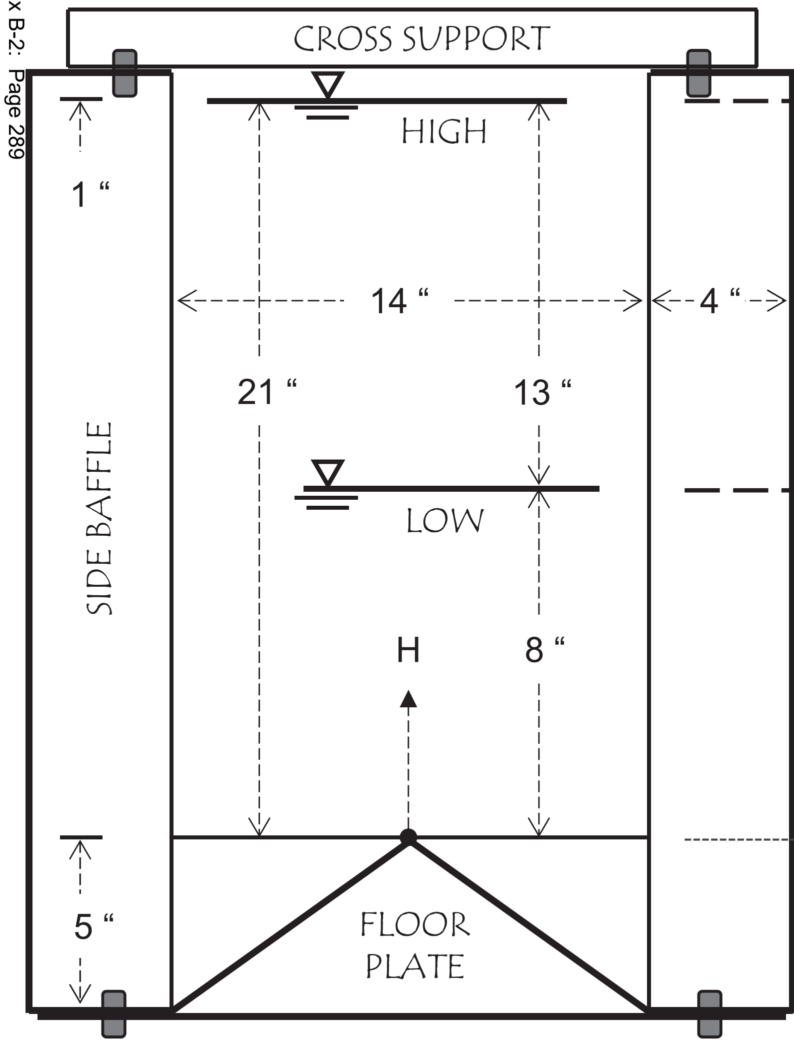
* UPPER LIMIT IS BASED ON A MAXIMUM VELOCITY CRITERION FOR RIVER HERRING (5 FT/S)

USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler, B. Sojkowski
Issued 6/19/2019; replaces "Standard Denil Operating Range" 2/28/2017

STANDARD DENIL OPERATING RANGE

REFERENCE PLATE 7-4

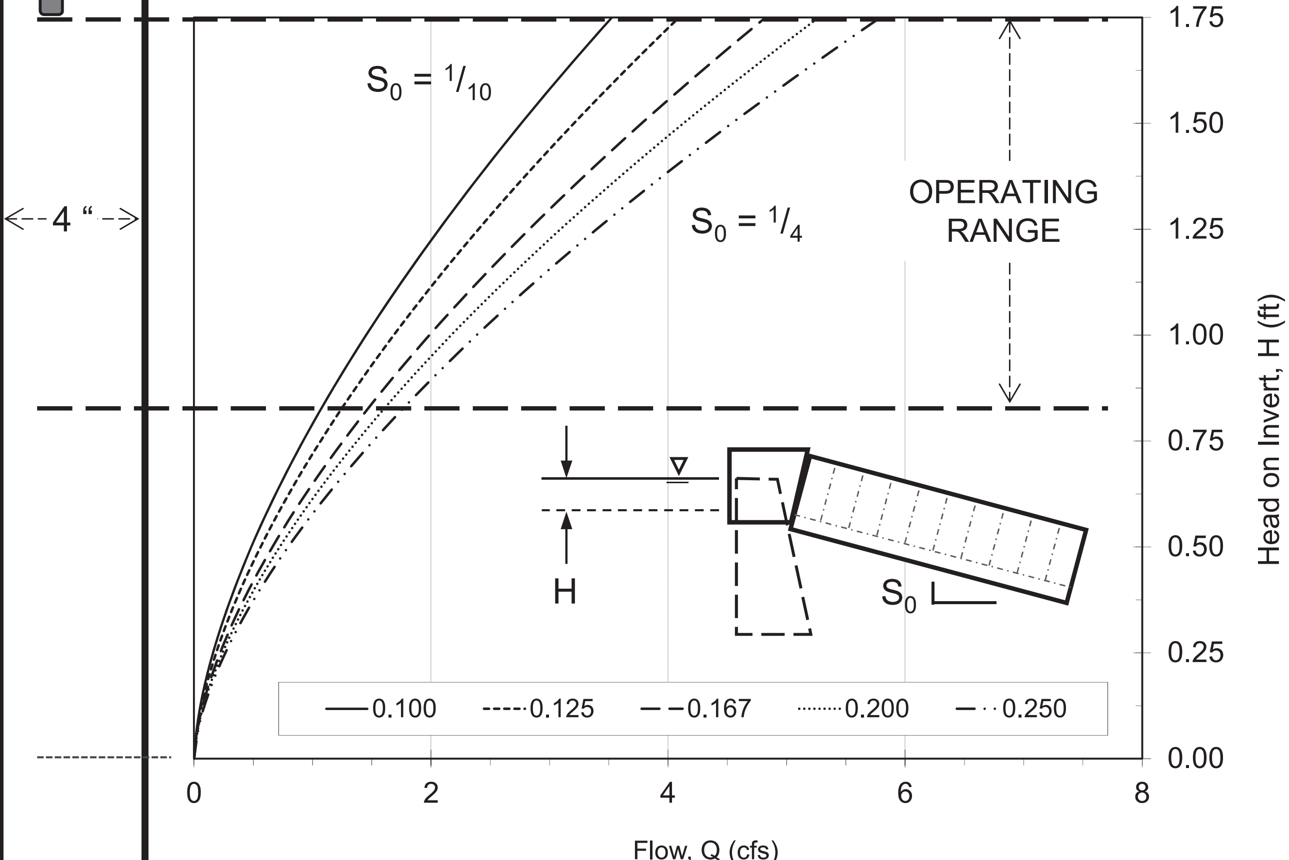
MODEL A CROSS-SECTION



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”



$$Q = \left(\frac{H}{0.0354\, S_0^{\,-1} + 0.4364} \right)^{\frac{1}{0.6307}} \quad \dagger$$

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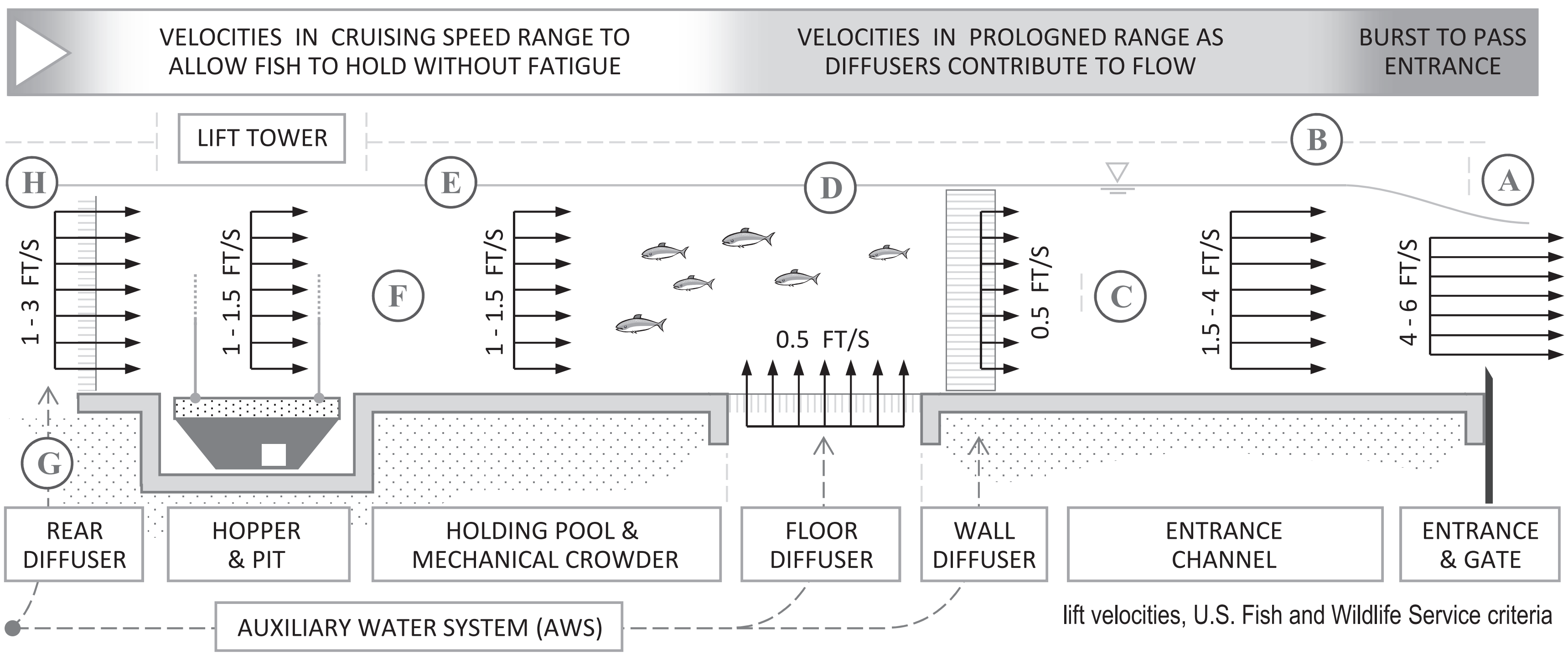
Fish Passage Engineering, B. Towler
Issued 6/20/2019; replaces “Model A Steeppass” 2/28/2017

MODEL A STEEPPASS

REFERENCE PLATE 7-5



lift velocities, U.S. Fish and Wildlife Service criteria

BIOLOGICAL LIFT CAPACITY

$$n_H = \text{V}\!\!\!/ \left(\frac{60\ min}{1\ hr}\right)\frac{r}{w_f \text{v}\!\!\!/_c [1 + C_n]}$$

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
$\text{v}\!\!\!/_c$ 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

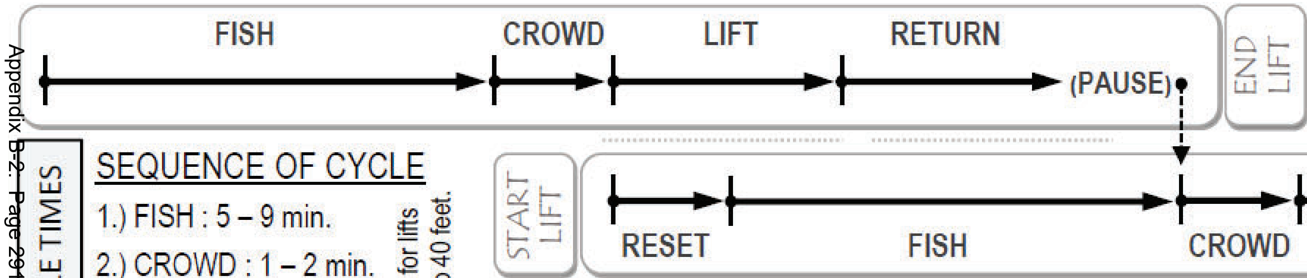
A. Attraction jet is created by acceleration due to entrance (lift) gate operations; jet typically results in 0.5 – 2 foot hydraulic drop into TW.
B. Flood walls and other lift components should be design to protect against a 50-year flood event.
C. Flow in the entrance channel, downstream of the diffusers, 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.

USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler
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 ‡

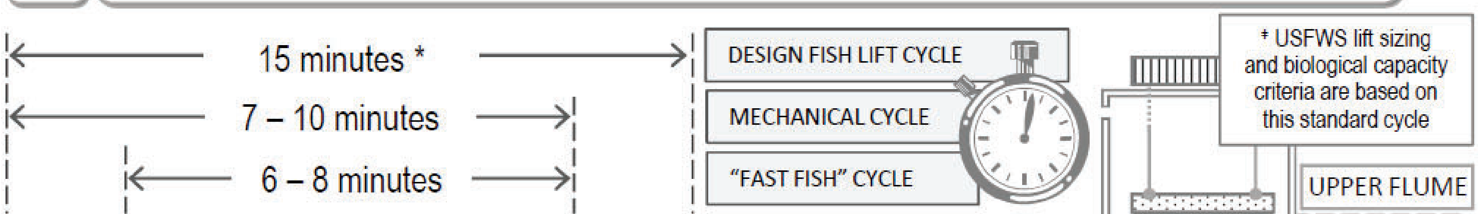


TYPICAL CYCLE TIMES

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.

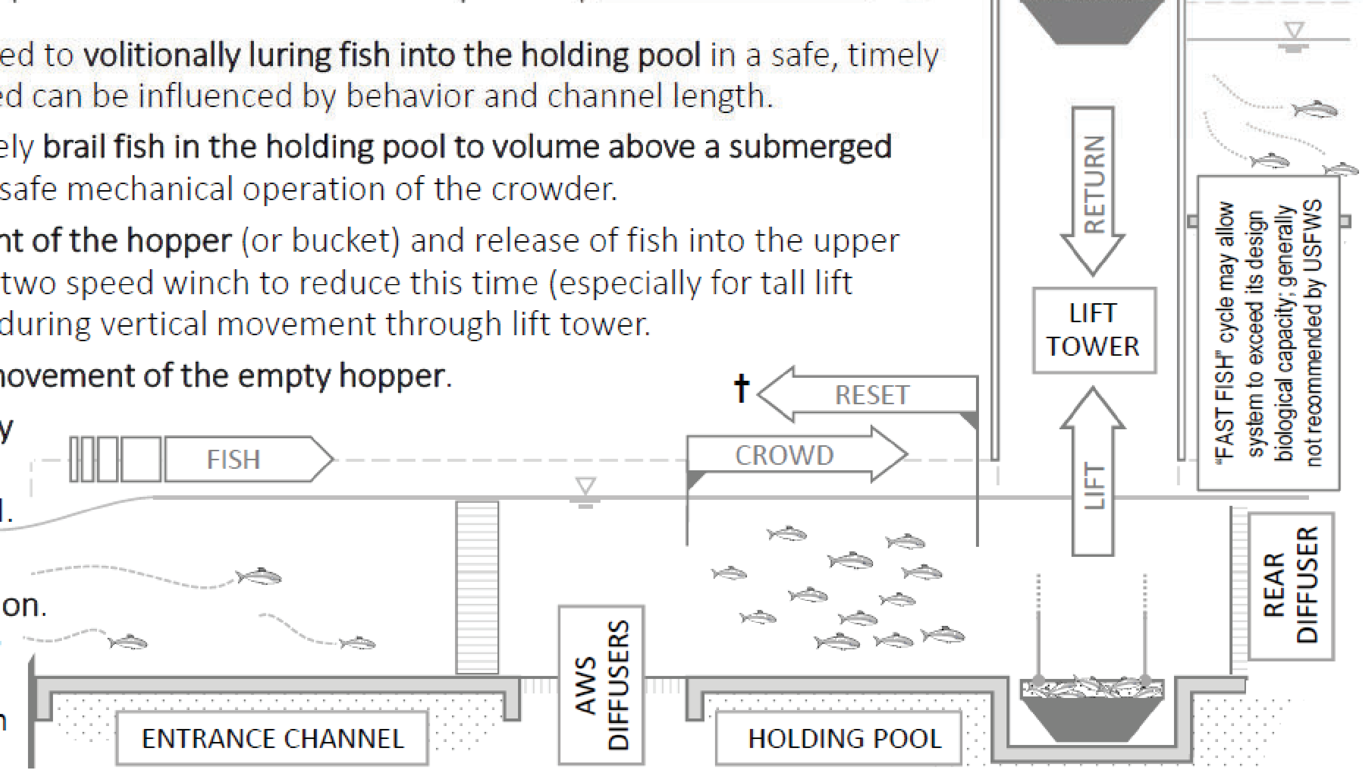
* times are typical for lifts less than or equal to 40 feet.



‡ 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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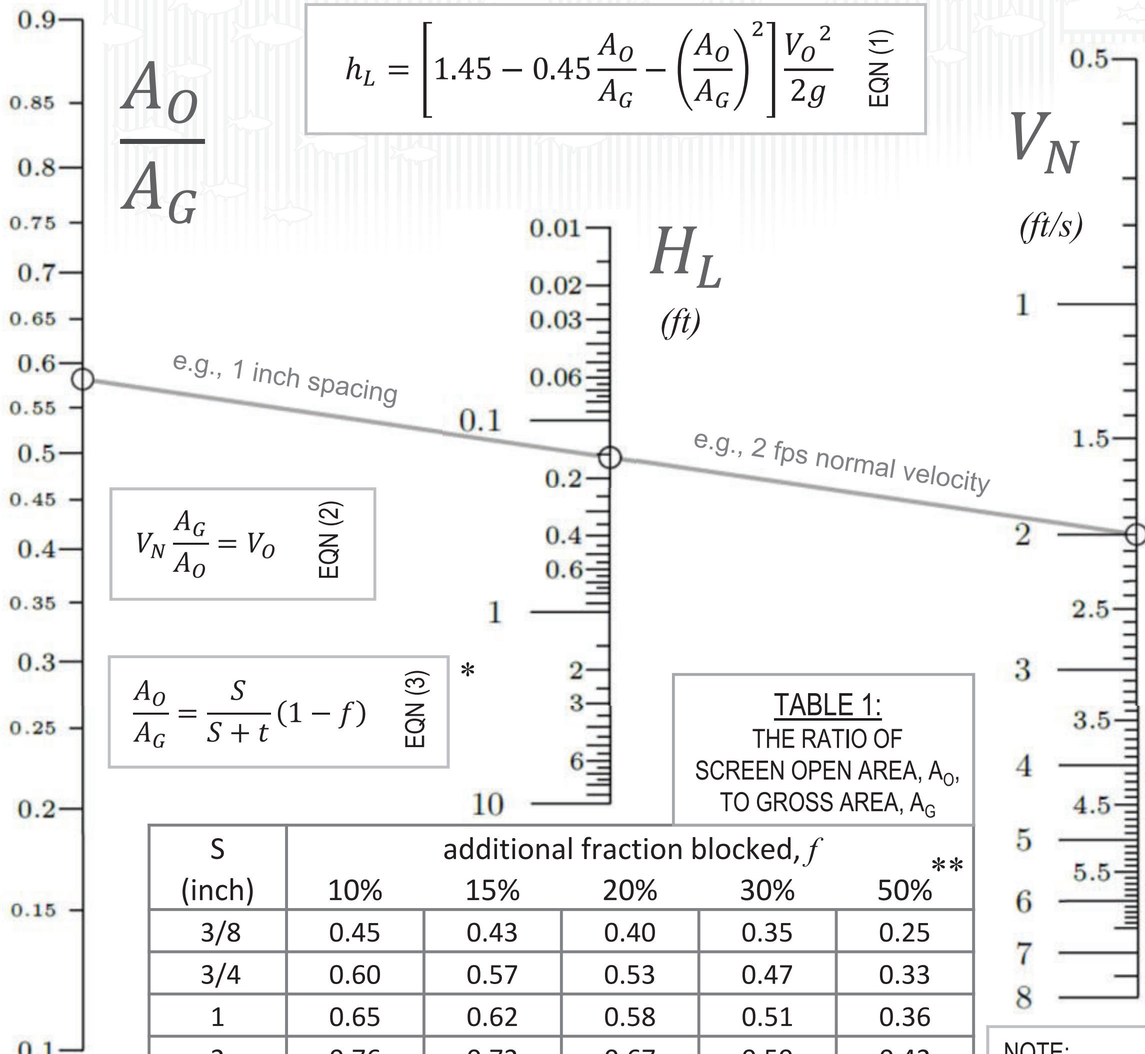
Fish Passage Engineering, B. Towler
Issued 2/28/2017; replaces "Fish Lift Cycle" 11/17/2014

FISH LIFT SEQUENCE
REFERENCE PLATE 7-7

ANGLED BAR SCREEN HEADLOSS NOMOGRAPH



$$h_L = \left[1.45 - 0.45\frac{A_O}{A_G} - \left(\frac{A_O}{A_G}\right)^2\right]\frac{{V_O}^2}{2g} \quad \text{EQN (1)}$$

$$V_N\frac{A_G}{A_O} = V_O \quad \text{EQN (2)}$$

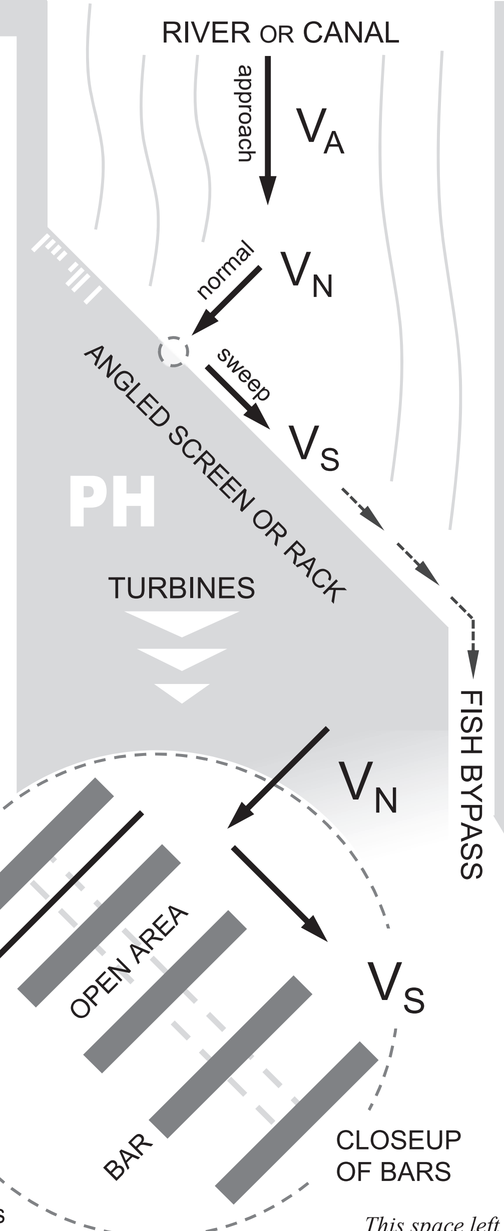
$$\frac{A_O}{A_G} = \frac{S}{S+t}(1-f) \quad \text{EQN (3)} \; *$$

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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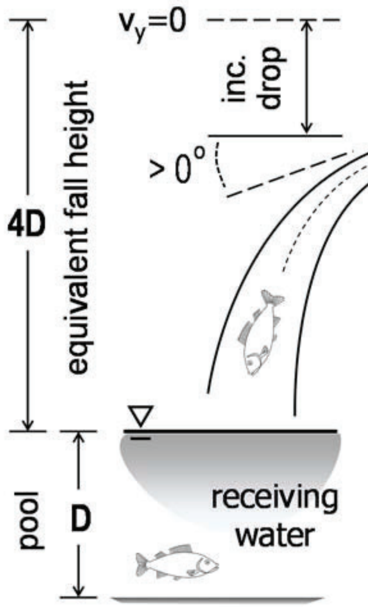
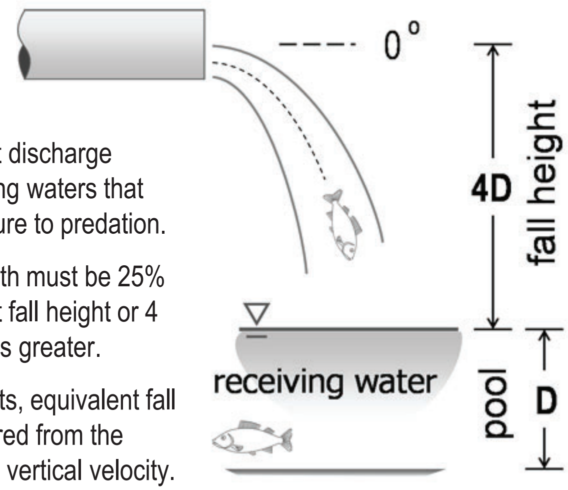
USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler, B. Sojkowski
Issued 1/6/2017; replaces "Angled Bar Screens" 12/21/2016

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.



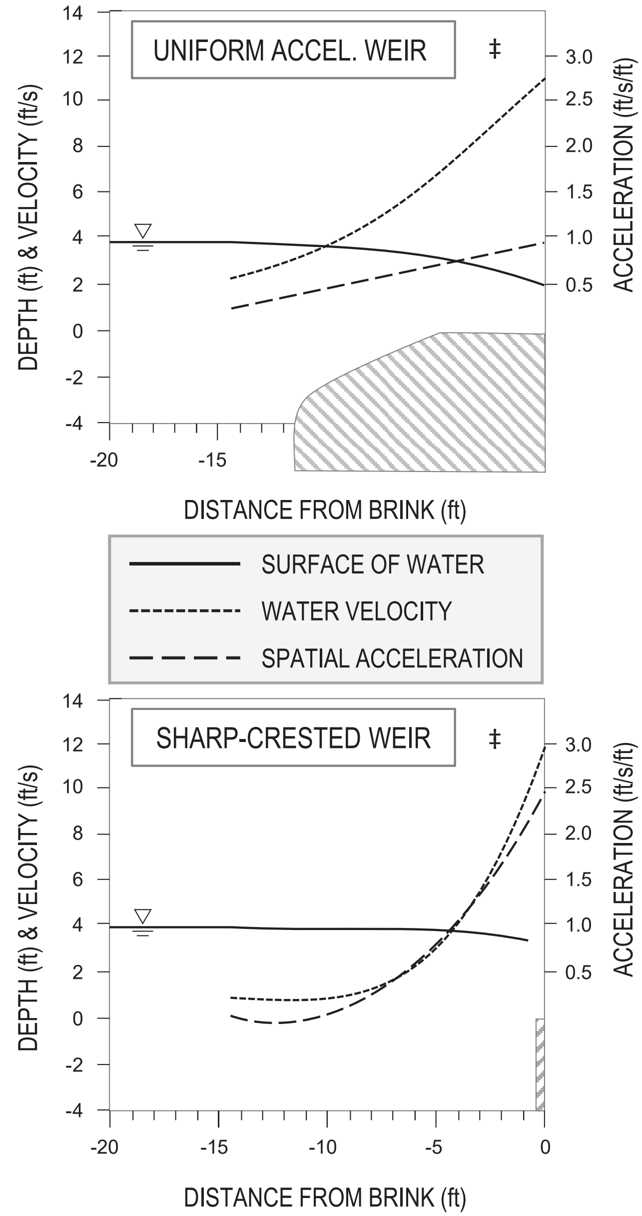
†

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

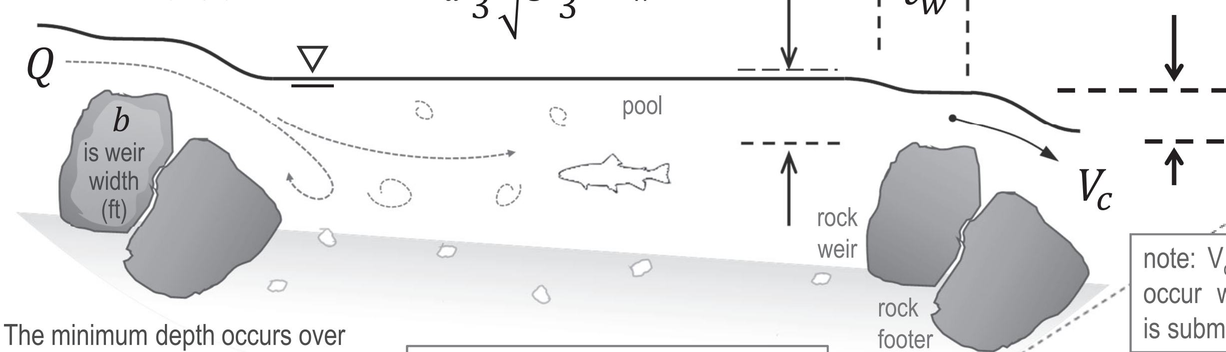
USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler
Issued 1/6/2017; replaces "Downstream Passage" 7/28/2014

BYPASS AND PLUNGE POOL

REFERENCE PLATE 9-2

HYDRAULICS OF STEP-POOL TYPE, NATURE-LIKE FISHWAYS CAN BE APPROXIMATED AS BROAD-CRESTED WEIRS.

$$Q = V_c b y_c \qquad Q = C_d \frac{2}{3}\sqrt{g\frac{2}{3}}\, b H_w^{\,1.5}$$



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:

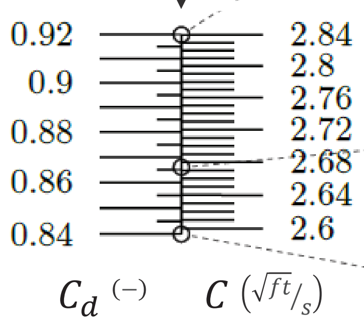
$$V_c = \sqrt{g y_c}$$

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

$$C_d \frac{2}{3}\sqrt{g\frac{2}{3}} = C$$

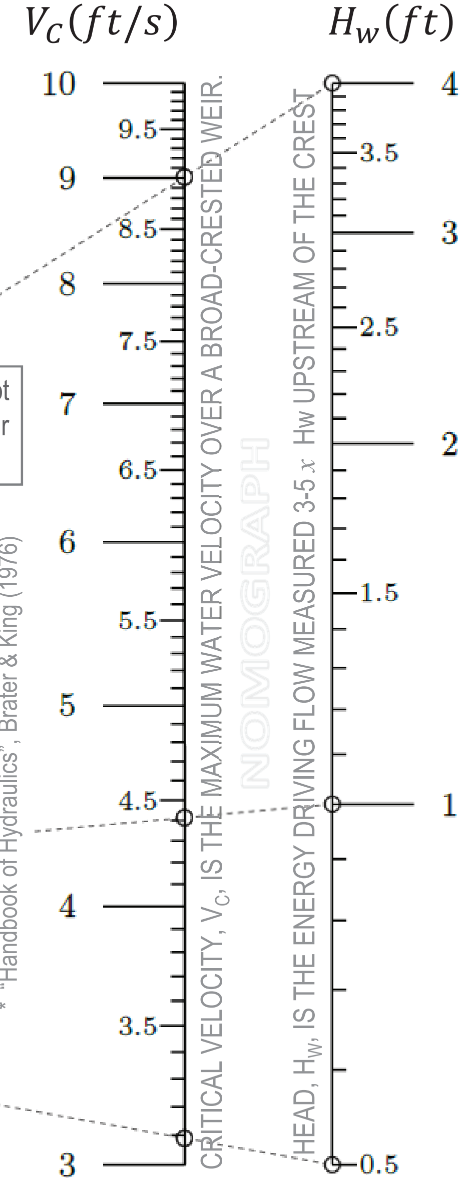


note: V_c may not occur when weir is submerged

Weir Thickness, t_w (ft) — Head Over Weir Crest, H_w (ft) — C $(\sqrt{ft}/s)$

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			

* "Handbook of Hydraulics", Brater & King (1976)



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).

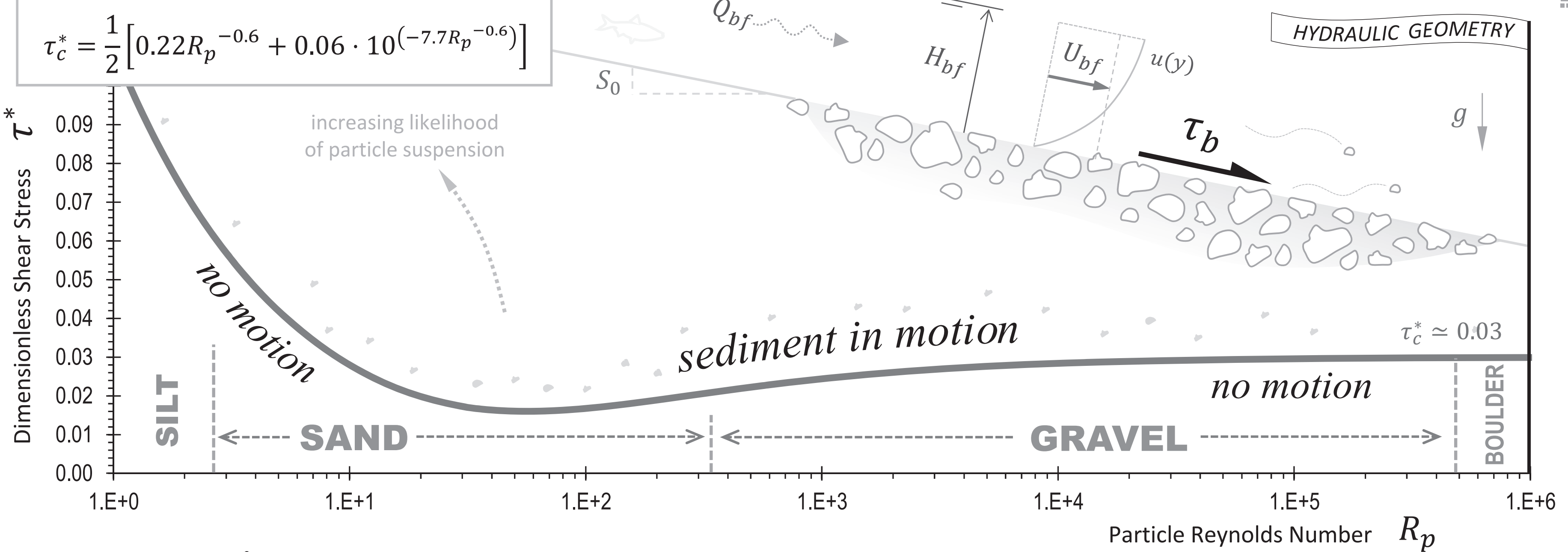
USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler
Issued 2/17/2017; replaces "Rock Weir Hydraulics" 21/6/2017

ROCK WEIR HYDRAULICS

REFERENCE PLATE 10-1

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*

$R = \dfrac{\rho_s}{\rho_w} - 1 \cong 1.65$ { *for silica*

$$\tau^* = \frac{\tau_b}{\rho g R D_{50}} = \frac{H_{bf} S_0}{1.65 D_{50}}$$

$$R_p = \frac{\sqrt{R g D_{50}}\, D_{50}}{\nu} \cong \frac{\sqrt{1.65\, g D_{50}}\, D_{50}}{\nu}$$

Shields (1936) "Appl. of Similarity Princ. & Turb. Res. to Bed Load Movement"
Parker et al, (2003) "Effect of Floodwater Extr. on Mountain Stream Morphology"

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!*

(grain size)

BOULDER
10.0 *in*
256 *mm*
GRAVEL
0.787 *in*
2.0 *mm*
SAND
0.00246 *in*
0.0625 *mm*
SILT
0.000154 *in*
0.00391 *mm*
CLAY

UDDEN-WENTWORTH
GRAIN SIZE SCALE

USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler
Issued 1/6/2017

INITIATION OF MOTION
REFERENCE PLATE 11-1

Appendix B
Fishway Inspection Guidelines

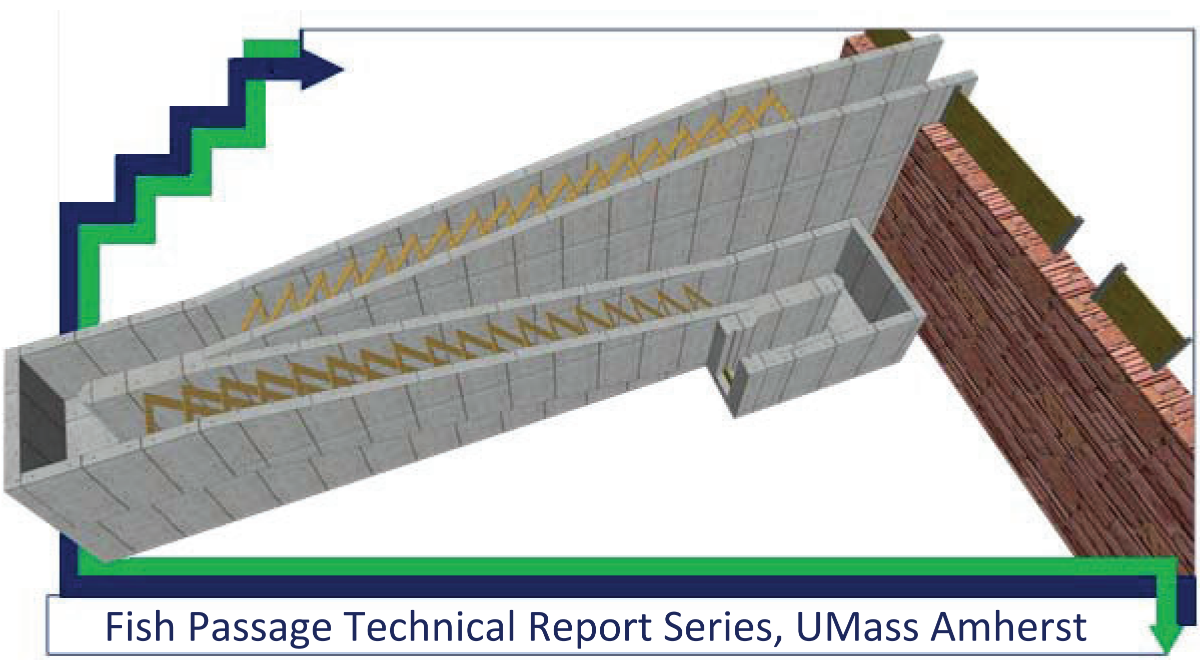
FISHWAY INSPECTION GUIDELINES

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



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Suggested citation: University of Massachusetts Amherst, Fish Passage Technical Report, TR-2013-1 (June 2013), UMass Amherst Libraries, University of Massachusetts.

Available at: http://scholarworks.umass.edu/fishpassage/

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

Fish Lifts/Locks: 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.

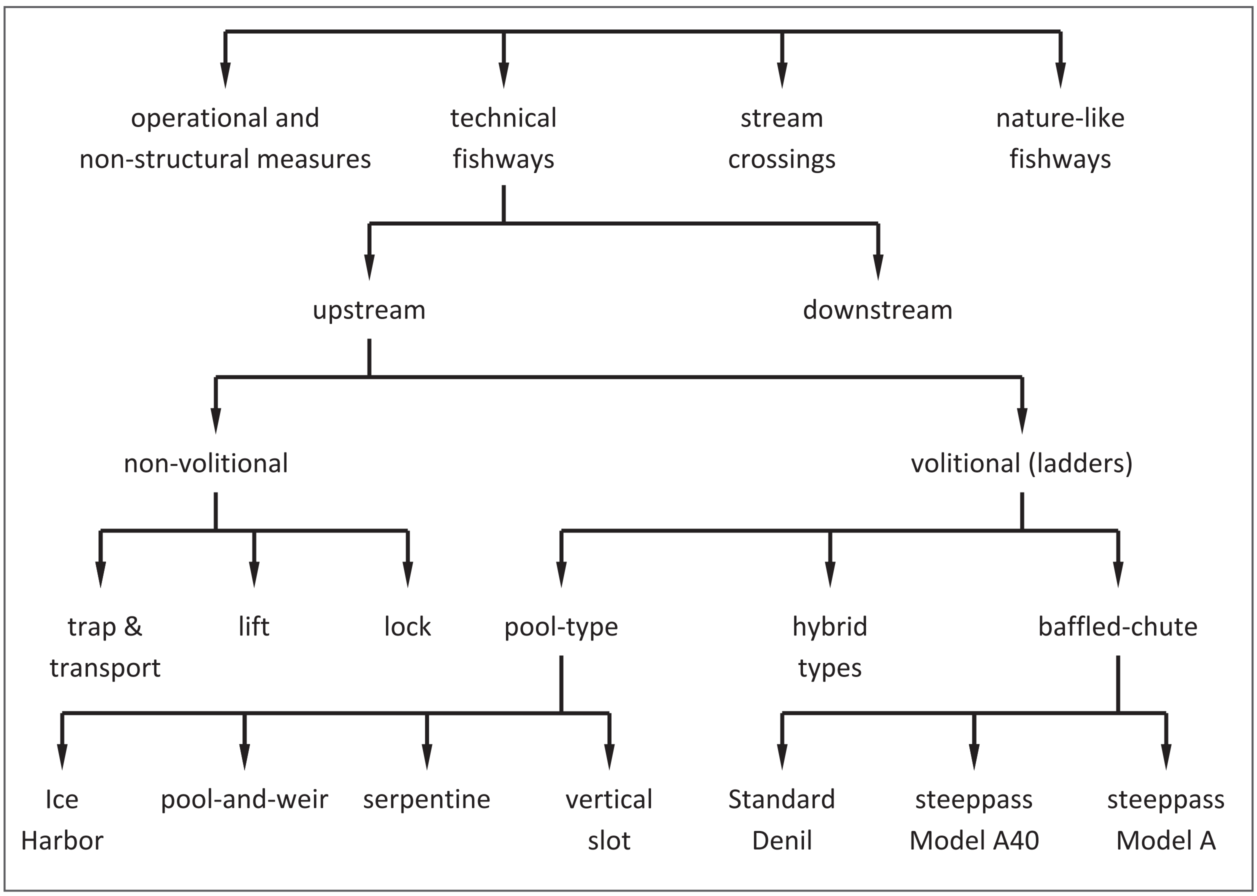

Figure 1. Common fishway types in the eastern U.S.

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.

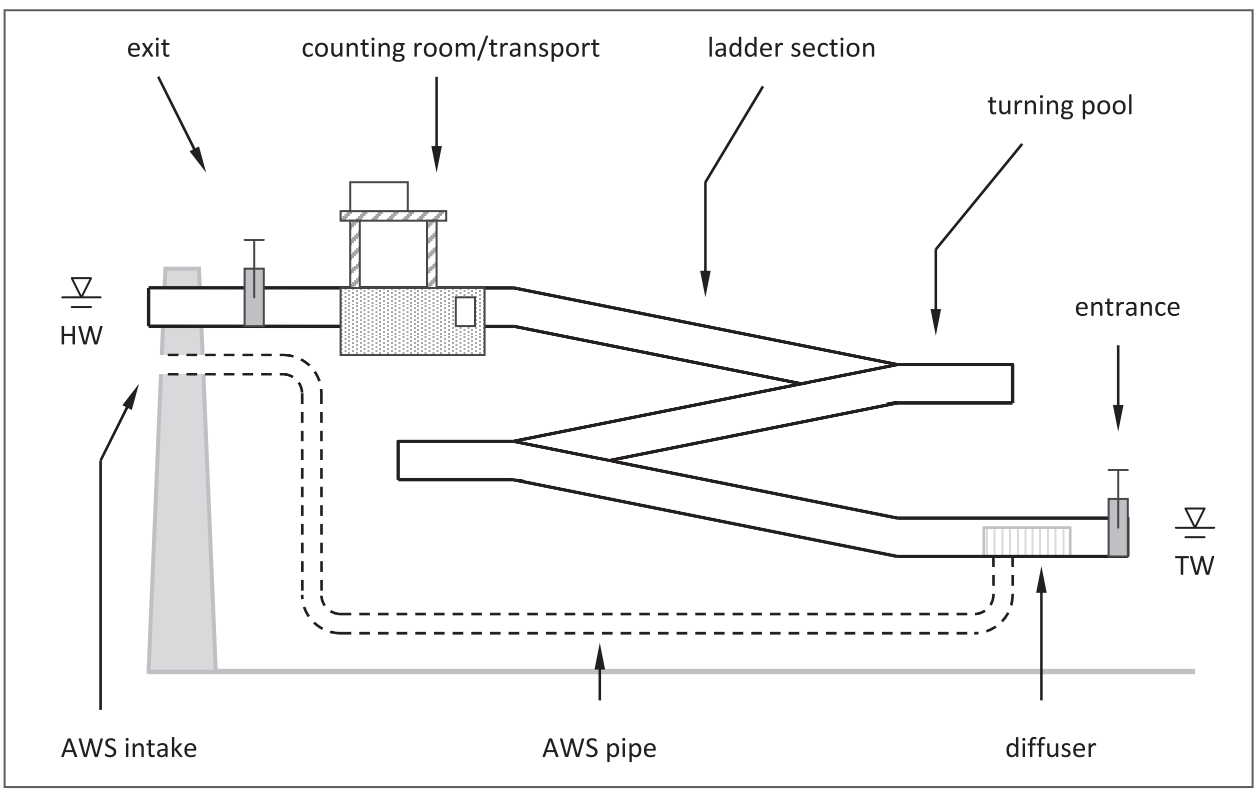

Figure 2. Major components in typical volitional fish ladders

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

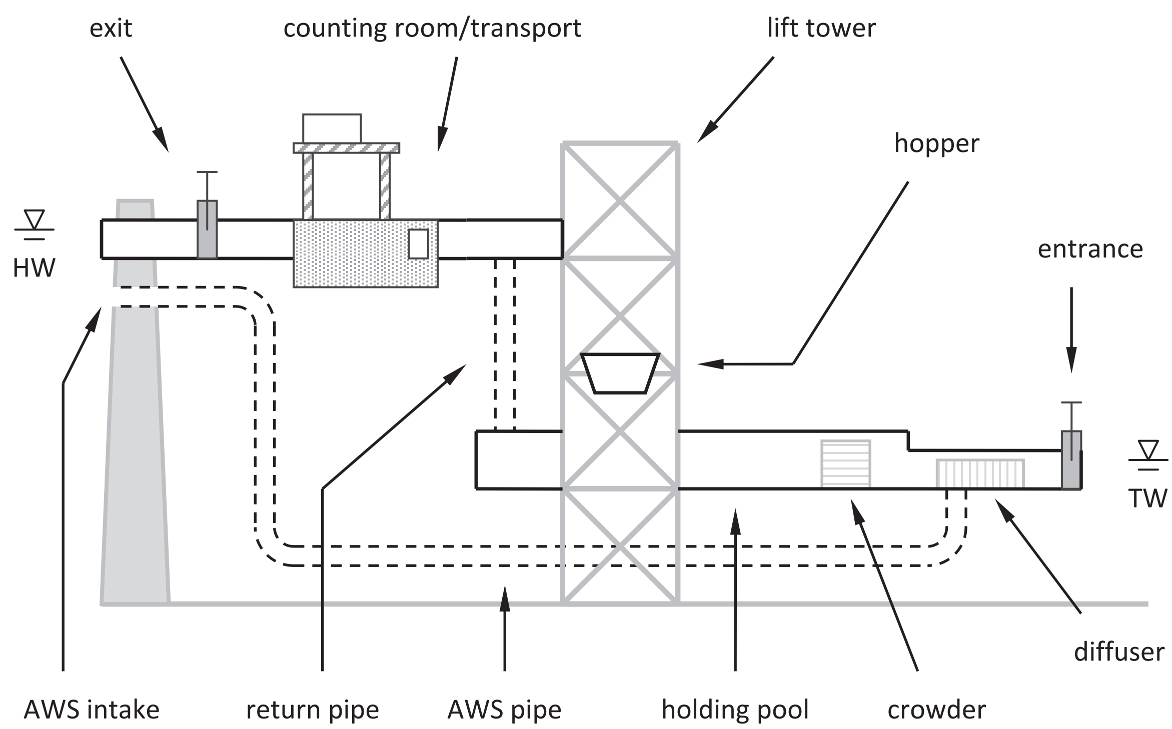

Figure 3. Major components in typical non-volitional fish lifts

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.

9.0 Acknowledgements

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The authors thank these individuals for their thoughtful contributions.

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: ____

____

____

____

____

____

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: ____

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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
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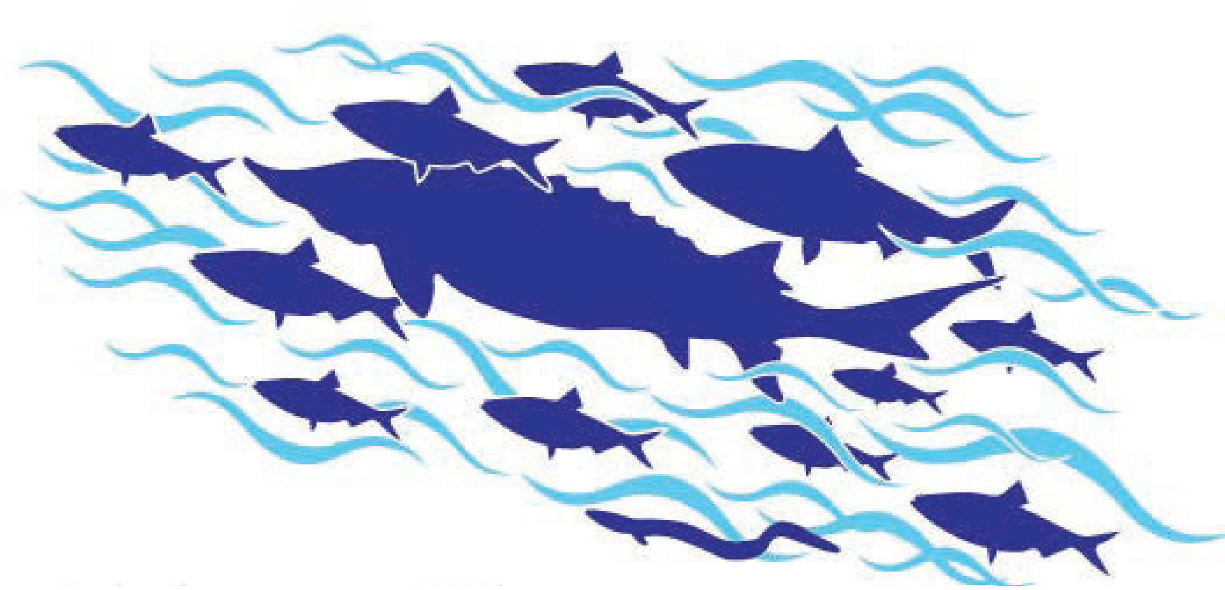

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

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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

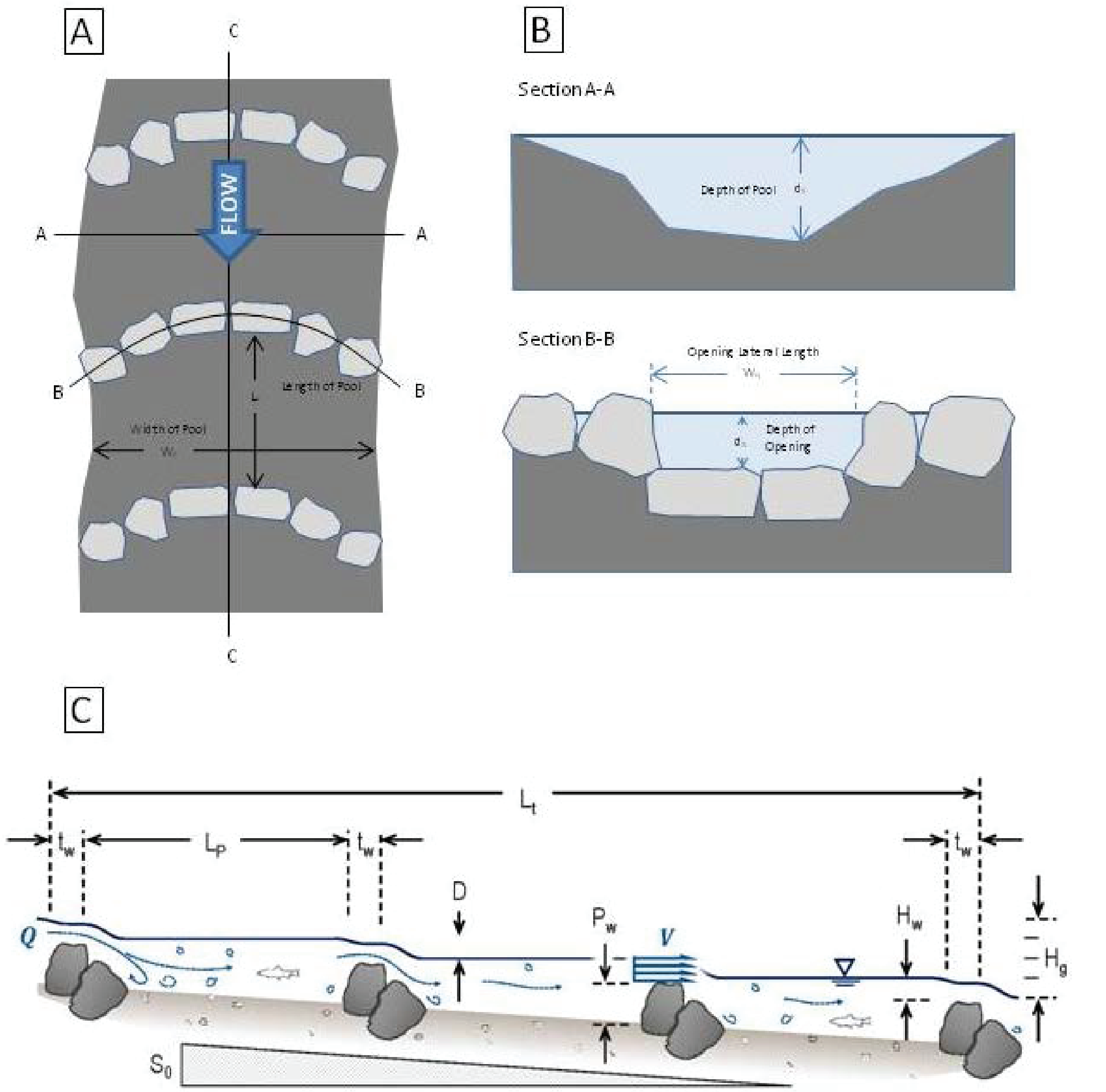
The following are key passage design guidelines that have been identified by the federal interagency team for application to passage of Atlantic Coast diadromous species, and for some species, more discrete guidelines according to life stage/body size categories for the species. These guidelines may 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 $\leq$ 15 cm ($\leq$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 ($\leq$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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