Exploring Upstream and Downstream Fish Passage Improvements on the Lower St. Croix River

Final Report
January 28, 2021

Prepared for the
International St. Croix River Watershed Board
and Workgroup

IJC Contract Number: GS10F150BA
IJC Order Number: 19AQMM19F4922

LimnoTech
Water Environment | Scientists Engineers

Cover images, clockwise from upper left: Woodland Dam fishway, looking north; Grand Falls Powerhouse fishway, looking northeast; Woodland Dam fishway, looking east; and Grand Falls Powerhouse fishway, looking east. (Images: LimnoTech)

TABLE OF CONTENTS

WORKGROUP MEMBERS*

Chief Hugh Akagi – Peskotomuhkati at Skutik, NB
Ed Bassett – Passamaquoddy Tribe, Perry, ME
Scott Beal – Woodland Pulp LLC, Baileyville, ME
Barbara Blumeris – ISCRWB-US, US Army Corps of Engineers, Concord, MA
Susan Daniel – IJC-US Section, Washington, D.C.
Kevin Dean–Woodland Pulp LLC, Baileyville, ME
Don Dow – NOAA Fisheries, Orono, ME
Adam Greeley – IJC-US Section, Washington, D.C.
Alex Hoar – Retired, U.S. Fish and Wildlife Service, Skutik River Advisor to Peskotomuhkati at Skutik
Bryan Hulbert – Department of Fisheries and Oceans, Moncton, NB
Sean Ledwin – ISCRWB-US, Maine Department of Marine Resources, Augusta, ME
Kathryn Parlee – ISCRWB-CA, Environment and Climate Change Canada, Dartmouth, NS
Rob Phillips – IJC-CA Section, Ottawa, ON
Nick Stasulis – US Geological Survey, Augusta, ME

ACKNOWLEDGEMENTS*

John Ames – Peskotomuhkati at Skutik, NB
Mike Burke – Inter-Fluve, Damariscotta, ME
Ralph Dana – Peskotomuhkati at Skutik, NB
Jamie Gibson - Department of Fisheries and Oceans, Dartmouth, NS
Lynn Lankshear – NOAA Fisheries, Gloucester, MA
Harvey Millar – Department of Fisheries and Oceans, St. George, NB
Lita O’Halloran – Peskotomuhkati at Skutik, NB
Rory Saunders – NOAA Fisheries, Orono, ME
Erica Stuart – Department of Fisheries and Oceans, St. George, NB
Gale Wipplehauser – Maine Department of Marine Resources, Augusta, ME

CONTRACTING AUTHORS

Doug Bradley – LimnoTech, Senior Project Scientist, Ann Arbor, MI
John Nestler – PhD, Retired, U.S. Army Engineer Research and Development Center, Vicksburg, MS
Greg Allen, PE – Alden Research Laboratory Inc., Holden, MA

*Alphabetical order by last name

EXECUTIVE SUMMARY

Study Findings

The St. Croix River watershed covers an area of 1,649 square miles along the Canada-United States border between New Brunswick and Maine, and the river serves as a natural boundary between Canada and the United States. The St. Croix River was originally named the Passamaquoddy River or Schoodic River by the native Passamaquoddy people and the area remains an important watershed within the center of their ancestral homelands. In the 1700s, settlers began developing the river for logging and manufacturing purposes, including the construction of dams throughout the St. Croix River system.

Early dam developments were constructed with little understanding of the importance of fish passage connectivity within the St. Croix River system to the success of the diadromous species stocks. As the earliest and lowermost dam in the St. Croix River system, the Milltown Dam developments lacked fish passage from the late 1700s through the late 1800s. In 1883, a primitive fish passageway was installed at the Milltown Dam site, although technology innovations in fish design and effectiveness would come much later. The second dam in the lower St. Croix River, Woodland Dam, was constructed in the early 1800s, and lacked a fish passageway until the mid-1960s. The third facility, Grand Falls Dam, was constructed in the early 1900s and also lacked a fish passageway until the mid-1960s.

Combined, these three facilities resulted in significant adverse effects on the St. Croix River diadromous fisheries, including modified hydrologic regime, blocked access to critical reproduction habitats, degraded water quality, and an elimination or modification in the population, distribution and behavior of native, ocean migrating fishes (Willis, 2009). With recent decommissioning commitments for the lowermost Milltown Dam facility (NBP 2020), regional stakeholders concerned with St. Croix River fisheries resources are likely to focus on reestablishing fish passage further upstream at the Woodland Dam and Grand Falls Dam, as part of a balanced, regional effort to improve and restore native, sea-run fish populations.

This study, *Exploring Upstream and Downstream Fish Passage Improvements on the Lower St. Croix River*, investigated a range of upstream and downstream fish passage concepts for the St. Croix River at Woodland and Grand Falls Dams. The study goal was to identify opportunities and constraints for options that maintain or restore fish passage in both upstream and downstream directions within the St Croix River at the Grand Falls and Woodland facilities, while accounting for natural and anthropogenic modifications within the river system. It produced a stepwise evaluation of species-specific options for fish passageway at the Woodland and Grand Falls facilities, which can be used in planning for ongoing support of sea-run anadromous species and their populations within the St. Croix River system. The study greatly benefited by local and regional experiences and the expertise of the International St. Croix River Watershed Board (ISCRWB), and a workgroup (WG) composed of selected regional experts and stakeholders with a shared interest in enhancing and recovering the sea-run populations of the St. Croix River.

The report is organized as follows:

The executive summary is an overview of the study purpose, process, findings, and recommendations.

Section 1 is an introduction into the study scope, and overall goals and objectives.

Section 2 provides background context for the subject sites and for the selection of the fish species used as a basis for design, along with other key criteria used in the passageway screening process.

Section 3 provides details of the technologies considered for upstream and downstream passage. This section describes the three-tiered screening process: preliminary, secondary, and tertiary screening. The preliminary screening identified fish passage technologies appropriate for the target species, while the secondary screening considered applicability of those remaining technologies for the site characteristics. The tertiary screening considered various configurations (alternatives) of technologies passing the secondary screening process.

Section 4 provides details of final (tertiary) selected upstream and downstream passageway concepts, along with rationale for their selection, site performance opportunities and constraints, and data gaps in understanding effectiveness and performance. Preliminary and approximate construction cost estimates are provided for consideration of concepts.

Section 5 provides a summary of overall and site-specific uncertainties, as well as recommendations for next steps.

Species Selection for Design Consideration

Section 2 of the study describes the critical design considerations used in the concept screening process. These included the identification of target fish species, their migration timing periods, and target population estimates, all of which provide a critical foundation for fish passageway concept assessments. It is important to note that the St. Croix River once supported large runs of diadromous alewife and blueback herring (collectively named river herring), Atlantic salmon, American shad, sea lamprey and American eel. Despite the presence of the three lower mainstem dams, the St. Croix River still supports smaller populations of most of these species (which is not the case for Atlantic Salmon). Further, the quality and availability of habitat in the St. Croix River watershed have the potential to support the largest sea-run alewife population in North America. Today, impounded waters associated with the dams form vital and abundant habitat for many of these species. Thus, while early development has adversely modified fish habitat and water quality, the watershed has been significantly rehabilitated through the efforts of dedicated stakeholders, indigenous peoples and governmental agencies. For this reason, fish passageway concepts in this study are designed for the current, improved state of the St. Croix River, with the goal that this project provides information to support increasing the population numbers of target species as envisioned by project stakeholders.

Finally, shortnose and Atlantic sturgeon are ocean migrating species found today within other watersheds of the region; they are culturally important to the Passamaquoddy/Peskotomuhkati people and are included in the list of target species for the study (Table ES.1). The passage design concepts identified in this study have the potential to support passage of sturgeon along with the other species in the target list.

Likewise, while the target species identified in the study include a limited set of diadromous species, the study concepts apply to and would support passage of other species important to the ecosystem.

Table ES.1. Study target species and annual population estimates

Target Species	Annual Population Estimates
1. Alewife/Gaspereau (*Alosa pseudoharengus*)	~27,000,000 (Maine DMR) to ~58,000,000 (DFO)
2. American eel (*Anguilla rostrate*)	Uncertain, passage improved with eel specific passage technologies
3. American shad (*Alosa sapidissima*)	~165,000 (Maine DMR)
4. Atlantic salmon (*Salmo salar*)	Considered extirpated (Fay et al., 2006) but included for future restoration planning
5. Blueback herring (*Alosa aestivalis*)	~1,600,000 (Maine DMR)
6. Sea lamprey (*Petromyzon marinus*)	Uncertain but within St. Croix River
7. Shortnose sturgeon (*Acipenser brevirostru*)	Uncertain as no offical records for the St. Croix River*
8. Atlantic sturgeon (*Acipenser oxyrhynchus)*	Uncertain as no official records within St. Croix River*

DFO = Canada Department of Fisheries and Oceans; DMR = Maine Department of Marine Resources;

*Inclusion recommended by Passamaquoddy/Peskotomuhkati workgroup partners and their project advisor.

Selected Site Concepts for Upstream and Downstream Passage

The final screening process considered various configurations (alternatives) of technologies that would support upstream and downstream passage for the target species selected for this study. **Section 4** details the final set of viable concepts for fish passage at Grand Falls Dam, Grand Falls Powerhouse, and the Woodland Dam and Powerhouse. Summaries of the results and study section locations are as follows:

Grand Falls Dam

Upstream Passage Alternatives (**Section 4.1.1**)

- Vertical slot fish ladder around the right dam abutment

Downstream Passage Alternatives (**Section 4.1.2**)

- Surface bypass weir (uniform acceleration weir) on spillway
- Remove section of flashboards
- Tainter gate modification with bypass weir

Grand Falls Powerhouse

Upstream Passage Alternatives (**Section 4.2.1**)

- Fish lift with entrance in vicinity of existing fish ladder
- Vertical slot fish ladder with entrance in vicinity of existing fish ladder
- Nature-like fishway using Grand Falls Brook (Canadian side)
- Nature-like fishway between Grand Falls Dam and Powerhouse (U.S. side)

Downstream Passage Alternatives (**Section 4.2.2**)

- Existing bar rack with new downstream bypasses
- New bar rack (slightly larger) with bypasses
- Angled bar rack and bypass

Woodland Powerhouse

Upstream Passage Alternatives (**Section 4.3.1**)

- Fish lift with entrance in vicinity of existing fish ladder

Downstream Passage Alternatives (**Section 4.3.2**)

- Existing bar rack with new downstream bypasses
- New bar rack (slightly larger) with bypasses

Cost Estimates

Order-of-magnitude cost estimates were developed for alternatives that were determined to have the most practical current potential for application at Grand Falls and Woodland. These costs reflect installation requirements, with assumptions and limits used to develop these estimated costs detailed in **Section 4.4**.

Table ES.2. Estimated construction costs for selected site concepts

Site	Migration	Alternative	Preliminary Construction Cost (USD)
Grand Falls Spillway	Upstream	Vertical slot ladder	$7,185,000
	Downstream	Surface bypass weir	$1,362,000
		Remove section of flashboards	$31,000
		Tainter gate modifications	$200,000
Grand Falls Powerhouse	Upstream	Fish Lift	$11,059,000
		Vertical slot ladder	$7,642,000
		Nature-like Fishway (NLF CN)	$5M to $11.5M
		Nature-like Fishway (NLF US)	$15M to $30M
	Downstream	Existing rack & new bypass	$1,786,000
		New bar rack & bypass	$3,470,000
		Angled bar rack & bypass	$7,169,000
Woodland	Upstream	Fish Lift	$14,446,000
	Downstream	Existing rack & new bypass	$2,212,000
		New bar rack & bypass	$3,802,000

Recommended Studies and Next Steps

As a concept study, analysis was based on available data and site-specific information, some of which was missing due to the age of the facilities. Key information and data gaps are further detailed in the discussions of Sections 3, 4 and 5. Although not comprehensive for this concept study, recommended next steps are included for filling some large data needs for further concept planning. These recommended studies are grouped in general categories for organization purposes as follows:

Grand Falls Dam and Grand Falls Powerhouse

1) For downstream migrating (outmigrants) fishes within the powerhouse conveyance channel upstream of the **Grand Falls Powerhouse**, the calculated water velocities within the conveyance channel exceed those of sustained swimming speeds of juvenile target species, creating a potential velocity trap. **Actual velocities within the conveyance channel should be measured and assessed** under a range of pool levels and operating conditions. Models may also be able to generate velocity estimates and outcomes.

2) Actual **discharge flows at Grand Falls Powerhouse should be measured** to clarify existing attraction flow conditions as well as support improved concept options.

3) **Nature-Like Fishways** (NLFs) appear to be an attractive method to bypass upstream migrants **at Grand Falls Dam**. Although we were unable to make firm recommendations for potential NLF designs due to a lack of site-specific data, we recommend that **detailed field surveys** be conducted to establish the alignment, constructability, attraction and head pond controls, so that more specific determinations of NLF design viability can be made. Field reconnaissance can form a supplemental phase of research to help **solidify recommendations regarding the suitability of NLFs at the study sites**.

Woodland Dam and Powerhouse

4) At **Woodland Dam**, the powerhouse, spillway, upstream bypass exit, and downstream bypass entrance converge in close proximity. The simultaneous operations of the spillway and powerhouse may result in high **water velocities and complex hydraulic patterns** likely to confuse and potentially exhaust upstream migrating fishes. The area **should be modelled**, using tools such as computational fluid dynamics (CFD), under a range of pool levels and operating conditions, to better characterize how upstream fishes may be affected by the site designs and operations.

5) The **intake racks at Woodland Dam should be remeasured**. The larger measurements, which may be in error, suggest that post-spawned alosines may become entrained within the intakes, which would alter the selection of using existing intake racks as a concept alternative for downstream passage.

Both Facilities

6) The **existing site data are not sufficiently accurate to differentiate some alternatives**, and generally insufficient to develop detailed engineering criteria to support design options. The addition of **a rigorous preliminary engineering phase is needed** to systematically identify data needs for final engineering design of probable alternatives.

7) **CFD modeling of forebay and tailrace hydraulic conditions would improve site understanding of flow and velocity patterns** for concept design (e.g., proper placement of fish ladder entrances) and

facility operations (e.g., identifying special operations to avoid excess velocities during outmigration) alternatives.

8) Legacy submerged (relict) dam and other flow diversion structures may exist above the Woodland and Grand Falls facilities, in addition to downstream of key flow routes of both facilities. Site reconnaissance conducted in 2020 found several, relict, low-head dams between Grand Falls Dam and the powerhouse, and other undocumented structures may exist as well. **Surveys that document and describe submerged structures are needed to support upstream and downstream design concepts at both facilities**.

9) **Facility-specific surveys and economic analyses are needed for both facilities** to better understand and quantify equipment, operational and maintenance commitments, and investments as well as benefits and risks of the proposed concepts. Data generated by this study would support the selection of proposed concepts using economic-driven discussions of alternatives.

10) A **total project survival study should be completed** for downstream passage at each facility to support the selection of downstream passage systems. This study will require estimates of fish number and survival through each of the possible passage route (i.e., turbine, bypasses, spillways), for various river flow conditions. Project survival estimates can then be measured against a range of acceptable plant operations, as well as potential fish passage investments using incremental benefits analysis. The projected fish survival rates could then be compared to total costs for each passageway concept.

11) Some upstream passage alternatives place entrances near the foot of the dam, yet uncertainty remains about main passage routes and the ability of upstream migrating fishes to swim up falls located in the immediate vicinity of the dams. We recommend that **monitoring studies (e.g., telemetry) be conducted to determine the dominant upstream path lines, potential barriers (natural and constructed) and upper endpoints of target fishes**.

12) Species-specific pathway preferences for downstream passage are uncertain at both facilities, causing ambiguities surrounding the likely performance of proposed concepts based on existing conditions. **Telemetry studies of key migrating species would greatly improve the understanding and selection of best-practice concept alternatives for downstream migrants**.

Watershed Level

13) **Flow duration curves for key migration periods of May, June and July should be developed** to better understand site operations and passageway flow capacity options.

14) Climate change models suggest ongoing alteration of precipitation patterns, including changes in timing, magnitude, and duration of flows, which may reduce the reliability of historical values used to predict passageway option efficacy and future operations. **St. Croix River precipitation models should be developed to better predict** timing, magnitude, **and duration of flows and potential effects on available habitats** for target population predictions.

Species/Population – Specific

15) Developing diadromous population target estimates is a complex multidisciplinary task. Establishing population estimates within the St. Croix River should be a bi-national, multi-stakeholder effort. **Bi-national efforts that support future, target species population planning, and goal setting** would help assess near-term passage solutions and costs against long-term goals for the St. Croix River watershed.

16) **Lamprey and eel passageway options should be further investigated for regional effectiveness**, as Pacific lamprey and sea lamprey (Atlantic) may have differing performances and capability requirements.

1 INTRODUCTION

The International Joint Commission (IJC) promotes collaboration between the United States and Canada to protect and preserve the water quality and resources of boundary waters. The St. Croix River (originally named the Schoodic River by the native Passamaquoddy people) flows along the boundary between Maine and New Brunswick. The International St. Croix River Watershed Board (ISCRWB) was established by the IJC to assist in reporting to governments on water levels and flows and the aquatic ecosystem of the St. Croix River basin. The Board keeps the IJC apprised of boundary waters' aquatic conditions, as measured by indicators of aquatic ecosystem health used by the ISCRWB.

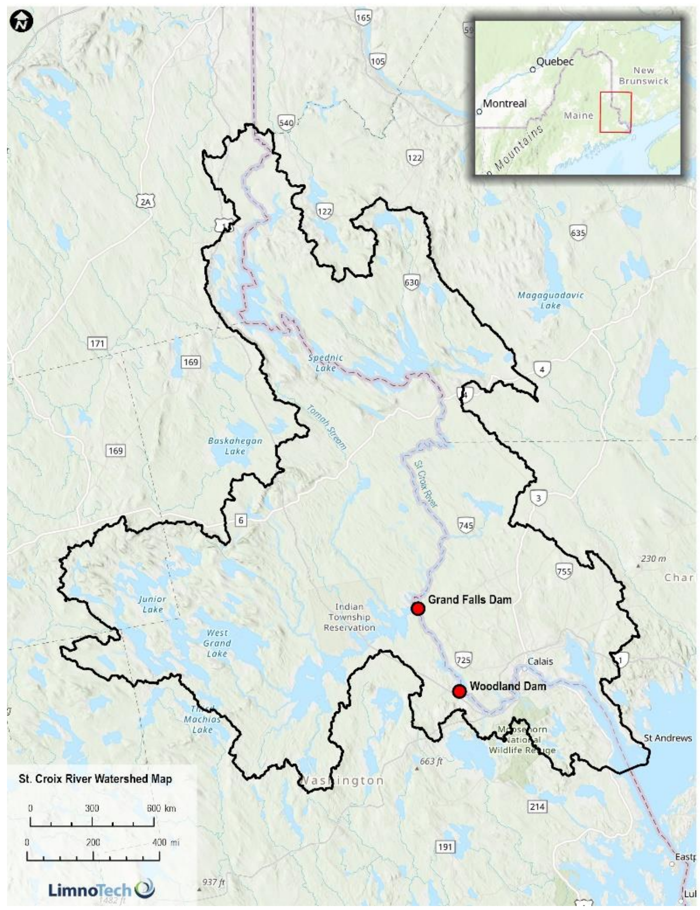


Figure 1.1. St. Croix River watershed area

This study was identified by the ISCRWB, and funded through the IJC's International Watersheds Initiative, to support an assessment of the state of health of the boundary waters aquatic ecosystem. Improving aquatic ecosystem health to permit the restoration of runs of anadromous and catadromous fishes to the St. Croix River basin is a longstanding recommendation of the IJC and the ISCRWB, stemming from the initial request from governments to the IJC to recommend actions to improve the use, conservation and regulation of the St. Croix River's basin waters. This analysis of challenges and opportunities for fish passage improvements provides planning information that can contribute to the survival and recovery of all diadromous species in the St. Croix watershed, while promoting to the fullest extent possible the proper function of ecological and physical riverine processes.

The St. Croix River watershed covers an area of 1,649 square miles (4,271 km^2) along the Canada-United States border between New Brunswick and Maine. The 110-mile (185 km) St. Croix River serves as a natural boundary between Canada and the United States (Figure 1.1). The watershed lies at the heart of the homelands of the Passamaquoddy people (including Passamaquoddy Native Americans in Maine and the Peskotomuhkati First Nation people of New Brunswick), and for thousands of years its waters and plentiful fish provided them with physical and spiritual sustenance (Paul, 2018). The fish and the river are included in treaties and agreements with the governments. Later the area came to be valued by settlers, traders and merchants for its timber resources and productivity of sea-run fish. In addition to providing nourishment for the new settler population, the abundance of sea-run fish in the St. Croix attracted worldwide attention. For decades, ships from every corner of the world came to the mouth of the river each spring to load up with seemingly endless barrels of sea-run fish destined for distant markets. The expanse of forested lands surrounding natural and backwater created lakes, along with the topography and climate of the watershed, led to rapid development of lake and river resources, which in turn led to habitat disruption and degradation (Bassett, 2015). In 1821, the tribe petitioned the state of Maine to put a stop to the destruction of resources within the St. Croix watershed. This included the building of dams and associated impoundments used as transport corridors and storage areas for the timber industry, eventually transitioning to hydropower generation. Impoundments now provide important natural recreational areas, wildlife habitat, and sources of regional economic activity (IJC, 2008; Flagg, 2007). Today, the Passamaquoddy people work with governments, neighbors, and allies to bring attention to and restore the state of the environment within the St. Croix River system.

At present there are an estimated 38 impoundments in the watershed, including seven major dams, three of which are on the lower mainstem St. Croix River, with the lowermost dam, Milltown Dam, in the planning and implementation phases of decommissioning (IJC, 2008; Ajmani, 2018; NBP, 202); Table 1.1). The EPA (1972) has noted that in modern times, dam operations within the system have played a greater role in affecting seasonal flows than precipitation. As in other river systems, the dams on the St. Croix River modified flow, stored sediments, and caused disruption among environmental variables, which in turn altered the ecosystem's aquatic biota and communities, with specific negative impacts on certain migratory species (Seliger and Zeiringer, 2018).

Table 1.1. Mainstem St. Croix River dams (IJC, 2008)

Facility Name	Owner	Date Built	Use	Watershed Area	Distance from estuary (tidal head)
Milltown*	N.B Power	1881	Hydropower	1,460 mi^2	0.6 mi
Woodland Dam	Woodland Pulp LLC	1906	Hydropower	1,350 mi^2	9.0 mi
Grand Falls Dam and Powerhouse	Woodland Pulp LLC	1915	Hydropower	1,320 mi^2	19.0 mi
*Not included in this concept study.					

Prior to mainstem dam construction, the St. Croix River supported large runs of diadromous fishes that ascended the river, relatively unobstructed, from its mouth at Passamaquoddy Bay to its headwaters and returned downstream on outmigration runs (Figure 1.2; DFO, 1988; IJC, 2005). The river historically supported large runs of Atlantic salmon, American shad, alewife, and blueback herring (collectively, river herring), with the largest alewife potential in Atlantic Canada and one of the largest river herring production sites within North America (Ledwin, 2018).

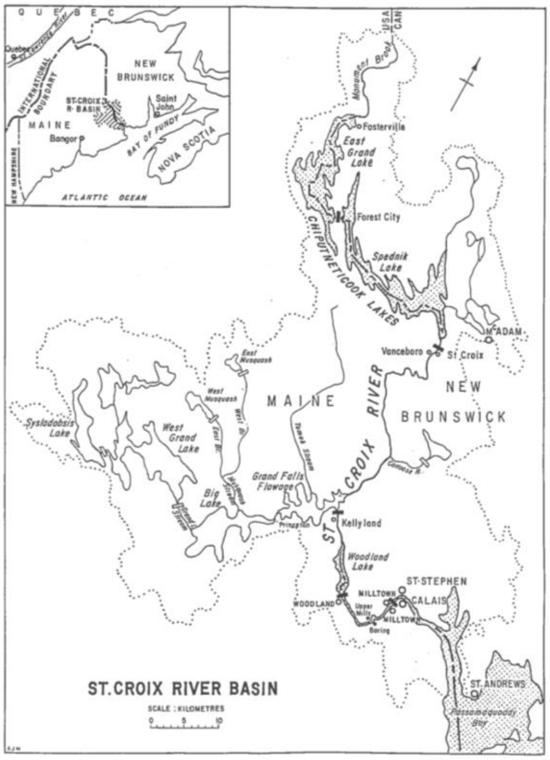


Figure 1.2. St. Croix River impoundments and dams (source: DFO, 1988)

Rapids and cascades are present in many locations in the St. Croix River, and served as locations for the Passamaquoddy People to secure migrating sea-run fish (Bassett, 2015, Wababaki Undated a-c). These natural features were later referred to as *falls*, and the three mainstem dams were built on these features, as they offered narrow, natural anchoring points for dam construction. The lowermost of these, Salmon Falls, is located in Calais/St. Stephen, approximately 0.6 miles (1 km) upstream of the mouth of the St. Croix River at Passamaquoddy Bay (USFWS, 2016). These natural features likely limited upstream movement for some regionally native species, reducing the potential for spawning population establishment for species like Atlantic and shortnose sturgeon. However, these natural features within the St. Croix River have not impeded migrations for other native and migrating species such as Atlantic salmon, blueback herring, alewife, American eel, and sea lamprey, which travel far into the upper watershed (FERC, 2016).

The first sawmill was built on the lower main stem of the St. Croix in 1780. Four years later there were two sawmills on the Canadian side. Several dams were built on the main stem in the Milltown area in the early 1800s. By 1819, there were 47 sawmills in operation on the St. Croix. In 1825 the Union dam was built from bank to bank, with no fishway. This dam eliminated diadromous fish runs in the St. Croix. The Union dam had no fishway until 1869, some 44 years later. The lowermost mainstem facility, the Milltown Dam, included a rudimentary fish passageway in its earlier years (circa 1890s), with upgrades for fish passage included some later date (Marshall, 1976). Neither Woodland Dam nor Grand Falls Dam included a fish passageway in their initial design or construction, so diadromous runs within the St. Croix River were greatly restricted, or blocked entirely to lower river reaches (SED, 2017). In the mid-1960s, Woodland and Grand Falls received approval and funding for fish passage retrofits and upgrades that attempted to accommodate diadromous species, targeting Atlantic salmon, alewife and American shad (Ledwin, 2018). However, these retrofits and upgrades were based on

Spotlight: Salmon Falls

Salmon Falls has been considered a barrier to Atlantic and shortnose sturgeon because of its bedrock outcrops and cascading falls and the lack of recent documentation of sturgeon passage. Since settler development, the site has been greatly modified by dams, mills, and a powerhouse built on the downstream extent or Salmon Falls. There is no record of how the modified portion covered by bricks and mortar is configured, or how it affected fish passage for species like sturgeon into the watershed. The first opportunity to see Salmon Falls daylighted will be in 2022, when Milltown Dam and powerhouse are currently scheduled to be removed. At that time, a clearer picture will emerge regarding the potential for passage by sturgeon and other migratory fish species.

early understandings of fish passage technologies and designs, and without the benefit of monitoring data, they were under-designed for target fish population numbers, considered ineffective and poorly maintained as effective passageway options for many of the St. Croix River migrating fishes (Cronin et al., 2002; SED, 2017).

At the lowermost Milltown Dam, dam operator New Brunswick Power (NBP) recently filed for an Environmental Impact Assessment (EIA) for dam decommissioning, scheduled to begin in 2022 (NBP, 2020). The Milltown Dam decommissioning is likely to improve upstream fish connectivity for many species within the lower St. Croix River to the next upstream facilities, Woodland and Grand Falls Dams, respectively (Figure 1.2).

Woodland and Grand Falls Dams were authorized and built over one hundred years ago (Table 1.1). Upstream fish passageways were added to each facility in the mid-1960s, using design criteria and specifications available at the time (Marshall, 1976). Over 30 years ago, Rizzo et al. (1989) identified a staged program to improve passage at both facilities, targeting benefits to Atlantic salmon and alewife/gaspereau. The fish passage facilities at both dams continue to structurally and functionally degrade, further preventing effective and efficient upstream fish passage, along with the associated lack of protective downstream fish passage options (DFO, 1988; Rizzo, et al., 1989).

1.1 Study Scope

This study explores a range of upstream and downstream fish passage improvements on the St. Croix River at Woodland and Grand Falls Dams. In order to incorporate regional experience and expertise, a Workgroup (WG) was formed, composed of experts with regional experience and an interest in advancing fish passageways for the St. Croix River. As a primary stakeholder in the watershed, Woodland Pulp LLC was consulted and kept informed as the study progressed and is represented on the WG. Study results offer an evaluation of standard fish passageway options as concepts to replace the deteriorating fishways at Woodland and Grand Falls facilities. This study is intended to be useful for resource agencies, indigenous people, and others involved in rebuilding diadromous fish populations in the St. Croix River and its tributaries.

1.2 Study Goal

The goal of this study is to identify opportunities and constraints for options that provide fish passage at the Grand Falls and Woodland dams, accommodating the design populations of selected species in both upstream and downstream directions, within the St. Croix River while accounting for natural and anthropogenic limits and modifications within the river system.

1.3 Study Objectives

1) Institute a team-based process for conducting the study.
2) Analyze diadromous species passage at Woodland and Grand Falls, including binational and cultural considerations as well as regulatory requirements.
3) Identify the spatial extent of the affected area and habitats upstream and downstream of the Grand Falls and Woodland facilities.
4) Identify and agree upon design hydrologic conditions as the basis for characterizing timing and ranges of flow conditions at Grand Falls and Woodland facilities.

5) Characterize debris and/or sediment transport dynamics at Grand Falls and Woodland facilities.
6) Compile and assess existing and future operation objectives for Grand Falls and Woodland facilities that affect passageway design and operations.
7) Select defined measures for facility-based, fish passage alternative.
8) Identify and document a range of potentially feasible design alternatives for upstream and downstream passage.
9) Select 2-3 primary passageway design options for workshop presentations/discussion/evaluation.
10) Establish planning level cost categories for primary design, build and operations, maintenance, repair, replacement, and rehabilitation.

1.4 Organization of the Report

Exploring Upstream and Downstream Fish Passage Improvements on the Lower St. Croix River is organized as follows: Section 2 provides background on the study area and study facilities; Section 3 provides a description of the target fish species used in passageway concept development and a description of the three-tier screening process for selected upstream and downstream alternatives at Grand Falls Dam, Grand Falls Powerhouse, and Woodland Dam; and Section 4 provides a detailed description of selected, effective upstream and downstream alternative concepts for each of the three sites. A cost description is provided for the selected upstream and downstream concepts. Section 5 is the conclusion and summarizes findings, data and information gaps, and recommendations for next steps.

2 BACKGROUND

The creation of dams throughout the St. Croix River system, and particularly on the 19 miles (31 km) of the lower mainstem river, resulted in the loss of diadromous species and had significant disruptive effects on the St. Croix River ecosystem. The effects included modifications in predator distribution and behavior as well as general population dynamics, and changes in marine-derived nutrient delivery to the freshwater system (Barber, 2018). As the first and lowermost dam in the St. Croix River system, Milltown Dam was initially installed as part of the early logging and mill system located across a narrow set of natural river falls, known as Salmon Falls, between 1791 and the 1880s (Wabanaki - a, Undated (UD)). In 1881, an electric power dam was built on the Salmon Falls site to power the mill, along with an early fish passageway installed in 1883 (Wabanaki - b, UD), one of the early fish passageways in North America. The Milltown fish passage structure, along with other facility upgrades, were improved in 1980 (Marshall, 1976). The other mainstem facilities upstream of Milltown Dam that obstructed diadromous fish passage were the Woodland Dam and Grand Falls Dam and Grand Falls Powerhouse, located 9 miles and 19 miles, respectively, above Milltown Dam (Table 1.1). Until modern fish passage retrofits were installed in the 1960s, both facilities created insurmountable barriers to St. Croix River diadromous fishes.

Woodland Dam, the second dam on the St. Croix River, was initially a timber crib dam built atop Sprague Falls in the early 1800s and included no fish passage structure (Wabanaki - b, UD). A concrete dam was built in 1905 for flow storage and power generation and may have initially included a wooden fishway (Wabanaki - b, UD), but the specifics of this original fishway or whether it was ever built or operable are unknown. Grand Falls Dam and Powerhouse are adjacent, but separate, facilities located 10 miles (16 km) upstream of the Woodland Dam. Grand Falls is located at the outlet of the Grand Falls Flowage, and the site is comprised of two sets of natural, cascades and falls. Construction was completed on the Grand Falls dam and powerhouse in 1915. This project included a long dam (Grand Falls Dam) and a separately constructed canal to the south, directing backwater flows toward a powerhouse (Grand Falls Powerhouse). Unfortunately, no fishway was included in the design or construction of either Grand Falls Facilities at that time (Wabanaki - c, UD).

In 1963, the State of Maine (SOM) initiated a plan to use federal funding to construct fish passageways at both Woodland and Grand Falls Dam sites (Marshall, 1976). The designs would include Denil type fish passageways primarily designed to accommodate alewife, brook trout and landlocked and Atlantic salmon (Marshall, 1976). Denil type fishways originated in the early 1900's and were widely used in the eastern U.S., because they were thought to accommodate a wide variety of diadromous and riverine fishes (OTA, 1995), although detailed research in migratory fish passage requirements and technical fishway design options and improvements would come much later. In 1965, the Woodland and Grand Falls Dam fishways were officially opened (Marshall, 1976; SOM, 1989). With the installation of the fishways, and other water quality improvements, diadromous populations began rebuilding (Marshall, 1976; IJC, 2005). However, both fish passage facilities are now severely degraded structurally, with associated challenges in passage effectiveness and efficiency in both upstream and downstream directions. This study evaluates upstream and downstream concepts for new fish passage at both the Grand Falls and Woodland facilities, in order to continue and expand science-based stewardship within the St. Croix River watershed.

2.1 St. Croix River Study Area

The St. Croix River study includes both Grand Falls and Woodland Dam facilities and immediate upstream and downstream river and tributary connections in proximity of each facility. The Woodland Dam study area includes the downstream region to the Milltown Dam reservoir and the upstream region of the Woodland Flowage upstream to the Grand Falls Facilities. The Woodland Flowage includes the backwatered area created by the Woodland Dam and its operations. The Grand Falls Dam and Powerhouse study area includes the upstream Grand Falls Flowage and downstream to Woodland Flowage. The Grand Falls Flowage is an expansive backwater area of the upper St. Croix River, created by the Grand Falls Dam and Grand Falls Powerhouse (also referred to as Kellyland Powerhouse) facilities and the flowage spatial extent is heavily influence by Grand Falls dam and powerhouse operations (Figures 2.1a and 2.1b). The upper St. Croix system, above Grand Falls contains other dams and impoundments that affect the system's hydrology and ecology, but not evaluated as part of this study (Figure 1.2).

Figure 2.1. Study areas of Woodland (2.1a, left) and Grand Falls Dams (2.1b, right)

2.2 Fisheries Management and Resources

The fisheries within the St. Croix River are coordinated through partners that include Tribe/First Nation partners as well as state, federal and associated partners (DFO, 1988). This approach includes a cooperative strategy with harvest allocations for both sport fisheries and commercial purposes, in addition to the following resource objectives:

- Restore, improve and maintain the fish populations of the St. Croix River System in cooperation with managing agencies;

- Create a long-term plan and annual fishing plans, which outline a flexible management system for the protection, development and utilization of the fish resources of the river system;
- Optimize net benefits to the public from both the existing resources and enhancement opportunities; and
- Ensure distribution of the benefits among authorized users of the fish resources in accordance with social and economic values.

The St. Croix watershed, from its confluence with Passamaquoddy Bay, is known to contain a rich and diverse mix of fish species, including diadromous and resident freshwater populations (Anon., 1988) (Table 2.1). This study is focused on diadromous species (Table 2.2), although three species (Atlantic salmon, rainbow smelt and alewife/gaspareau) are known to have both anadromous and resident freshwater strains (Cronin et al., 2002). The St. Croix River once supported large diadromous runs of alewife and blueback herring (collectively, these species are also known as "river herring" and as "gaspereau"), Atlantic salmon, American shad (DFO, 1988) and sea lamprey (Barbar, 2018). The St. Croix River also supports the catadromous species American eel (ASMFC, 2000).

Within the region, sturgeon (Atlantic and shortnose), rainbow smelt and striped bass are common anadromous species, although they have not been recently documented within the watershed, they may have been present prior to dam construction. Atlantic sturgeon have large home ranges that include the Gulf of Maine (Wippelhauser et al., 2017) and Passamaquoddy Bay. Shortnose sturgeon, overlap in distribution with Atlantic sturgeon and have smaller home ranges that include the Gulf of Maine (Altenritter, et al., 2017). Neither sturgeon species have recently documented sightings in the St. Croix River above Salmon Falls (USFWS, 2014). Similarly, rainbow smelt and striped bass lack documented presence above Salmon Falls (DFO, 1988). Although some key regional species are not currently present within the study area, future presence in the watershed the study area should be monitored and assessed relative to the decommissioning of Milltown Dam, as an adaptive approach within the St. Croix River to document new migrants, their populations and associated watershed uses.

Table 2.1. Native and introduced freshwater fish species known to currently inhabit the St. Croix watershed, Maine and New Brunswick[1,2,3]

Common Names of Fishes		
Native Fish Species	Blacknose shiner	Ninespine stickleback
American eel*	Creek chub	White perch
Atlantic salmon (landlocked)*	Fallfish*	Yellow perch
Brook trout*	Fathead minnow	**Introduced Fish Species**
Lake trout	Pearl dace	Smallmouth bass*
Lake whitefish	Slimy sculpin	Pumpkinseed*
Round whitefish	White sucker*	Redbreast sunfish
Rainbow smelt*	Brown bullhead	Chain pickerel
Northern redbelly dace	Banded killfish	Largemouth bass
Finescale dace	Cusk (Burbot)	Landlocked alewife
Lake chub	Fourspine stickleback	**Reported Fish**
Golden shiner*	Brook stickleback	Bridled shiner
Common shiner*	Threespine stickleback	Longnose sucker
Blacknose dace	Blackspotted stickleback	Rainbow trout

* Species recorded as having passed upstream of Milltown Dam through the fishway [4,5,6]

[1] Cronin, et al., 2002.; [2] MDIF, 2012; [3] Kircheis, 1994. [4] The St. Croix International Waterway Commission (SCIWC) administers the fishway count at Milltown Dam; [5] Although not in the table, the SCIWC has recorded brown trout in the fishway at Milltown Dam.

[6] The SCIWC has recorded a number of freshwater species ascending the Milltown fishway, including brook trout (possibly sea-run brook trout).

Table 2.2. Diadromous fish species endemic to the Atlantic Coast – common names listed in alphabetical order

Alewife*	Atlantic sturgeon	Hickory shad	Shortnose sturgeon
American eel*	Atlantic tom cod	Rainbow smelt*	Striped bass*
American shad*	Blueback herring*	Sea lamprey*	
Atlantic salmon[1]*	Gizzard shad	Sea-run brook trout	

*Species documented to have ascended the Milltown Dam fishway.

[1]Wild Atlantic salmon (Salmo salar) has not been recorded at the Milltown fish trap since 2006.

Between Tables 2.1 and 2.2, several species have been recorded as passing upstream through the fishway at Milltown Dam. In addition, although not listed in Tables 2.1 or 2.2, steelhead trout have also been recorded passing upstream at Milltown. Wild Atlantic salmon (*Salmo salar*) have not been recorded at the Milltown trap since 2006.

This diverse and complex fisheries community represents a component of the St. Croix River ecosystem that would benefit from restored fish passage within the lower St. Croix River, providing a significant step toward an improved ecosystem.

2.3 Target Species

USFWS (2019) provides a typical evaluation process for fishway design planning. The identification of target species, with design population estimates, and seasonal passage timing are among the many critical site-specific factors for fishway assessment (USFWS, 2019; Silva et al., 2017). Target species for this study were discussed during the study kickoff meeting of the St. Croix River Workgroup on November 18, 2019.

Preliminary target species were also presented to the International St. Croix River Watershed Board on December 3, 2019 in Bangor, Maine.

The final target list (Table 2.3) is focused on six key migrating species with recent, documented presence of migrating populations upstream of Salmon Falls. Atlantic salmon are included because they formerly resided within the St. Croix River and have potential to be included in future restoration actions (SCRIWC, 2020). The list of target species also includes two sturgeon species—shortnose sturgeon and Atlantic sturgeon. The inclusion of sturgeon is supported by the cultural importance of sturgeon to the Passamaquoddy people and the hope that passage improvement efforts like Milltown Dam decommissioning, and other passageway improvements in the St. Croix River will offer support to these species in the future. The project also recognizes the ecological and cultural importance of other diadromous species not selected as design target species or not documented in the watershed. The intent of the selected target species is primarily for developing passage concepts and a range of passage behaviors and constraints that may also support passage for other species of ecosystem, management, and cultural importance within the St. Croix River system.

Population estimates for target species help guide concept design and alternative selection process by providing species timing and capacity needs for the passageways (USFWS, 2019). Population estimates for large waterways like the St. Croix River are complex to derive, highly variable because they are based on many biotic and abiotic factors and tend to be developed for fewer species of management importance. For the St. Croix River, species population estimates are available for few species and these efforts are conducted by Maine Department of Marine Resources (MDMR) and Canada's Department of Fisheries and Oceans (DFO).

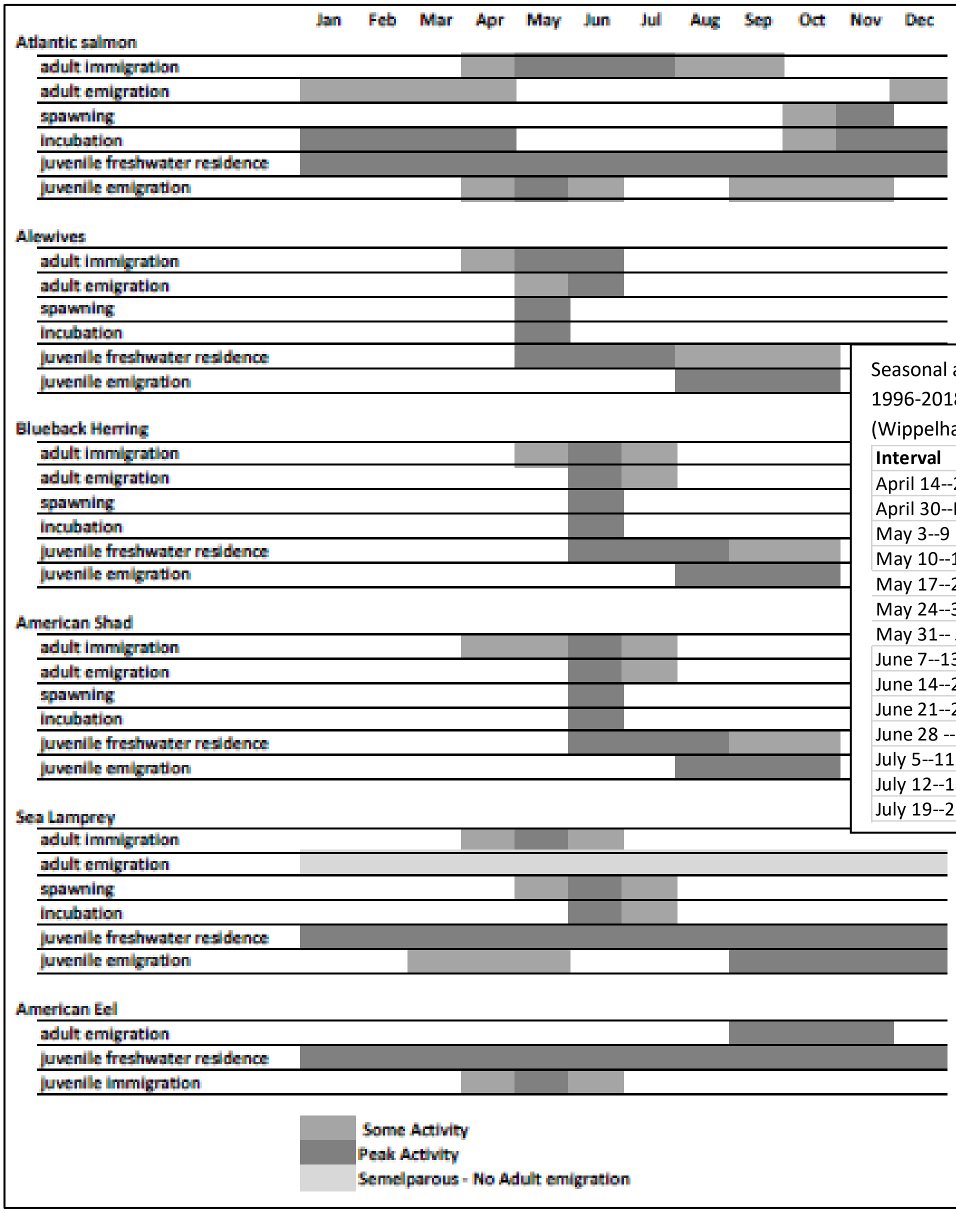
For the St. Croix River, these population estimates are established for some of the target species, using differing approaches of MDMR and DFO. For the purpose of this study, only alewife/gaspereau, American shad and blueback herring have established population estimates for passageway concept development (Table 2.3).

Table 2.3. Study target species and annual population estimates

Target Species	Annual Population Estimates
1. Alewife/Gaspereau (*Alosa pseudoharengus*)	~27,000,000 (MDMR) to ~58,000,000 (DFO)
2. American eel (*Anguilla rostrate*)	Uncertain, passage improved with eel specific passage technologies
3. American shad (*Alosa sapidissima*)	~165,000 (MDMR)
4. Atlantic salmon (*Salmo salar*)	Considered extirpated (Fay et al., 2006) but included for future restoration planning
5. Blueback herring (*Alosa aestivalis*)	~1,600,000 (MDMR)
6. Sea lamprey (*Petromyzon marinus*)	Uncertain
7. Shortnose sturgeon (*Acipenser brevirostrum*)	Unknown and undocumented (inclusion recommended by Passamaquoddy Tribe)
8. Atlantic sturgeon (*Acipenser oxyrinchus*)	Unknown and undocumented (inclusion recommended by Passamaquoddy Tribe)

DFO = Canada Department of Fisheries and Oceans; MDMR = Maine Department of Marine Resources

The timing of target species' passage is also critical, because the design limits and operations of passageway alternatives (USFWS, 2019) are ideally based on the life history habits of species life stages. Saunders et al. (2006) developed a general guide for diadromous fishes in Maine that includes the study target species and their various life stages (Figure 2.2). Wippelhouser (2020) provided monthly population estimates for alewife within the St. Croix River, based on long term monitoring data from Mill Town Dam.



Seasonal alewife migration timing 1996-2018 for the St. Croix River (Wippelhauser 2020)

Interval	Total	%
April 14--29	0	0.0
April 30--May2	5,460	0.0
May 3--9	88,219	0.6
May 10--16	1,228,278	8.7
May 17--23	3,452,879	24.5
May 24--30	4,647,716	33.0
May 31-- June 6	3,244,344	23.0
June 7--13	1,216,344	8.6
June 14--20	199,850	1.4
June 21--27	13,161	0.1
June 28 -- July 4	6,030	0.0
July 5--11	392	0.0
July 12--18	61	0.0
July 19--25	7	0.0

Figure 2.2. General migration and residence timing of target species (from Saunders et al., 2006), with seasonal timing estimates for alewife (inset, Wippelhauser, 2020).

2.3 River Design Flows

River flow dynamics play a dominant role in determining site operation requirements, and passageway design criteria. River flow characteristics are evaluated and defined as the relationship between 1) the river system dynamics during key periods of upstream and downstream movements of the target species and 2) key operational needs of the facilities. Figure 2.3 provides flow duration curves for upstream and downstream migrating periods for Woodland Dam and Grand Falls Powerhouse. Flow duration curves were developed for periods of April to June (Figure 2.3a) and July to November (Figure 2.3b) using data from the USGS Baring Gage Station (01021000), located downstream of Woodland Dam. Monthly flow curves should be developed for the two locations for species such as alewife whose passage windows are well documented.

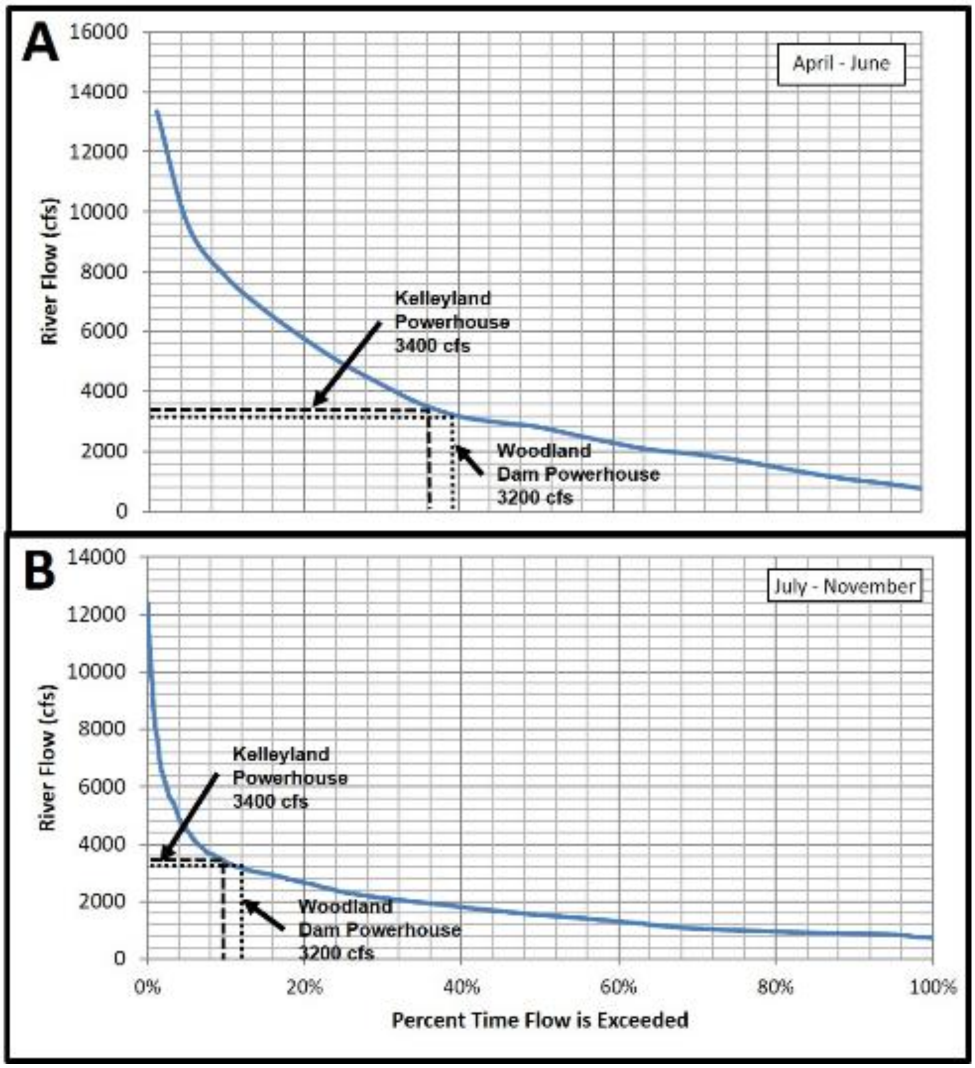


Figure 2.3. Flow duration curves for key periods of migration. 2.3a provides spring flow volumes and percent exceedance flows, while 2.3b provides fall flow volumes and percent exceedance flows for both facilities

2.4 Grand Falls and Woodland Dams

The fish passage improvement study includes two locations and three separate facilities on the lower St. Croix River, located on a boundary water of the U.S. and Canada, with the international border running down the centerline of the mainstem St. Croix River (Figure 1.1; Figures 2.4 and 2.5). Grand Falls Dam and Powerhouse and Woodland Dam are owned and operated by Woodland Pulp LLC. Each site includes a dam and powerhouse, although many distinct features of each site require individual characterization for fish passageway concept evaluation. The following key design criteria and important site features were used to develop upstream and downstream fish passage alternatives for the three study sites: Grand Falls Dam, and

Grand Falls Powerhouse (a separate facility at Grand Falls, Figure 2.4) and Woodland Dam (includes the connected powerhouse, Figure 2.5).

Figure 2.4. Grand Falls Dam and Powerhouse (image: Google Maps)

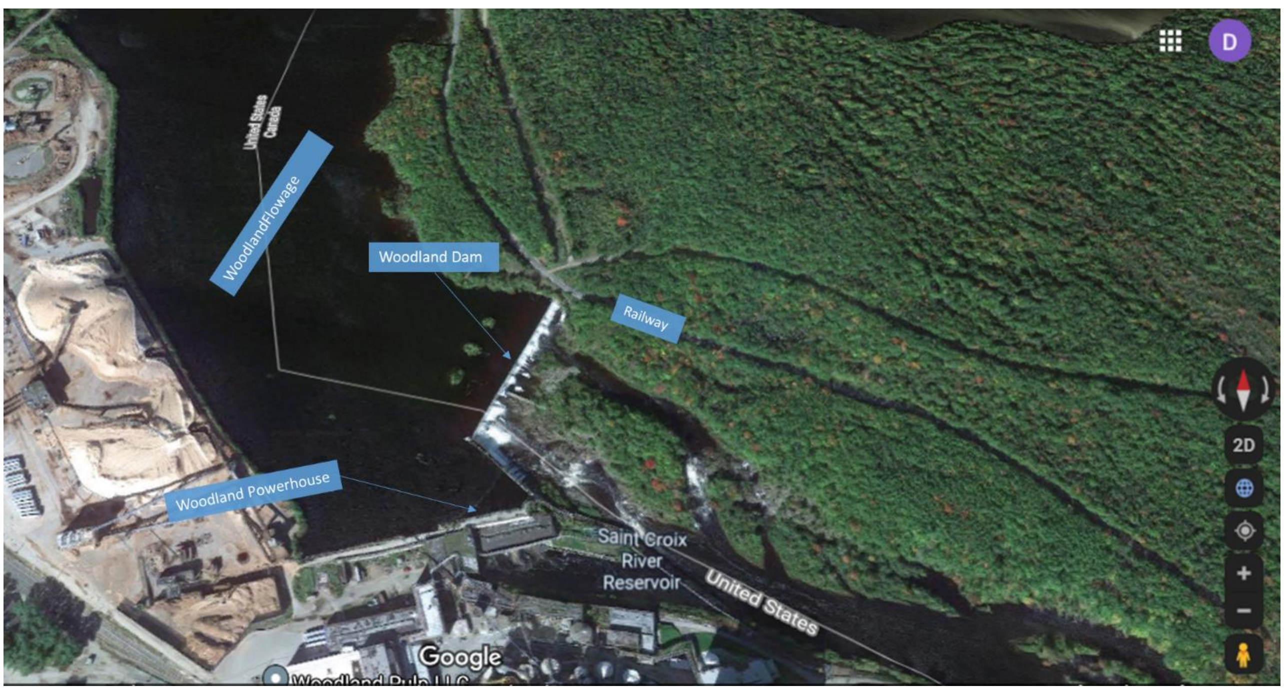


Figure 2.5. Woodland Dam and Powerhouse (image: Google Maps)

2.4.1 Summary of Relevant Design Data for Study Sites

Design criteria form the basis for the understanding and planning of fishways. Site-specific details of the study sites are described in-depth throughout this report. Table 2.4 provides a summary of the baseline design data used to evaluate fish passage alternatives. Much of the information comes from Rizzo et al., (1989) while other data was collected during discussions with site engineers from Woodland Pulp LLC and derived from independent analysis.

Table 2.4. Key site characteristics for site design considerations during alternatives development

Site Characteristics	Grand Falls Dam	Grand Falls Powerhouse	Woodland Dam and Powerhouse
Project at River Mile	19	19	9
Drainage Area (Sq. Mi.)	1,320	1,320	1,360
Impoundment Length (Miles	20	20	5
Impoundment Area (Acres)	18,000	18,000	1,200
River Flow			
Exceeded 5% of time (cfs)	9,550	9,550	9,950
Exceeded 50% of time (cfs)	2,832	2,832	2,950
Exceeded 95% of time (cfs)	943[1]	943[1]	982
Head Pond Elevation			
Design high El. (ft.)	203.5	203.5	141.4
Normal El. (ft.)	198.3	198.3	140.4
Low El. (ft.)	not available	not available	139.4
Top of Flashboards El. (ft.)	198.3	not applicable	140.4
Spillway Crest El. (ft.)	not available	not applicable	not available
Headpond Drawdown (ft.)	5.0	5.0	2.0
Tailwater Elevation			
Design high El. (ft.)	n/a (~ 165)	152.4	97.5
Normal El. (ft.)	not available	149.0	94.4
Low El. (ft.)	n/a (~ 160)	147.6	92.6
Normal Head @3000 cfs (ft.)	~ 40	49.3	46.0
Powerhouse			
Number of Turbines	0	3	7
Generating Capacity (Kw)	not applicable	9,480	11,560
Powerhouse Discharge (cfs)	not applicable	~3000 - 3400	~3000 - 3400
Intake Bar Rack Clear Spacing (inches)	not applicable	1.0	1.0
Intake width (ft.)	not applicable	not available	not available
Intake sill El. (ft.)	not applicable	not available	not available
Intake approach velocity (ft./sec)	not applicable	(< 2 ft./sec, need intake details)	(< 2 ft./sec, need intake details)
EXISTING FISHWAY DATA			
Type	None	Denil	Denil
Width (ft.)	not applicable	4	4
Slope	not applicable	1 on 8	1 on 8
Length (ft.)	not applicable	600	745
Normal Maximum Lift (ft.)	not applicable	51	48
Total Attraction flow (cfs)	not applicable	35	35
Downstream Passage Facilities	None	Log Sluice	None
[1] Reflects combined site flows			

Grand Falls Dam and Grand Falls Powerhouse (Figures 2.4 and 2.5) impound Grand Falls Flowage, which stores approximately 88,000 acre-feet of water spread over ~6,000 acres (Wabanaki, undated c).

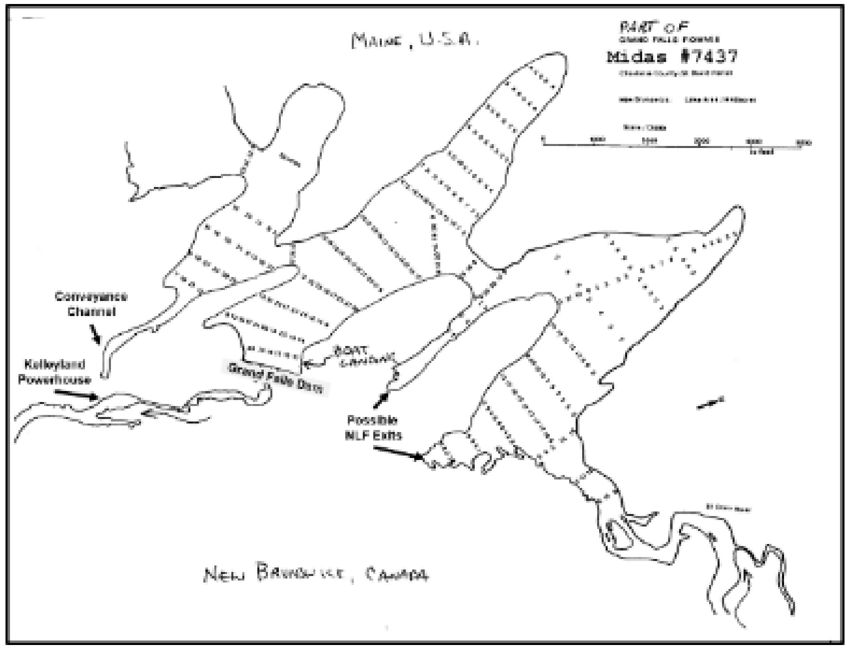


Figure 2.6. Bathymetric map of Grand Falls Flowage showing features important for selecting upstream and downstream fish passage alternatives (Maine Department of Inland Fisheries & Wildlife, unknown date)

Grand Falls Flowage is not symmetrical relative to the location of Grand Falls Dam. The main St. Croix River (the East Branch) continues eastward not far from Grand Falls Dam. The West Branch is impounded by several dams that together form an extensive set of interconnected lakes. The Grand Falls Flowage provides a variety of aquatic habitats, from lacustrine (preferred by alewife) to fluvial (preferred by American shad, blueback herring and former Atlantic salmon populations) for spawning and rearing. The East Branch is assumed to be the primary spawning habitat for target riverine species, being larger than any other tributaries entering Grand Falls Flowage. The west branch of Grand Falls Flowage is primarily lacustrine, with the exception of 3+ miles of the St. Croix River that is free flowing from West Grand Dam to Big Lake. The free-flowing reach and West Grand Lake are well-known for land-locked-Atlantic-salmon fisheries (Hoar 2020, pers com). This reach would also provide spawning habitat for sea-run species that require fast moving (well oxygenated) water and a gravel/cobble bottom, such as blueback herring and American shad. Habitat mapping indicates that about 2/3 of the spawning habitat for alewife occurs in the west branch of Grand Falls Flowage and 1/3 occurs in the east branch of the Grand Falls Flowage (Hoar 2020, pers com).

Grand Falls Flowage is generally characterized as a shallow impoundment (Figure 2.6) with a maximum reported depth of 44 ft., although reported maximum depth varies depending on the information source. Figures 2.6 depicts maximum water depths of only around 20ft., suggesting that updated bathymetry needs to be collected to understand within-reservoir fish movement.

Grand Falls Dam is a non-hydropower dam built upon Grand Falls that regulates St. Croix River discharges using a controlled spillway. A separate dam, Grand Falls Powerhouse, is located about 4,000 ft. away from the main channel downstream of Grand Falls Dam. The separated dams have outlet works that function independently and they are, therefore, evaluated as separate, but related, facilities for the purpose of this study.

Grand Falls Dam measures 48 ft. (maximum) in head height and 1,100 ft. in length from bank to bank. The dam is bound by Highway 725 on the Canadian side and by Grand Falls Road on the U.S. side (Figure 2.7). The dam includes nine steel Tainter gates on the right (facing downstream) of the spillway, and a concrete emergency spillway of approximately 800 to 850 feet in length running from the concrete gatehouse to its terminus at the left shoreline. The gatehouse is located between the gates and the emergency spillway, with a floating walkway allows access to the entire upstream length of the spillway. Lake levels are recorded at a gauging station on the right bank of the dam. There is no fish passageway at the Grand Falls Dam.

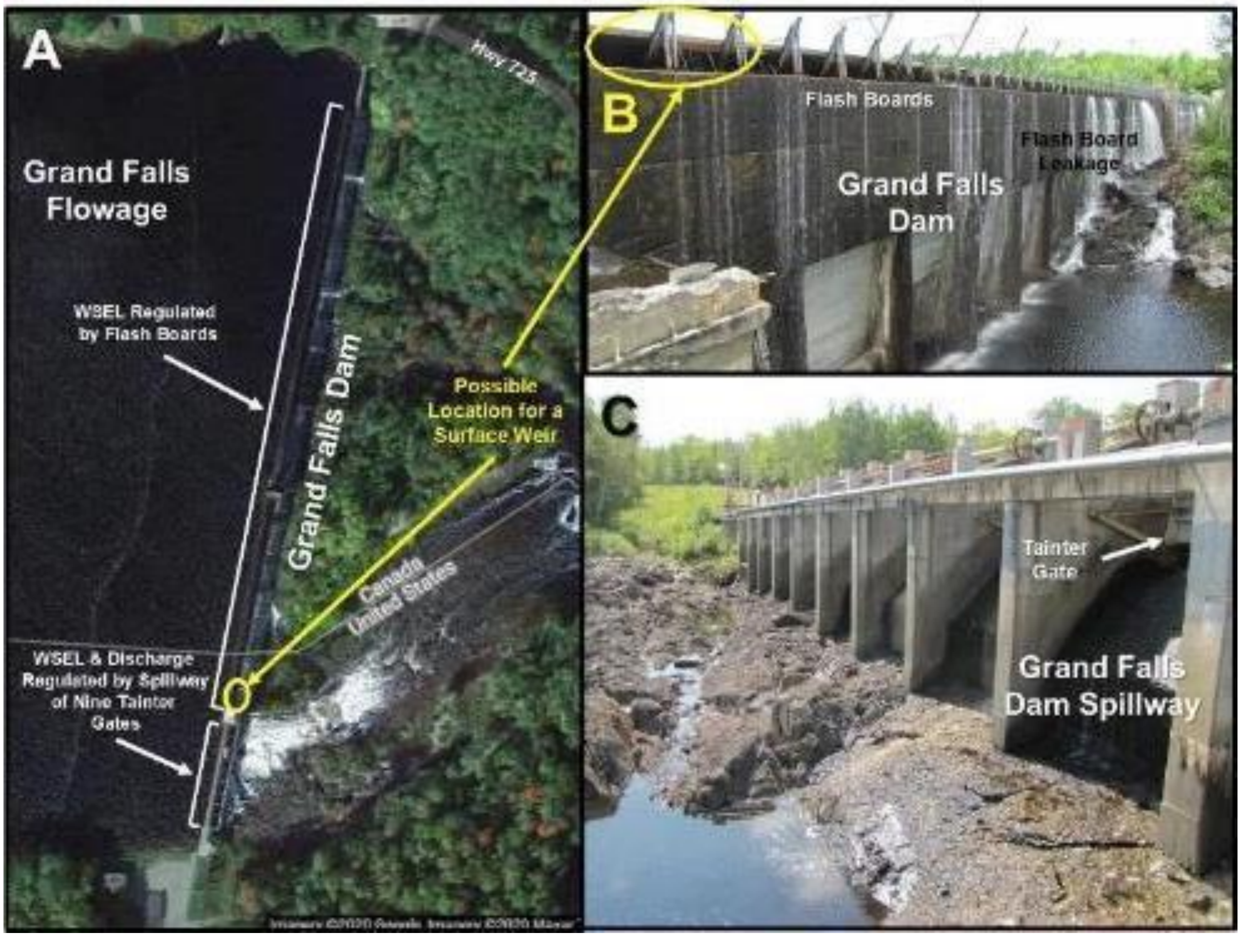


Figure 2.7. Aerial view of Grand Falls Dam showing (A) non-discharge section where the water surface elevation (WSEL) is controlled by flashboards (B) and the controlled Spillway (where water flow and elevation are also regulated) are comprised of nine Tainter gates (C) (photographs B and C provided by A. Hoar)

2.4.1.a Upstream Passage Key Characteristics

Grand Falls Dam is constructed at the upper end of Grand Falls, which is an extensive series and complex mix of riffles, glides, cascades and falls (Bassett, 2020). There is no upstream fish passage structure on Grand Falls Dam, and it is uncertain if, or how frequently upstream migrating fishes reach the dam base because of the presence of the high gradient reaches, and lack of fish monitoring data during the migration season for target species. Site images suggest that the steep gradient reaches may present a passage challenge for migrating fishes, at least at some flow levels. The proportion of migrating fish that may select the left river channel to the dam verses the right powerhouse channel (where an existing fishway is present) should be assessed. The predominant downstream pathways (i.e., dam or powerhouse passage) of migrating fish are also unknown at the site. Assessments and field studies should be conducted to more accurately describe the potential species mix, numbers and timing of fishes that may reach the base of the dam or pass downstream over the spillway.

2.4.1.b Downstream Passage Key Characteristics

The hydrologic regime for downstream migration differs considerably from the flow regime for upstream migration. The flow duration curve for the Baring Gage (Figure 2.3) indicates that the maximum powerhouse discharge of 3,400 cfs is exceeded by approximately 40% during the upstream migration season. However, the 3,400 cfs powerhouse discharge is exceeded only approximately 10% of the time during the July-November downstream passage season for emigrating juveniles of most target species. For example, the passage season for adult American shad immigration occurs primarily in June, while juvenile emigration occurs primarily from July to October, when water for operation of the downstream passage system spillage is much less available. Duration curves for primary upstream and downstream migration periods are needed.

Under existing conditions, emigrating fish can exit Grand Falls Dam only during spill, through missing or damaged flash boards, or through turbines when not excluded by bar racks. Controlled spill (as opposed to leakage) occurs through the nine Tainter gates (Figure 2.7C) that comprise the controlled spillway of Grand Falls Dam. Most of the rest of the dam helps regulate the reservoir water surface elevation for the powerhouse and minimizes waves from overtopping the dam through the use of flashboards (Figure 2.7). Note that leakage occurs through damaged or missing flash boards, which photographs indicate may be numerous. Outmigrants that exit the reservoir via flashboard leakage or release are likely to be injured or killed as they collide with the exposed granite of the tailrace.

Operations adjustments for downstream movement of fishes at Grand Falls Dam could improve out-migrating efficiency when outmigrants are staged at the dam for downstream passage, although it is unknown if emigrating fishes use the existing outlets for downstream passage. Further, water availability to provide a downstream passage season may result in operational conflicts between powerhouse flow needs and attraction needs for downstream passage at the dam.

Finally, a relict, submerged dam is located immediately upstream of Grand Falls Dam (pers. comm. Ledwin during a telecom with the WG and invited participants, 11 May 2020). It is possible that this older dam affects the distribution of outmigrating fishes before they reach Grand Falls Dam. For example, if this older dam has not been breached or partially removed and its outlet works remain closed, those outmigrants swimming at a depth greater than the crest of the relict dam would need to swim upwards to pass over the relict dam. This suggests that surface-oriented outmigrants like juvenile salmon and alosines may be less likely to approach Grand Falls Dam at the depth of the bottom of the Tainter gates. In addition, the presence of the relict dam, particularly if outlet works were left closed, may form a barrier for benthic fishes to reach Grand Falls Dam. A field investigation into the position, condition, shape and dimensions of the relict dam would greatly improve characterization of downstream passage at Grand Falls Dam, allowing associated concerns to be either further quantified or ruled out.

2.4.2 Grand Falls Powerhouse Overview

In addition to the descriptions above, impounded waters behind Grand Falls Dam are delivered to the separate Grand Falls Powerhouse hydroelectric plant located at the downstream end of a constructed, 2,400 ft. long by 240 ft. wide intake canal. The Grand Falls Powerhouse is located south of the dam and separated by lands owned by Woodland Pulp LLC (Figure 2.4). Water flows to the turbines via three steel penstocks to generating units with a combined flow of 2,700 cfs at 50 ft. of head with a maximum discharge of 3,400 cfs (Figure 2.8). For background, components of a typical powerhouse are illustrated in Figure 2.9.

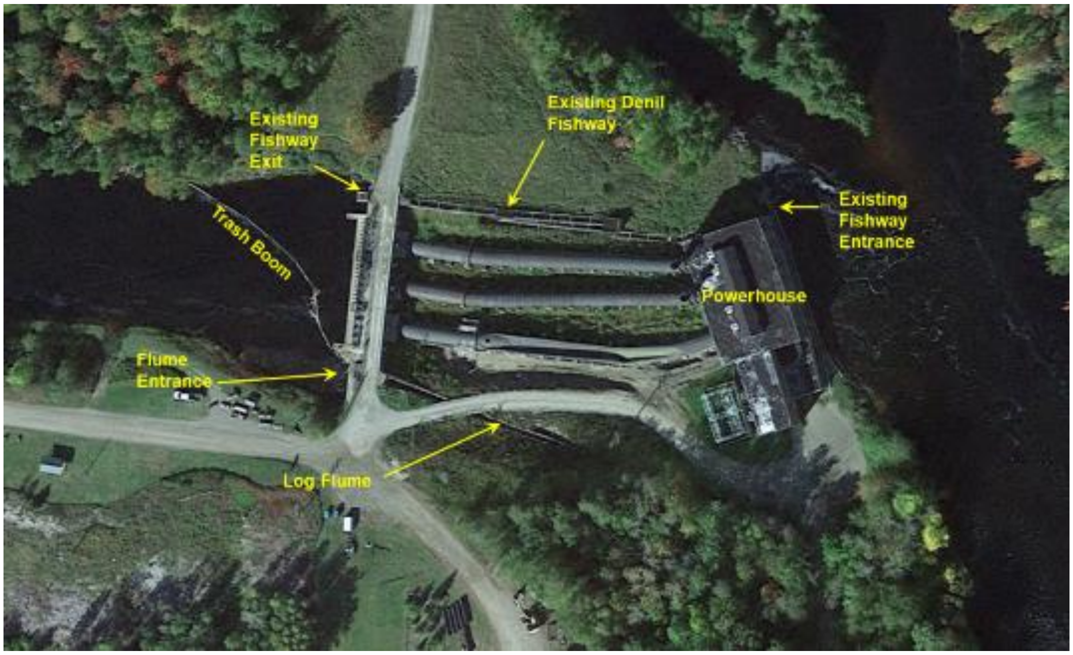


Figure 2.8. Grand Falls Powerhouse features (credit: Google Maps)

2.4.2.a Upstream Passage Key Characteristics

Grand Falls Powerhouse receives its water supply from the main body of Grand Falls Flowage via a constructed conveyance channel. Upstream migrants bypassed around powerhouse dam must migrate through the conveyance channel to reach upstream spawning habitats. The accumulation of fatigue in the fishway, when combined with high water velocities within the conveyance channel near the powerhouse, intakes may prevent some fishes from reaching resting habitat within the main body of Grand Falls Flowage. Fish fatigued or stressed when exiting a bypass system will be more susceptible to turbine entrainment and impingement on bar racks or similar physical features typically used to guide outmigrants to a downstream bypass. The severity of entrainment or impingement depends upon the species of immigrating fishes and the stress and fatigue imposed by the selected bypass technology. The rate of accumulation of fatigue depends upon the magnitudes and durations of water velocities within the fishway, and the rate of fish fatigue is likely very high in a long Denil type fishway (ASMFC, 2010), where fish must swim at prolonged burst speeds.

Accurate dimensions of the conveyance channel are unavailable for the complete analysis of hydraulic environmental conditions that upstream migrating fishes may encounter. A simple calculation of available conveyance channel dimensions, however, estimates a worst-case maximum average downstream channel water velocity of ~1.70 feet per second (fps), which is a sufficiently high, water velocity of concern, for migrating juvenile fishes. Accurate bathymetry, flow and velocity data for the conveyance channel should be collected spanning a range of operating conditions, including migration periods if a fishway system is expected to have an exit in the conveyance channel (as in current design).

Powerhouse and unit discharges into the tailwaters are two of the most important fishway planning variables at hydropower dams (Figure 2.9) because they provide information on the size, shape and location of the discharge plume, and its potential effect on locating the fishway entrances. The reported maximum combined flow of the three-unit operation at the Grand Falls Powerhouse varies from 2,700 cfs – 3,400cfs. 3,000 cfs is used as the maximum average flow at Grand Falls Powerhouse for fishway planning purposes.

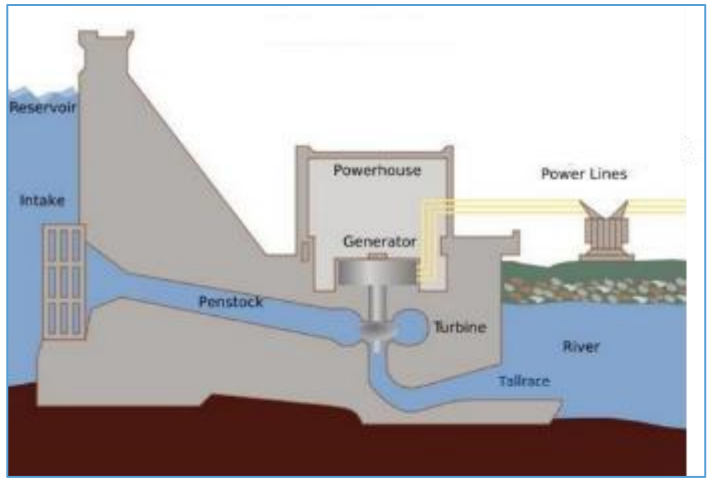


Figure 2.9. Generation flow through a typical hydro generation unit (source: Bright Hub Engineering)

The following design and operational factors also affect the shape and extent of the discharge plume and, thus, also influence the ability of fishes to locate the entrance to a fishway.

1) Flow exiting a draft tube is often in the shape of a helix and, therefore, the discharge plume from a turbine is typically not perpendicular to the downstream face of the powerhouse. The direction in which the turbines spin determines the direction of the offset of the discharge plume from perpendicular. This offset can be substantial, e.g., 30 degrees from perpendicular. Additional factors can affect the shape of the discharge plume, including the following: the depth and bathymetry of the immediate tailrace, the presence of submerged walls and/or berms, and the orientation of the powerhouse to the thalweg.

2) The shape of the discharge plume from a powerhouse is affected by the distribution of the operating units (when only some of the units are operating), even if all of the units are of similar design, because the discharge plume from one unit interacts with discharge plumes from surrounding units.

Adverse hydraulic conditions (e.g., excessive turbulence and eddies) can confuse and disorient fish and potentially delay or impede passage. The behavior of the discharge plume should therefore be characterized as part of the engineering studies to design a selected fishway alternative.

Figure 2.10. Grand Falls Powerhouse fishway and deteriorating and leaking segments (credit: LimnoTech)

A Denil fishway (built in 1965) is located on the north side of the hydroelectric plant. It is a 4 ft. (1.2 m) wide, 600 ft. (183 m) long, concrete structure with a series of seven resting pools, and design flow of 20 cfs. It is equipped with wooden V notched baffles to modify flows to levels acceptable for fish migration. The fishway is very degraded with deteriorating concrete, degraded baffles, and leaks caused by cracking infrastructure (Figure 2.10). The fish ladder should be replaced as part of the restoration of migrating fishes in the St. Croix River. In 2018, despite the degraded infrastructure, the Passamaquoddy Ecology Program, Sipayik Environmental Department, installed a tube counter that recorded over 10,000 upstream migrating alewife (Wabanaki, undated c), although this number is well below the estimated potential population range for this species.

A report by Rizzo et al. (1989) provided a list of passageway deficiencies, as well as recommended maintenance, operational, and structural improvements based on their late 1980's assessment, including the following:

- Additional attraction flow is needed.
- Headpool drawdown adversely affects fishway.
- Poorly located log sluiceway is too distant from the turbine intakes for use as a downstream fishway.
- Fishway entrance submerges at higher river flows.

Whether the existing entrance location adjacent to the discharge plume is effective in its present location is unknown. The discharge plume size and shape should be characterized with fish telemetry studies to determine how upstream migrant movement behavior is affected by the existing discharges across a range of flows. Results of these studies would inform decision-making regarding determining the best location for the fishway entrance.

2.4.2.b Downstream Passage Key Characteristics

Several project features at the Grand Falls Powerhouse debris management system may be important to the development of downstream passage for emigrating fishes. The upstream part of the Grand Falls Powerhouse (Figure 2.11), for instance, is comprised of an existing debris management system that includes five elements: 1) a trash rack comprised of vertical slats with a clear space of 1" between slats (Figure 2.11A and 2.11B) preventing trash and woody debris from entering the penstock; 2) a log boom angled toward the entrance of an ice and trash sluice used to bypass the majority of floating material intercepted by the log boom, so material does not waterlog, sink, and block the penstock entrances; 3) a guide wall to which the log boom is attached (Figures 2.11A), to guide floating debris to the log flume entrance (originally, the guide wall extended to a greater depth than the log boom; its current condition suggests that large parts under and near the water surface have deteriorated); 4) an entrance to the log flume regulated by stoplogs (Figure (2.11C); and 5) a log flume (Figure 2.11D) that empties downstream of the powerhouse.

Another important feature of the Grand Falls powerhouse are the elevated penstocks that convey water from the intakes to the powerhouse turbines. Pictures of these penstocks indicate that they are supported at intervals by concrete pylons, with clear space underneath the penstocks (Figure 2.11E). The space between pylons and underneath the penstocks may be an important design opportunity, if dewatering is considered for the fish bypass. A dewatering system is often employed downstream of the entrance to a bypass, because the flow used for attraction is substantially greater than the flow required to convey fish from the bypass entrance to the bypass outlet. Dewatering using a wedge wire screen can substantially reduce the size (and therefore the weight and cost) of the conduit connecting the bypass entrance to the bypass outlet. The dewatered flow can then be routed to either a penstock to be used for power generation, or underneath the penstocks to the entrance of an upstream fishway, where the flow can contribute to attraction flow to the fishway entrance located on the upstream side of the powerhouse draft tubes.

For minimizing fish mortality and injury, the 686-m long conveyance canal connecting Grand Falls Flowage to Grand Falls Powerhouse is the most significant project feature of the two study dams. Water velocity within the canal under operation of all three turbines (and possibly two turbine operation) may exceed the sustainable swimming speed of emigrating fishes. A simple estimate of the maximum cross sectional water velocity in the canal indicates a value of about 1.7 fps at capacity generation discharge of 3,400 cfs. Approach velocities upstream of the trash racks are reported to vary from 1.9-2.2 fps, although this could not be confirmed due to lack of complete intake design information. At these velocities, it is estimated that juvenile target fishes may become impinged on barrier screens or entrained in the intake flows and pass through the turbines. Previous observations confirm that juvenile alewife enter the penstocks and pass through the turbines (Bassett 2020, pers com), although timing, numbers and survival should be further examined.

USFWS guidelines (2019) do not consider turbine passage to be a viable means of downstream fish passage because of a high potential of injury or mortality. The consequences of turbine passage at the Grand Falls Powerhouse specifically are unknown. Studies could be conducted by 1) passing tagged fish through the turbines, 2) recovering them downstream, and 3) assessing them for necropsy and injury, once emigrating fishes are available with the completion of the upstream bypass systems. Alternatively, modeling studies using barotrauma and blade strike models could be used to estimate and assess the risk of injury or mortality to juvenile fishes that pass through the turbines, which has been accepted by resource agencies as a viable alternative to turbine passage studies. Without such information, it will be difficult to determine the tradeoffs in injury and mortality associated with existing site conditions and operations from screen impingement, barotrauma, blade strike (and associated physical damage from shear and collision with other moving and stationary parts of the turbine), and operation of the turbines at the Grand Falls Powerhouse.

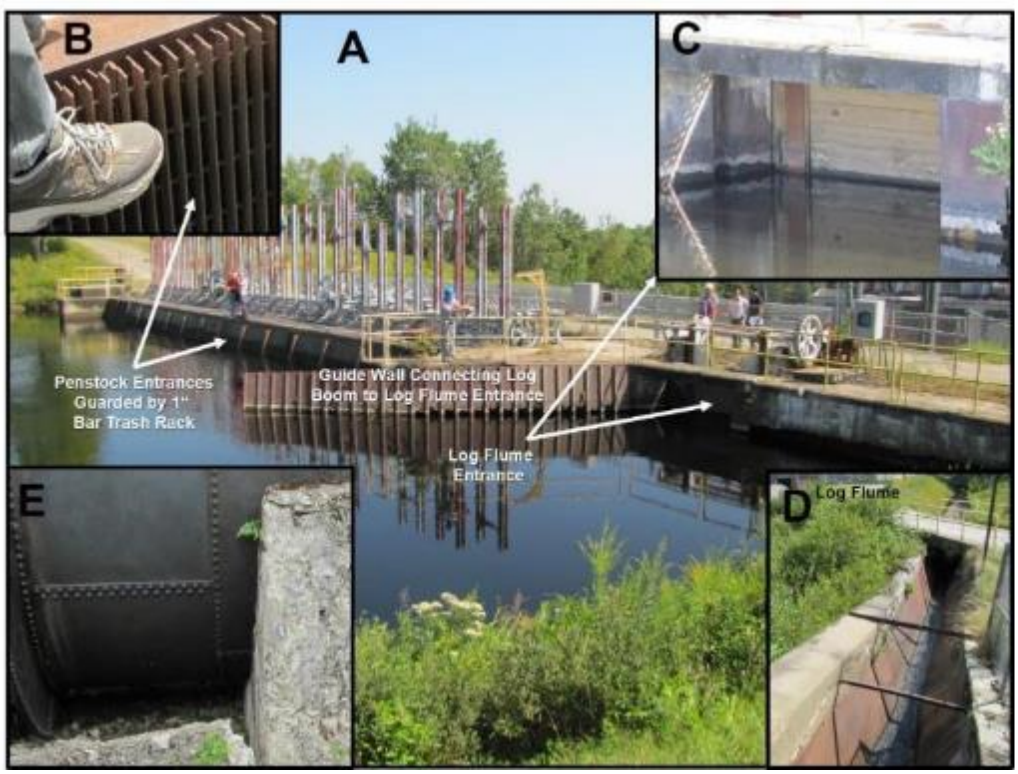


Figure 2.11. Features important for downstream passage planning for Grand Falls Powerhouse (A). The penstock entrance (A and B) is guarded by a 1" inclined bar screen/trash rack. A log flume (C and D) is used to bypass floating trash and woody material, including logs, around the dam. The powerhouse entrance transitions to a set of three suspended penstocks (E). (Photo Credit: by A. Hoar)

2.4.3 Woodland Dam and Powerhouse Overview

Woodland Dam and Powerhouse (collectively, Woodland Dam) is located in the town of Baileyville, Maine, approximately 8.5 miles (13.7 km) upstream of Milltown Dam at Salmon Falls (Figure 1.2). Woodland Flowage includes the Woodland Dam impounded backwaters at about 1,200 acres in size, and encompasses three connected waterbodies, with a drainage area of 1360 sq. mi. The site is bounded by the Canadian lands on the northeast bank and a pulp facility on the U.S. side of the river. A large portion of the dam is situated on the Canadian side of the river. The slopes on the northeast portion of the site are gradual; however, a train rail line runs adjacent to the toe of the northeastern corner of the dam (Figure 2.12). Woodland Dam is approximately 700 ft. long, with a max structure height of 48 ft. high. The power generation facility operates seven individual generating units with a combined flow of 3,200 cfs at 48 ft. operating head.

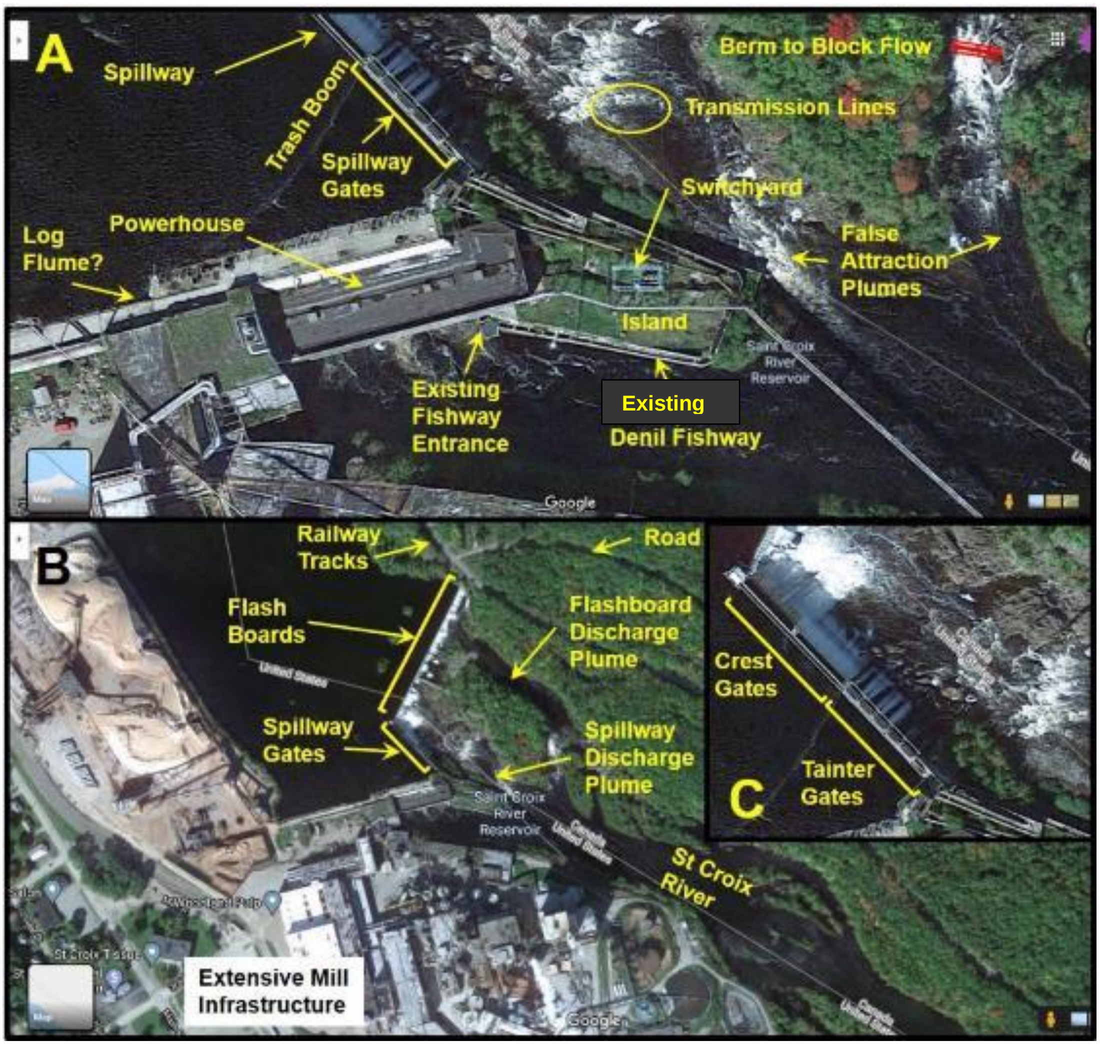


Figure 2.12. Detailed aerial image of Woodland Dam and powerhouse (A) and general aerial image (B) of Woodland Dam showing features important for Identifying and selecting fish passage alternatives; insert (C) showing crest and Tainter gates (credit: Google Maps)

Woodland Dam includes a Denil fishway (built in 1965) located on the north side of the hydroelectric plant (Figure 2.12). It is a 4 ft. (1.2 m) wide, 745 ft. (227 m) long, concrete structure with a series of four resting pools and design flow of 20 cfs (0.57 cms). It is equipped with wooden, V-notched baffles acceptable for fish migration. The fishway is currently degraded, with deteriorating concrete, degraded baffles, and passageway leaks caused by cracking infrastructure (Figure 2.13).

Figure 2.13. Woodland fishway and deteriorating elevated segments (credit: LimnoTech)

A report by Rizzo et al. (1989) provided a list of passageway deficiencies, as well as maintenance, operational, and structural improvements based on their late 1980's assessment. Deficiencies of the Denil fishway included the following:

- The need for additional fish passage entrances with guidance and improved attraction flows
- Ineffective fishway design at high (up to 6,000 cfs) river flows
- Excessive fishway flow depth that create pockets of high velocity and turbulence, reducing passage efficiency
- Leakage at fishway construction joints apparent at elevated portions of the fishway
- Further, there is no fishway available at the spillway for fishes that may continue to the base of the dam

2.5.4.1 Upstream Passage Key Characteristics

Woodland Flowage is a shallow impoundment (Figure 2.14) with maximum reported depths of approximately 24 ft. Unlike Grand Falls Flowage, Woodland Flowage is relatively long and narrow. Woodland Flowage also provides relatively little spawning habitat, so that the location of the exit of a fishway across the width of the reservoir should have relatively little ecological impact on target fish species. Woodland Dam Flowage functions primarily as a migration corridor for fish access to aquatic habitats upstream of Grand Falls Dam and the Grand Falls Powerhouse.

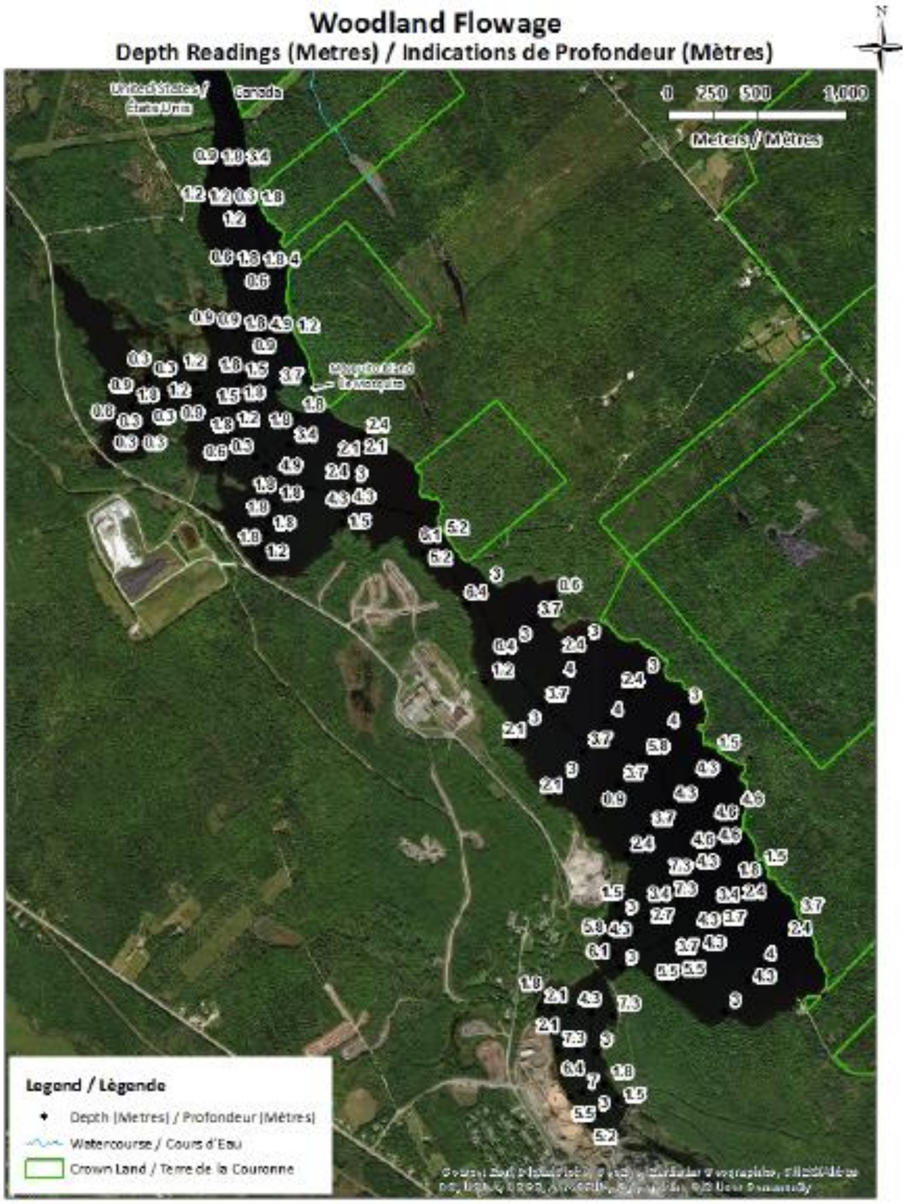


Figure 2.14. Bathymetric map of Woodland Flowage depicting the shallow nature of the flowage (credit: MDIFW)

Unlike the Grand Falls site, which features a separate powerhouse and spillway situated approximately 2,800 linear ft. apart, Woodland Dam is a more typical contiguous structure. It consists of the following components from the U.S. to the Canadian side: a powerhouse, an island that separates the powerhouse from the rest of the dam (also the location of the existing Denil fishway), a controlled spillway, and a section of dam featuring flashboards to maintain water levels and (possibly) to prevent wave over-splash (Figure 2.12). With its extensive infrastructure of Woodland Pulp on the U.S. side of the St. Croix River (Figure 2.12), Woodland Dam resembles an urban river site in many respects. This existing infrastructure seems to conflict with space requirements associated with construction of a fishway of any design on the U.S. side of the river. General site conditions include very few low-contour areas suitable for construction of traditional fishway alternatives that require substantial area to accommodate the length needed to meet slope requirements for ladders and NLFs (Figures 2.12).

The powerhouse of Woodland Dam contains seven turbines with a combined flow of either 3,200 cfs (per estimate provided by Woodland Pulp staff during a coordination telephone conference) or 3,000 cfs. Water level and discharge of flows above powerhouse capacity are regulated by five original Tainter gates, with a capacity of 2,050 cfs each (for a total Tainter gate discharge of 10,250 cfs), plus two crest gates with a discharge capacity of 1,600 cfs each (for a total crest gate discharge of 3,200 cfs), yielding a total spillway discharge capacity of 13,450 cfs.

In addition to a regulated spillway, nearly the entire length of the top of the north side of the dam is topped with racks containing flash boards that maintain water levels above the concrete crest of this portion of the dam. The total project-regulated discharge (spillway and powerhouse) is about 16,500 cfs, with a reoccurrence frequency of less than 1% during the upstream passage season (Figure 2.3). A reoccurrence interval of less than 1% translates into the occurrence of a flow large enough to require discharges from the part of the dam supporting flashboards about once every passage season. A number of aerial images of Woodland Dam indicate substantial flow originating from the part of the dam where the flashboards are located. It is unknown if the flow from the flashboards represents purposeful operation of the dam, or if this flow consists solely of leakage from the flashboards.

The tailrace, located immediately downstream of the controlled spillway and the portion of the dam supporting the flashboards, can be separated into two parts, divided by a structure of unknown purpose that currently functions as a discharge splitter (Figure 2.15). Leakage from the flashboards occurring north of the discharge splitter appears to concentrate in a secondary channel on the Canadian side of the dam (for brevity referred to as the flashboard channel) that reconnects with the main channel of the St. Croix River about 460 ft. downstream of the powerhouse. Spillway and flashboard releases occurring south of the flow splitter concentrate in a channel that borders the island on which the existing Denil fishway is located (for brevity referred to as the island channel).

Figure 2.15. Aerial image of Woodland Dam showing a structure of unknown function that separates the spillway and flashboard flows the flashboard channel and the island channel (credit: Google Maps)

These flows from the spillway and flashboard channels create a serious false attraction that is predicted to compete for fish with fishway entrances located near the powerhouse. Fish attraction to the spillway channel can be mitigated by constructing a second fishway entrance near the toe of the island. This entrance would lead fish to the same passageway used by fishes using the powerhouse entrance to the fishway. The exact location and configuration of the second entrance can be determined only after the downstream passage strategy is identified, because the outfall of the downstream bypass system will probably occur in the Spillway Channel and affect flow pattern within this channel.

Some dams feature a gallery behind their downstream face that connects to the primary fishway entrance. This internal gallery could be exploited for upstream passage, because it can be pierced by orifices that intermittently connect to the tailrace that adult fishes can use to access the primary fishway entrance. An evaluation of the dam could determine if a gallery exists within the downstream face of Woodland Dam that could be used in a similar way to link entrances along the downstream face of the dam to a powerhouse fishway entrance. An internal gallery could also be used to construct a second entrance to a fishway near the U.S. side of the powerhouse, making this an important area of exploration.

It is also important to ascertain how flow from the flash boards contributes to the operation of Woodland Dam in order to manage or mitigate the false attraction resulting from flashboard leakage on the section of dam north of the discharge splitter. It is uncertain if discharge over the flashboards plays a significant role in operating Woodland Dam because the highest discharge capacity (based on flow durations in Figure 2.3) is generally required only once during the passage season.

The existing fishway at Woodland Dam is constructed on the island separating the powerhouse and spillway, and while this location might appear attractive as a construction site for a new fishway, the island currently includes important project infrastructure that can only be modified with great expense (Figure 2.12). This effectively eliminates construction of any fishways on the island that require a substantial footprint, such as vertical slot or NLFs. The project switch yard is also located on this island. The switchyard adjusts the electrical current output by the turbines to meet the requirements of the transmission lines that distribute power to the grid. These transmission lines, which originate at the switchyard and run parallel to the dam toward the Canadian side of the river, have a height low enough to pose a safety hazard, a factor that must also be considered when assessing cost and constructability of alternatives.

Finally, powerhouse and unit discharges into the tailwaters are two of the most important fishway planning variables at hydropower dams. As described in Section 2.4.2.a, attraction flows can be calculated several ways to ensure that immigrating fishes can efficiently discover the entrance to the fishway. The challenge of effective attraction flows at the Woodland facility are similar to those at Grand Falls Powerhouse and the reader is directed the discussion in Section 2.4.2.a for a description that also applies to Woodland Powerhouse.

2.5 Lamprey and Eel Passage Considerations

2.5.1 Sea Lamprey

Sea lamprey are rarely considered in the overall development of fish passageway concepts (Noonan et al. 2012), despite migratory requirements that resemble those of other diadromous species. Pereira et al., (2016) provide an update and study on the effectiveness of vertical slot fishways on European sea lamprey, and the USACE (2014), Northwest U.S. have also completed assessments on effective and efficient upstream and downstream passageways for sea lamprey. While the recent Pereira et al. (2016) study found passage efficiency of ~ 30% for their vertical slot fishway, other lamprey-specific passageways are more efficient and effective. A study of four fishways on the Connecticut River (Castro-Santos et al., 2016) reported an internal passage efficiency of 57.1% for the Gatehouse double Hell's Gate style vertical slot fish ladder, while the Ice-Harbor fish ladders for Cabot Station and the Spillway reported 38.7% and 31.0% internal effectiveness respectively. Considerable work on Pacific sea lamprey has been conducted by USACE on the Columbia and Snake Rivers. The experiences of the USACE in the Northwest may provide value in Northeast planning and design because Atlantic sea lamprey resemble Pacific sea lamprey in general size and form, and also exhibit similar swimming behavior, including the use of an oral disk for attachment to relatively flat substrates. Although they belong to different genera (Atlantic lamprey and Pacific lampreys), both species are members of the Northern lamprey family.

> ***Spotlight: Sea lampreys***
>
> Sea Lampreys are considered a keystone species in watersheds like the St. Croix. They import marine-derived nutrients and minerals into tributaries that have low productivity (Nislow and Kynard 2009). Carcass decomposition provides nutrients and minerals to the aquatic and riparian ecosystem and it is likely that Sea Lamprey eggs and larvae provide more direct positive effects to the fish community by serving as prey for their entire life cycle in freshwater. Other ecological contributions of Sea Lamprey are related to nest construction and diversification of the streambed (Hogg et al, 2014).

Based on USACE research on Pacific lamprey for Columbia River projects, the following insights and guidance can help inform how to accommodate sea lamprey passage for a fish ladder or fish lift designed for Grand Falls and Woodland.

1) Plan for velocity of < 7 ft./sec – Pacific lamprey burst speed 7 ft./sec.
2) Target differential head < 1.5 ft. – Pacific lamprey obstructed by head > 1.5 ft.
3) Avoid weir openings.
4) Provide smooth surfaces – Pacific Ocean sea lamprey are adept at moving through traditional fish ladders as long as they can attach to smooth surfaces using their oral disk to rest between bouts of swimming.
5) Avoid 90 deg. corners – Round corners, or approximate with multiple angles < 15 deg.
6) Avoid sills in the bottom of a vertical slot – provide ramps or a continuous flat floor through the slot.
7) Provide smooth pathways, or *sidewalks*, around any substrate such as grating that prohibits lamprey attaching with their oral disk. Grating is often used in a floor diffuser to introduce supplemental

attraction flow to a fishway entrance. The grating needs to be small enough to exclude lamprey and include smooth metal/pvc pathways to aid lamprey passage.

These principles and guidance described can be extended to fishways proposed for the St. Croix. For example, the entrance and entrance galley of a fish lift should not contain openings that are large enough for sea lamprey entry; gratings should be provided with lamprey sidewalks; and sharp corners should be replaced by curves or chamfers to which the sea lamprey can successfully attach using their oral disks.

Separate sea lamprey passageways should be developed for upstream movement at the Grand Falls Powerhouse and Woodland Powerhouse. Based on research from the Northwest, dedicated sea lamprey fishways are similar to eel ramps, where designers use small cross-sectional channels measuring approximately 1.5 to 2 ft. wide by 6 inches high, set at a steep incline of about 30 to 45 degrees. A thin stream of water is discharged down the ramp, but the interior surface remains smooth to allow oral disk attachment to aid in climbing, as shown in Figure 2.16.

Sea lamprey traps in the Great Lakes are similar to eel traps used in the Northeast, but they use solely plastic pegs as a substrate and have been shown to effectively trap sea lamprey. In addition, a project in Ireland at Annacotty Weir used a similar plastic peg substrate to pass sea lamprey over a small dam. Given this information, it may be possible to consider a dual-purpose ramp for both eels and sea lamprey.

Figure 2.16. Lamprey ladder example (source: US Army Corps of Engineers)

2.5.2 American Eel

American eel is a catadromous species that migrate upstream from about April through October as juveniles (glass or elver life stages) after entering freshwater systems from the ocean. Larger yellow-stage eels also move upstream during various times of the year. Upstream passage for American eel typically involves an eel ramp or trap near one or both banks adjacent to the dam. Eels tend to migrate upstream in the margins of the river in slower river currents. A typical eel ramp consists of a shallow channel measuring approximately 1.5 to 2 ft. wide by 4 to 6 inches high in cross section. Eel ramps are typically placed at an inclined angle of approximately 30 to 45 degrees, with a thin stream of water discharging down the ramp. Additional attraction flow is discharged from a pipe near the base of the ramp. The channel is typically lined with substrate to aid eels ascend the ramp. Various substrates are used for different size eels (i.e., glass, elver, and yellow life stages) and ramps often include combinations of substrate within the same ladder. A geotextile mesh is recommended for smaller elvers or glass eels, while a substrate with protruding pegs is recommended for larger yellow eels. Specific design guidance for eel ramps is provided in FWS (2019). Examples of a substrate eel ramp and eel trap are shown in Figure 2.17 and Figure 2.. Eel ramps should also include covers to reduce predation by birds and mammals (FWS 2019).

Dedicated eel ramps are recommended for Grand Falls Dam, Grand Falls Powerhouse and Woodland. Ramps should be located on both banks of the spillways in low flow areas and informed by an eel abundance study.

Figure 2.17. Eel ramp example (source: CTDEEP)

Figure 2.18. Eel trap example (source: CTDEEP)

3 IDENTIFYING AND SCREENING FISH PASSAGEWAY ALTERNATIVES

3.1 Screening Approach

Many different technologies exist to pass fish around or through a dam structure. Selection of an optimum fishway for a particular application should consider site conditions, upstream and downstream migration needs of target species, facility opportunities, active or passive options for the facility and species, or any combination of these (USFWS, 2019; DFO, 1988). Active passage occurs using mechanized structures such as fish lifts and locks, with electrical power and manual or automated systems used to facilitate operation. Passive passage occurs through static structures such as fish ladders and natural bypass river channels. The goal of upstream fish passage is to attract migrating fish species to a specified point below the dam and entice them to move upstream through a technical or nature-like waterway, or by collecting and transporting them upstream. Effective downstream passages should provide a safe conduit for downstream movement through or around the facility while minimizing stress and physical injury to the fish (WIDNR, 2018).

Individual dam facilities may accommodate several options for efficient and effective upstream and downstream passage to meet the species, population and timing needs for fish passage. This study considered fish passage options that are generally considered viable and well tested within the Northeastern U.S. and Canada. The study used a stepwise screening approach as follows:

Primary Screening included a high level, qualitative assessment of regionally accepted, upstream and downstream passage technologies for the target species identified for the study. This screening level is not facility specific but was included as a first step in reducing the range of less applicable passageway technologies for the target species based on a simplified opportunities and limits assessment. Primary screening approach and results were provided, reviewed and commented on by the Workgroup.

Secondary Screening used a set of metrics and a scoring system for the remaining upstream and downstream options that passed the primary screening assessment. The secondary screening level used a scoring system of seven metrics to assign rankings and establish elimination thresholds for upstream passage alternatives for the three facility locations – Grand Falls Dam, Grand Falls Powerhouse, Woodland Dam. A conceptually similar scoring system was used for downstream passage alternatives at the same three facility locations, except that it was based on six metrics. Secondary screening approach and results were provided, reviewed, and commented on by the Workgroup. The secondary screening served to reconcile the professional opinions and rankings among the report authors with members of the Workgroup and others with technical input

Tertiary Screening was a focused, qualitative evaluation and elimination assessment using simple advantage and disadvantage descriptors for selecting the most effective final alternatives for upstream and downstream passage alternatives and concept-level cost estimation.

The screening approach included opportunities for input, review and comment by the St. Croix River Workgroup to compare upstream and downstream options using a set of common metrics. Primary and secondary screening options for upstream and downstream passage were presented to and discussed with the entire St. Croix River Workgroup during the following meetings:

February 11, 2020 – Project update discussion on goals and objectives of the study, first half of the study report outline, site data needs and discussion of plans for an initial screening approach.

March 11, 2020 – Project update discussion on second half of the study report outline, additional site data needs and progress on the screening approach.

April 17, 2020 – Presentation of target species tables, site screening approaches, rationale and initial findings for upstream and downstream passage at the study sites. The meeting included comments for potential changes on the initial screening results.

April 30, 2020 – Updated tables with target species, primary and secondary screening tables and results were then provided to the Workgroup for review and comment.

May 4 – May 11, 2020 – Received tables review comments and recommendations from Workgroup members.

May 21, 2020 – Coordination call with Woodland Pulp members and members of the Workgroup to present study approach, initial screening results, information needs and next steps.

June 3, 2020 – International St. Croix River Watershed Board Meeting. Presentation on approach, initial findings, status and next steps of study.

September 25, 2020 – International St. Croix River Watershed Board Meeting. Presentation on study findings, solicitation for draft report comments, and report schedule.

October 28, 2020 – Alternating side baffle fishway presentation and discussion. Presentation on research and potential applications of this unique technical fishway in the St. Croix River.

The following sections detail the screening levels, findings and rationale for eliminating and selecting alternatives for final, conceptual cost estimations for each facility.

3.2 Primary Screening

The initial primary screening of alternatives considered the merits of a range of passage technologies against multiple diadromous fish species found in the St. Croix River.

Primary screening tables were initially introduced during the March 11, 2020 meeting, subsequently adjusted based on input (Tables 3.1 and 3.2), and then used for screening level elimination and forward planning analysis. As depicted below, this best professional judgement level of qualitative level of screening resulted in the elimination and selection of technologies for secondary level screening. Alternative selection was influenced by input from the St. Croix River Workgroup, but did not exclusively rely on these comments, due to occasional conflicts in recommendations. Tables 3.1 and 3.2 depict final, primary screening decisions, where red rows designate eliminated alternatives and green rows designate alternatives carried to secondary level screening.

Sea lamprey have upstream and downstream passage requirements that are unique among the target species (USACE, 2014). Although they are grouped among the other target species for the purpose of screening, recommendations for species-specific passage methods are identified at the tertiary screening level (see Section 3.3).

Table 3.1. Primary screening summary of upstream passage alternative designs for target species for Grand Falls Dam, Grand Falls Powerhouse, and Woodlands Dam; included in 11 March 2020 teleconference with the St. Croix River Workgroup

Alternatives	Site and Infrastructure Limitations and Opportunities		Target Species					
Upstream Fishway Technology	**Advantages**	**Disadvantages**	***River Herring**	**American Shad**	**American Eel**	**Sea Lamprey**	**Atlantic Salmon**	**** Sturgeon**
Pool & Weir	Smaller footprint than a vertical slot with generally greater slopes. Effective for passing salmonids	Not self-regulating for flow ranges and cannot adjust to wide fluctuation in head pond levels ≤10% slope. Not preferred for shad and sturgeon. No advantages over vertical slot design. Lack info for Atlantic sea lamprey design needs	y	n	n	n	y	n
Ice Harbor & variants	Variant of a pool and weir fishway. Effective for salmonids.	≤10% slope cannot handle a wide fluctuation in head pond levels. Not preferred for shad or sturgeon.	y	y	y	n	y	n
Vertical Slot	Self-regulating – can handle fluctuation in head pond. Supports passage of all species	Larger footprint than a pool and weir due to shallower required slopes (< 5%)	y	y	y	y	y	y
Denil	Smaller footprint due to greater slope. Common for passing salmonids and herring.	Very long fish ladder due to the high head. Not recommended for sturgeon, or for American shad for head height > 20-25 ft. Lacks capacity for design populations.	y	n	n	n	y	n
Steep pass Fishways	Compact design, small footprint due to steeper slope. Effective for salmonids and river herring.	Lacks capacity for design populations. Not suitable for shad or sturgeon.	y	n	n	n	y	n
Fish Lifts	Well tested experience in NW; scalable design to accommodate design populations and all target species.	High maintenance requirements and may require multiple facilities to accommodate design populations. Automated lift cycles need to account for diel and seasonal staging patterns.	y	y	y	y	y	y
Fish Locks	Functions very similar to fish lift.	Rarely used on the East Coast. No advantages over comparable fish lift. Engineering challenges with existing structures as retrofit. Requires large, free-standing columnar structures.	y	y	y	y	y	y
Nature Like Fishway (NLF)	Mimics natural stream hydraulic patterns, providing variety of hydraulic conditions. Effective for all target species.	Large footprint due to shallow slope required. Requires detailed site-specific hydraulic evaluation, as there are no standard designs.	y	y	y	y	y	y

*blueback herring and alewife/Gasperau; **Atlantic sturgeon and shortnose sturgeon; ***Design flow dependent

Note: Combination alternatives are not considered here. Green rows are carried into secondary screening, while pink rows are excluded from further exploration.

Table 3.2a. Primary screening summary of structural downstream passage alternative designs for target species for Grand Falls Dam, Grand Falls Powerhouse, and Woodlands Dam

Alternatives – Structural		Site and Infrastructure Limitations and Opportunities		Target Species					
	Downstream Fishway Technology	Advantages	Disadvantages	*River Herring	American Shad	American Eel	Sea Lamprey	Atlantic Salmon	** Sturgeon
Structural	Louver	Good experience in NE. Effective for salmon and alosines with appropriate approach angle, velocities, and spacing.	Requires uniform approach flow conditions typically within an intake canal. Uncertain effectiveness for eels. Larger footprint than angled or inclined rack	y	y	?	?	y	y
Structural	Angled Bar Screen	Effective for eels, salmon and alosines depending on angle, clear spacing and approach velocity. Common in NE.	Narrow spaced racks cause issues with debris loading and frazil ice.	y	y	y	?	y	y
Structural	Inclined Bar Screen	Fewer experiences in NE although expected to perform similar to an angled bar rack. May offer added protection for eels.	Narrow spaced rack cause issues with debris loading and frazil ice. Long rack will require long trash rake.	y	y	y	?	y	y
Structural	Guidance Nets	Can provide effective physical exclusion and guidance to bypass. Effective for target species with appropriate mesh sizes. Best applied in reservoir with lower water velocities.	Debris management and biofouling potential high at sites (including gilling of fishes). Debris issues may compromise the net performance and lead to failure without extensive maintenance plan. Limited experience in NE.	y	y	y	?	y	y
Structural	Guidance Boom	Provides physical guidance similar to net with fewer debris fouling challenges. Positive performance examples in NE. Expected to be effective for salmonids and alosines species with appropriate depth preferences	Uncertainty of site challenges related to ice flows and buildup. Not effective for benthic species (eels and sturgeon)	y	y	n	?	y	n

Note: Based on 11 March 2020 teleconference with St. Croix River Workgroup, behavioral technologies were considered secondary and supplemental to structural technologies because of their inconsistent but potentially valuable results. Pink rows are not carried into secondary screening, while green rows are carried forward into secondary screening.

Table 3.2b Primary screening summary of behavioral downstream passage alternative designs for target species for Grand Falls Dam, Grand Falls Powerhouse, and Woodlands Dam

Alternatives – Behavioral		Site and Infrastructure Limitations and Opportunities		Target Species					
	Downstream Fishway Options	Advantages	Disadvantages	*River Herring	American Shad	American Eel	Sea Lamprey	Atlantic Salmon	** Sturgeon
Behavioral	Light – Continuous	"Streetlights" used to attract fishes. Very inexpensive compared to structural technologies. Some good examples for light attraction. Effective co-technology.	Effectiveness varies with turbidity. Only works at night.	y	n	?	?	n	n
	Light - Strobe	Underwater lights used to repel fishes in the near-field. Very inexpensive compared to structural technologies.	Inconsistent results because of penumbra effect. Effectiveness varies with distance and turbidity. Effectiveness uncertain across target species and expected to differ.	y	y	y	y	n	n
	Sound (high frequency)	Relatively inexpensive compared to structural technologies. Some successful applications in NE & Atlantic coast states. Effective co-technology.	Effective only on Alosines. Difficult to shape acoustic field for desired repelling effect. Phantom sources and signal acclimation by target species must be considered.	y	y	n	n	n	n
	Electric fields	Subject of ongoing experimentation. No known applications in NE or NA for intake guidance.	No full-scale applications. Considered experimental. Human safety concern						
	Flow field manipulation – Methods include 1) operation modifications, 2) alterations in approach channel or 3) use of high-volume / low-head pumps	Some successful applications in NE. Similar effect as AWS, but without loss of flows for hydropower.	Limited experience and effectiveness in Northeast. Could be applied with another technology to enhance effectiveness. Generation shutdowns may be necessary at certain times. Effectiveness may vary among species.	y	y	y	y	y	/

*blueback herring and alewife/Gasperau; **Atlantic sturgeon and shortnose sturgeon; ***Design flow dependent

3.2.1 Upstream Passage Alternatives Passing Primary Screening

Three upstream passage technologies passed primary screening: vertical slot fishways, nature like fishways, and fish lifts. These technologies may apply to Grand Falls Dam, Grand Falls Powerhouse, and Woodland Dam depending upon site conditions. Below are general descriptions of each type of upstream fish passage technology that passed primary screening. The details of alternatives that passed secondary and tertiary screening are presented later in this report. The reader is also directed to the excellent reviews in Linnansaari et al. (2015) and USFWS (2019) for additional background.

Vertical Slot Fishway

The following description of the vertical slot fishway is based primarily on USFWS (2019) and Linnansaari et al. (2015). A vertical slot fishway is a pool-type fish ladder applicable to medium head dams 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 that runs from the top of the baffle to the bottom (or close to the bottom) of the fishway sluice (Figures 3.1 and 3.2). The primary attribute that separate vertical slot fishways from other technical fishways is their ability to self-regulate. Self-regulation means that the flow to the fishway remains relatively constant as the water surface elevation varies in the head pond. This self-regulation breaks down under lower flows so make-up water may be required to maintain flow design conditions within the fishway.

Vertical slot fishways, like most technical fishways, efficiently dissipate energy to create a constructed hydraulic corridor around a dam, with sufficiently low velocity to support upstream fish migration, while also at a high enough slope to shorten the length of the fishway and, thus, reduce construction costs. Vertical slot fishways dissipate energy by directing the water jet through the slot into downstream pools, where it is dissipated before it exits through the next slot/pool chamber (Figure 3.1b). Interestingly, the hydraulic conditions in the pools comprising the fishway can be surprisingly variable, thus mimicking natural systems, even though the structural design of each pool is identical.

Important design elements of a vertical slot fishway include slope (4%-10%), pool geometry, slot width (which is determined by the width of target fishes along with the maximum burst swimming speeds of all target species). A baffle plate within the slot can be used to further regulate flow. Linnansaari et al. (2015) summarize the performance of vertical slot fishways by species and should be consulted for further information.

Vertical slot fishways have been shown to be an effective corridor for bypassing large obstructions in rivers; however, their design performance needs to be tailored to the swimming ability of the target species. For example, an overly narrow slot width can physically exclude large species such as sturgeon, while other species such as American shad may reject a narrow slot. The effectiveness of vertical slot fishways for upstream passage of eels and Atlantic sea lamprey is not well studied, although Pereira et al. (2016) suggested the technology can be effective for European lamprey species. Vertical slot fishways may be prone to clogging by woody debris which can disrupt the formation of the energy-dissipating hydraulics. Overall, vertical slot fishways are a good option at passing a diverse species mix (pelagic and benthic) because the slots span the entire water column and have a proven level of success throughout the U.S. (ACOE, 2020). Further, vertical slot fishways are found across the northeastern U.S. and are considered effective for target fishes for this study.

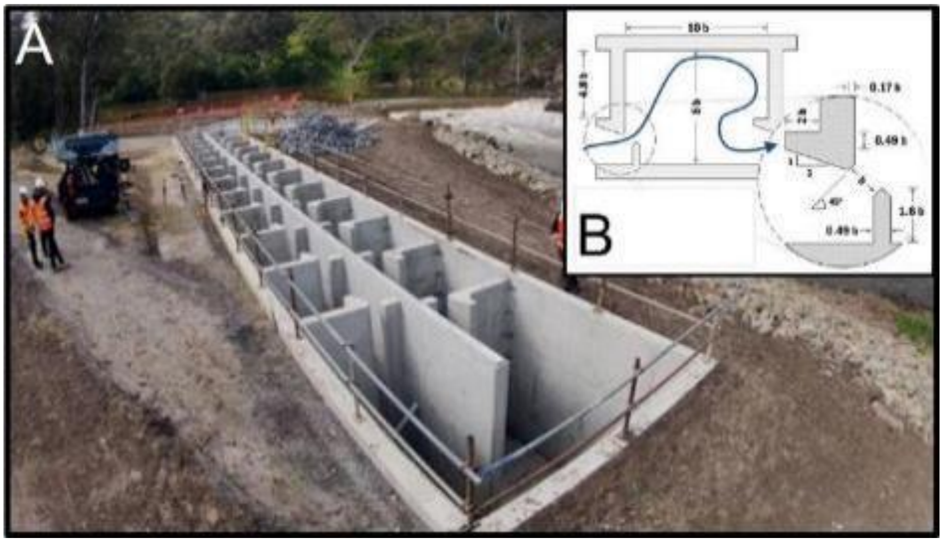


Figure 3.1. A vertical slot fishway in final stages of construction.

Note: Figure 3.1. Notice the relatively large depth to width relationship to accommodate variation in upstream headpond levels (A). A key design consideration for the geometry is the slot size (B)(from Rajaratnam et al. (1986) as depicted in USFWS (2019)). The blue line represents the dominant streamline in a well-designed system; however, it is common for this pattern to change as headpond and tailrace water surface elevations change, potentially accounting for the variations in passage performance among species.

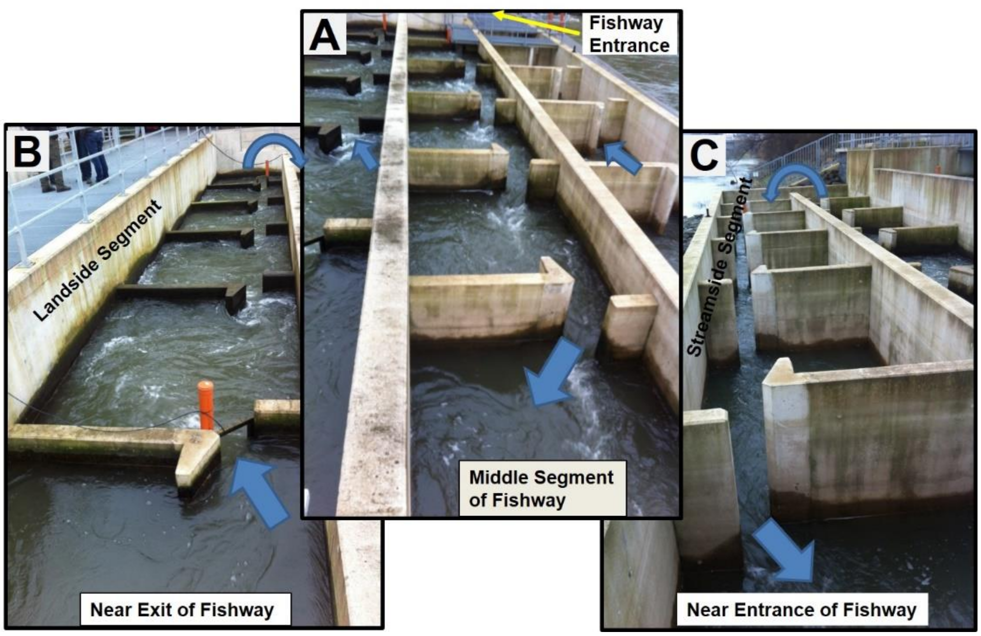


Figure 3.2. Example of a vertical slot fishway on the Mosel River, near Koblenz, Germany (credit: J. Nestler).

Note: Figure 3.2. The fishway is comprised of three runs (A). Photos were taken during relatively high flows and Illustrate how the water surface elevations changes as flow progress from the upstream (B) to the lowest pool (C). Blue arrows depict flow direction.

Nature-Like Fishways

This description of nature-like fishways is primarily taken from USFWS (2019) as well as Turek et al. (2016). Nature-like fishways (NLFs) are artificial instream structures that bypass stream barriers where the site cannot be fully restored (Turek et al., 2016). NLFs are generally constructed of boulders, cobble, and other natural materials to create complex geometries and diverse hydraulic conditions that dissipate energy and provide attractive cues and complex flows that can be more effective and efficient passage for multiple species (Turek et al., 2016). Design standards for NLFs have not been fully developed because the approach fits between the complex realm of infrastructure protection, stream restoration and technical fishway design. As such, NLFs are site and species specific and represent a relatively new fish passage technology which has received relatively little evaluation (Turek et al., 2016). Importantly, while many of the concepts underpinning NLFs are similar to those of technical fishways, the USFWS does not categorically support extension of technical fishway criteria to the design of NLFs.

Turek et al. (2016) provide a recent summary and guidance for Northeastern diadromous species and length-specific, design parameters that include specifications for study target species (Figures 3.3 and 3.4). NLFs include a wide variety of designs and may only be limited by the imagination of the designer, as long as the design fit within the complex nature of the site's hydrogeomorphic conditions and the basic fish passage principles of energy dissipation and creation of suitable migration corridors generally complying with passage criteria of target fishes. Nature-Like Fishways may be generally categorized as the following:

1) Rock ramps - sloped watercourses that link two pools of different elevation (e.g., headpond and tailrace of a dam), constructed as an extension of the existing channel (i.e., partial ramps) or spanning the entire river. Rock ramps are considered a variation of the NL in-channel approach. Rock ramps are typically constructed at low head dams (e.g., 6 m). Rock ramps can be constructed with a relatively large slope depending upon the size, distribution, and anchoring methods (if any) of the construction materials. However, rock ramps are prone to damage by high flows unless primary components are anchored to the channel. Rock ramps and partial-width rock ramps may not be suitable for the St. Croix River study sites, because dam heights are too great; however, they might be able to be constructed as a bypass channel within lower gradient slopes.

2) Bypass channels – channels designed to convey water and pass fish around a dam or other barrier, constructed as a connected extension outside of the main channel and resembling a natural stream channel in many ways, except that energy dissipation features are organized into more recognizable patterns typical of the energy dissipation features of a technical fishway (Figures 3.3 and 3.4). Unlike rock ramps, bypass channels typically consist of a wide, lower gradient channels, usually with less than 1:20 slope, and a concave stream channel cross section. NLFs may have compound channels to meet hydraulic criteria over a range of flows as discharge and head pond water surface elevations vary. The exit to a NLF must be carefully designed and constructed to prevent the river from "jumping" from the existing main channel and cutting a new channel through the NLF. For brevity, the bypass category of NLF in this report does not consider the rock ramp category as a viable alternative for the St. Croix River at this time.

A well-documented NLF installation at an operating hydroelectric power plant is not yet available to serve as an established precedent. The few NLF examples within the northeastern U.S., however, show promise for broader, adaptive application. Step-pool and non-step-pool options can also be explored, for either in-channel or bypass channel application (Mike Burke, personal communication). General concerns related to NLF design for this study include headpond control for hydropower efficiency and positioning for attraction flows. Overall, the general concepts of minimal maintenance and low operations costs of a nature-based design make the NLF an attractive option.

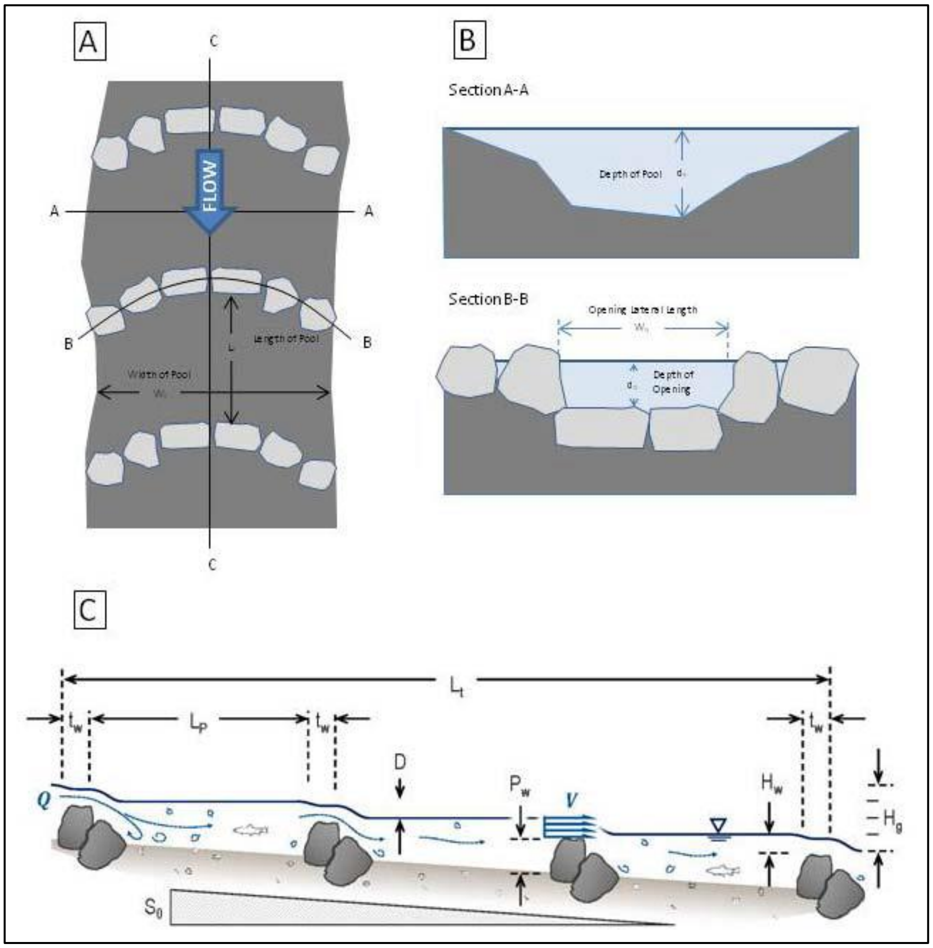


Figure 3.3. Schematic of NLFs showing plan view (A), cross sectional view (B), and profile views (C) (from Turek et al. 2016).

Note Figure 3.3. As much as possible, NLFs preserve the hydraulic and geomorphic diversity of natural channels, often using local native materials. Engineering principles are used to gradually dissipate kinetic energy of flowing water to create an array of possible migration corridors for migrants of a range of different swimming speeds.

Figure 3.4. Pictures of lower gradient NLFs showing a larger scale example at Kenyon Mill, Pawcatuck River, Richmond, RI (A) and a smaller scale example at Saw Mill Park, Acushnet River, Acushnet, MA (B) (images: Turek et al. 2016)

Fish Lifts

Fish lifts or fish elevators are non-volitional upstream technologies designed to attract fish into an entrance channel, mechanically crowd them above a hopper before lifting them into an elevated impoundment (or alternatively, into an exit channel hydraulically linked to an impoundment). Fish lifts differ from volitional ladders in that they require numerous mechanical, hydraulic, and electrical components. They can be operated remotely, but often require an operator.

A fish lift has an entrance and an exit, similar to other technical fishways (Figure 3.5). An auxiliary water supply is required to create the attracting flow at the lift entrance. The downstream flows at the exit guide migrating fishes into the head pond through an exit flume (or exit pipe) that can also contributes to attraction flow at the fishway entrance. A lift tower with a hopper replaces what would normally be the part of the fishway where kinetic energy is dissipated to create a migration corridor for upstream migrating fishes. A fish lock is generally similar to a fish lift except that a columnar water tower (with a grate that forces fishes upward during the rise cycle) is used to raise fishes to the level of the exit.

A fish lift is particularly suited for high head dams because fishway slope is not a design consideration; therefore, a fish lift has a reduced footprint compared to other fishway alternatives. Its reduced footprint makes it an ideal solution in settings where space is limited or for application at high dams where a conventional fish ladder would be excessively long and with large footprint. However, unlike a vertical slot fishway or a NLF, a fish lift is not a passive technology and must be routinely inspected, maintained, and repaired. They also require significant electrical service (i.e., parasitic electric load) to raise and lower the hopper. They are not a viable alternative for remote locations where neither power sources nor personnel are available. However, effective fish lifts for target species are found throughout the northeastern region and considered an effective option for upstream fish passage. An example of a free-standing fish lift that could be considered for application in the St. Croix River is shown in Figure 3.6.

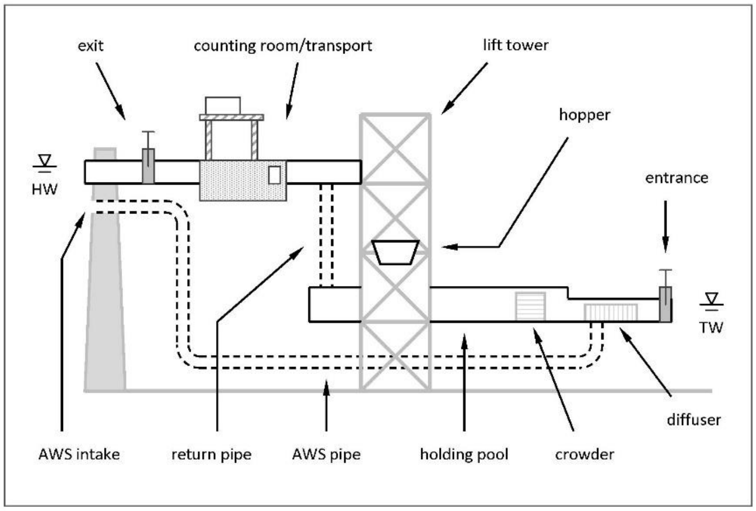


Figure 3.5. Side view of a typical fish lift design showing individual components (USFWS, 2019)

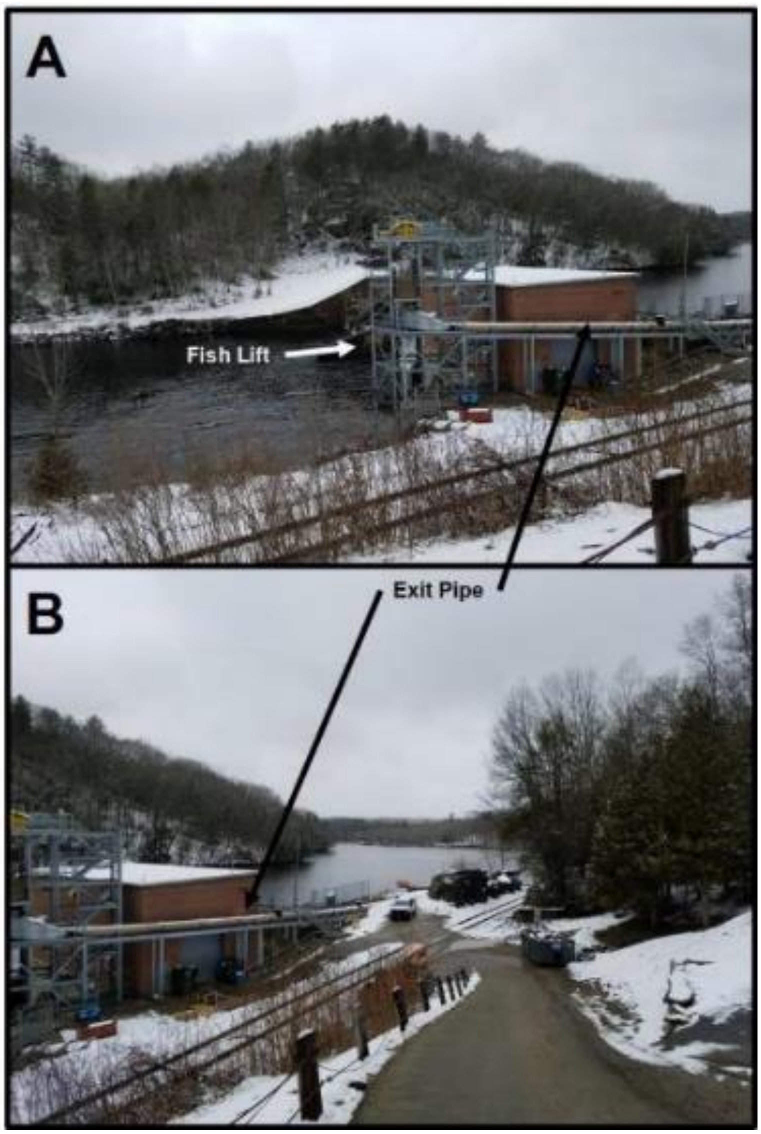


Figure 3.6. Example of an existing freestanding fish lift showing the main lift (A) and exit pipe used to transfer fish to the tailrace (source: G. Allen)

3.2.2 Downstream Passage Alternatives Passing Primary Screening

Downstream passage planning is more complicated than upstream passage planning because there can be many more routes and options for downstream passage. For typical hydropower facilities there are three primary routes of downstream passage for a fish (USFWS, 2019) - 1) through the turbine intakes; 2) over a spillway; and 3) through a fish bypass system. Although improvements for turbine intake passage exists, injury and survival among sites and species in the northeastern U.S. are lacking. USFWS (2019) does not consider passage through turbine intakes as an acceptable downstream route.

As additional challenges, there are substantial differences in spatial considerations between the forebay and tailraces of dams, as well as differences between the sizes and swimming abilities of upstream vs. downstream migrating fishes. Downstream fish passage planning typically should consider both guidance toward the passageway as well as attraction into the passageway. Downstream guidance is important because reservoir forebays tend to be wide and juveniles are weak swimmers (sustained swimming speed for juvenile alosines is about 1.0 fps (0.3 mps)). For example, it is more difficult for alosine outmigrants to locate the entrance to a 2-m wide entrance to a downstream bypass system in a 335-m wide structure that has multiple competing (but unacceptable) outlets. Without a guiding structure or entrance stimulus, a juvenile outmigrant may be delayed for a significant period as it searches for an acceptable downstream path, during which time it will burn energy reserves and be subject to predation and other sources of time-dependent mortality (Larinier, 2001).

There are many different design considerations for downstream bypass systems depending upon biological variables such species composition and size of targeted fishes and structural, hydrological, operational and other non-biological variables. In addition, there are differences in downstream bypass options employed among regions within the USA. For example, net-based surface collectors appear common in the Northwest, but uncommon in the Northeast.

Downstream bypasses structures can be broadly separated into several categories, summarized below:

Structural Guidance and Barrier Systems

These systems physically exclude downstream migrating fishes (e.g., angled bar screens and inclined bar screens) or create hydraulic conditions that fish are reluctant to penetrate (e.g., louver screen – it can be classified as a structural or behavioral protection system) (Figure 3.7). All three of these systems can be used to guide fishes to a bypass entrance if the screen is properly designed (angle of the slats to the flow field and gap between the slats), sized, and located.

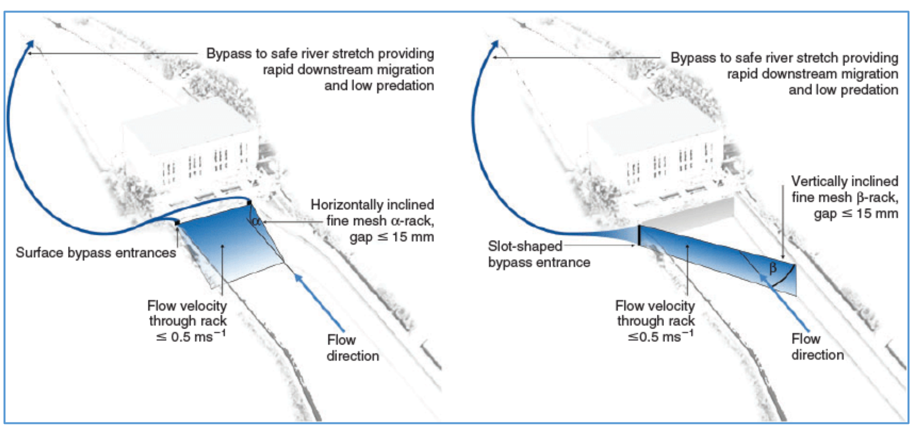


Figure 3.7. Examples of structural systems of inclined and angled screens used to guide fish to downstream bypass systems (Fjeldstad et al., 2018)

Behavioral Guidance Systems

Downstream passage alternatives also include behavioral methods such as light, shade, sound, designer flow fields (created by low-head, high-volume pumps), guide booms, and methods to generate stimuli to which fish are known to respond, at least in laboratory settings (Figure 3.8). However, no successful stand-alone behavioral barriers at large-scale hydropower projects are known and therefore not recommended for application at the two subject dams except as a supplement to physical barriers or as a fish guidance technology.

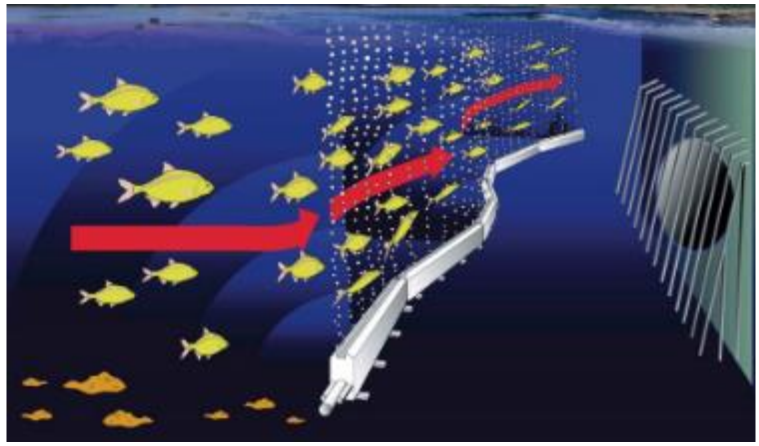


Figure 3.8. Example of behavioral guidance using a bubble curtain (Someah, 2011)

Bypasses

These systems occur at or near the dam to guide, prevent or deter downstream migrating fishes from entering the turbine intakes (Figure 3.9). They can be designed in different forms but generally include categories of dam face systems or net or pump systems.

Dam face systems may include a spillway or a guidance and collector system directing downstream fishes to a downstream bypass channel or pipe. Collector systems are most effective if their entrance flows have high discharge capacities that compete or exceed turbine intake flows. While dam face surface collectors may not be practical for the St. Croix River dams, it is still useful to consider surface collector principles when selecting and designing downstream passage alternatives.

Net or pump designs can be deployed upstream of the dam in relatively low water velocity (<0.3 mps) and terminate in a floating surface collector. An attraction plume system may use high-volume, low-head pumps to create an attracting flow near the surface collector entrance.

A description of different types of downstream passage systems including surface collectors at the dam face can be found in NPCC (2016).

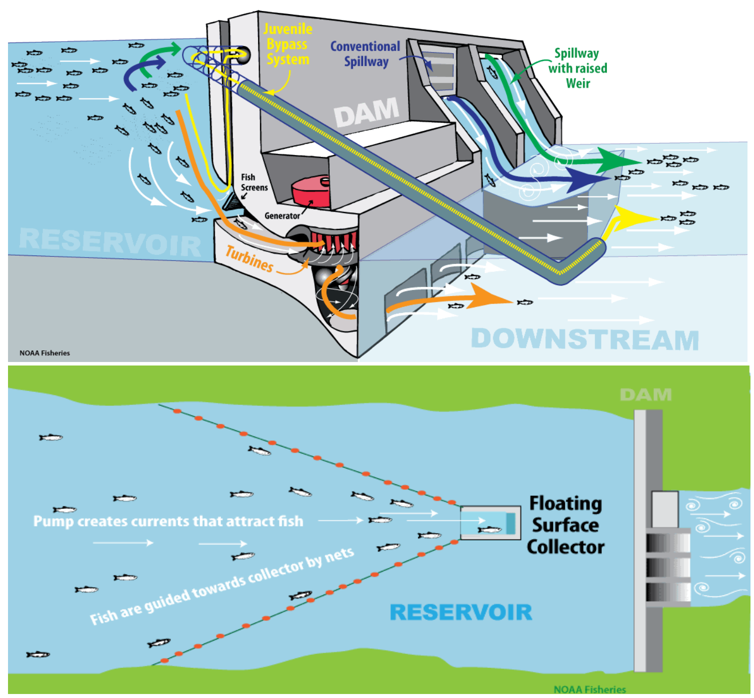


Figure 3.9. Examples of some fish bypass options for downstream guidance (NOAA, 2020)

3.3 Secondary and Tertiary Screening Methods and Results

The secondary level screening involved the consideration and assessment of fish passageway technologies that passed the primary screening assessment discussed in Section 3.2. Combining of alternatives is not included at this secondary screening level, although recognized as important for final concept options evaluated during Tertiary Screening. The screening approach for secondary screening options for upstream and downstream passage were presented to, and discussed with, the entire St. Croix River Workgroup during the several meetings described in Section 3.2. Tertiary screening was then conducted by the implementation team.

The **secondary screening** level included a scoring system to rank alternatives using single-and double-weighted scoring criteria important for decision-making. Scoring for single weighted and double weighted criteria is based on best professional judgement but considers key aspects of alternative applications for the three study facility locations—Grand Falls Dam, Grand Falls Powerhouse, and Woodland Dam.

- **Double weighted decision criteria** are scored as such because they are more important for ranking alternatives and include 1) effectiveness for target species (Table 2.3), 2) the population capacity needs of the passage alternative during key migration periods (Table 2.3), and 3) the overall footprint and layout needs for the passageway. Double weighted criteria have a min-max range of *-2* to *+2*, where *-2* represents a maximum site disadvantage and *+2* represents a maximum site advantage. Except for *Species Effectiveness*, *0* represents an uncertain, unknown, or not applicable decision score.
- **Single weighted decision criteria** are scored as such based on 1) proven and accepted experience in the region for passageway alternatives for the target species, 2) the ability to control water levels and self-regulate at these impoundments of operating hydropower facilities, 3) overall maintenance requirements of the alternatives as time demands on facility staff, 4) overall operations needs as time demands on facility staff, and 5) the ability of the alternative to contribute to bidirectional passage. Single weighted criteria contribute proportionately less scoring weight to decision-making having a range of -1 to +1.
- **Decision Scores** are the sum of the average of the double weighted and single weighted scores. A maximum high score for the average of the double weighted criteria is 2.00. The maximum score for the average of the single weighted criteria is 1. A total maximum Decision Score is 3.00. Averages had to be used because there are more single-weighted variables than double-weighted variables.
- **Scoring Notes:** For upstream passage alternatives, performance is affected by several factors, such as effective attraction flows (i.e., an attraction water system (AWS)). For downstream passage alternatives, performance is affected by several factors, such as effective attraction flows (e.g., elimination of false attract or operation of auxiliary water supply). Integrated systems include behavioral technology combined with a physical barrier and are generally necessary for effective attraction to the passageway as well as encouragement to enter the systems. Pink rows are not carried into final detailed evaluation, while green rows are carried forward into final detailed evaluation.

The final alternative selections considered input by the St. Croix River Workgroup, the available data on efficacy of alternatives, and feasibility considerations.

Tertiary screening level evaluations are based on best professional judgement of the project team. This included a general evaluation of advantages and disadvantages of each site and their potential to effectively support one or more of the final set of remaining options. Descriptions of secondary and tertiary screening results provide the basis for engineering concepts in Section 4.

3.3.1 Grand Falls Dam – Upstream Passage Secondary and Tertiary Screening

Secondary and tertiary screenings were used to select three upstream passage alternatives: fish lift, vertical slot fishway and nature-like fishway (NLF). Fish lift alternatives were eliminated from consideration in the secondary screening (Table 3.3) primarily because of two reasons – 1) the best site for a fish lift is on the Canadian side of the river where it would be difficult to access by maintenance and operations relative to access from the U.S. owned facility, and 2) there is also uncertainty if, or how many immigrating fish can pass the falls to reach the foot of the dam where a fish lift would be located.

A tertiary screening was applied to further evaluate vertical slot and nature-like fishways at Grand Falls Dam (Table 3.4). The details of concepts carried forward are described in Section 4.1.1. One of the two NLF alignments, is less appealing because it has a potentially challenging entrance location and would require extensive excavation, making its viability somewhat uncertain at this stage because of costs. It is more difficult to determine cost and constructability of NLFs than technical fishways at the concept stage because the exact alignment and cost of excavation and construction cannot be accurately determined until detailed site assessments have been made.

Vertical Slot Fishway (VSF)

The vertical slot fishway appears to be the most viable alternative for upstream passage at Grand Falls Dam based on the secondary and tertiary screenings summarized in Tables 3.3 and 3.4.

Advantages include:

1) Effective passage performance experience of a VSF at Vanceboro Dam (a Woodland Pulp facility on the St. Croix River upstream from Grand Falls Flowage.
2) Estimations of cost of the vertical slot alternative will be more accurate, because the design is more straight-forward and involve fewer site uncertainties.

Disadvantages include:

1) Passage efficiency may not be as consistent as once thought, and the reasons for this inconsistency are not completely known.
2) Constructability may be affected by the high slopes on the right shoreline area.
3) Realignment of the St. Croix River may be necessary to efficiently and effectively guide fishes to the fishway entrance.

Nature-Like Fishway (NLF)

The results of the secondary and tertiary analysis for NLF alternatives are summarized in Tables 3.3 and 3.4. Only one NLF concept passed secondary and tertiary screening (Table 3.4). Both alternatives have entrances at the base of the dam, on either the right bank (south) or left bank (north). This assumes a portion of upstream migrating fish reach the base of the dam. The southern abutment alternative is expected to be more effective because of its close proximity to the Tainter gates for better control over attraction flows and to minimize straying (assuming fish reach the base of the dam).

Advantages include:

1) Provides passage for fishes reaching the base of the dam, assuming fishes reach that point.
2) The alternative is more likely to pass all target species including Atlantic sea lamprey.

Disadvantages include:

1) Uncertainty of best route to avoid affecting the integrity of the dam structure or earthen property immediately adjacent to the dam.
2) Design and cost are difficult to determine because site characteristics are not adequately known.
3) Realignment of the St. Croix River may be necessary to more efficiently guide fishes to the fishway entrance.
4) Constructability may be affected by the high slopes on the right shoreline area.

Design to control the headpond level in support of generation flows and fish passage among seasons is uncertain.

Table 3.3. Secondary screening scores of upstream passage alternatives for Grand Falls Dam as a decision matrix

Alternatives	Double Weighted Decision Criteria			Single Weighted Decision Criteria					Decision Score
	Species[1] Effectiveness	Capacity Adequate	Footprint Requirements Met at Site	Proven/Accepted Northeast Experience	Self-Regulating	Maintenance Requirements	Operations[2]	Contributes to Downstream Passage[3]	
Fish Lift	2 (8 of 8)	2	1	1	1	-1	-1	0	1.67
Vertical Slot	2 (8 of 8)	2	2	1	1	0	1	0	2.60
Nature –Like Fishwa	2 (8 of 8)	2	2	1	0	1	1	1	2.80

[1]Includes the 8 target species (Table 2.3). Note that a separate eelway is assumed for this unique species but not scored as an alternative in secondary screening

[2]US/CN – Implementation of operational changes (daily checklists), manual vs automated operation. Personnel access and training for support of passage operations may be necessary.

[3]Values for this criterion run from "0" (no benefit or information is limited, but unlikely adverse) to "1" because considered as a secondary benefit.

Note: Table includes alternatives that passed primary screening. Combining of alternatives is not included at this screening level, although recognized as important for options evaluated during Tertiary Screening.

Table 3.4. Results of tertiary screening for upstream migration technologies at the Grand Falls Dam and Spillway with recommendations

ID	Description	Advantages	Disadvantages	Status
GFS – 1 – VSF	Entrance located on right bank (south) just downstream of spillway falls. Ladder follows right abutment to head pond with a slope of 3.8%. Pools are16 ft. wide by 20 ft. long. Baffles with full depth 2 ft. wide slots separate pools with a hydraulic drop of 9 inches.	Can operate 24/7 without attendant personnel. Entrance location near spillway offers better attraction than left bank alternatives. Requires less maintenance than a lift. Standardized ladder design well suited for target species. Smaller footprint than NLF alternatives.	Slot susceptible to clogging by woody debris causing loss of hydraulic function. Inconsistent results at some sites. Requires excavation in bedrock.	Recommend
GFS - 2A - NLF	North entrance located ~350 ft. downstream of spillway. Fishway extends upstream along right bank at an assumed average slope of ~1.5% with an exit upstream of the right spillway abutment (US side of dam). Total length ~2600 ft.	Can operate 24/7 without attendant personnel. Hydraulic conditions similar to natural stream channel & suitable for a variety of species. Potentially shallow slope suitable for effective passage for target species. Fewer O & M requirements than lift. Easier access for maintenance than GFS-2B. Better entrance location than CN side. No interference with roadway.	Complex design process. Fish may attract to spillway flow & miss entrance (barrier & diversion dams could mitigate this concern). Alignment would require extensive excavation into what is assumed to be bedrock along the right bank. Uncertainties of integrity of earthen area in close proximity to the dam,	Maybe/Many Uncertainties
GFS - 2B – NLF	Entrance located ~700 ft. downstream of spillway on left bank (CN side). The fishway extends upstream with average slope of 1.5% and exits upstream of Grand Falls left spillway abutment. Total length ~2600 ft.	Can operate 24/7 without attendant personnel. Hydraulic conditions similar to natural stream channel & suitable for a variety of species. Shallow slope suitable for effective passage for target species. Requires less O&M than a lift and less excavation than GFS – 2A.	Complex design process. Fish may attract to spillway flow and miss the entrance (barrier and diversion dams could mitigate this concern). O&M requires Canadian access. Suboptimum entrance location because of space constrains with slopes and uncertain bed material. Likely to require realignment of existing roadway. Uncertainties of integrity of earthen area in close proximity to the dam	No

Note: Light green background indicates a possible alternative, but with concerns and uncertainties.

3.3.2 Grand Falls Dam – Downstream Passage Secondary and Tertiary Screening

Secondary and tertiary screenings were applied to aid in the selection of Grand Falls Dam downstream passage alternatives: passage through the Tainter gates, spillway modification for a uniform acceleration weir, flashboard modification and, Tainter gate modification for gradual acceleration weir (Tables 3.5 and 3.6). A dedicated spill gate option was eliminated because of seasonal attraction flow reliability, head pond control concerns, and anticipated reluctance of surface-oriented species (e.g., juvenile alosines and Atlantic salmon) to dive to pass under the Tainter gate. A multiport/ deep entrance was eliminated because of the shallow nature of the site and the concern about the relic dam feature inhibiting access to benthic species to the entrance.

Any option for downstream passage will require an assessment of the effects of the exposed bedrock of the tailrace on fish injury and death. It is likely that excavation of a plunge pool may be necessary to minimize fish injury or death. This approach also assumes that fish have enough flow depth for safe passage through the falls during outmigration. Availability of downstream migration corridors to prevent injury to migrants from collision with the exposed bedrock of the tailrace is an unanswered question. The details of concepts carried forward are described in Section 4.1.2.

Surface Bypass Weir

A uniform acceleration weir is proposed to be located on the spillway adjacent to the Tainter gate to provide effective attraction and entrance for downstream passage at the dam (Table 3.6). The weir would have a width of 6 ft., an entrance depth of 10 ft., a weir crest depth of 4 ft. below normal water and an overall length of 15 ft. A 6 ft. wide by 4 ft. notch would be required in the spillway to accommodate the weir geometry.

Advantages include:

1) A uniform acceleration weir is a proven technology
2) A uniform acceleration weir geometry provides ideal hydraulic conditions to optimize downstream passage effectiveness.
3) The location is ideal because the attraction from the spillway intake plume will attract surface-oriented fishes to the weir.
4) The weir can be easily closed for maintenance and when outmigrating density is low.

Disadvantages include:

1) Water level in Grand Falls Flowage may need to be reduced.
2) Access to a crane may be needed to open/close the entrance of the weir.
3) Notching the concrete in an Ambursen (i.e., buttress) section of dam will require a review of dam structural integrity and stability.
4) Requires structural modifications of notching the existing spillway, fabricating unique weir geometry, and greater construction challenges than other options.

Flashboard Modification

A section of flashboards would be removed to provide a surface bypass with a depth of at least 2 ft., (assuming the existing flashboards are 2 ft. or greater). Approximately 18 ft. of flashboards would be removed to provide approximately 160 cfs at normal water. Two feet is the minimum design depth recommended for a surface bypass (FWS 2019).

Advantages include:

1) Requires minimal to no structural modifications to the dam.
2) Constructability should be relatively easy because the concrete itself does not need to be slotted and integrating the sides of the weir to the existing line of flashboard sections should be straight-forward.

Disadvantages include:

1) Shallow weir depth or wave action may deter fish from accepting passage route, and
2) Does not provide ideal surface bypass hydraulic conditions (i.e., depth may not be sufficient).

Tainter Gate Modification

An existing Tainter gate, closest to the spillway flashboard section, would be modified to include a surface weir notch in the top of the Tainter gate. The Tainter gate would be modified with a notch 6 ft. wide by 4 ft. deep (below normal water) notch to accommodate a surface bypass weir. A plunge pool would be installed at the gate outlet.

Advantages include:

1) Does not include modifications to the existing spillway or the concrete portions of the dam.
2) Grand Falls Flowage may not require dewatering depending upon the availability of stoplogs slots to isolate the Tainter gate from the reservoir with stoplogs.
3) It does not sacrifice the flood management function of the Tainter gate to support fish emigration.

Disadvantages include:

1) Does not provide ideal surface bypass hydraulic conditions
2) Structural reinforcement/redesign of the Tainter gate and operators may be needed

Table 3.5. Secondary screening of downstream passage alternatives for a fish passage system for Grand Falls Dam as a decision matrix

Alternatives	Double Weighted Decision Criteria			Single Weighted Decision Criteria			Decision Score
	Species[1] Effectiveness	Certainty of Success	Lack of Unintentional or Negative Impacts	Proven/Accepted Northeast Experience	Major Short-Comings	Expected Maintenance Needs	
Dedicated Spill Gate (in line with the thalweg)	0.0 (4 of 8)	-2	0	0	-1	1	-0.67
Surface Bypass Weir	0.0 (4 of 8)	1	1[2]	1	[3]1	1	1.67
Raised Weir	0.0 (4 of 8)	1	2	0	1	1	1.67
Deep Entrance	-0.5 (3 of 8)	0	1	1	1	0	0.83

[1]Includes the 8 target species (Table 2.3).
[2]No benefit for benthic species.
[3]Operation challenges.
Note: Downstream concepts are simplified for the site and does not include behavioral alternatives because of its distance from the powerhouse and access for regular operations and maintenance. Flow Duration Curve Indicates that maximum powerhouse

capacity of 3,400 cfs occurs at about 50% exceedance during the downstream passage season. Therefore, Grand Falls Dam Spillway releases are leakage about 50% of the time during the passage season and spill gate releases and leakage the rest of the time during the passage season. The need for a downstream passageway at Grand Falls Dam should be integrated with the selection criteria of upstream migration alternative and coordinated with Grand Falls Powerhouse. If an NLF is selected, the fishes from the continuation of the St. Croix River upstream of the Grand Falls Flowage can utilize the NLF for downstream passage. However, if another alternative is selected, then downstream passage should be considered at Grand Falls Dam. Any downstream passage alternative must be accompanied by excavation of a receiving pool of sufficient depth prevent impact injury by fish entrained in the discharge plume, but sufficiently shallow to not cause gas supersaturation.

Table 3.6. Tertiary screening results of Grand Falls Dam and Spillway

ID	Description	Advantages	Disadvantages	Status
GFS - 1 Surface Bypass Weir	A surface bypass weir would be installed in a slot in the concrete adjacent to the Tainter gate nearest the Canadian side of the dam. The weir would be designed to provide a uniform acceleration which has been shown improve efficiency of downstream passage as compared to unmodified spillway weirs.	Provides greater flow depth and ideal hydraulic conditions for downstream passage than the existing spillway.	Requires modifying the spillway to accommodate the new weir.	Yes
GFS - 2 Weir on Crest of Dam	A section of flashboards adjacent to the Tainter gates will be removed to provide a surface bypass. The installation includes all necessary support structures for a seamless continuation for the flashboards on the Canadian side of the channel. This section of the dam appears to discharge into sufficient water depth to minimize injury of downstream migrants.	Requires less modifications to the existing spillway than a surface weir.	May require modifications to current procedures to maintain flashboard - floating maintenance walkway modifications. There may not be sufficient depth to accommodate the weir.	Yes
GFS – 3 Weir in Tainter Gate Notch	Tainter gate is notched to accept a “piggyback” weir that can be operated when the Tainter gate is in the closed position.	Leverages attraction of spillway intake plume. Provides ideal hydraulic conditions if uniform acceleration weir geometry used. Does not remove a Tainter gate from flood management. Relatively inexpensive.	Limited applications, with no NE applications. May be structurally impossible/ difficult to install on existing Tainter gate.	yes

Note: After further research and consultation, three alternatives were included that were not initially identified for the secondary screening, but emerged as more reasonable alternatives for Grand Falls Dam.

3.3.3 Grand Falls Powerhouse – Upstream Passage Secondary and Tertiary Screening

Secondary and tertiary screenings (described in the introduction) were used to aid selection of upstream passage alternatives for the Grand Falls Powerhouse. The secondary screening (Table 3.7) did not eliminate any of the three upstream passage methods identified in the primary screening. Therefore, two viable alternatives were developed for each of the three passage methods for tertiary analysis (Table 3.8). The details of the selected alternatives are provided in Section 4.2.1.

Fish Lift Alternatives

Two fish lift alternatives were considered for Grand Falls Powerhouse on the northern and southern sides of the powerhouse. The southern lift location was eliminated because it offered no advantages over the northern site, where the existing fishway is currently located. Further, the southern location may prove more complex and costly because its exit flume and fish transfer piping could interfere with powerhouse access and road traffic. The components of the northern fish lift alternative include an attraction flow requirement of 165 cfs, which is substantially greater than the attraction flow for the current Denil fishway, at the same location at the powerhouse.

Advantages include:

1) There is good access to the site for construction of the fish lift.
2) A fish lift doesn't require much space and the selected alternative can use the space freed up by the future removal of the existing Denil fishway to minimize encroachment on project land.
3) Costs may be reduced by repurposing for attraction flow (although additional flow capacity may be needed).
4) The close proximity of the powerhouse may be a source of power and, perhaps, staff to operate and maintain the fish lift.
5) It may be possible to dewater flows used to attract outmigrants to the downstream bypass to contribute to fish lift attraction flow.

Disadvantages include:

1) The powerhouse discharges into the St. Croix River from the right bank. Fishes may avoid the powerhouse and continue upstream when Tainter gates at Grand Falls Dam are operational. Channel realignment or berm construction may be needed to increase the efficiency with which fish can locate the fishway entrance.
2) Additional study of hydraulics of the conveyance channel will be needed to more accurately determine water velocity.
3) Two of the three turbines spin clockwise, and one spins counterclockwise so that generation boil characteristics may change substantially depending upon which turbines are in service. At a minimum, visual inspection should be conducted to determine how discharge jet changes with the selection of operating turbines.
4) If future study indicates that the water velocity within the conveyance channel is sufficient to cause excess fatigue, then either a resting zone may have to be provided or an exit pipe may have to be constructed to transport fishes from the powerhouse to the mouth of the conveyance channel.
5) A diversion dam upstream of the powerhouse may be needed to redirect flows from Grand Falls Dam into the right channel to eliminate false attraction flows to Grand Falls Dam (unless a separate fishway is constructed at Grand Falls Dam).

Vertical Slot Fishway Alternatives
Two vertical slot fishway alternatives were considered for the Grand Falls Powerhouse location, one located on the north side of the powerhouse, located in the general vicinity of the existing Denil ladder, and a second location on the south side of the powerhouse. The southern location was eliminated because it did not have any specific benefit over the northern site and there were concerns that the fish transfer pipe and attraction water supply pipe may interfere with powerhouse access and interrupt road traffic.

Advantages include:

1) Determining the cost of the vertical slot alternative will be more accurate because the design is more straight-forward and there are fewer site uncertainties than for a NLF, particularly because of the site challenges caused by the relatively great slopes and limited space availability downstream of the dam.
2) A vertical slot fishway at Grand Falls Powerhouse is self-regulating so that it is not as sensitive to head pond or tailwater water surface elevation fluctuations as other fishways.
3) It may be possible to dewater flows used to attract outmigrants to the downstream bypass to contribute to fish lift attraction flow.

Disadvantages include:

1) There is some evidence that passage efficiency is not as consistent as once thought, although the reasons for the inconsistency are not completely known.
2) Constructability may be affected by the high slopes on the right shoreline area.
3) Realignment of the St. Croix River or berm construction may be necessary to more efficiently guide fishes to the fishway entrance.
4) The hydraulics of the slot are easily disrupted by woody debris so that routine maintenance may be required.

Nature-Like Fishway (NLF) Alternatives

Two potential NLF concept alternatives were identified – NLF US (US side of the St. Croix River) and NLF CN (Canadian side of the St. Croix River). Both have entrances in the general vicinity of the Grand Falls Powerhouse but potentially serve passageways alternatives purposes for both the powerhouse and dam. Both are both conceptually viable, but will need further ground truthing for actual alignment assessment, constructability for capacity needs, and both would benefit from a documented understanding of dominate routes of upstream and downstream migrating fishes to understand attraction flow options and challenges.

The river segment between the powerhouse and the dam is divided into two channels, with an island between and along the US-CN boarder, and both with exposed bedrock cascades and falls (Figure 2.4). The US side of the channel appears be the primary, perennial flow route of the river through this reach while the CN channel appears intermittent and receives flows during higher discharge periods.

One alternative (NLF US) places an NLF within the property, between the powerhouse and the dam, entirely on the US side of the river. The other NLF alternative (NLF CN) follows an existing, natural brook (Grand Falls Brook) located across the channel (east side) from the powerhouse, and entirely on the Canadian side of the river.

With site-specific details from LIDAR imagery, and preliminary site survey data (Dana et al. 2020), a NLF within Grand Falls Brook is an attractive concept because it would follow an existing, natural (intermittent) creek that already exhibits landscape features conducive to a NLF, with low gradient slopes for fish passage and bed and bank channel characteristics that would need to be assessed for added flow capacity, among other uncertainties. Further, the brook is not directly connected upstream to Grand Falls Flowage so there are other unknowns related to constructability and head-pond controls. Grand Falls Brook enters the St. Croix River nearly opposite the powerhouse. As the brook and the CN side are both intermittent, the dry confluence currently appears as elevated, exposed bedrock and would need to be modified for an entrance and exit concept. The existing brook channel naturally meanders upstream to within 1,400 ft. to a natural bay of Grand Falls Flowage. This is a segment that may require construction to connect the upstream flowage to the existing brook channel. The brook flows under a Highway 725 bridge, which parallels the St. Croix River near the Grand Falls/ Grand Falls Powerhouse site, and the capacity of added flow under the bridge remains uncertain. Overall, the existing brook and the surrounding landscape have many features that make it an attractive NLF concept for the Grand Falls Dam and Powerhouse passage.

Advantages of NLF CN include:

1) The concept uses an existing stream channel for much of the route, with an existing confluence to the St. Croix River, located across the river from the powerhouse.
2) The downstream confluence is located between Grand Falls Dam and Grand Falls Powerhouse (but closer to the powerhouse) and might provide fish passage opportunities for both structures.
3) With added design details, this alternative could avoid the need for alternatives for an upstream fishway at Grand Falls Dam.
4) The natural, although intermittent, discharge of Grand Falls Brook may contribution to the NLF attraction flow.
5) The majority of property ownership for this alternative path are Canadian, federally own lands except for three plots, two of which are owned by Woodland Pulp.
6) As an NLF the option has the potential to pass all target species.
7) The alternative could contribute to both upstream and downstream migration passage, although primarily benefiting East Branch, St. Croix River migrating fishes.
8) Site surveys conducted by Dana et al. (2020) suggest that site slope and bed material are suitable for NLF construction and there appears to adequate natural material for NLF construction that takes advantage of the presence of Grand Falls Brook.

Uncertainties or Disadvantages include:

1) Uncertainty: The alternative was initially identified using aerial images and LIDAR elevation contour plots. Detailed surveys are needed along the entire existing channel and potential new alignment which may reveal challenging or cost-prohibitive features.
2) Uncertainty: It is assumed that the Highway 725 bridge crossing is wide enough to accommodate the necessary flow volume to NLF requirements. The dimensions and capacity of the bridge need to be better described.
3) Uncertainty: A preliminary survey of Grand Falls Brook suggest that slopes may be sufficiently low for an NLF. LIDAR images show the steepest slopes in Grand Falls Brook occurs near the St. Croix River channel, while preliminary site surveys describe a lower gradient channel, below Highway 725. The acceptable slope at any point along an NLF should be less than 3.0% (Turek 2018) with goal of 1-1.5%. The entire route should be surveyed to better understand the feasibility of the NLF route.

4) Uncertainty: The feasibility and cost of an NLF will be largely determined by the slope of the first 660 ft. of channel from the mouth of Grand Falls Brook to when its slope flattens out. If a high gradient, the concept may consider adding a hybrid fishway in higher slope segments.
5) Uncertainty: The current discharge frequency and duration of the Grand Falls Brook is unknown and therefore, the combination of the natural stream discharges with additional flows from the connection to the flowage needs to be assessed for attraction, passage flow, and feasibility, within the existing channel.
6) Challenge: The St. Croix River channel will likely need to be modified downstream of the mouth of the Grand Falls Brook to create a conveyance channel within the bedrock, high gradient segment of the channel. The left side of the St. Croix River could be redesigned to provide attracting flow from the mouth of Grand Falls Brook to compete against flows coming from the dam and powerhouse.
7) Challenge: Downstream passage use of the NLF needs to be assessed among species, and relative to their upstream originating locations. The connection to the flowage is within a bay closer to the East Branch of the St. Croix River and it is uncertain at this time what proportion of fish might use the NLF versus other competing downstream passage options.
8) Disadvantage: A gravel road will have to be constructed to service the upstream control of the fishway and perform routine maintenance of the channel.
9) Disadvantage: Grade controls may have to be added to Grand Falls Brook to prevent damage to the channel with the increase in discharge associated with attracting flows combined with the natural flows, particularly in the region between the mouth and Highway 725 crossing.
10) Uncertainty: A NLF length of 5900 ft. may cause some fishes to reject the fishway, but if designed effectively passage may be used by fishes as if natural habitat.

The second nature like fishway alternative (NLF US) is proposed for the right (US) side of the channel, on the property between the powerhouse and the dam, with an entrance immediately north of Grand Falls Powerhouse.

Advantages of NLF US include:

1) This NLF alternative is of shorter distance than NLF CN, and the entire property is owned by Woodland Pulp, potentially expediting the approval process.
2) There may be minor anticipated benefit for outmigrants passage because the exit of the NLF will be just to the southeast of Grand Falls Dam. Fishes following bulk flow to Grand Falls Dam during spillway releases may attract to the exit of the NLF, with an appropriate design.
3) With added design details, this alternative could avoid the need for alternatives for an upstream fishway at Grand Falls Dam.
4) As an NLF the option has the potential to pass all target species.

Disadvantages/Uncertainties of a NLF A include:

1) Disadvantage: The right bank has steep granite slopes which will increase the construction costs of the NLF.

2) Uncertainty: Space is limited on the right bank so that the design length would need to be restricted to about 3,300 ft. which would raise the average slope to about 1.5% and possibly higher for short distances.
3) Uncertainty: The base/earthen material on the property needs to be better understood for constructability and dam safety and stability.
4) Challenge: Some reconfiguration of the channel upstream of the entrance to the NLF or berm construction may be necessary to ensure that migrants can successfully locate the entrance to the NLF.
5) Uncertainty: Pool level controls, relative to powerhouse operation would need to be incorporated into the NLF US design, given the proximity to the dam and powerhouse facilities. Few NLF examples exist at operating hydropower facilities.

Table 3.7. Secondary screening of individual upstream passage alternatives for Grand Falls Powerhouse as a decision matrix

Alternatives	Double Weighted Decision Criteria			Single Weighted Decision Criteria					Decision Score
	Species[1] Effectiveness	Capacity Adequate	Footprint Requirements	Proven/Accepted Northeast	Self-Regulating	Maintenance Requirements	Operations[2]	Contributes to Downstream Passage[3]	
Fish Lift	2 (8 of 8)	2	2	1	1	-1	-1	0	2.00
Vertical Slot	2 (8 of 8)	2	0	1	1	0	1	1	2.13
Nature Like	2 (8 of 8)	2	-2	0	0[4]	1	1	1	1.47

[1]Includes the 8 target species (Table 2.3). Note a separate eelway is assumed but not scored as an alternative in secondary screening; [2]US/CA – Implementation of operational changes (daily checklists), manual vs automated. Personnel access and training for ops; [3]Values for this criterion run from "0" (no benefit) to "1" considered as a secondary benefit.; [4]Can be combined with a vertical slot fishway.

Note: Combining of alternatives is not included at this screening level, although recognized as important for options evaluated during Tertiary Screening.

Table 3.8. Summary of results for tertiary screening upstream passage alternatives for the Grand Falls Powerhouse

ID	Description	Advantages	Disadvantages	Status
GFP - 1A –FL	Located immediately upstream of powerhouse with entrance at same location as existing ladder. Attraction water provided via piping from forebay. Fish transported via a pipe to the impoundment from elevated hopper tower.	Entrance located adjacent to powerhouse enhances attraction. Small footprint compared to ladder & NLF. Near 100% internal effectiveness for target species.	Requires significant O&M because of large number of moving parts & complex controls. During high flows fish may miss entrance & continue upstream to spillway, which an optional barrier dam could mitigate.	Recommend
GFP - 1B- FL	Located just downstream of powerhouse on right bank with entrance adjacent to powerhouse discharge. Attraction water supplied via piping from forebay. Fish transported via a pipe to the impoundment from elevated hopper tower.	No advantages over Alternative 1A.	Requires significant O&M because of number of moving parts & complex controls. During high flows fish may miss entrance & continue upstream to spillway, which an optional barrier dam could mitigate. Exit flume piping interferes with powerhouse access & roadways.	No
GFP - 2A—VSF	Entrance location same as existing ladder. Ladder runs downstream following grade of right bank with slope of 3.8%. Fishway switches back & is routed to left bank of conveyance channel upstream of powerhouse. Pools are 16 ft. x by 20 ft. long. Baffles with full depth 2 ft. wide slots separate pools with hydraulic drop of 9 inches.	Can operate 24/7 without attendant personnel. Requires less maintenance than a lift. Standardized ladder design well suited for target species. Smaller footprint than NLF alternatives.	Ladder length may impact internal passage efficiency, which would be less than a lift. Large footprint compared to fish lift alternatives. During high flows fish may miss the entrance and continue upstream toward spillway, which an optional barrier dam could mitigate.	Recommend
GFP - 2B – VSF	Similar in design to Alternative 2A but entrance located just downstream of powerhouse. Ladder gradually ascends as it extends downstream before reversing direction to head toward intake forebay. It exits into forebay upstream of intakes.	No advantages over Alternative 2A	Similar disadvantages as listed for Alternative 2A.	No
GFP - 3A – NLF C	Follows alignment of Grand Falls Brook on left bank beginning with mouth on the St. Croix river just upstream of the powerhouse. It has an average slope of about 1% with a total length of 5900 ft. & exits into a bay on the southeastern shore of the impoundment.	Can operate 24/7 without attendant personnel. Hydraulic conditions similar to natural stream & suitable for many species. Shallow slope suitable for effective passage for weak swimmers. Fewer O & M requirements than a lift. Most of length incorporates Grand Falls Brook channel. Some ecological benefits.	Complex design process. Entrance located upstream & away from the bulk flow from the powerhouse discharge, which may impact fish ability to find entrance (barrier & diversion dams could help mitigate this). Large footprint over a mile in length. Excessive length could impact passage effectiveness.	Maybe
GFP - 3B-NLF A	Entrance located just upstream of powerhouse discharge. Fishway runs upstream along right bank at average slope of 1.5% with an exit upstream of the Grand Falls right spillway abutment. Total length ~3300 ft.	Ideal entrance location enhances attraction. Can operate 24/7 without attendant personnel. Hydraulic conditions similar to natural stream channel & suitable for many species. Shallow slope suitable for effective passage of weak swimmers. Fewer O&M requirements than a lift.	Complex design process. During high flows fish may be attracted the spillway flow and miss the entrance (barrier and diversion dams could mitigate this concern). Alignment would require excavating the channel into what is assumed to be a bedrock along the right bank of the river leading to the spillway.	Maybe

FL=Fish Lift, VSF=Vertical Slot Fishway, NLF=Nature Like Fishway

3.3.4 Grand Falls Powerhouse - Downstream Secondary and Tertiary Screening

Secondary and tertiary screenings (described in the introduction) were used to aid selection of downstream passage alternatives for the Grand Falls Powerhouse (Tables 3.9, 3.10, and 3.11). As mentioned previously, effective downstream bypass systems usually possess two primary functions: 1) a guidance functionality to guide fishes to a bypass entrance, and 2) a barrier function to prevent fishes from entering the turbine intakes. Both functions are generally separated into structural methods (e.g., angled bar screen) or behavioral methods (e.g., light or sound). Only two structural alternatives passed initial secondary and tertiary screening – louver racks and angled bar racks. However, two additional alternatives were identified following the receipt of diver information about the dimensions and design of the existing racks of the turbine intakes. The existing trash rack has fish barrier functionality, although there is disagreement about the size of the clear space between slats, so species-specific protections remain uncertain. For example, recent dive surveys measured the distance between slats as 1.0", but published reports indicate the clear space is 0.75". The distance must be confirmed before a decision can made about using part of the existing rack for structural support. These two new alternatives both have minimal fish guidance functionality so that a behavioral alternative must be used to enhance the rack with guidance functionality. The need to add a guidance functionality to two new alternatives resulted in reconsidering of guidance booms from an eliminated option (originally), to a viable candidate alternative. Two behavioral alternatives passed secondary and tertiary screening as complementary methods to structural guidance systems: surface lights and flow manipulation using low-head, high volume pumps. The final alternatives are detailed in Section 4.2.2.

Existing Trash Racks

This option may offer fish barrier functionality because of its clear spacing and overall configuration, which is similar to an angled bar screen, but with a reduced angle. However, from the existing information of the site, the nearly vertical orientation (12^0 from vertical) of the existing racks and nearly perpendicular orientation to the inflow streamlines, eliminate the presence of low velocity corridors that would guide fishes to the entrance of a bypass. If this alternative is preferred, multiple bypasses would be required or one or more of the behavioral alternatives should be considered to enhance the existing trash rack with a guidance functionality.

Advantages include:

1) The primary advantage of using the existing trash rack is low cost.
2) It may be possible to use parts of the existing flume and its entrance as part of the bypass system. However, consideration of such an option requires additional information on the design of the entrance and flume.
3) Drawings by divers describe a sill about 3 ft. high located on the foundation of the trash rack. Sills are known to be a barrier to benthic fishes (sauger, walleye, and sturgeon) because they swim laterally along the sill searching for passage instead of swimming vertically up the sill. Provision of a deep bypass entrance at the end of the sill can take advantage of this inherent guidance functionality of the sill for benthic fishes.

Disadvantages include:

1) The reported water velocity at the trash rack appear to exceed the maximum water velocity recommended by USFWS of 0.46 mps (1.5 fps), although it is unclear how and under what conditions these measurements were made. There is a potential risk of impingement and

entrainment unless water velocity through the slats is reduced (e.g., by expanding the size of the trash rack or reducing the output of powerhouse during the downstream passage season),

2) An effective guidance functionality must be added to the existing trash rack to guide fishes to one or more bypasses.

3) The relatively small distance between the slats of 2.54 cm (1.0 in) (although the distance between slats may be 0.75") increases the potential for entrainment of emigrating juveniles and impingement of post spawn adults.

4) The state of the blockage or the rate of accumulation of trash at the base of the rack is unknown. Partial blockage at the base of the existing screen will increase the water velocity through the unblocked bars of the rack closer to the surface. While partial blockage may have relatively little effect on hydropower operation, it will increase water velocities and may increase impingement on the bar screen for larger fishes and increase entrainment of smaller, weaker swimming fishes that fit between the bars of the bar rack.

5) Additional structural details of the trash rack must be made available to further assess its potential as a bypass system component.

New Bar Rack

The new bar rack design is a compromise between a standard trash rack similar to the existing bar rack and an inclined bar rack. Like the existing bar rack, it is oriented perpendicular to the streamlines of the intake plume, but it has a greater incline than the existing rack to reduce approach velocities. The incline is approximately sufficient to reduce the approach velocity perpendicular to the rack to meet the USFWS guidelines. Final design specifications would be confirmed once the water depth, width of the powerhouse, and water velocities are confirmed at the location of the new rack.

Advantages include:

1) An inclined screen can fit within the lateral footprint of the existing trash rack and reduce water velocity through the slats.

2) The cost is reduced because it can be attached to the frame of the existing trash rack for support.

3) Benthic fishes can be guided to a deep entrance if a sill is included in the design.

Disadvantages include:

1) Does not provide a guidance component to a bypass.

2) In the present design of a new rack (described later), multiple depth entrances to a bypass system are shown. However, the entrance locations are preliminary, and a final entrance and bypass configuration must include a guidance functionality to direct fishes to the entrances.

Angled Bar Racks

The angled bar screen is an attractive alternative for downstream passage. A description and examples of an angled bar screen can be found in Section 3.2.2 – Description of Downstream Passage Alternatives Passing Primary Screening. The location and configuration of an angled bar screen can be seen in Figure 4.13.

Advantages include:

1) Angled bar screens are a common NE solution for downstream passage that are well studied and whose design parameters are well understood.
2) They exhibit elements of the behavioral response elicited by louver systems as the angle of the screen becomes less perpendicular to the flow lines because the sharp angle of the slats of the angled bar rack distorts the flow field making it detectable before fishes physically encounter the screen.
3) Angling the screen increases the screen area and therefore reduces the water velocity between the bars. This is important for the Grand Falls Powerhouse because water velocity at the trash rack of the existing trash rack exceed USFWS specifications.
4) Fish are readily guided to a bypass entrance by swimming against the current immediately upstream of the screen and repeatedly "tail-touching" the barrier as they gradually follow the angle of the screen toward the bypass entrance.
5) The trash rack function of the existing bar screen can also be performed by an angled bar rack possibly reducing the frequency of cleaning, although debris removal near the bypass entrance may need to be considered.
6) An angled bar screen can guide both benthic fishes and pelagic fishes, although for maximum efficiency, benthic fishes require a separate deep bypass entrance to enter the bypass system. A properly location and orientation angled bar screen may be effective upstream of the Grand Falls Powerhouse.

Disadvantages include:

1) The primary disadvantages of an angled bar screen are its high cost and the need for a cleaning system, although the vertical orientation of the screen makes the cost of cleaning less than for an inclined bar screen.
2) Juvenile alosines are fragile fishes and easily injured by contact with structural features of bypass systems, unlike juvenile salmonids that are much more robust and can survive screen contact.
3) Structural alternatives that have a behavioral component to minimize fish contact to the screen may be needed as a bypass system feature, particularly for juvenile alosines.
4) An attractive option may include the use of the existing entrance to the log flume and the log flume itself. However, the estimated cost of retrofitting the existing flume and its entrance may be greater than building an entrance on the north side of the conveyance channel. This proposed north side location will also make it easier to design a dewatering for the downstream bypass that routes excess water to the entrance of the upstream bypass entrance.

Behavior Support Systems

Surface lights, flow manipulations, and log booms (or enhanced boom) passed primary screening. Upon further examination, high frequency sound and high-volume, low-head pumps were re-considered as technologies for general consideration. However, the Grand Falls Powerhouse forebay is not a good application for high-frequency sound because it is difficult to generate a stable, shaped acoustic field in the relatively narrow and shallow conveyance channel.

Surface Lights

Both alosines and juvenile salmon attract to light and light has been used to manipulate their distribution for both capture and protection. The purpose of the light field at Grand Falls Powerhouse forebay is to gradually move surface swimming outmigrants attracted to light toward the side of the canal where the bypass entrance is located before they encounter a physical barrier.

Guide Boom

The surprising efficiency with which log booms can distribute emigrating juvenile salmon is described in the chapter section entitled "Description of Downstream Passage Alternatives Passing Primary Screening". It is possible that surface booms can guide alosines, because, like juvenile salmon, they are known to migrate in the upper water column at night during emigration. An existing log boom is presently used in the forebay to divert floating debris to the entrance of a log flume for periodic downstream diversion. It would be relatively easy to perform studies using standoff fixed-aspect hydroacoustic monitoring to determine if land-locked alewife respond to the existing log boom.

Advantages:

1) The guide boom works 24 hours a day, unlike attracting lights that only work at night. However, guide booms work best when fishes are near the surface, which is often the case at night. Juvenile salmon in the Columbia River often migrate deeper in the water column in the daytime as a predator avoidance behavior.
2) A guide boom is already deployed in the forebay that may serve to guide fish toward the side of the channel where the bypass entrance is located.
3) It would be a dual-purpose alternative, contributing to both guidance and debris management.
4) It is non-invasive, so that physical damage to alosines from contact with a solid structure is avoided.
5) It requires minimal maintenance and repair.

Disadvantages:

1) Not considered effective for benthic migrating species.
2) Some experimentation may be needed to optimally locate the boom relative to a bypass entrance.

Table 3.9. Secondary screening decision matrix of downstream passage alternatives for Grand Falls Powerhouse for structural guidance systems including alternatives that divert fishes away from the powerhouse turbines

Alternatives		Double Weighted Decision Criteria			Single Weighted Decision Criteria			Decision Score
		Species[1] Effectiveness	Certainty of Success	Lack of Unintentional or Negative Impacts	Proven/Accepted Northeast Experience	Major Short-comings	Expected Maintenance Needs	
Structural	Louver Rack [2]	1 (6 of 8)	1	2	0	0	-1	1.0
	++Angled Bar Rack[3]	1 (6 of 8)	2	0	1	0	-1	1.0
	Inclined Bar Rack[2]	1.5 (7 of 8)	1	0	0	1	-1	-0.5
	Guidance Boom[4]	-1.5 (1 of 8)	0	1	1	-1	1	0.5

[1]Includes the 8 target species (Table 2.3).

[2]Assume proven spacing and/or design angle.

[3]Assumed deep angled design.

[4]May include behavioral functionality.

Table 3.10. Secondary screening of downstream passage alternatives for Grand Falls Powerhouse for behavioral guidance systems that divert fishes away from turbines and toward downstream passage locations

Alternatives		Double Weighted Decision Criteria			Single Weighted Decision Criteria			Decision Score
		Species[1] Effectiveness	Certainty of Stimulus Success	Lack of Unintentional or Negative	Proven/Accepted Northeast Experience	Major Short-comings	Expected Maintenance Needs	
Behavioral	++Continuous Light	-0.5 (3 of 8)	2	0	0	0	1	0.83
Behavioral	High Frequency Sound	-0.5 (3 of 8)	2	1	-1	-1	-1	-0.17
Behavioral	Flow Field Manipulation	0.0 (4 of 8)	1	2	-1	0	-1	0.33

[1]Includes the 8 target species (Table 2.3).

3.3.5 Woodland Dam and Powerhouse Upstream Secondary and Tertiary Screening

Three upstream migration alternatives passed the secondary screenings for the Woodland Dam and Powerhouse location - vertical slot fishway, nature-like fishway, and fish lift (Table 3.12). However, only the fish lift alternative located at the site of the existing Denil fishway passed the Tertiary screening (Table 3.13), given site constraints described in Section 2.4.3. A vertical slot or auxiliary fishway for intermittent use could be considered for the Canadian side (north side) of the channel if the flashboard leakage cannot be controlled through flashboard maintenance. Current flashboard leakage is a concern because it creates confusing (i.e., false) attraction flows for upstream migrating fishes. A description of the rationale used to eliminate the vertical slot and NLF alternatives is also included.

Fish Lift

A fish lift has the smallest footprint of the upstream passage alternatives and is the only viable alternative for the island separating the powerhouse and spillway. The existing Denil fishway on the island would be removed as part of the concept alternatives, providing space for the footprint of a fish lift.

Advantages:

1) Passes all target species including Atlantic sea lamprey if properly modified.
2) Passes all target species at numbers to meet population targets.
3) Should fit within the space occupied by the existing Denil fishway.
4) Power likely available at the dam to operate the fishway, but a 30-ton electric hoist has significant power demands.

5) The recommended design will contribute to downstream migration by using the AWS intake to provide attracting flow for the downstream bypass, and
6) Project staff may be available on-site for operations and maintenance.

Disadvantages:

1) Multiple discharge channels (i.e., multiple sources of false attraction) from Woodland Dam complicate the siting of fishway entrances.
2) The direction and degree of offset of the turbine discharge boils are unknown.
3) Fish lifts tend to require more maintenance and repair than other fishway alternatives.
4) A bermed channel, located downstream of the flashboards, at the dam foot may be needed to divert flow into the spillway channel to further control false attraction if flows from flashboards cannot be better managed.
5) A smaller, secondary lift or vertical slot fishway may be considered for construction at the northern end of the flashboard channel if leakage from the flashboards cannot be substantially and permanently reduced.
6) Access and construction challenges will be encountered on the congested island.

Table 3.12. Secondary screening of individual upstream passage alternatives for Woodland Dam as a decision matrix

Alternatives	Double Weighted Decision Criteria			Single Weighted Decision Criteria					Decision Score
	Species[1] Effectiveness	Capacity Adequate	Footprint Requirements Met at Site	Proven/Accepted Northeast Experience	Self-Regulating	Maintenance Requirements	Operations[2]	Contributes to Downstream Passage[3]	
Fish Lift	2 (8 of 8)	2	2	1	1	-1	-1	0	2.0
Vertical Slot	2 (8 of 8)	2	-2	1	1	0	1	1	1.47
Nature Like	2 (8 of 8)	2	-2	1	-1	1	1	1	1.27

[1]Includes the 8 target species (Table 2.3). Note that a separate eelway is assumed but not scored as an alternative in secondary screening.
[2]US/CA – Implementation of operational changes (daily checklists), manual vs automated. Personnel access and training for ops.
[3]Values for this criterion run from "0" (no benefit) to "1" because considered as a secondary benefit.
Note: Combining of alternatives is not included at this screening level, although recognized as important for options evaluated during tertiary screening.

Table 3.13. Results of tertiary analysis of upstream migration alternatives

ID	Description	Advantages	Disadvantages	Status
W - 1A-Fishlift	Entrance adjacent to power-house discharge at same location as existing ladder. Attraction water supplied through piping from forebay. Fish transported from lift hopper to impoundment via elevated pipe discharging into impoundment.	Entrance ideally located next to powerhouse discharge enhances attraction, provides best external passage effectiveness of all alternatives. Provides nearly 100% internal effectiveness for all species. Small footprint compared to ladder or NLF alternatives.	Operation and maintenance requirements. Lots of moving parts and complex controls. Construction access may be difficult.	Recommend
W - 1B - Fishlift	Entrance on spillway side of island (opposite side of powerhouse discharge). Attraction water supplied by piping from forebay. Fish transported via an elevated pipe to impoundment.	Lift provides nearly 100% internal effectiveness for all species. Small footprint compared to ladder or NLF alternatives.	Potential interference with overhead utilities. Entance located away from powerhouse attraction flow. External passage effectiveness depends on spill amount. High operation and maintenance requirements, with many moving parts.	No
W – 2 –Vertical Slot Fishway	**E**ntrance location same as for existing ladder. Routed at a 5% slope around island with 180º switchbacks near spillway. Additional attraction water would supplement ladder flow with piping routed from forebay.	Passive ladder operation requires less operation and maintenance than fish lift. Entrance ideally located near the powerhouse discharge providing better external effectiveness than other options. Ladder design well suited for target species.	Length may impact internal passage, which would be less than a lift. Configuration interferes with existing utilities and infrastructure which may make it unfeasible or too costly. 5% slope (12 inch drop per pool) is upper limit for American shad and greater than preferred drop per pool of 9 inches or less.	No
W – 3 – Nature Like	A feasible NLF route was not found. After extensive searching through LIDA elevation contours.	Passive fishway providing varied hydraulic conditions similar to a natural stream channel intended to be suitable for a wide variety of species (slope dependent). Less O&M requirements than a lift.	Complex design process. Route providing suitable slopes (less than 1.5%) was not found. Great length and large footprint. Fish may miss entrance and continue to powerhouse discharge.	No

Note: The most viable alternative is fish lift alternative-1A because of muliple site constraints.

3.3.6 Woodland Dam and Powerhouse Downstream Secondary and Tertiary Screening

Unlike the Grand Falls Powerhouse, the powerhouse at Woodland Dam is in close proximity (Figure 2.12) to additional outlet works that can regulate discharge and water surface elevations. The dam site includes Tainter gates, crest gates, and flashboards. Each of these water regulation features also have the potential to bypass fishes, with the assumption that the downstream receiving waters, into which they are discharged, offer a receiving pool deep enough to minimize fish injury. Because of the close proximity of operation features, the site has the advantage of integrating components of upstream and downstream alternatives rather than as independent technologies. Note: following the original secondary screening process, new information from Woodland Pulp was provided for the existing turbine intake, debris bar racks (i.e., bar racks), as discussed for Grand Falls Powerhouse. This information offered additional screening options that are proposed to support some alternatives as described below. Recommended concept alternatives are detailed in Section 4.3.2.

Auxiliary Water System

All upstream fish passage alternatives require an auxiliary (or attraction) water system (AWS) to provide flow to attract fishes to the fishway entrance that is in addition to the water flowing through the fishway sluice.

The configuration of Woodland Dam creates an opportunity for efficient water use because the upstream fishway and downstream bypass are forced into close proximity because of their joint location on the small island separating the powerhouse and spillway (Figure 2.12). That is, the inflow used to create the attracting intake water plume to the downstream bypass entrance can be partially dewatered and then routed to fish ladder to contribute to the AWS for the upstream fishway because of their close proximity. This location is ideal for the entrance to a downstream fishway because it is adjacent to the powerhouse and therefore in close proximity to the intake plume for the powerhouse, which most outmigrants will follow as part of their downstream migration.

Advantages:

1) This entrance alternative is water efficient.
2) The location of the bypass entrance adjacent to intake plume of the powerhouse is ideal because it minimizes the distance over which fish guidance must be implemented.
3) This configuration maximizes the use of the limited space available on the island between the spillway and powerhouse.
4) The location is approximately the same as the exit to the existing Denil fishway which should increase constructability of this option.
5) There should be adequate depth to accommodate multi-level entrances to the bypass similar as described for the Grand Falls Powerhouse entrance.

Disadvantages:

1) The close proximity of the upstream fishway exit to the powerhouse and spillway may result in fallback of adult upstream migrating because of the hydraulic complexity in the forebay.
2) There may be constructability issues because of the close proximity of both upstream and downstream bypass systems in a small area.
3) This alternative only applies if the existing trash rack alternative is selected. It is not compatible with the new rack alternative.

Two structural downstream passage alternatives passed secondary (Table 3.14) and tertiary screening (Table 3.15). The existing trash rack alternative has an exclusion functionality (assuming it has a clear spacing of ¾ inches between slats) and can be modified to accommodate the downstream bypass systems. An additional alternative was later identified and included in tertiary screening and is (Table 3.15): which is referred to as a “new rack”. The louver alternative was eliminated because of uncertainties about its effectiveness at this location, its uncertain ability to guide eels, its large footprint compared to other alternatives, and, because of this large size, high maintenance and cost. Even though it is common in the NE, the angled bar screen was eliminated for several reasons: difficulty of construction, non-traditional design, and larger footprint compared to the new rack design. It has a greater cost than a modification of the bar racks and an inclined bar screen because it cannot incorporate any of the existing trash rack into its structure, meaning an entirely new structure must be built. The inclined bar rack alternative was also eliminated and replaced with a design for a new rack that has some of the same attributes as an inclined screen, such as multiple bypass entrances on the screen surface. However, the new structure will have a more gradual incline than the 45-degree angle of traditional inclined screen designs.

Remaining alternatives for downstream package are described below.

Existing Trash Racks

This option may offer fish barrier functionality because of its clear spacing and overall configuration, which is similar to an angled bar screen. The existing trash racks can be a viable alternative for downstream bypass if potentially excessive water velocity between the slats (which should be re-measured because of uncertainties associated with the original measurements) can be mitigated by reducing powerhouse discharge capacity during the downstream passage season. The degree to which the powerhouse discharge must be reduced will depend on the results of future detailed velocity and trash rack dimension measurements. In addition, a guidance functionality must be added to the existing trash rack using one of the candidate behavioral alternatives.

Advantages:

1) The primary advantage of using the existing trash rack alternative is its low cost.
2) Several methods were identified for adding a guidance functionality to the existing trash rack.
3) Excessive water velocities of the existing screen may be easily mitigated by slightly reducing powerhouse discharges (water velocities at the screen are reported to be 0.4-1.9 fps, which is not far from the 1.6 fps recommended by the USFWS guidelines.

Disadvantages:

1) The reported water velocity at the trash rack may exceed the maximum water velocity recommended by USFWS of 1.5 fps. There is a danger of impingement and entrainment unless water velocity through the slats is reduced (e.g., by expanding the size of the trash rack, limiting operation to two turbines, or reducing the output of three turbines during the downstream passage season). The approach velocities should be confirmed.
2) An effective guidance functionality must be added to the existing trash rack for surface-oriented fish.
3) The relatively small distance between the slats of either 1.9 cm (0.75 in) or 2.54 cm (1.0 in) increases the potential for entrainment of emigrating juveniles and impingement of post spawn adults.
4) The status of debris blockage of the existing trash rack and rate of accumulation of trash at the base of the rack are unknown and may affect intake velocities and the rate of fish impingement or entrainment.
5) Additional structural details of the trash rack must be made available to further assess its potential as a bypass system component.
6) New multi-level bypass entrances must be added between the powerhouse and spillway as described in the first alternative (Downstream Gradual Acceleration Bypass) in this section.

New Bar Screen

The location and general configuration of a concept bar screen requires more details on the existing rack, (e.g., depth of the water at the existing trash rack, width of the existing rack, and length of the existing rack), but is promising as an entrainment reduction and guidance system.

Advantages include:

1) Can be supported from the existing rack
2) Effective method for reducing water velocity at the screen face
3) Can be designed to meet the USFWS velocity criterion
4) Fits well within the available area

Disadvantages include:

1) A new sill would be required upstream of the powerhouse.
2) The new rack has less guidance functionality than an angled bar screen or traditional inclined screen
3) A supplemental guidance functionality using a behavioral technology must be added to the primary structural design.

Behavioral Support Systems
Candidate behavioral guidance alternatives are described in the section on downstream passage alternatives for the Grand Falls Powerhouse. The same alternatives apply to downstream passage at the Woodland Powerhouse, as detailed in Section 3.3.4. for a description and evaluation of candidate behavioral technologies.

Table 3.14. Secondary screening of downstream passage, structural guidance systems as a decision matrix including alternatives that divert fishes away from the turbines at Woodland Dam

Alternatives		Double Weighted Decision Criteria			Single Weighted Decision Criteria			Decision Score
		Species[1] Effectiveness	Certainty of Success	Lack of Unintentional or Negative Impacts	Proven/Accepted Northeast Experience	Major Short-comings	Expected Maintenance Needs	
Structural	Louver Rack [2]	1.0 (6 of 8)	-1	2	1	-1	0	0.67
Structural	++Angled Bar Rack[2]	0.5 (5 of 8)	1	0	1	1	0	1.17
Structural	Inclined Bar Rack[2]	1.5 (7 of 8)	1	0	1	1	0	1.5
Structural	Guidance Boom	0 (4 of 8)	1	1	1	-1	1	1.0

[1]Includes the 8 target species (Table 2.3).

[2]Assumes proven spacing and/or design angle.

[3]Assumed deep- angled design

Note: Table scoring conventions are the same as in Table 3.9.

Table 3.15. Tertiary screening for alternatives passing secondary screening shows that the existing rack and an inclined rack concept are both viable alternatives for downstream package whereas the angled bar rack can be eliminated from consideration

ID	Description	Advantages	Disadvantages	Status
W - 1 **Existing Bar Rack**	Existing bar rack has 1.0" inch clear opening in line with FWS recommendations for exclusion of American eel, salmon, and alosines. Existing rack protects target species if velocity is less than 1.5 ft./sec. However, approach velocity has not been verified, nor could it be calculated due to missing information.	No need for new structures to limit entrainment and impingement of target species.	Existing system needs to be modified for submerged downstream bypasses for American eel. A new surface bypass should be included for salmon and alosines.	Recommend
W - 2 **New Rack**	Provides greater screening area if velocities of existing rack exceed guidelines. Rack to be angled 20 to 30 degrees (off vertical) out into the impoundment depending on how much additional area is needed. New rack structure has a clear opening of 0.75 inches, approach velocity less than 1.5 ft./sec and incorporate bottom and surface bypasses.	Supported from the existing intake. Less structural modifications than an angled bar rack or louver.	New footing supports needed for the bottom sill of the new rack structure.	Recommend
W - 3 **Angled Bar Rack**	**P**rovides greater screen area (if current velocity is excessive) and improves guidance to downstream bypasses. Angled racks ideally suited for uniform approach flow conditions in an intake canal. An angled rack implemented at Woodland would require channel upstream of the intake or reconfiguring rack in an inverted Vee to guide fish to bypasses at either end of rack.	Smaller footprint than louver. Potential for lower approach velocities than other options.	Larger footprint than an inclined rack. Traditional 45-degree angled rack not possible due to the lack of an intake canal where the rack could be adjusted at both ends. Requires a non-traditional inverted Vee configuration with bypasses at either end.	No

4 FINAL CONCEPT ALTERNATIVES AND CONCEPTUAL COSTS

Conceptual level designs were developed for those alternatives identified in the Tertiary Screening. The conceptual level designs were then used to develop an estimate of probable construction costs and to review engineering, construction and operation, and maintenance considerations for each selected alternative.

4.1 Grand Falls Dam

4.1.1 Upstream Passage

4.1.1.a Vertical Slot Fish Ladder around Right Dam Abutment

A vertical slot ladder would be located adjacent to the right abutment of Grand Falls Dam Tainter gates with an entrance located just below the rapids approximately 435 ft. downstream of the dam (Figure 4.1). The ladder alignment would be routed inland of the dam abutment with an exit channel located approximately 337 ft. upstream of the gate structure. A conceptual design was developed based on U.S. Fish and Wildlife Service guidelines (FWS 2019) for the targeted species. Supplemental attraction flow would be provided to the ladder entrance channel via a new intake just upstream of the dam and piping. Pertinent design details of the vertical slot ladder include the following:

- Operating range:
  - River flows between 95% and 5% river flow exceedance
- Entrance:
  - 6- to 12-inch drop
  - Hinged flap gate automated to track tailwater levels to provide a constant entrance velocity
- Ladder:
  - 9-inch drop per pool
  - Slot width – 24 inches
  - Pool dimensions – 16 ft. wide by 20 ft. long
  - Slope – 3.8%
  - Overall length – 1460 ft.
  - 4 ft. minimum depth
  - Maximum assumed head – 40 ft. (to be verified with tailwater studies)
  - Ladder flow – 50 to 90 cfs (depending on head pond elevation)
- Supplemental Attraction Water System (AWS):
  - Flow: up to 100 cfs
  - Wedge wire intake screen or closely spaced racks w/clear spacing less than 0.375 inches,

Engineering Considerations

The design of the vertical slot fish ladder would require detailed topography and bathymetric surveys of the project area. This information would be used to optimize the fish ladder alignment to minimize excavation of bedrock. An evaluation of tailwater elevations via review of historic data or by hydraulic analysis is needed to properly set the fish ladder entrance invert and wall heights for the range of expected operating conditions. A review of the bypass reach from Grand Falls Powerhouse to the spillway is needed to determine if there are any barriers to fish passage. This would be accomplished through hydraulic analysis and/ or a fish telemetry study. In addition, a thorough understanding of the tailrace hydraulics is needed to properly site the fishway entrance relative to the base of the rapids, so that the entrance is not masked from turbulent flow from the rapids or located too far downstream, which would risk fish swimming past the entrance. The following is a list of studies that may be needed to execute the design, depending on available information:

- Existing conditions survey the project area
- Bathymetric survey of the tailrace and head pond
- Engineering inspections of existing infrastructure
- Geotechnical soil/rock borings
- Evaluation of tailwater elevations using historic data if available, or hydraulic analysis
- Hydraulic evaluation of bypass reach (to determine if fish can reach spillway)

Construction Considerations

Construction of the vertical slot ladder would involve installing temporary cofferdams around the construction extents within the river downstream of the dam and upstream in the impoundment. The cofferdam would consist of sheet pile anchored to existing bedrock, or other designs suited for the water depth. Turbidity curtains would be installed to enclose the cofferdams. An existing road provides good access to the construction area. Access to the gate structure and dam and existing utilities would need to be maintained throughout construction. Excavation of bedrock would be accomplished with hoe rams or controlled blasting.

Construction of the vertical slot fish lift is expected to take approximately 12 months depending on river and weather conditions.

Operation and Maintenance

The vertical slot fish ladder will operate similarly to the existing Denil ladder, with additional features to control attraction water and to provide a constant velocity at the entrance. A bottom hinged entrance gate would maintain a water surface differential to provide a constant velocity entrance jet controlled by a PLC. In addition, the AWS would include flow control valves to vary attraction flow to the fish ladder entrance. During normal operation the facility would require personnel to inspect the fish ladder daily to ensure the ladder is free from debris and ensure appropriate hydraulic conditions.

The vertical slot fish ladder will require maintenance and periodic repairs of the valves, gates, operators and AWS intake. An operation and maintenance manual developed specifically for the facility would detail recommended maintenance and start-up, shutdown and operating procedures.

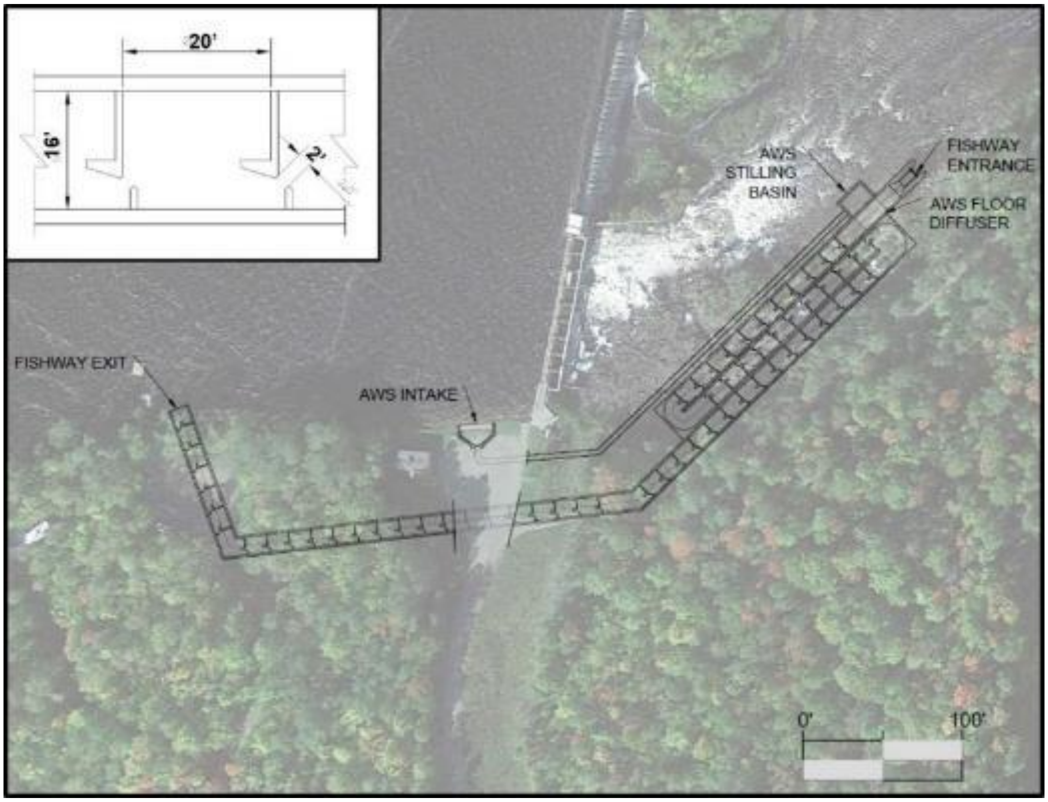


Figure 4.1. Conceptual plan for vertical slot fishway at Grand Falls Dam

4.1.1.b Nature-like Fishways

The initial NLF options evaluated in close proximity of Grand Falls Dam included resulted in viability and construction concerns and were dropped from further consideration (Table 3.4). However, the two NLF options considered for Grand Falls Powerhouse may offer viable and reasonable alternatives that would support fish passage above Grand Falls Dam. See Section 4.2.1.c for NLF details.

4.1.2 Downstream Passage

4.1.2.a Surface Bypass Weir

A uniform acceleration weir (also known as an Alden weir) would be installed on the dam spillway adjacent to the Tainter gates. The spillway would be modified to accommodate a weir with an entrance width of 6 ft., an entrance depth 8.8 ft., a weir crest depth of approximately 4 ft. (below normal water) and a length of about 15 ft. from the discharge at the face of the spillway. The mouth of the weir would include a smooth bell mouth transition to the 6 ft. width and an entrance gradually sloped upward to the 4 ft. depth at the weir crest. An example Alden weir is provided on (Figure 4.2) and the location on the spillway is shown on (Figure 4.3).

The spillway would require modification by notching the spillway 6 ft. wide by 4 ft. deep (below normal water). The notch through the spillway would be formed in concrete. The remaining geometry of the weir extending into the impoundment could be made of steel or formed out of concrete.

The surface bypass weir would have the following features:

- Alden weir geometry
- 8.8 ft. entrance depth
- 4 ft. crest depth
- 6 ft. crest width
- 15 ft. length
- Isolation gate or stoplogs
- Flow of 160 cfs at normal water

Engineering Considerations

The design of the surface bypass weir would require engineering inspections and accurate measurements of the existing spillway dam structure. The existing dam is an Ambursen type dam and will require a review of dam stability with any proposed changes. The existing floating walkway used to access the flashboards may need to be stabilized or rerouted around the surface weir. A survey of the tailwater area would be needed to verify adequate plunge pool depth. The weir will likely require concrete piers to transition to the existing flashboards. A review of project discharge capacity would be needed to determine if the proposed design impacts flood discharge capacity.

Construction Considerations

Construction of the surface bypass would include installation of a bulkhead cofferdam to modify the spillway in the dry. The cofferdam would consist of a steel bulkhead or full depth sheet pile structure. Floating work platforms, boats and barges would be needed for access and to transport prefabricated components to the surface weir location.

Construction of the surface bypass weir is expected to take up to 10 weeks.

Operation and Maintenance

Operation and maintenance of the surface bypass would be similar to existing discharge structures at the dam. Periodic inspections would be needed to be sure the weir stays free of debris.

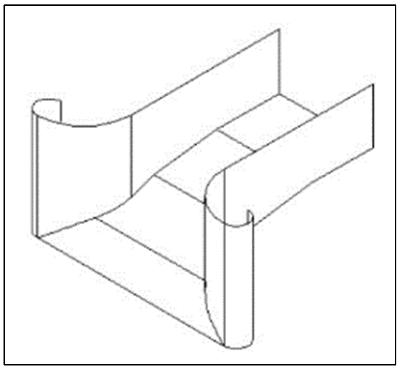


Figure 4.2. Conceptual illustration of surface bypass with uniform acceleration weir (i.e.,Alden Weir) geometry (Source: Alden Labs)

Figure 4.3. Conceptual plan of surface bypass weir at Grand Falls Spillway (source: Alden Labs)

4.1.2.b Remove Section of Existing Flashboards

The height of the existing flashboards has not been verified, but based on photographs, they appear to be 2 ft. or greater. A section of flashboards, removed adjacent to the existing Tainter gates, would provide a surface bypass over the spillway. Approximately 18 ft. of removed flashboards would provide approximately 160 cfs flow capacity at a 2 ft. depth. A photograph of the existing flashboards is provided on (Figure 4.4).

The bypass through removed flashboards would have the following features:

- ~ 2 ft. crest depth at normal water (to be verified)
- 18 ft. width (dependent on to be verified flashboard height)
- Flow of 160 cfs at normal water

Engineering Considerations

The concept would require engineering inspections and accurate measurements of the existing spillway structure. The existing floating walkway used to access the flashboards may need to be stabilized or rerouted to maintain access to the remaining flashboard sections. A survey of the tailwater area would be needed to verify adequate plunge pool depth.

Construction Considerations

This concept may not require installation of new components, as it involves removing portions of the flashboards. The existing floating walkway may require modifications. Any required modifications would be likely accomplished with the use of work boats and floating platforms.

Operation and Maintenance

Operation and maintenance would be similar to existing flashboards at the dam. Periodic inspections would be needed to be sure the bypass stays free of debris.

Figure 4.4a (Above). Photograph of Grand Falls Spillway flashboards (source: A. Hoar)

Figure 4.4b (Below). Conceptual plan to remove section of flashboards at Grand Falls Spillway (source: Alden Labs)

4.1.2.c Tainter Gate Modification with a Notched Weir

An existing Tainter gate, closest to the spillway, would be modified to include a surface bypass weir for downstream migrants. The top of the modified Tainter gate would incorporate a 6 ft. wide by 4 ft. deep (below normal pool depth). The weir would include short 3 ft. flare walls shaped as a bell mouth to provide a smooth approach flow conditions to the weir crest to enhance passage conditions. The notch would incorporate a stoplog slot to stop flow in the off-season (Figure 4.5a). A photograph of the existing Tainter gate structures is provided in Figure 4.5b.

A plunge (i.e. landing) pool would be installed in the tailwater at the outlet of the Tainter gate to provide sufficient water depth to prevent fish injury (Figure 4.5). A plunge pool depth of at least 25% of the total head is needed per FWS guidelines. The gate piers would be extended downstream 20 ft. with a wall height of 10 ft. The downstream opening between the walls would incorporate stoplog slots.

The Tainter gate surface bypass weir would have the following features:

- 4 ft. crest depth
- 6 ft. crest width
- Short 3 ft. bell mouth geometry
- Stoplogs
- Flow of 160 cfs at normal water
- Plunge pool dimensions: 14 ft. wide, 20 ft. long, 10 ft. deep

Engineering Considerations

The design of the Tainter gate modifications would require detailed engineering inspections of the existing gate structure and design. The gate would be evaluated to determine necessary structural reinforcement and to review any change in loading on gate components. A survey of the tailwater area would be needed to design the plunge pool.

Construction Considerations

Modifications to the Tainter gate would include installation of a bulkhead cofferdam if stoplogs are not included as part of the existing Tainter gate bay design. Modifications to the gate would be completed in the field. Alternatively, the gate would be removed and modified, or replaced with a new prefabricated gate. Floating work platforms, boats and barges would be needed for access and to transport prefabricated components to the surface weir location.

Modification to the existing Tainter gate is expected to take 8 to 10 weeks.

Operation and Maintenance

Operation and maintenance of the modified Tainter gate would be similar to existing operations of the Tainter gate. The notched weir would be integral to the gate structure and operate with the Tainter gate in the closed position. The notch depth would be set 4 ft. below normal water in the top of the Tainter gate and would include a stoplog slot to shut down flow during the off season. The weir would need to be periodically inspected to be sure it remains free of debris.

Figure 4.5a. Conceptual plan of Tainter gate modifications with a notched weir and landing pool at Grand Falls Spillway (source: Alden Labs)

Figure 4.5b. Photograph of Grand Falls Spillway Tainter gate structures (source: A. Hoar)

4.2 Grand Falls Powerhouse

4.2.1 Upstream Passage

4.2.1.a Fish Lift

A fish lift proposed for Grand Falls Powerhouse would have an entrance adjacent to the powerhouse discharge, similar to the existing Denil ladder entrance location (Section 2.4.3). The lift would include a constant velocity entrance gate, entrance channel, Vee trap, hopper, exit pipe and an attraction water system (AWS), see Figures 4.6 and 4.7. The AWS would provide attraction flow to the fish lift via an intake weir in the impoundment that could also be used as a downstream passage bypass. Pertinent design details of the proposed fish lift include the following:

- Operating range:
  - River flows between 95% and 5% river flow exceedance
- Entrance:
  - 6- to 12-inch drop
  - 8 ft. width
  - Hinged flap gate automated to track tailwater levels to provide a constant entrance velocity
- Entrance channel:
  - 12 ft. wide
  - Vee trap
- Hopper:
  - 490 ft^3, 3665 gal
  - Two-sided brail – no crowder
  - 30 TN hoist
  - 15 min cycle time
- Exit flume:
  - 20-inch smooth fiberglass pipe
  - 5% slope
- Attraction water system (AWS):
  - Flow: 5% of station capacity, ~ 165 cfs
  - Uniform acceleration weir geometry (Alden weir)
  - Wedge wire screen

Engineering Considerations

The design of the fish lift would require a thorough review of available design information for the existing infrastructure to identify data gaps. An existing conditions survey is needed to identify all infrastructure that may interfere with the fish lift layout and to provide topography data. Routing the exit pipe to the impoundment will require careful review of the intake channel hydraulic conditions to limit fall back and a review of the access roadway crossing.

The following is a list of studies that may be needed to execute the design, depending on available information:

- Existing conditions survey the project area
- Bathymetric survey of the tailrace and head pond
- Engineering inspections of existing infrastructure

- Geotechnical soil/ rock borings
- Electrical load study
- Evaluation of tailwater elevations using historic data if available or hydraulic analysis

Construction Considerations

The location of the proposed fish lift on the downstream side of the powerhouse would require a temporary construction access road from the existing road down to the powerhouse elevation. Construction would take place in the dry with use of cofferdams enclosing the construction area within the tailrace. Steel sheet pile style cofferdams would be appropriate given the water depth and would potentially allow one or two of the units to operate during construction.

Construction of the fish lift is expected to take 12 to 18 months depending on river and weather conditions.

Operation and Maintenance

The fish lift would be operated by a programmable logic controller, (PLC) and accompanying operator interface terminal (OIT) touch screen. The PLC would operate the various components in sequence for a fish lift cycle and display progress on the OIT. An example of component actions for a fish lift cycle is provided below:

Step	Component/ Action	Action
1	V-gates	close V-gates
2	hopper hoist	hopper hoist lifts at slow speed
3	hopper hoist	hopper hoist lifts at normal speed
4	hopper at top position	hopper hoist slows and stops
5	hopper gate	gate opens
6	Exit flume water supply valve	valve opens
7	hopper hoist	slow speed to bottom position
8	hopper hoist	hopper settles to bottom position
9	hopper gate	gate closes
10	V-gate	V-gate opens

The entrance gate would be controlled by the PLC to maintain a constant water surface differential at the entrance. In addition, the AWS would include flow control valves to vary attraction flow to the fish lift. During normal operation, the facility would require personnel to oversee operations to ensure the system is free from debris and ensure appropriate hydraulic conditions throughout the fish lift entrance flume, entrance gate and exit pipe.

The various mechanical components of the fish lift require maintenance and periodic repairs to keep the facility in good working condition. An operation and maintenance manual developed specifically for the facility would detail recommended maintenance and spare parts to keep on hand. Approximately one week would be needed to winterize the facility for the off season and two weeks to start the facility up in the spring and to perform any necessary repairs.

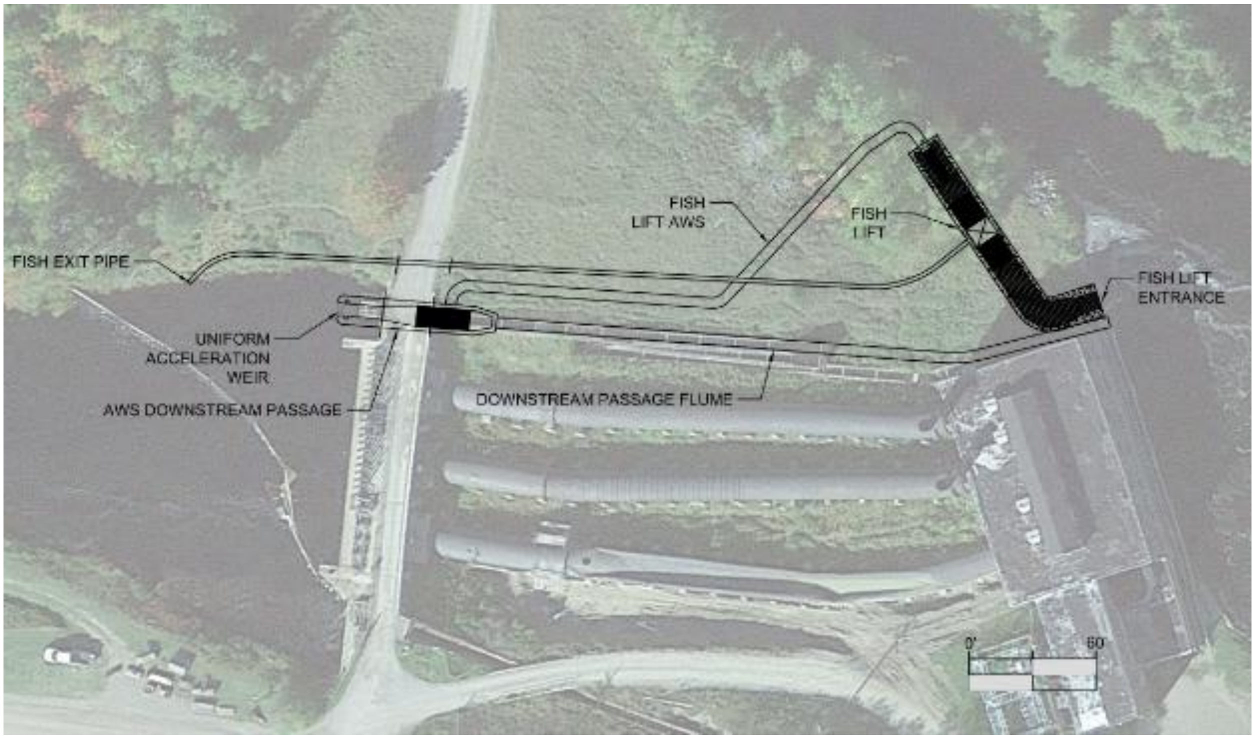


Figure 4.6. Conceptual plan for a fish lift at Grand Falls Powerhouse (source: Alden Labs)

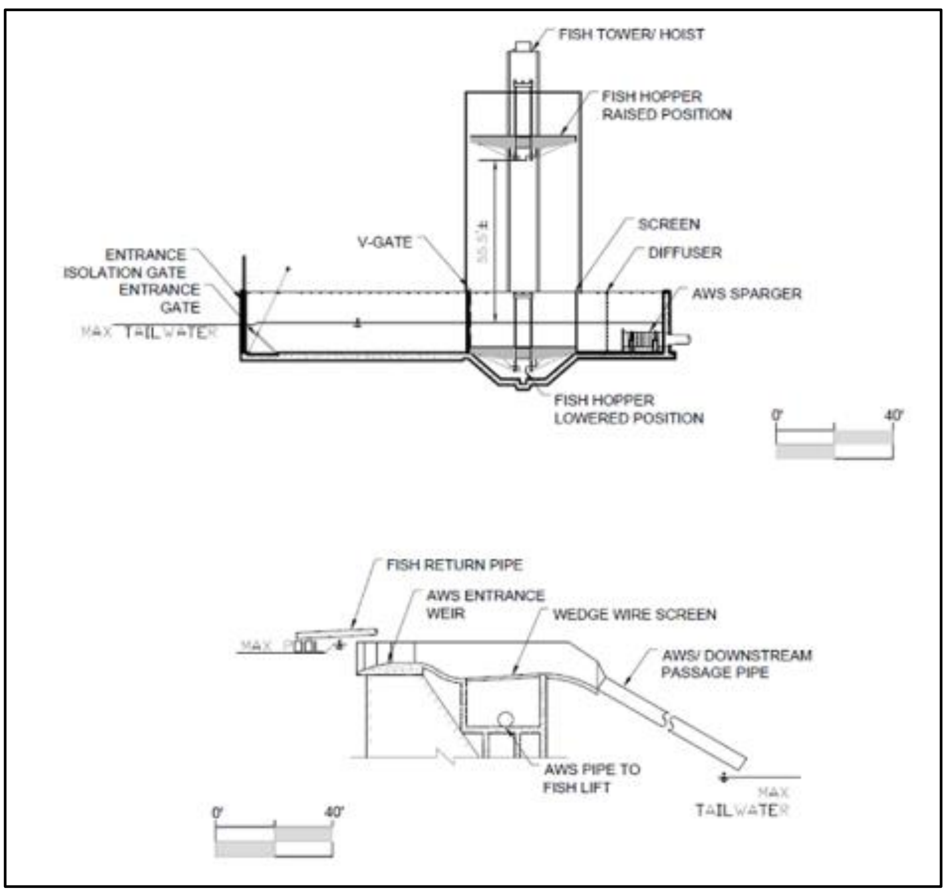


Figure 4.7. Conceptual details for a fish lift at Grand Falls Powerhouse (Source: Alden Labs)

4.2.1.b Vertical Slot Fish Ladder

A vertical slot ladder would be located with an entrance located adjacent and downstream of the powerhouse where the existing Denil ladder entrance is located. The ladder would be routed following the bank contours upstream 700 ft., switchback 180 degrees extend with an exit channel located approximately 160 ft. upstream of the existing hydropower intake (Figure 4.8). A conceptual design was developed based on US Fish and Wildlife Service guidelines (FWS 2019) for the targeted species. Supplemental attraction flow would be provided to the ladder entrance channel via a new intake on the left bank of the intake channel just upstream of the intake. Pertinent design details of the vertical slot ladder include the following:

- Operating range:
    - River flows between 95% and 5% river flow exceedance
- Entrance:
    - 6- to 12-inch drop
    - Hinged flap gate automated to track tailwater levels to provide a constant entrance velocity
- Ladder:
    - 9-inch drop per pool
    - Slot width – 24 inches
    - Pool dimensions – 16 ft. wide by 20 ft. long
    - Slope – 3.8%
    - Overall length – 1550 ft.
    - 4 ft. minimum depth
    - Total assumed head – 49 ft.
    - Ladder flow – 50 to 90 cfs (depending on head pond elevation)
- Supplemental Attraction Water System (AWS):
    - Flow: up to 100 cfs
    - Wedge wire intake screen

Engineering Considerations

The design of the vertical slot fish ladder would require detailed topography and bathymetric surveys of the project area. This information would be used to optimize the fish ladder alignment to minimize excavation. An evaluation of tailwater elevations via review of historic data or by hydraulic analysis is needed to properly set the fish ladder entrance invert and wall heights for the range of expected operating conditions. The following is a list of studies that may be needed to execute the design, depending on available information:

- Existing conditions survey the project area
- Bathymetric survey of the tailrace and head pond
- Engineering inspections of existing infrastructure
- Geotechnical soil/ rock borings
- Electrical load study
- Evaluation of tailwater elevations using historic data if available or hydraulic analysis

Construction Considerations

The construction area would be easily accessible from the existing powerhouse and dam access road. Cofferdams would be required in the tailrace and intake channel, along with turbidity curtains. Steel sheet pile style cofferdams would potentially allow one or two of the units to operate during construction.

Construction of the vertical slot fish ladder is expected to take approximately 12 to 18 months depending on river and weather conditions.

Operation and Maintenance

The vertical slot fish ladder will operate similarly to the existing Denil ladder, with additional features to control attraction water and to provide a constant velocity at the entrance. A bottom hinged entrance gate would maintain a water surface differential to provide a constant velocity entrance jet controlled by a PLC. In addition, the AWS would include flow control valves to vary attraction flow to the fish ladder entrance. During normal operation the facility would require personnel to inspect the fish ladder daily to ensure the ladder is free from debris and ensure appropriate hydraulic conditions.

The vertical slot fish ladder will require maintenance and periodic repairs of the valves, gates, operators and AWS intake. An operation and maintenance manual developed specifically for the facility would detail recommended maintenance and start-up, shutdown and operating procedures.

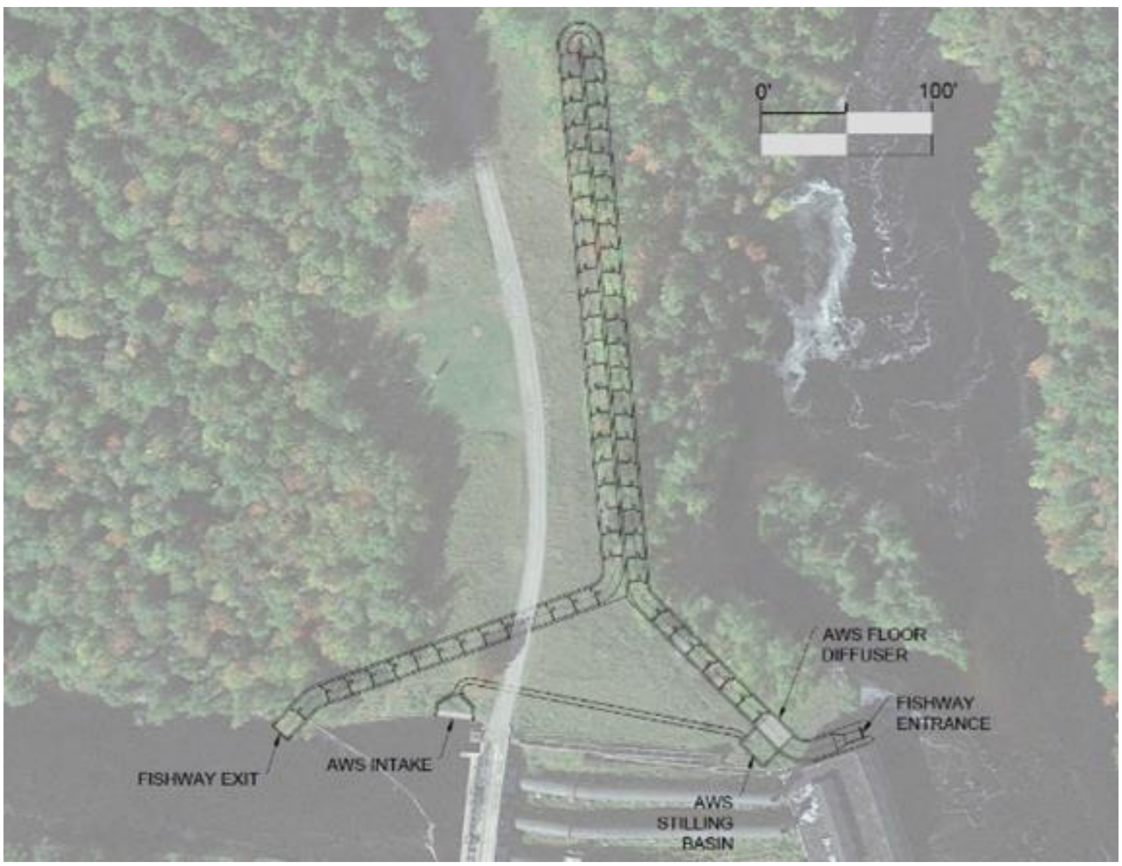


Figure 4.8. Conceptual plan for a vertical slot ladder at Grand Falls Powerhouse (source: Alden Labs)

4.2.1.c Nature-like Fishway

Two nature-like fishway (NLF) alternatives are viable for the Grand Falls site, both with entrances located in close proximity, and upstream of the Grand Falls Powerhouse, on the north (Canadian) and south (U.S. side) sides of Grand Falls Dam (Figure 4.9). The concepts are based on a mix of available Lidar processed data (Figure 4.10), site data and preliminary survey data collected by project partners (Dana et al. 2020 and Bassett 2020). Although these alternatives are initially promising, detailed site surveys are needed best clarify the opportunities and constraints on either side of the river, below Grand Falls Dam. These alternative concepts are characterized as Canadian side (NLF C) and U.S. side (NLF A) (Figure 4.9).

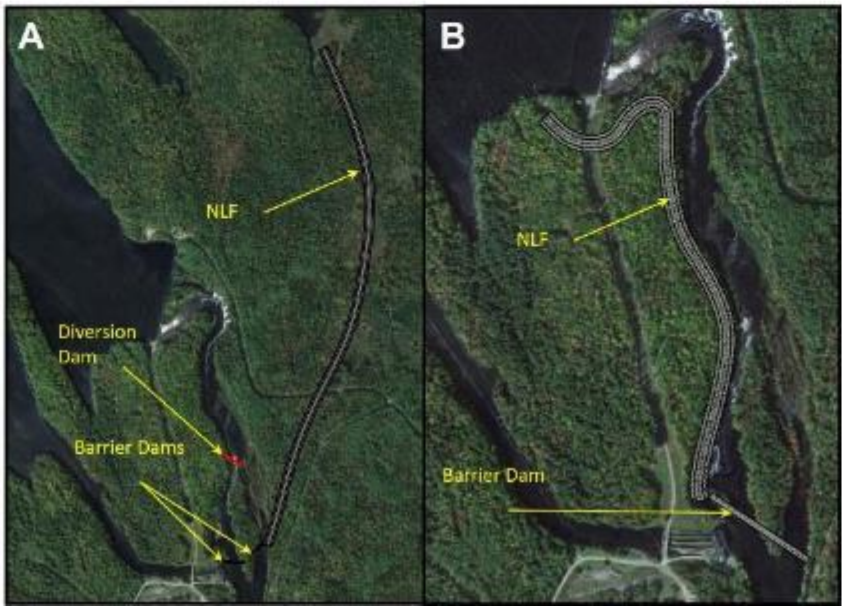


Figure 4.9. NLF concepts for Grand Falls Dam. Image A depicts a Canadian side option while image B depicts a U.S. side concept.

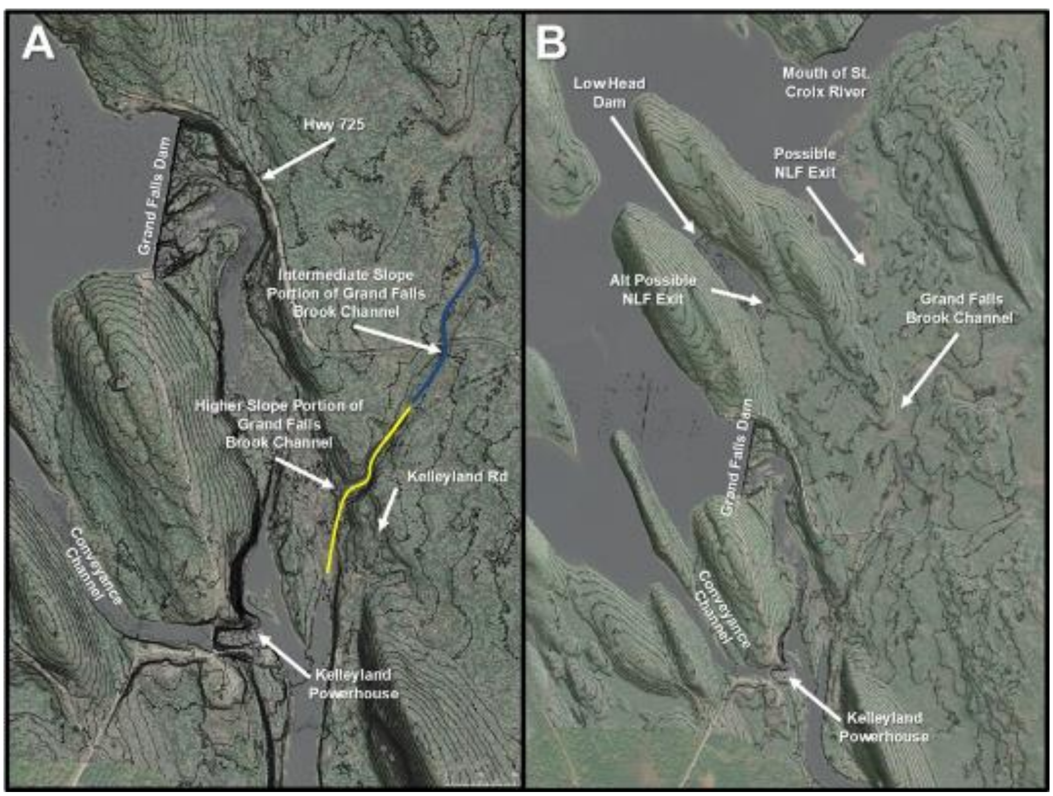


Figure 4.10. LIDAR Images Showing Elevation Contours at 5.0 ft. intervals for the near the dam and powerhouse (A) as well as the further upstream of Grand Falls Brook (B).

Note: Figure 4.10. Grand Falls Brook has eroded through the bluff on the left side of the river channel, potentially offering a natural entrance channel, if the brook slopes are not too severe near the river (LimnoTech, 2020).

Canadian Side (NLF C)

NLF C concept follows a natural brook (Grand Falls Brook) whose mouth is located on the northeastern shore approximately opposite the Grand Falls Powerhouse. It appears that properties of the NFL C route are owned by the Crown except for three parcels, two of which are owned by Woodland Pulp. NLF C is an attractive alternative because it could potentially use an existing, natural stream channel that exhibits landscape features conducive to the construction of a NLF (Figures 4.9-4.10). For example, there is no project infrastructure located within the footprint for this alternative and only a road (HWY 725) with a bridge spanning the Grand Falls Brook occurs that could be an impediment to construction. Further, the greatest known slope of 1.3% (to be confirmed) for this site appears to occur from the HWY 725 Bridge downstream to the confluence with the St. Croix River. Assuming this max slope is correct, it is well within accepted design criterion for NLF slopes, with a target gradient of 1.5%. The slope upstream of the HWY 725 was not measured during field surveys, but visual observations confirmed by LIDAR survey results (Figure 4.10) suggest that the slope is low gradient compared to the reach downstream of the HWY 725 Bridge.

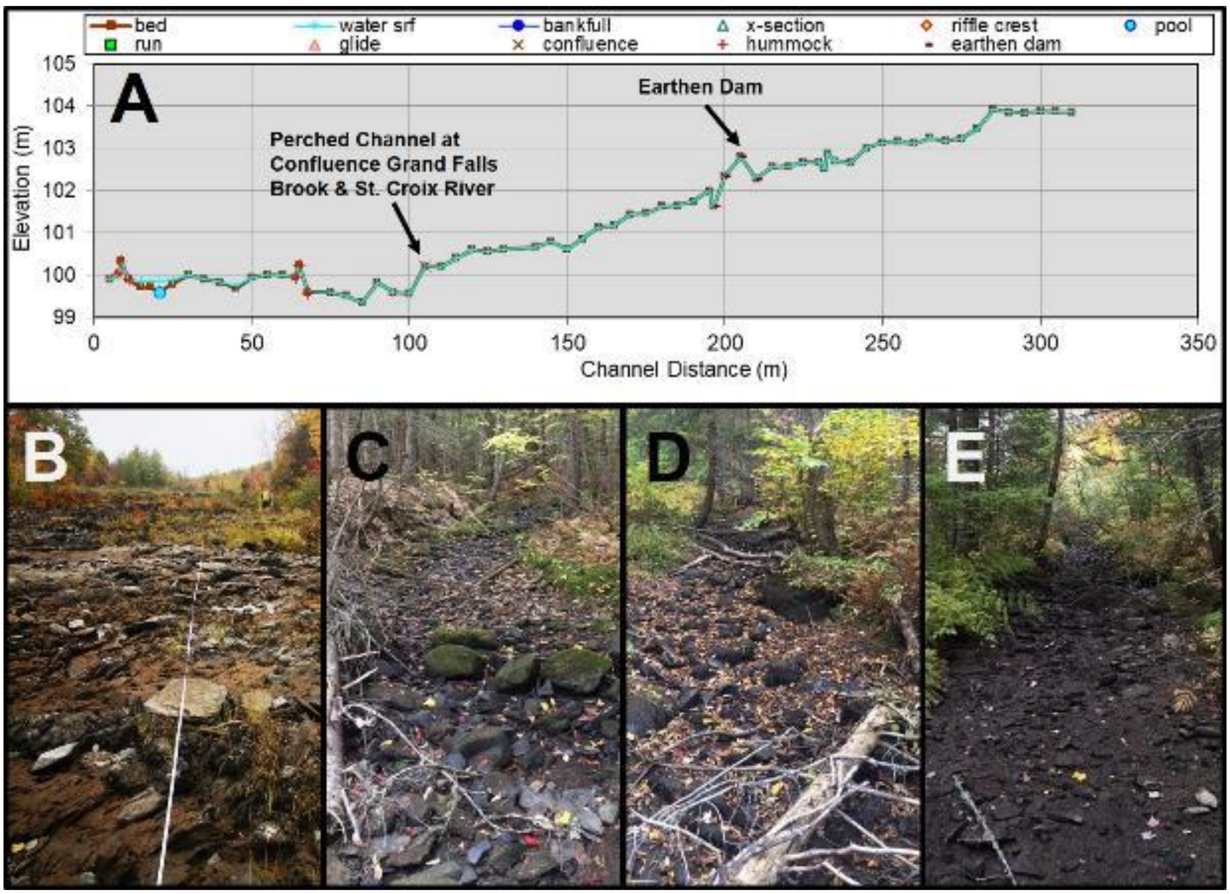


Figure 4.11. Grand Falls Brook profile and confluence images of lower 300m of reach (Credit Dana et al. 2020).

Note: Figure 4.11. Panel A depicts the elevation profile of Grand Falls Brook extending from the confluence (labeled as "Perched Channel") with the St. Croix River . A low-head dam of unknown purpose and several beaver dams were also noted. Note that the confluence of Grand Falls Brook is perched at the confluence with the St. Croix River (B). Images taken (C-E) from the mouth toward HWY 725 showing bedrock (Credit Dana et al. 2020). a substrate of dark-gray and olive-green quartz wacke, silty slate, and slate typical of the Digdequash Formation (formerly named the Canoose Formation) (Ruitenberg and Ludman 1978).

Also note that images (Figure 4.11) of the dry channel of Grand Falls Brook at the confluence of the St. Croix River show the presence of shale rocks of a range of useful sizes suggesting that native materials in and near the channel could be used to construct an effective NLF. Major unknowns for the NLF C alternative also include confirming the slope of the upper 350 m of the NLF C channel before it connects to a cove of Grand Falls Flowage (Figure 4.12-4.13), how the alternative may affect the pool levels within the flowage, and capacity and potential that the channel (with a lower reach, average bankfull width of 3.91m) could accommodate the range of needed fish passage flows.

Figure 4.12. Potential exit locations of NLF C, connecting Grand Falls Brook to the flowage.

Note: Figure 4.12. *Concept NLF C connects Grand Falls Brook to the northern cove depicted in Figure 4.13a. Figure 4.13a-d provides examples of ground-based photos of the site.*

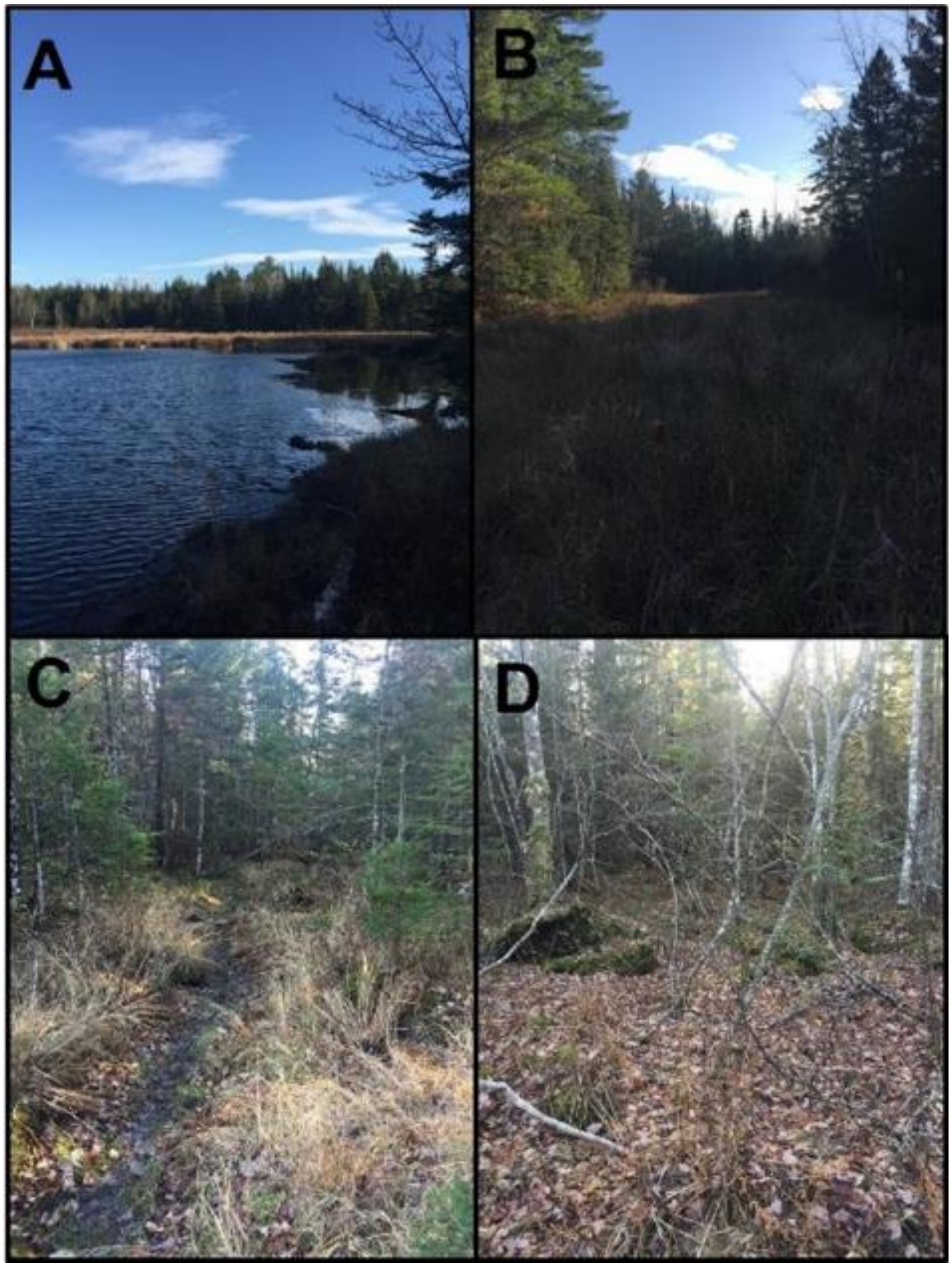


Figure 4.13. Images taken in and near the flowage cove at the upstream extent of the NLF C concept. (Credit: Dana et al. 2020).

***Note**: Figure 4.13. Potential NLF exit cove (A), and potential channels (B and C), and further downstream (D) approximately 50 meters where the channel becomes nondescript.*

Attraction flows would need to be assessed for NLF C for both upstream and out-migrating fishes. Much of the aquatic habitat immediately upstream of Grand Falls Dam, and within the flowage, is lacustrine with several bays to the east and west. The multiple bays may create homing challenges for out-migrating fish coming from either direction. Further research should be conducted to how homing may be improved with this concept. Finally, NLF C concept is approximately 5,900ft in length and may offer spawning opportunities for some native species within the concept reach.

Advantages of NLF C include:

1) The Grand Falls Brook confluence with the St. Croix River is between Grand Falls Dam and Grand Falls Powerhouse (but closer to the powerhouse) and, thereby, may provide fish passage capability for both Grand Falls facilities.
2) All of the concept lands are on Canadian properties and owned by the Crown.
3) If viable, this alternative could eliminate the need for an upstream fishway at Grand Falls Dam.
4) The natural discharge of Grand Falls Brook may contribute to the NLF attraction flow.
5) The option could pass eels and lamprey without a species dedicated passageway.
6) The Grand Falls Brook alternative could contribute to both upstream and downstream migration passage, although probably primarily benefiting East Branch migrating fishes because of the proximity of the exit to the continuation of the St. Croix River toward Vanceboro Dam.
7) Site survey of channel characteristics of the lower 220 m of Grand Falls Brook conducted by Dana et al. (2020) suggest that site slope and bed and bank material may be suitable for NLF construction.
8) Dana et al. (2020) also noted that there also appears to adequate natural material for NLF construction including shale rock of a range of sizes that could be used to construct the energy dissipation structures typical of NLFs.
9) The relatively flat, rocky landscape in the vicinity of the proposed footprint of NLF C indicates easy access and firm substrate for the movement and operation of heavy construction equipment.
10) The apparent flat slope from the cove of Grand Falls Flowage to the Grand Falls Brook channel suggests that a channel could be constructed to connect the head pond to the nearest part of Grand Falls Brook channel. This eliminates the need for energy dissipation structures over a substantial part of the NLF and may reduce construction cost of this alternative.
11) The NLF C alternative could have dual purposes of fish passage for upstream and downstream migration and as an artificial spawning channel for fishes requiring riverine spawning habitat.

Disadvantages and uncertainties include:

1) The width of the HWY 725 Bridge that spans Grand Falls Brook is unknown and discharge of the Grand Falls Brook is unknown and therefore, the combination of required, supplemental attraction flow and the natural stream discharge may exceed the conveyance area under the bridge or require flow control at the upstream end of the NLF to prevent damage to the bridge.
2) The entire footprint of Grand Falls Brook has not been inspected by a ground survey so that natural features (i.e., bedrock) may exist that could cause construction challenges.
3) The mouth of Grand Falls Brook appears to be perched by bedrock, above the main channel of the St. Croix River (Figure 4.11). It appears that the brook connection to the river becomes seasonally dry. It may be necessary to excavate a connection to Grand Falls Brook of a suitable slope that can be used by immigrant fish to access the channel of Grand Falls Brook.

4) A gravel road may need to be constructed to service the upstream control of the fishway and perform routine maintenance of the channel.
5) Grade controls may have to be added to Grand Falls Brook to prevent damage to the channel with the increase in discharge associated with fishway flows combined with the natural flows of Grand Falls Brook, particularly in the region between the mouth and the Highway 725 crossing.
6) A NLF length of 5,900 ft. may cause some fishes to reject the route, but if designed effectively passage may be used by fishes as if natural habitat.
7) It may be difficult to design an entrance to NLF C that can attract fishes migrating up both shorelines because turbine discharges of the Grand Falls Powerhouse my continue to create dominant attraction flows. The northern side of the St. Croix River channel may need to be modified to provide attracting flow patterns for the mouth of Grand Falls Brook that compete for the attention of upstream migrants.
8) The potential for adaptive downstream homing within complex waterways, with newly sited entrances should be better understood for this alternative.

Engineering Considerations

Recommended slopes for NLF vary from 1.5% to 5% depending on the target species. A slope of 1.5% is ideal for Grand Falls Brook, based on Alden's experience with hydraulic modeling for similar projects and target species. The design should be evaluated with a hydraulic mode to confirm hydraulic conditions suitable for fish passage. Computational Fluid Dynamic (CFD) modeling is recommended as a design tool to optimize fish passage performance.

The proposed NLF would include an exit channel to control flow through the NLF with the target design flow of 150 to 200 cfs. This structure would need to be assessed for elevation control of Grand Falls Flowage levels. An entrance channel structure at Grand Falls Brook is recommended to create velocities that would attract upstream migrants.

The design of the NLF through Grand Falls Brook may require an expansion of the existing channel width and, potentially, a newly routed upstream connection. These may require detailed topography survey and accompanying soil borings to determine substrate, overburden depth and bedrock profile to assess. This information would be used to optimize the channel alignment, as needed, to refine design details and develop construction cost estimates. The following is a list of studies that may be needed to execute the design:

- Existing conditions survey the project area
- Assessment of Grand Falls Brook capacity for target flows of 150 to 200 cfs
- Bathymetric survey of the tailrace and head pond
- Engineering inspections of bridge crossing or other affected infrastructure
- Geotechnical soil/ rock borings
- Evaluation of tailwater elevations using historic data if available or hydraulic analysis

Construction Considerations

Construction of the NLF using Grand Falls Dam would be accessible from the access road connected to HWY 725, downstream (below bridge), with a new construct assess needed for upstream (above bridge) developments. Cofferdams would be required for work in the tailrace and head pond. Construction may require substantial excavation and a detailed understanding of soil conditions and bedrock profile is needed to determine construction means and methods and to establish cost estimates. Bulk bedrock removal, if needed, would be accomplished by drilling and blasting while detailed channel construction would likely be accomplished with hydraulic hammers. Conceptual cost estimate are uncertain because of the number of site uncertainties such as;

- Required channel width and bed and bank conditions
- Rock excavation – Uncertain at this time
- Soil (not rock) excavation – Uncertain at this time
- Construction of the NLF is expected to be less than 18 months

Operation and Maintenance

Depending on the final design, the NLF could be operated either entirely passive (traditional NLF design with no active operation from gates) or with an entrance velocity, head pond control gate and/or an exit channel flow control gate. Active gates will improve the performance of the fishway by maintaining optimum design flow conditions within the NLF by maximizing the likelihood of fish finding the entrance by maintaining an appropriate entrance jet. Gates will also allow the channel to be dewatered periodically for maintenance and debris removal. An operation and maintenance manual would detail recommended operating and maintenance requirements.

U.S. Alternative (NLF A)

NLF A is a concept for the U.S. side of the St. Croix River channel between Grand Falls Powerhouse and Grand Falls Dam, with an entrance immediately north of Grand Falls Powerhouse (Figure 4.9b; Figure 4.14). Bassett (2020) conducted a site visit immediately downstream of Grand Falls Dam and within the general area of the NLF A concept and located a number of important features that could affect the selection and cost of this alternative. The site visit located three low-head, concrete dam structures (Figure 4.15 and 4.16) that may be described in the blueprints used to construct Grand Falls Powerhouse. The impact of these dams on upstream passage and fishway attraction to the entrances of either NLF concepts is uncertain. The site visit also identified old, assumed, log sluice structures on the U.S. side that include concrete-lined and unlined excavated (earthen) channels (Figure 4.15 and 4.16). These channels are lengthy and appear intact. They were generally described as concrete-lined channels, 6 to 8 feet wide at bottom and 12 to 16 feet wide at top. From Figure 4.16, we estimate that the earthen sluice shown in the image has a depth of approximately 5-ft. The slope and actual length of each sluiceway remains to be measured. The concrete-lined channels might be further investigated to determine the feasibility of incorporating as a component of a fishway concept.

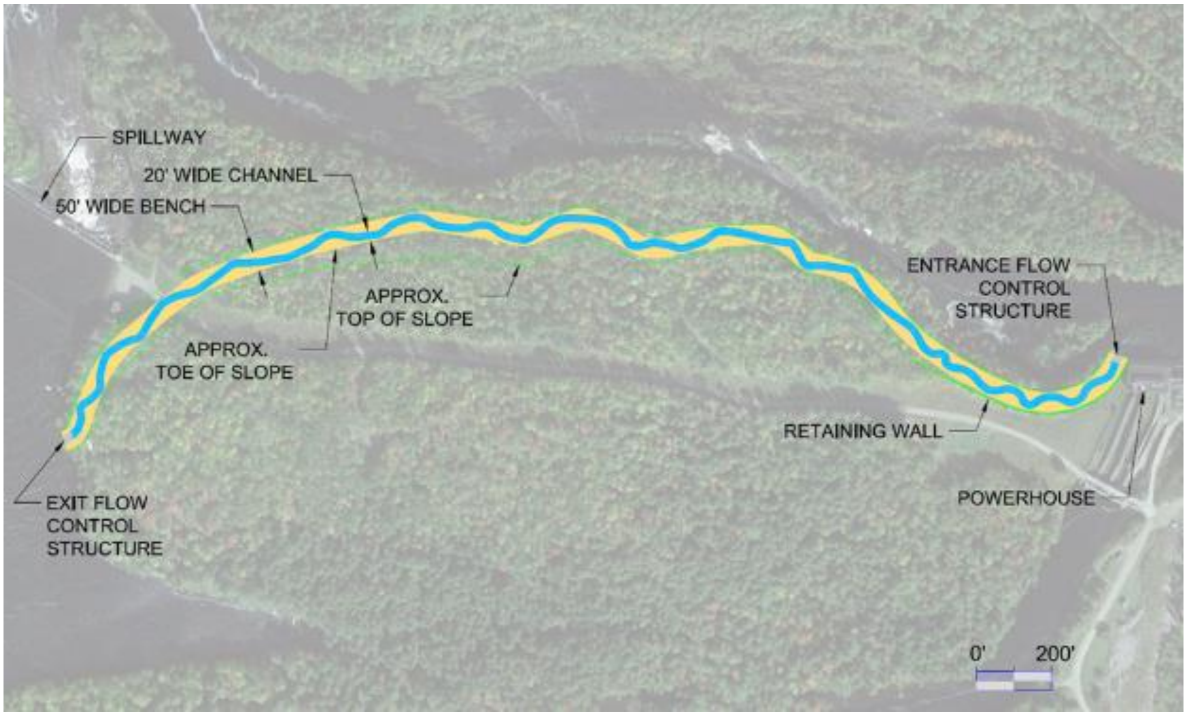


Figure 4.14. Conceptual Plan for NLF A at Grand Falls Powerhouse (Source: Alden Labs).

NLF A would have an entrance adjacent to the powerhouse discharge and follow the right bank of the bypass reach with an exit located about 300 ft upstream of the right spillway abutment (Figure 4.14). The design would emulate a natural stream channel with a sinuous alignment and roughened bed to dissipate energy. The NLF would be excavated from bedrock and constructed with irregular natural materials creating diverse hydraulic conditions intended for a wide variety of aquatic species. Pertinent design details of a NLF proposed for Grand Falls powerhouse include the following;

- Slope – 1.5%
- Excavated bench width ~ 50 ft
- Sinuous channel width – 20 ft
- Length – 3300 ft
- Flow rate – target 150 to 200 cfs over a range of head pond and design of a flow control structure
- Entrance channel velocity control structure
- Exit channel flow control structure
- Total assumed head – 49 ft

Advantages of NLF A include:

1) There is minor anticipated benefit for outmigrants passage because the exit of the NLF will be just to the southeast of Grand Falls Dam. Fishes following bulk flow to Grand Falls Dam during spillway releases may attract to the exit of the NLF and use it as a downstream fishway.
2) The option can pass eels and lamprey without a species dedicated passageway.
3) All of the property on which NLF-A would be located is owned by Woodland Pulp.

4) The shorter distance may reduce construction costs, depending on other identified site challenges.

5) The option may offer upstream and downstream passage.

Disadvantages of NLF-A include:

1) The slopes of this site have not been ground-truthed and the exact location of path of this alternative is unknown so that the construction costs of this alternative are difficult to determine.

2) The bank may include steep granite and earthen slopes which will increase the construction costs along with uncertainties of earthen dam stability affects on the Grand Falls Dam complex.

3) Space is limited on the right bank so that the length would be restricted to about 3,300 ft. which would raise the average slope to about 1.5% and possibly higher for short distances.

4) Some reconfiguration of the channel upstream of the entrance to NLF-A or berm construction may be necessary to ensure that migrants can successfully locate the entrance.

Engineering Considerations

Recommended slopes for NLF vary from 1.5% to 5% depending on the target species. A slope of 1.5% is proposed for Grand Falls based on Alden's experience with hydraulic modeling for similar projects and target species. The design should be evaluated with a hydraulic mode to confirm hydraulic conditions suitable for fish passage. Computational Fluid Dynamic (CFD) modeling is recommended as a design tool to optimize fish passage performance.

The proposed NLF would include an exit channel to control flow through the NLF near the target design flow of 150 to 200 cfs. This structure would include an isolation gate to shut the fishway down for maintenance and for the off season and could include a flow control gate, v-notch weir or vertical slot to control flow, depending on the level of flow control required. An entrance channel structure is recommended to create velocities that would attract upstream migrants. This entrance structure could include a velocity control gate or passive vertical slot.

The design of the NLF would require detailed topography survey of the bypass reach right bank along the proposed alignment. Soil borings to determine substrate, overburden depth and bedrock profile are also be needed. This information would be used to optimize the NLF alignment, refine design details and update construction cost estimates. The following is a list of studies that may be needed to execute the design:

- Existing conditions survey the project area
- Bathymetric survey of the tailrace and head pond
- Engineering inspections of existing infrastructure
- Geotechnical soil/ rock borings
- Evaluation of tailwater elevations using historic data if available or hydraulic analysis

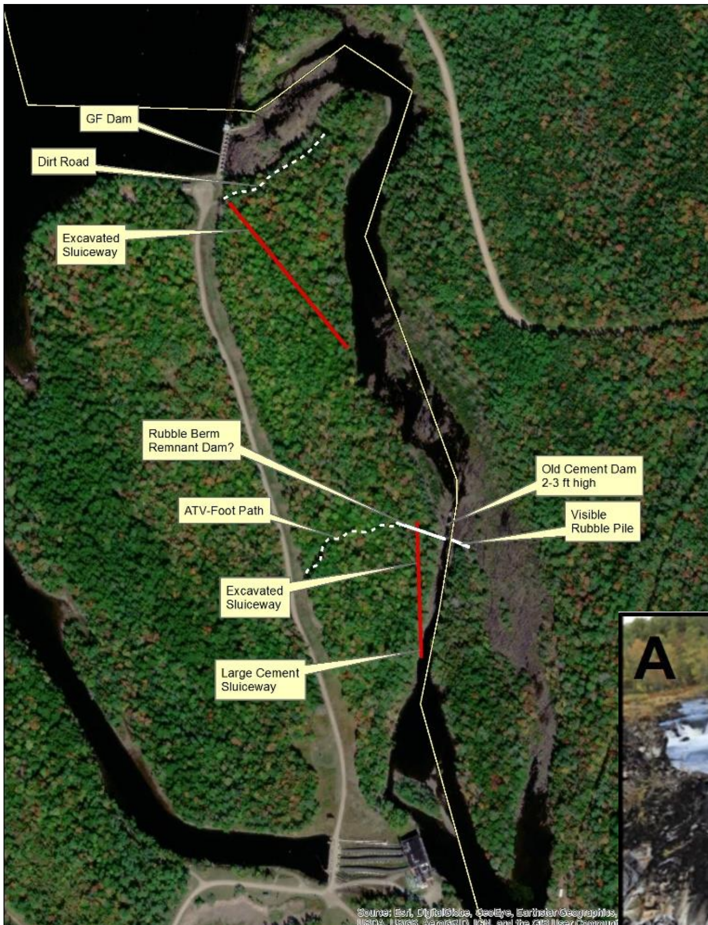


Figure 4.15 (Left). Aerial image of the tailwater of Grand Falls Dam showing various remnant logging features.

Note: Figure 4.15. on the right bank of significance to fish passage design. The original plans for Grand Falls Dam show the presence of three lowhead dams in the tailwater. The purpose of the lowhead dams is unknown. Close-up images of some of these features can be seen in the next figure (Credit: Bassett, 2020).

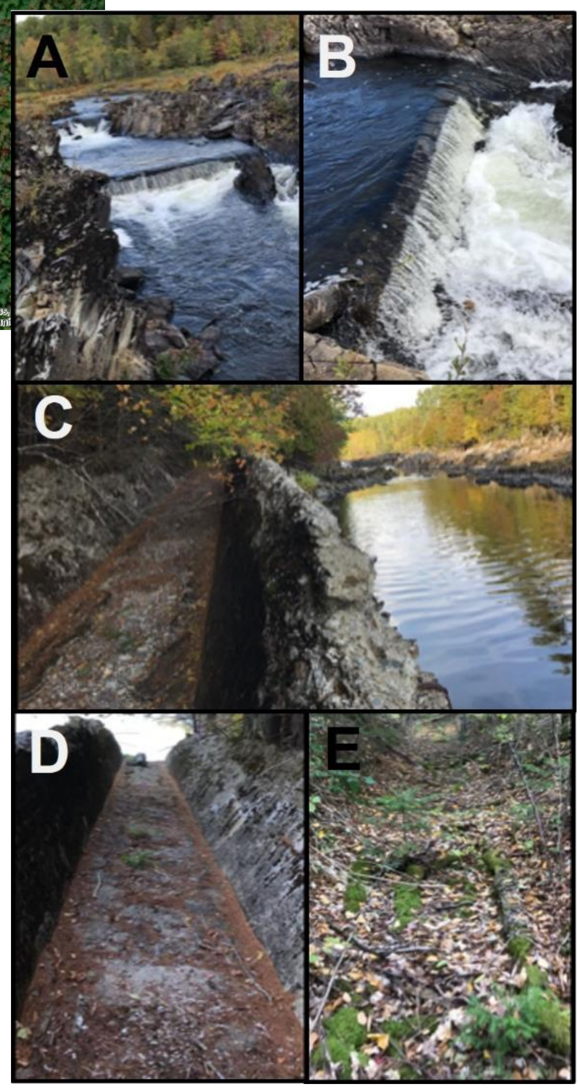


Figure 4.16 (Right). Photos of some of the features described in Figure 4.15.

Note: Figure 4.16. Images of significant features on the right bank of the tailwater downstream of Grand Falls Dam: One of three small dams having a head of 2.3 ft (A & B), log sluice next to the right channel of the St. Croix River, a concrete lined portion of the log sluice (D), and an excavated portion of the log sluice (E). (Credit: Bassett, 2020).

Construction Considerations
Construction of NLF A would be accessible from the Grand Falls dam access road from the upstream or downstream ends of the alignment. Cofferdams would be required for work in the tailrace and head pond. Construction will require substantial excavation and a detailed understanding of soil conditions and bedrock profile is needed to determine construction means and methods and to refine cost estimates. Bulk bedrock removal would be accomplished by drilling and blasting while detailed channel construction would be accomplished with hoe rams. For the purpose of the conceptual cost estimate the following conservative estimates of quantities were assumed;

- Rock excavation – 180,000 CY
- Soil (not rock) excavation – 60,000 CY
- Construction of the NLF is expected to take approximately 12 to 18 months

Operation and Maintenance
Depending on the design, NLF A would be operated either entirely passive (traditional NLF design with no active operation from gates) or with an entrance velocity control gate and an exit channel flow control gate. Active gates will improve the performance of the fishway by maintaining optimum design flow conditions within the NLF and by maximizing the likelihood of fish finding the entrance by maintaining an entrance jet. Gates will also allow the channel to be dewatered periodically for maintenance and debris removal. An operation and maintenance manual would detail recommended operating and maintenance requirements.

4.2.2 Downstream Passage

4.2.2.a Existing Rack with New Bypass
The existing intake bar rack at Grand Falls Powerhouse (Figure 4.17) may provide suitable exclusion of the target species depending on verified approach velocity conditions and rack clear spacing. Information reviewed indicates conflicting rack clear spacing and the approach velocity could not be calculated due to lack of complete design information for the existing intake bar rack. An approach velocity of less than 1.6 ft/sec would be sufficiently low enough to prevent risk of eel impingement (with a 0.75 inch clear spacing per FWS guidelines) and an approach velocity of less than 2 ft/sec would be suitable to prevent impingement of salmon, shad and herring downstream migrants (with a clear spacing of approximately 1 inch). This alternative assumes the existing rack meets these requirements and provides new downstream fish bypasses.

A new uniform acceleration surface weir would be installed on the left side of the intake (see Figure 4.17). The weir would be similar to the surface weir described for the Grand Falls Spillway, with a width of 4.7 ft., an entrance depth of 8.8 ft., and a weir crest depth of 4 ft. at normal water level. The bypass would transition from a rectangular cross section at the weir crest to a round 42-inch pipe downstream of the weir crest. The bypass pipe would discharge into the tailrace adjacent to the powerhouse near the existing fish ladder entrance. An additional bypass would be located in the middle of the rack mid-depth.

The new bypasses proposed for the existing rack would have the following features:

<u>Surface bypass (uniform acceleration weir (UAW))</u>

- Appropriate UAW geometry
- 8.8 ft. entrance depth
- 4 ft. weir crest depth (at normal water)

- 4.7 ft. crest width
- 15 ft. length
- Isolation gate or stoplogs
- Flow of 120 cfs at normal water

Mid-depth bypass

- Bypass opening within bar rack structure plane located at mid-depth
- 2 ft. width
- 6 ft. height
- Gated conveyance conduit to connect with surface bypass conduit
- Flow of 40 cfs at normal water

Bypass conveyance conduit

- 42-inch diameter smooth steel or fiberglass pipe
- Smooth surface with no protuberances and flush joints
- Minimum turning radii of 17.5 ft. (horizontal and vertical)
- Free surface flow conditions

Engineering Considerations

This alternative is dependent on the design of the existing intake rack, which is uncertain. A thorough review of the intake design is needed to verify the approach velocity conditions and to confirm the existing clear spacing.

The design of the surface bypass weir would require engineering inspections and accurate measurements of the existing intake structure, powerhouse and bypass piping route. An existing conditions survey is needed to identify all infrastructure that may interfere with the layout and to provide topography data. A survey of the tailwater area would be needed to verify adequate plunge pool depth.

The following is a list of studies needed to execute the design, depending on available information:

- Evaluation of existing rack design relative to entrainment and impingement risk of target species
- Existing conditions survey the project area
- Bathymetric survey of the tailrace and head pond
- Engineering inspections of existing infrastructure
- Geotechnical soil/ rock borings

Construction Considerations

Construction of the surface bypass would include installation of a bulkhead or sheet pile style cofferdams to install the surface and mid depth bypasses. Installation of the mid-depth bypass would require a review of construction techniques to minimize impacts to the hydropower project operation. Alternatives techniques to consider include partial reservoir drawdown, cofferdam to dewater the entire intake area or installation in-the-wet by divers.

Construction of the surface bypass weir is expected to take 4 to 6 months.

Operation and Maintenance

Operation and maintenance of the surface bypass would be similar to existing discharge structures at the dam. Periodic inspections would be needed to be sure bypasses are free of debris. The mid-level bypass would require periodic maintenance by divers to remove any debris within the intake.

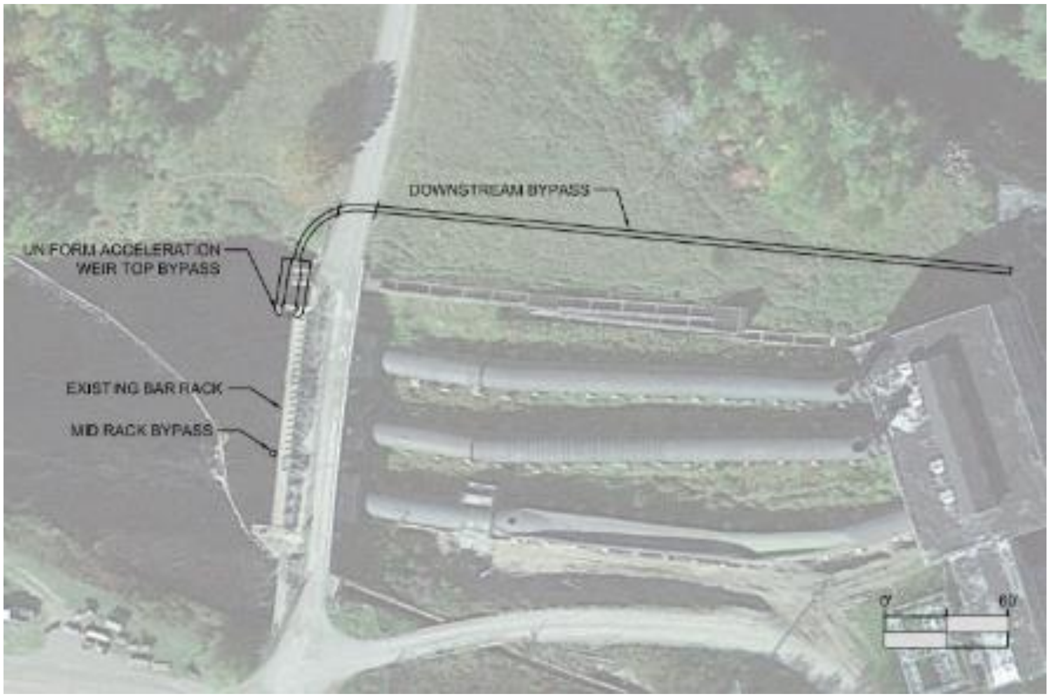


Figure 4.17. Conceptual plan for new bypasses added to the existing bar rack for Grand Falls Powerhouse (source: Alden Labs)

4.2.2.b New Bar Rack and Bypass

A new slightly inclined rack would be installed off of the existing intake with the intent to provide greater rack area to reduce approach velocity, if it is found that the existing approach velocities do not meet FWS guidelines (i.e., approach velocities < 1.6 ft/sec). Lowering approach velocity would reduce the risk of fish impinging on the rack. The new rack would be designed for an approach velocity of less than 1.6 ft./sec and a rack clear spacing of 0.75 inches. The rack would be inclined at a 20-degree angle from vertical spanning the entire width of the existing intake.

A downstream fish passage bypass would be located at the left side of the new bar rack (Figure 4.18). The bypass would consist of a new uniform acceleration surface weir with a width of 4.7 ft., entrance depth of 8.7 ft. and a weir crest depth of 4 ft. at normal water level. The bypass would transition from a rectangular cross section at the weir crest to a round 42-inch pipe. The bypass pipe would discharge into the tailrace adjacent to the powerhouse near the existing fish ladder entrance. An additional bypass would be located in the middle of the rack mid-depth.

The new bar rack and bypasses would have the following features:

<u>New bar Rack</u>

- 0.75-inch clear bar spacing
- Average velocity less than 1.6 ft./sec
- 20 degree inclined from vertical

<u>Surface bypass (uniform acceleration weir)</u>

- Alden weir geometry
- 8.7 ft. entrance depth
- 4 ft. weir crest depth (at normal water)
- 4.7 ft. crest width
- 15 ft. length
- Isolation gate or stoplogs
- Flow of 120 cfs at normal water

<u>Mid-depth bypass</u>

- Bypass opening within bar rack structure located mid-depth
- 2 ft. width
- 6 ft. height
- Gated conveyance conduit to connect with surface bypass conduit
- Flow of 40 cfs at normal water

<u>Bypass conveyance conduit</u>

- 42-inch diameter smooth steel or fiberglass pipe
- Smooth surface with no protuberances and flush joints
- Minimum turning radii of 17.5 ft. (horizontal and vertical)
- Free surface flow conditions

Engineering Considerations

This alternative is dependent on the design of the existing intake rack, which is uncertain. A thorough review of the intake design is needed to verify the approach velocity conditions.

The design would require engineering inspections and accurate measurements of the existing intake structure, powerhouse and bypass piping route. An existing conditions survey is needed to identify all infrastructure that may interfere with the bar rack and bypass layout and to provide topography data. A survey of the tailwater area would be needed to verify adequate plunge pool depth.

The following is a list of studies needed to execute the design, depending on available information:

- Evaluation of existing rack design relative to entrainment and impingement risk of target species
- Existing conditions survey the project area
- Bathymetric survey of the tailrace and head pond
- Engineering inspections of existing infrastructure
- Geotechnical soil/ rock borings

Construction Considerations

Construction of the new bar rack would require a cofferdam across the intake channel to dewater the intake area and perform construction in the dry. The rack would require a footing installed upstream of the existing intake.

Construction of the new bar rack and bypasses is expected to take 10 to 12 months.

Operation and Maintenance

Operation and maintenance of the new bar rack would be similar to the existing bar rack. The rack will require cleaning via a trash rake to keep clean and free of debris. Periodic inspections would be needed to be sure bypasses are free of debris. The mid-level bypass would require periodic maintenance by divers to remove any debris within the intake.

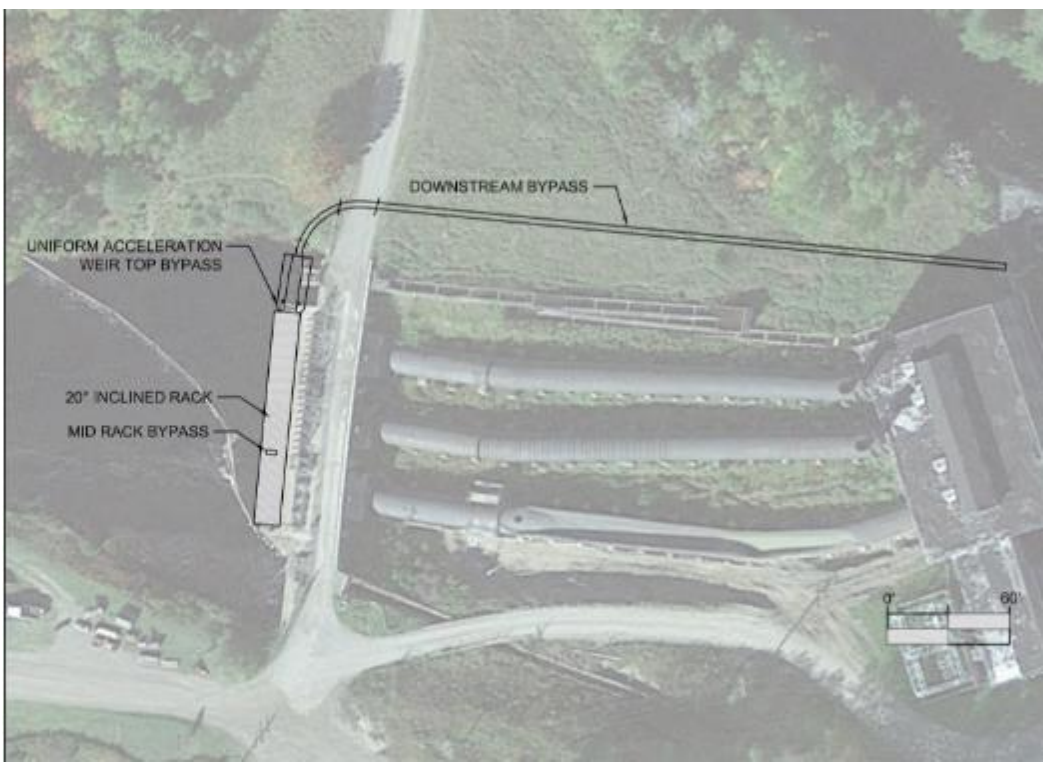


Figure 4.18. Conceptual plan for new bar rack and bypasses for Grand Falls Powerhouse (source: Alden Labs)

4.2.2.c Angled Bar Rack and Bypass

An angled bar rack (Figure 4.19) with an average approach velocity of 1.6 ft./sec or less would be an effective downstream passage technology for most target species (i.e., uncertain performance for juvenile Atlantic sea lamprey), at Grand Falls Powerhouse. This alternative would include the installation of a new angled rack structure immediately upstream of the existing intake as well as a new bypass routed from the downstream end of the rack to the tailrace. The rack would be oriented at a 45-degree angle to increase overall length, reduce the average rack velocity, and maximize guidance toward the bypass. The rack would consist of 0.25-inch wide by 3-inch deep bars with 0.75-inch clear spacing. A 15-ft. wide steel work deck would be installed above the rack to support a new automated trash rake.

A bypass would be located at the downstream end of the angled bar rack to convey fish to the tailrace. The bypass would consist of a new uniform acceleration surface weir with a width of 4.7 ft., entrance depth of 9.5 ft. and a weir crest depth of 4.8 ft. at normal water level. The bypass would transition from a rectangular cross section at the weir crest to a round 42-inch pipe. The bypass pipe would discharge into the tailrace adjacent to the powerhouse near the existing fish ladder entrance.

The angled rack and bypasses would include the following features:

<u>Angled bar rack</u>

- 0.75-inch clear bar spacing
- Average velocity less than 1.6 ft./sec
- Angled 45 degrees to approach flow
- 15 ft. wide work deck
- Automated trash rack

<u>Surface bypass (uniform acceleration weir)</u>

- Alden weir geometry
- 9.5 ft. entrance depth
- 4.8 ft. weir crest depth (at normal water)
- 4.7 ft. crest width
- 15 ft. length
- Isolation gate or stoplogs
- Flow of 160 cfs at normal water

<u>Bypass conveyance conduit</u>

- 42-inch diameter smooth steel or fiberglass pipe
- Smooth surface with no protuberances and flush joints
- Minimum turning radii of 17.5 ft. (horizontal and vertical)
- Free surface flow conditions

Engineering Considerations

The design would require engineering inspections and accurate measurements of the existing intake structure, powerhouse and bypass piping route. An existing conditions survey is needed to identify all infrastructure that may interfere with the bar rack and bypass layout and to provide topography data. Bathymetry surveys and soil borings are needed in the intake channel for the bar rack layout and additionally a survey of the tailwater area to verify adequate plunge pool depth.

The following is a list of studies needed to execute the design, depending on available information:

- Existing conditions survey the project area
- Bathymetric survey of the tailrace and head pond
- Engineering inspections of existing infrastructure
- Geotechnical soil/ rock borings

Construction Considerations

Construction of the new bar rack would require a cofferdam across the intake channel to dewater the intake area and perform construction in the dry. The rack would require a footing installed upstream of the existing intake.

Construction of the new bar rack and bypasses is expected to take 10 to 12 months.

Operation and Maintenance

Operation and maintenance of the new bar rack would be similar to the existing bar rack. The rack would be cleaned via a new automated trash rake to keep clean and free of debris. Periodic inspections would be needed to be sure bypasses are free of debris.

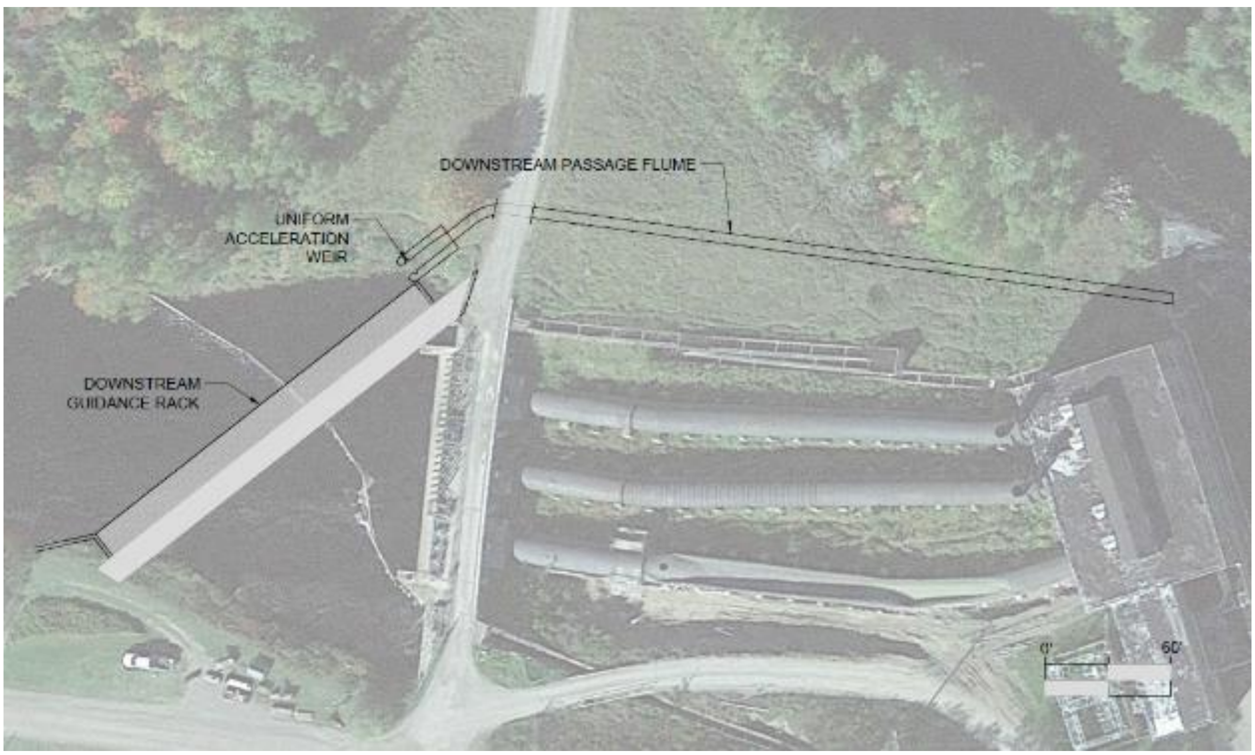


Figure 4.19. Conceptual plan for an angled rack and bypasses for Grand Falls Powerhouse (source: Alden Labs)

4.3 Woodland Dam and Powerhouse

4.3.1 Upstream Passage

4.3.1.a Fish Lift

A fish lift proposed for Woodland would have an entrance adjacent to the powerhouse discharge, similar to the existing Denil ladder entrance location (Section 2.4.3). The lift would include a constant velocity entrance gate, entrance channel, Vee trap, hopper, exit pipe and an attraction water system (AWS) (Figures 4.20 and 4.21). The AWS would provide attraction flow to the fish lift via an intake weir in the impoundment that could also be used as a downstream passage bypass. Pertinent design details of the proposed fish lift include the following:

- Operating range:
    - River flows between 95% and 5% river flow exceedance
- Entrance:
    - 6- to 12-inch drop
    - 8 ft. width
    - Hinged flap gate automated to track tailwater levels to provide a constant entrance velocity
- Entrance channel:
    - 12 ft. wide
    - Vee trap
- Hopper:
    - 490 ft^3, 3665 gal
    - Two-sided brail – no crowder
    - 30 TN hoist
    - 15 min cycle time
- Exit flume:
    - 20-inch smooth fiberglass pipe
    - 5% slope
- Attraction water system (AWS):
    - Flow: 5% of station capacity, ~ 165 cfs
    - Uniform acceleration weir
    - Wedge wire screen

Engineering Considerations

The design of the fish lift would require a thorough review of available design information for the existing infrastructure to identify data gaps. Limited information was made available for this current study. Depending on the review of available data, various field investigations would be needed to map existing pipelines, utilities and infrastructure, conduct geotechnical soil borings and bathymetry surveys. Results of these studies will determine available routing for piping and inform design requirements. In addition, a thorough understanding of the head pond and tailrace hydraulics is needed to properly site the fishway entrance and exit flume discharge location. The following is a list of studies that may be needed to execute the design, depending on available information:

- Existing conditions survey of the island and adjacent area to identify all structures and features in the project area
- Bathymetric survey of the tailrace and head pond

- Engineering inspections of existing infrastructure
- Geotechnical borings
- Electrical load study
- Historic review of tailwater elevations or 1 dimensional HEC-RAS modeling
- Entrance location performance studies (may include existing location or alternatives like the end of the island, downstream of the current location).

Construction Considerations

The location of the proposed fish lift on the island between the powerhouse and spillway is congested with existing infrastructure and poses many construction and site access challenges. Thorough field investigations are needed to identify all existing infrastructure that may be impacted during construction.

Construction would take place in the dry, with use of cofferdams to dewater the area for demolition of portions of the existing fish ladder that interfere with the fish lift footprint and to excavate and pour the base concrete structure. Steel sheet pile style cofferdams could be considered to minimize the dewatered area and to allow some hydropower units to operate during construction or the entire tailrace could be dewatered. An earthen cofferdam, doubling as an access road to the island, was assumed for the cost estimates. The access road would extend from shore, parallel and upstream of a pipeline crossing to the tip of the island.

The location of the switchyard and high voltage power lines on the island constrain operation of a crane to build the facility. A close review of construction techniques and potential crane pad locations that can safely access the site is warranted during the design phase of the project to assure feasible constructability.

Construction of the fish lift is expected to take 12 to 18 months depending on river and weather conditions.

Operation and Maintenance

Similar to the fish lift described for Grand Falls, the Woodland lift would be operated by a programmable logic controller, (PLC) and accompanying operator interface terminal (OIT) touch screen. The PLC would operate the various components in sequence for a fish lift cycle and display progress on the OIT. An example of component actions for a fish lift cycle is provided for the Woodland fish lift alternative.

The entrance gate would be controlled by the PLC to maintain a constant water surface differential at the entrance. In addition, the AWS would include flow control valves to vary attraction flow to the fish lift. During normal operation the facility would require personnel to oversee operations to ensure the system is free from debris and ensure appropriate hydraulic conditions throughout the fish lift entrance flume, entrance gate and exit pipe.

The various mechanical components of the fish lift require maintenance and periodic repairs to keep the facility in good working condition. An operation and maintenance manual developed specifically for the facility would detail recommended maintenance and spare parts to keep on hand. Approximately one week would be needed to winterize the facility for the off-season and two weeks to start the facility up in the spring and to perform any necessary repairs.

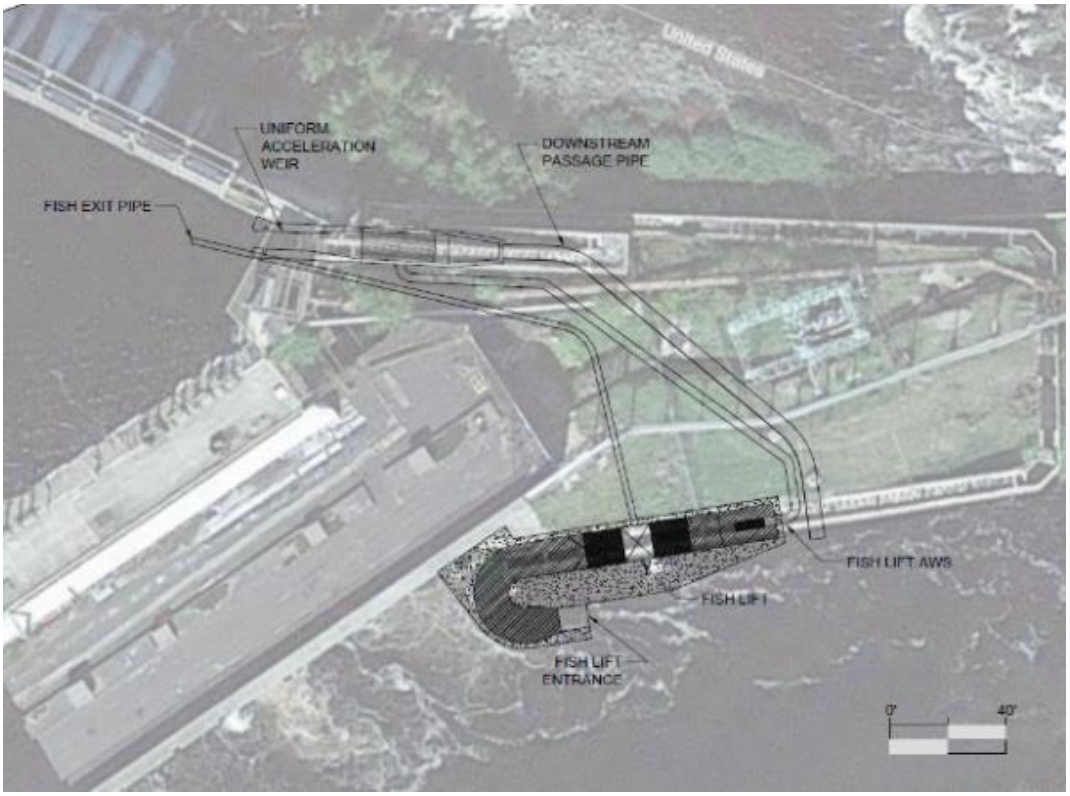


Figure 4.20. Conceptual plan for a fish lift at Woodland (source: Alden Labs)

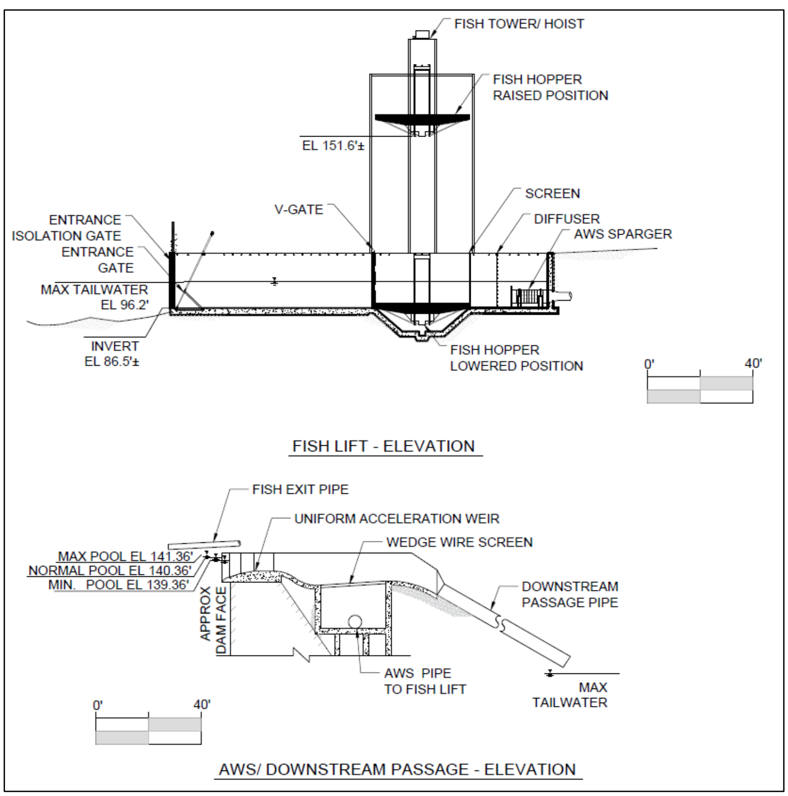


Figure 4.21. Conceptual sections for a fish lift at Woodland (source: Alden Labs)

4.3.2 Downstream Passage

4.3.2.a Existing Rack and New Bypass

The existing intake bar rack at Woodland may provide suitable exclusion of the target species depending on verified approach velocity conditions and bar rack clear spacing. Information reviewed indicates conflicting information for the existing bar rack clear spacing, with both 0.75 inch and 1.0 inch clear spacing reported in separate documents. A clear spacing of 0.75 inches would be required to exclude American eel, and 1.0 inch would be required to exclude salmon, shad and herring, based on FWS 2019 guidelines. In addition, the approach velocity could not be verified due to lack of complete design information for the existing intake bar rack. An approach velocity of less than 1.6 ft/sec would be sufficiently low to prevent risk of eel impingement, and an approach velocity of less than 2 ft/sec would be suitable to prevent impingement of salmon, shad and herring downstream migrants. This alternative assumes the existing rack meets these requirements and provides new downstream fish bypasses.

A new uniform acceleration surface weir (Figure 4.22) would be installed on the left side of the intake in the approximate location of the existing Denil ladder exit channel (Section 2.4.3). The bypass surface weir would have an entrance width of 4.7 ft., an entrance depth of 8.8 ft., and a weir crest depth of 4 ft. at normal water level. The bypass would transition from a rectangular cross section at the weir crest to a round 42-inch pipe. The bypass pipe would discharge into the tailrace adjacent to the powerhouse near the existing fish ladder entrance. An additional bypass would be located in the middle of the rack mid-depth.

The new bypasses proposed for the existing rack would have the following features:

<u>Surface bypass (uniform acceleration weir)</u>

- Alden weir geometry
- 8.8 ft. entrance depth
- 4 ft. weir crest depth (at normal water)
- 4.7 ft. crest width
- 15 ft. length
- Isolation gate or stoplogs
- Flow of 120 cfs at normal pool level depth

<u>Mid-depth bypass</u>

- Bypass opening within bar rack structure plane located at mid-depth
- 2 ft. width
- 6 ft. height
- Gated conveyance conduit to connect with surface bypass conduit
- Flow of 40 cfs at normal water

<u>Bypass conveyance conduit</u>

- 42-inch diameter smooth steel or fiberglass pipe
- Smooth surface with no protuberances and flush joints
- Minimum turning radii of 17.5 ft. (horizontal and vertical)
- Free surface flow conditions

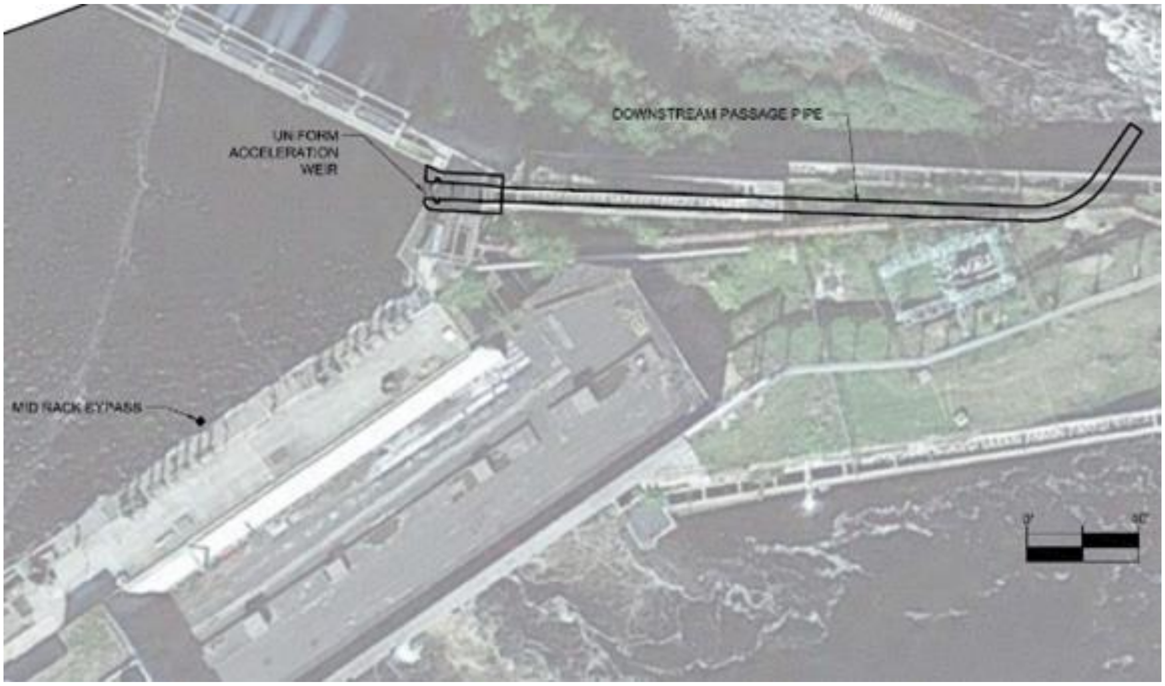


Figure 4.22. Conceptual plan for new bypasses added to the existing bar rack for Woodland (source: Alden Labs)

Engineering Considerations

This alternative is dependent on the design of the existing intake rack, which is uncertain. A thorough review of the intake design is needed to verify the approach velocity conditions and to confirm the existing clear spacing.

The design of the new bypasses would require engineering inspections and accurate measurements of the existing intake structure, powerhouse and bypass piping route. An existing conditions survey is needed to identify all infrastructure that may interfere with the layout and to provide topography data. A survey of the tailwater area would be needed to verify adequate plunge pool depth.

The following is a list of studies needed to execute the design, depending on available information:

- Evaluation of existing rack design relative to entrainment and impingement risk of target species
- Existing conditions survey of the island and adjacent area to identify all structures and features in the project area
- Bathymetric survey of the tailrace and head pond
- Engineering inspections of existing infrastructure
- Geotechnical soil/ rock borings

Construction Considerations

Construction of the new surface and mid-level bypasses include routing the bypass pipe through the island between the powerhouse and spillway, which is congested with existing infrastructure and poses many constructability challenges. Thorough field investigations are needed to identify all existing infrastructure that may be impacted during construction.

Construction of the surface bypass would include installation of a bulkhead or sheet pile style cofferdams to install the surface and mid-depth bypasses. Installation of the mid-depth bypass would require a review of construction techniques to minimize impacts to the hydropower and mill operations. Alternative techniques to consider include partial reservoir drawdown, cofferdam to dewater the entire intake area, or installation in-the-wet by divers. Floating work platforms, boats, and barges would be needed for access and to transport prefabricated components and construction materials to the intake and surface weir location.

Special care and review of construction techniques and access is needed for the installation of the bypass conduit routed through the island, considering the location of the switchyard and high voltage power lines on the island.

Construction of the surface bypass weir is expected to take 6 to 8 months.

Operation and Maintenance

Operation and maintenance of the surface bypass would be similar to existing discharge structures at the dam. Periodic inspections would be needed to be sure bypasses are free of debris. The mid-level bypass would require periodic maintenance by divers to remove any debris within the intake.

4.3.2.b New Bar Rack and Bypass

A new slightly inclined rack would be installed off the existing intake with the intent to provide greater rack area to reduce approach velocity, if it is found that the existing approach velocities do not meet FWS guidelines (i.e., approach velocities < 1.6 ft./sec). Lowering approach velocity would reduce the risk of fish impinging on the rack. The new rack would be designed for an approach velocity of less than 1.6 ft./sec and a rack clear spacing of 0.75 inches. The rack would be inclined at a 30-degree angle from vertical spanning the entire width of the existing intake.

A downstream fish passage bypass would be located at the left side of the new bar rack (Figure 4.23). The bypass would consist of a new uniform acceleration surface weir with a width of 4.7 ft., entrance depth of 8.7 ft. and a weir crest depth of 4 ft. at normal water level. The bypass would transition from a rectangular cross section at the weir crest to a round 42-inch pipe. The bypass pipe would discharge into the tailrace adjacent to the powerhouse near the existing fish ladder entrance. An additional bypass would be located in the middle of the rack mid-depth.

The new rack and bypasses would have the following features:

<u>New Bar Rack</u>

- 0.75-inch clear bar spacing
- Average velocity less than 1.6 ft./sec
- 30 degree inclined from vertical

<u>Surface bypass (uniform acceleration weir)</u>

- Alden weir geometry
- 8.7 ft. entrance depth
- 4 ft. weir crest depth (at normal water)
- 4.7 ft. crest width
- 15 ft. length
- Isolation gate or stoplogs
- Flow of 120 cfs at normal water

<u>Mid-depth bypass</u>

- Bypass opening within bar rack structure plane located mid-depth
- 2 ft. width
- 6 ft. height
- Gated conveyance conduit to connect with surface bypass conduit
- Flow of 40 cfs at normal water

<u>Bypass conveyance conduit</u>

- 42-inch diameter smooth steel or fiberglass pipe
- Smooth surface with no protuberances and flush joints
- Minimum turning radii of 15 ft. (horizontal and vertical)
- Free surface flow conditions

Engineering Considerations

This alternative is dependent on the design of the existing intake rack, which is uncertain. A thorough review of the intake design is needed to verify the approach velocity conditions.

The design would require engineering inspections and accurate measurements of the existing intake structure, powerhouse and bypass piping route. An existing conditions survey is needed to identify infrastructure that could interfere with the bar rack and bypass layout, and to provide topographical data. A survey of the tailwater area would be needed to verify adequate plunge pool depth.

The following studies are needed to execute the design, depending on available information:

- Evaluation of existing rack design relative to entrainment and impingement risk of target species
- Existing conditions survey of the island and adjacent area to identify all structures and features in the project area
- Bathymetric survey of the tailrace and head pond
- Engineering inspections of existing infrastructure
- Geotechnical soil/rock borings

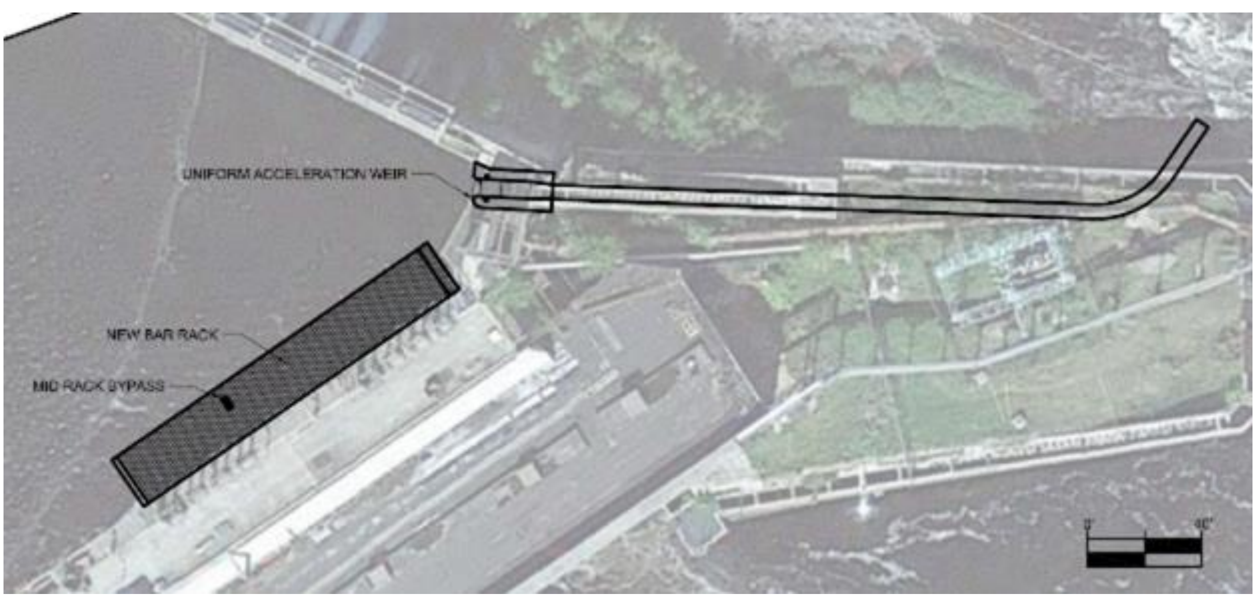


Figure 4.23. Conceptual plan for a new bar rack and bypasses for Grand Falls Powerhouse (source: Alden Labs)

Construction Considerations

Construction of the new bar rack and bypasses include routing the bypass pipe through the island between the powerhouse and spillway, which is congested with existing infrastructure and poses many constructability challenges. Thorough field investigations are needed to identify all existing infrastructure that may be impacted during construction.

Construction of the new rack and bypasses would include installation of a sheet pile style cofferdam to dewater the intake to install the new bar rack and bypasses. A review of construction techniques to minimize impacts to the hydropower and mill operations is warranted. Alternative techniques to consider include partial reservoir drawdown, cofferdam to dewater the entire intake area, or installation in-the-wet by divers. Floating work platforms, boats, and barges would be needed for access and to transport prefabricated components and construction materials to the construction site.

Special care and review of construction techniques and access is needed for the installation of the bypass conduit routed through the island, considering the location of the switchyard and high voltage power lines on the island.

Construction of the surface bypass weir is expected to take 10 - 12 months.

Operation and Maintenance

Operation and maintenance of the new bar rack would be similar to the existing bar rack. The rack requires cleaning via a trash rake to remain clean and free of debris. Periodic inspections would also be needed to be sure the bypasses are free of debris. The mid-level bypass would require periodic maintenance by divers to remove any debris within the intake.

4.4 Probable Construction Costs

Order-of-magnitude cost estimates (Cost Opinions) were developed for alternatives that were determined to have potential for application at Grand Falls and Woodland (Table 4.1). These costs, which reflect installation, were estimated using material quantities and labor estimates developed from the conceptual designs and from Alden's database of similar projects. Unit cost information is based on published materials and labor costs (RSMeans 2019) from projects of similar size and scope, adjusted for inflation and location, and on best judgment. These estimated costs allow a comparison of the cost differences among alternatives. Cost opinions were created assuming a Class 4 level estimate as defined by the Association of Advancement of Cost Engineering (AACE). A Class 4 estimate assumes a project definition of 1% to 15%, used for comparative screening of alternatives with a typical accuracy range of -30% to +50% (AACE 2005). This is in line with the conceptual level of design presented in this report.

The estimated costs are based on the following assumptions:

- Prices and fully contracted labor rates as of July 2020.
- Forty-hour workweek with single-shift operation for construction activities that do not impact plant operations; and, fifty-hour workweek with double-shift operation for construction activities that would impact plant operations.
- Direct costs for material and labor required for construction of all project features. The direct costs include overhead and profit (O&P). O&P for the installing contractor are included in the RS Means O&P rates and assumed as 10% of the materials, labor, and equipment costs where applicable.
- Mobilization and demobilization costs are costs associated with transportation of the installing contractor's personnel, equipment, and operating supplies to and from the site. These costs were included in the direct costs and estimated as 10% of the costs for material and labor, including overhead and profit for the installing contractor.
- Distributable costs are expenditures that are not associated with any specific direct cost and can include the following: site non-manual supervision, temporary facilities, equipment rental, and support services incurred during construction. These costs have been taken as 15% of the direct costs for each alternative, excluding mobilization and demobilization.
- Indirect costs include labor and related expenses for engineering services to prepare drawings, specifications, and design documents. Indirect costs have been taken as 10% of the direct and distributable costs for each alternative.
- Allowance for indeterminants and contingency covers uncertainties in design and construction at this preliminary stage of study. The allowance for indeterminants and contingency is a judgment factor added to estimated figures to complete the final cost estimate, while still allowing for other uncertainties in the data used in developing these estimates, to account for possible additional costs that may develop but cannot be predetermined (e.g., labor difficulties, delivery delays, weather). The budget allowance for indeterminants and contingency has been taken as 25% of the direct, distributable, and indirect costs of each alternative.
- Administrative cost for the management of the oversite and management of the project has been calculated as 10% of the total project cost.

- NLF CN, order of magnitude estimated cost ranges included an assumed slope (~1.3%), an average width of 20 ft. and channel depth of 2.5 ft. (Burke 2021).

The project costs do not include the following items that are typically needed to obtain total capital cost estimates:

- Costs to perform additional engineering and biological laboratory or field studies that may be required, including: bathymetric, topographic, hydraulic modeling, geotechnical, geomorphological, seismic soil sampling, habitat assessments and fish migration and abundance studies.
- Permitting costs.
- Soil sampling, and wetlands delineation and mitigation.
- Costs to dispose of any hazardous or non-hazardous materials that may be encountered during excavation and dredging activities.
- Owner administration of project contracts and for engineering and construction management.
- Price escalation.

Table 4.1. Estimated construction costs for selected site concepts

Site	Migration	Alternative	Preliminary Construction Cost[1]
Grand Falls Spillway	Upstream	Vertical slot ladder	$7,185,000
	Downstream	Surface bypass weir	$1,362,000
		Remove section of flashboards	$31,000
		Tainter gate modifications	$200,000
Grand Falls Powerhouse	Upstream	Fish Lift	$11,059,000
		Vertical slot ladder	$7,642,000
		Nature-like Fishway (NLF CN)	$6M to $11.5M
		Nature-like Fishway (NLF US)	$15M to $30M
	Downstream	Existing rack & new bypass	$1,786,000
		New bar rack & bypass	$3,470,000
		Angled bar rack & bypass	$7,169,000
Woodland	Upstream	Fish Lift	$14,446,000
	Downstream	Existing rack & new bypass	$2,212,000
		New bar rack & bypass	$3,802,000

Note 1 – dependent on rock excavation quantities, unit pricing, and assumptions stated in Section 4.4

5 CONCEPT SUMMARIES, UNCERTAINTIES, AND RECOMMENDATIONS

This study represents an exploratory concept evaluation and selection of potential fish passage options at two Woodland Pulp LLC facilities on the lower mainstem of the St. Croix River. The research and analysis produced a site-specific list of upstream and downstream fish passage alternatives for Grand Falls Dam, Grand Falls Powerhouse and the Woodland Dam and Powerhouse. The evaluation process included a three-tiered screening process: preliminary, secondary and tertiary. The preliminary screening process identified fish passage technologies appropriate for the target species, while the secondary screening process considered applicability of those remaining technologies for the site characteristics (primarily total head and design populations). The secondary screening was also the platform used to systematically obtain technical input from the St. Croix River Workgroup and a range of regional technical experts and other project partners. The final, tertiary screening process considered the various configurations (alternatives) of technologies that passed the secondary screening process. Detailed evaluations, conceptual designs and cost estimates were developed for the alternatives identified in tertiary screening. The overall assessment identified promising alternatives, considering the selected target species, expected biological performance and site constraints, as described below:

5.1 Grand Falls Dam

Upstream Passage Alternatives

- Vertical slot fish ladder around the right dam abutment

Prior to considering upstream passage at Grand Falls dam, an evaluation of river passage conditions between the spillway and powerhouse should be conducted. The bypass reach includes remnant barrier dams that may currently impede passage.

Downstream Passage Alternatives

- Surface bypass weir (uniform acceleration weir) on spillway
- Remove section of flashboards
- Tainter gate modification with bypass weir

The surface bypass weir alternative involves notching the spillway to accommodate a uniform acceleration weir. Although this alternative is expected to provide the best performance, it requires civil/structural modifications to the existing dam that need to be evaluated, because the existing Ambursen style dam may not easily accommodate these changes. Notching the dam would not be needed if the flashboards elevate the water surface two or more feet above the concrete crest of the dam. In this case, the uniform acceleration weir could be installed directly on the crest of the dam and tied into the system of flashboards.

5.2 Grand Falls Powerhouse

Upstream Passage Alternatives

- Fish lift with entrance in vicinity of existing fish ladder
- Vertical slot fish ladder with entrance in vicinity of existing fish ladder
- Nature-like fishways

- Grand Falls Brook Route (Canadian side)
- New construction (US side)

<u>Downstream Passage Alternatives</u>

- Existing bar rack with new downstream bypasses
- New bar rack (slightly larger) with bypasses
- Angled bar rack and bypass

The design of the existing trash rack needs to be verified to determine if the existing rack adequately mitigates risk of entrainment and impingement (with the addition of bypasses), considering the approach velocity and rack clear spacing.

5.3 Woodland Powerhouse

<u>Upstream Passage Alternatives</u>

- Fish lift with entrance in vicinity of existing fish ladder

Given the head space available and target species, a fish lift is considered the only viable alternative for the Woodland project. Further review of the existing infrastructure is needed to determine viable routing for the fish exit and attraction water piping. A review of the discharge location of the exit pipe is warranted to limit risk of fall back, considering the vicinity of the Tainter gates.

<u>Downstream Passage Alternatives</u>

- Existing bar rack with new downstream bypasses
- New bar rack (slightly larger) with bypasses

Similar to Grand Falls, the design of the existing trash rack needs to be verified to determine if it adequately mitigates risk of entrainment and impingement with the addition of downstream passage bypasses. Consideration of alternatives to the existing rack should be viewed in the context of total project survival and incremental benefits of the alternatives considered.

5.4 Uncertainties and Risks

There are two major uncertainties that could have implications for the recovery of target migratory fishes. The first and most potentially severe is associated with the conveyance channel that conveys flow to the Grand Falls Powerhouse. This channel could become an ecological trap for upstream migrating fishes following the bulk flow toward the powerhouse. Preliminary analyses indicate that the average maximum water velocity in the channel of 1.7 fps exceeds the 1.0 fps sustained swimming speed of juvenile alosines. Emigrants that enter the conveyance channel may be trapped in the channel if the bypass system becomes inoperable because they lack the swimming speed to return to the main body of the reservoir. The possibility that the conveyance channel may become an ecological trap if the bypass system becomes inoperable should receive further study. Contingencies such as a reduction in powerhouse discharge to a level that reduces the velocity of the channel below the sustained swimming speed of juvenile should be considered.

The second major uncertainty is associated with the part of Woodland Dam where the powerhouse, spillway, upstream bypass exit, and downstream bypass entrance all converge in close proximity within head pool. The simultaneous operation of the spillway and powerhouse will result in the potential of high water velocities and complex hydraulic patterns that can negatively impact immigrants. Immigrating fishes may be blocked from continuing their upstream migration through Woodland Flowage, fall back to the tailrace through the spillway or turbines, or impinge on the surface of a structural barrier. This zone should be further evaluated with CFD modeling under a variety of hydrologic conditions and project operations that could be expected during the upstream migration season to determine how migrating fishes could be affected.

In addition to the uncertainties described in the previous two paragraphs, there are a number of further unknowns that add risk to the successful selection of optimum passage alternatives. Surprisingly, there are conflicts within the data that was used for alternatives identification and evaluation. For example, the maximum powerhouse discharge reported for Grand Falls Dam varies from 2,700-3,400 cfs, depending upon the source of information. Uncertainty over powerhouse discharge affects estimation of attraction flows for upstream bypasses (usually set at 5% of maximum powerhouse discharge), accurate calculations of water velocities to evaluate the potential for entrainment and impingement, and development of useful CFD modeling scenarios to help guide alternatives design. Additionally, there is conflict in the clear space between slats of the trash racks: divers retained by Woodland Pulp reported a clear space of 1.0 inches between slats, whereas summaries of the dam list a clear space of 0.75 inches. These alternate clear spaces between slats likely limit width range of adult post-spawn alosines. The uncertainty in clear space width may affect the selection of the existing trash rack as a preferred alternative.

5.5 Recommended Studies and Next Steps

The following list summarizes several important findings of this study. These considerations and characterizations are intended to assist in effective and successful fish passageway selection, design and implementation:

As a concept study, analysis was based on available data and site-specific information, some of which was missing due to the age of the facilities. Key information and data gaps are further detailed in the discussions of Sections 3, 4 and 5. Although not comprehensive for this concept study, recommended next steps are included for filling some large data needs for further concept planning. These recommended studies are grouped in general categories for organization purposes as follows:

Grand Falls Dam and Grand Falls Powerhouse

1) For downstream migrating (outmigrants) fishes within the powerhouse conveyance channel upstream of the **Grand Falls Powerhouse**, the calculated water velocities within the conveyance channel exceed those of sustained swimming speeds of juvenile target species, creating a potential velocity trap. **Actual velocities within the conveyance channel should be measured and assessed** under a range of pool levels and operating conditions. Models may also be able to generate velocity estimates and outcomes.

2) Actual **discharge flows at Grand Falls Powerhouse should be measured** to clarify existing attraction flow conditions as well as support improved concept options.

3) **Nature-Like Fishways** (NLFs) appear to be an attractive method to bypass upstream migrants **at Grand Falls Dam**. Although we were unable to make firm recommendations for potential NLF designs due to a lack of site-specific data, we recommend that **detailed field surveys** be conducted to establish the alignment, constructability, attraction and head pond controls, so that more specific determinations of NLF design viability can be made. Field reconnaissance can form a supplemental

phase of research to help **solidify recommendations regarding the suitability of NLFs at the study sites**.

Woodland Dam and Powerhouse

4) At **Woodland Dam**, the powerhouse, spillway, upstream bypass exit, and downstream bypass entrance converge in close proximity. The simultaneous operations of the spillway and powerhouse may result in high **water velocities and complex hydraulic patterns** likely to confuse and potentially exhaust upstream migrating fishes. The area **should be modelled**, using tools such as computational fluid dynamics (CFD), under a range of pool levels and operating conditions, to better characterize how upstream fishes may be affected by the site designs and operations.
5) The **intake racks at Woodland Dam should be remeasured**. The larger measurements, which may be in error, suggest that post-spawned alosines may become entrained within the intakes, which would alter the selection of using existing intake racks as a concept alternative for downstream passage.

Both Facilities

6) The **existing site data are not sufficiently accurate to differentiate some alternatives**, and generally insufficient to develop detailed engineering criteria to support design options. The addition of **a rigorous preliminary engineering phase is needed** to systematically identify data needs for final engineering design of probable alternatives.
7) **CFD modeling of forebay and tailrace hydraulic conditions would improve site understanding of flow and velocity patterns** for concept design (e.g., proper placement of fish ladder entrances) and facility operations (e.g., identifying special operations to avoid excess velocities during outmigration) alternatives.
8) Legacy submerged (relict) dam and other flow diversion structures may exist above the Woodland and Grand Falls facilities, in addition to downstream of key flow routes of both facilities. Site reconnaissance conducted in 2020 found several, relict, low-head dams between Grand Falls Dam and the powerhouse, and other undocumented structures may exist as well. **Surveys that document and describe submerged structures are needed to support upstream and downstream design concepts at both facilities**.
9) **Facility-specific surveys and economic analyses are needed for both facilities** to better understand and quantify equipment, operational and maintenance commitments, and investments as well as benefits and risks of the proposed concepts. Data generated by this study would support the selection of proposed concepts using economic-driven discussions of alternatives.
10) A **total project survival study should be completed** for downstream passage at each facility to support the selection of downstream passage systems. This study will require estimates of fish number and survival through each of the possible passage route (i.e., turbine, bypasses, spillways), for various river flow conditions. Project survival estimates can then be measured against a range of acceptable plant operations, as well as potential fish passage investments using incremental benefits analysis. The projected fish survival rates could then be compared to total costs for each passageway concept.
11) Some upstream passage alternatives place entrances near the foot of the dam, yet uncertainty remains about main passage routes and the ability of upstream migrating fishes to swim up falls located in the immediate vicinity of the dams. We recommend that **monitoring studies (e.g.,**

telemetry) be conducted to determine the dominant upstream path lines, potential barriers (natural and constructed) and upper endpoints of target fishes.

12) Species-specific pathway preferences for downstream passage are uncertain at both facilities, causing ambiguities surrounding the likely performance of proposed concepts based on existing conditions. **Telemetry studies of key migrating species would greatly improve the understanding and selection of best-practice concept alternatives for downstream migrants**.

Watershed Level

13) **Flow duration curves for key migration periods of May, June and July should be developed** to better understand site operations and passageway flow capacity options.
14) Climate change models suggest ongoing alteration of precipitation patterns, including changes in timing, magnitude, and duration of flows, which may reduce the reliability of historical values used to predict passageway option efficacy and future operations. **St. Croix River precipitation models should be developed to better predict** timing, magnitude, **and duration of flows and potential effects on available habitats** for target population predictions.

Species/Population – Specific

15) Developing diadromous population target estimates is a complex multidisciplinary task. Establishing population estimates within the St. Croix River should be a bi-national, multi-stakeholder effort. **Bi-national efforts that support future, target species population planning, and goal setting** would help assess near-term passage solutions and costs against long-term goals for the St. Croix River watershed.

1) **Lamprey and eel passageway options should be further investigated for regional effectiveness**, as Pacific lamprey and sea lamprey (Atlantic) may have differing performances and capability requirements.

The lower mainstem of the St. Croix River provides an important conduit for a complex mix of social, economic and environmentally important resources within the watershed. This study benefited from the work of many resource managers, researchers, tribal partners, and other stakeholders from U.S. and Canada as a concept assessment of fish passage at the two Woodland Pulp facilities. The results offer valuable preliminary and foundational evaluation of options for fish passage for the improvement of populations of diadromous fishes, which play a key role in ecosystem, cultural and management importance within the St. Croix watershed.

The contracting authors would like to express appreciation for the support of project partners amid the challenges associated with defining guiding opportunities to support the St. Croix River ecosystem and community while balancing the many values shared by diverse watershed stakeholders. We appreciate the input and discussions with the many regional experts and stakeholders throughout the study along with the associated reference material provided.

REFERENCES

Ajmani, A. 2018. Fish Conveyance and Migration in the International St. Croix River. Prepared for the IJC by Sipayik Environmental Department, Passamaquoddy Tribe at Pleasant Point.

Altenritter, M, E. Barbin-Zydlewski, G. M. T. Kinnison, J. D. Zydlewski, G. S. Wippelhauser. 2017. Understanding the basis of shortnose sturgeon (*Acipenser brevirostrum*) partial migration in the Gulf of Maine. *Canadian Journal of Fisheries and Aquatic Sciences*. 00: 1–10 (0000) dx.doi.org/10.1139/cjfas-2017-0083.

Anonymous. 1988. Long-term management plan for diadromous fisheries of the St. Croix River. Canadian MS Report. *Fisheries and Aquatic Sciences*. No. 1969.

ASMFC (Atlantic States Fisheries Commission). 2000. Interstate Fishery Management Plan for American Eel (*Anguilla rostrata*). Prepared by the American Eel Plan Development Team for Atlantic States Marine Fisheries Commission November 1999.

ASMFC. 2009. AMENDMENT 2 to the Interstate Fishery Management Plan for Shad and River Herring (River Herring Management). Prepared by the Atlantic States Marine Fisheries Commission Shad and River Herring Plan Development Team.

ASMFC. 2010. Upstream Fish Passage Technologies for Managed Species. Fish Passage Working Group report, September 2010. https://www.asmfc.org/uploads/file/FishPassTechnologyForASMFCspecies_Oct2010.pdf. Accessed 2020.

Barber, B. L., A. J. Gibson, A. J. O'Malley, J. Zydlewski. 2018. Does What Goes up Also Come Down? Using a Recruitment Model to Balance Alewife Nutrient Import and Export. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science.* 10:236–254.

Bassett, E. 2015. Cultural Importance of River Herring to the Passamaquoddy People. Sipayik Environmental Department, Pleasant Point Reservation, Passamaquoddy Tribe.

Bassett, E. 2020. Grand Falls Dam reconnaissance. Provided photos and an overview of site characteristics and some key passage planning features from a site visit on September 24, 2020. Photos and information available upon request.

Beckwith, R., T. Greene, M. Sheely, L. Pierce, R. Padilla, J. Kleinfelter, and O. Al-Shafie. 2013. "Technologies for Passing Fish at Large Dams." California Natural Resources Agency, Department of Water Resources FloodSAFE Environmental Stewardship and Statewide Resources Office.

Britten, GL, M Dowd, L Kanary and B Worm. 2017. Extended fisheries recovery timelines in a changing environment. *Nature Communications.* 8**,** 15325 (2017). https://doi.org/10.1038/ncomms15325. Accessed 2020.

Brownell, P., A. Hoar, S. McDermott, A. Blott, and F. Rohde. 2015. "Diadromous Fish Passage: A Primer on Technology, Planning, and Design for the Atlantic and Gulf Coasts." National Oceanic and Atmospheric Administration, Silver Spring, MD.

Burke, M. 2020. Personal communications regarding NLF applications at study sites with contracting authors (D. Bradley, G. Allen, J. Nestler).

Burke, M. 2021. Personal communications regarding NLF CN order of magnitude cost estimates, with D. Bradley (LimnoTech).

Burgi, P., R. Christensen, A. Glickman, P. Johnson, and B. Mefford. 2006. "Fish Protection at Water Diversions: Chapter IV. Positive Barrier Screens." https://www.usbr.gov/tsc/techreferences/hydraulics_lab/pubs/manuals/fishprotection/Fish%20chapter%20IV.pdf. Accessed 2020.

Castro-Santos, T. X. and S.A. Haro. 2016. Migratory behavior of adult sea lamprey and cumulative passage performance through four fishways. *Canadian Journal of Fisheries and Aquatic Sciences*. 74(5).

Cronin, J.C., P. Seymour, M. Sabine, R. Brokaw, M. Smith, and F. Cowie. 2002. Freshwater Fisheries of the St. Croix System: The Freshwater fish species that inhabit the International watershed and the recreational fisheries which they support. Draft for IJC Presentation Only. Presented at State of the Ecosystem: A Science Workshop, Washington County Technical College, Calais, Maine. Maine November 13-14, 2002.

Dana, R. et al. 2020. Grand Falls Brook reconnaissance. Provided photos and an overview of site characteristics and creek cross sections and photos of planning features from a site visit on November 6, 2020. Photos and information available upon request.

DFO (Department of Fisheries and Oceans Canada). 1988. Long-term Management Plan for the Diadromous Fisheries of the St. Croix River. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1969. Halifax, Nova Scotia. February 1988.

Dotson, C. 2015. "Priest Rapids Fish Bypass: A Case Study from Start to Finish." *International Conference on Engineering and Ecohydrology for Fish Passage*. 18. 24 June 2015, Groningen, NL. https://scholarworks.umass.edu/fishpassage_conference/2015/June24/18. Accessed 2020.

Dunning, D. J., Q. E. Ross, P. Geoghegan, J. J. Reichle, J. K. Menezes, and J. K. Watson. 1992. "Alewives avoid high-frequency sound." *North American Journal of Fisheries Management.* 12: 407-416.

Dunning, D., C. Gurshin. 2012. "Downriver Passage of Juvenile Blueback Herring near an Ultrasonic Field in the Mohawk River." *North American Journal of Fisheries Management.* 32(2): 365-380.

EPA (Environmental Protection Agency). 1972. A Study of Water Quality and benthic Conditions in the St. Croix River, Grand Falls to Milltown, Maine and New Brunswick. August 1972. US EPA, Region I, Boston MA.

FERC (Federal Energy Regulatory Commission). 2016. Order issuing new license to continue operating and maintaining the Vanceboro Dam Storage Project No. 2492. Issued March 22, 2016. https://elibrary.ferc.gov/eLibrary/idmws/common/OpenNat.asp?fileID=14176485. Accessed 2020.

Fjeldstad, H., U. Pulg, and T. Forseth. 2018. Safe two-way migration for salmonids and eel past hydropower structures in Europe: A review and recommendations for best-practice solutions. *Marine and Freshwater Research.* 69(12) 1834-1847 https://doi.org/10.1071/MF18120. Accessed 2020.

Flagg, L. N. 2007. Historical and Current Distribution and Abundance of the Anadromous Alewife (*Alosa pseudoharengus*) in the St Croix River. A Report to the State of Maine, Atlantic Salmon Commission. 161 Capitol Street 172 State House Station, Augusta, Maine 04333-0172

Frick, K. 2017. "Up and Over: Improving upstream passage of adult Pacific lamprey in the Columbia River basin." NOAA Fisheries. Northwest Fisheries Science Center, Seattle, WA.

http://scholar.google.com/scholar_url?url=https://repository.library.noaa.gov/view/noaa/4045/noaa_4045_DS1.pdf&hl=en&sa=X&scisig=AAGBfm30gKnA9dxQMH9Hj-asKkK62jOilw&nossl=1&oi=scholarr. Accessed 2020.

Gephard, S. 2008. "The State of the Art of Fish Passage." Connecticut Department of Energy and Environmental Protection. Atlantic States Marine Fisheries Commission Workshop. April 3 – 4, 2008, Jacksonville, FL. http://www.asmfc.org/uploads/file/fishpassageWorkshopPresentations.pdf. Accessed 2020.

Hoar, A. 2020. Personal communication with workgroup regarding general distribution of alewife use in Grand Falls Flowage and the distribution of free flowing reaches use by land locked salmon, above Grand Falls Dam (May 2020).

Hogg, R. S., S. M. Coghlan Jr., J Zydlewski, and K. S. Simon. 2014. Anadromous sea lampreys (*Petromyzon marinus*) are ecosystem engineers in a spawning tributary. *Freshwater Biology.* 59, 1294–1307.

IJC (International Joint Commission). 2005. Board Discussion Paper on Alewife in the St. Croix River. INTERNAL DRAFT FOR BOARD REVIEW. August 2005.

IJC. 2008. St. Croix River: State for the Watershed Report. Maine and New Brunswick. Prepared for St Croix River Watershed Board and the IJC. Prepared by FB Environmental. Portland, Maine.

Kircheis, F.W. 1994. Update on freshwater fish species reproducing in Maine. *Maine Naturalist*. 2(1): 25-28.

Larinier, M. 2001. Environmental issues, dams and fish migration. *In*: Dams, fish and fisheries: Opportunities, challenges and conflict resolution. G. Marmulla (Ed). FAO Fisheries Technical Paper 419. http://www.fao.org/3/Y2785E/y2785e03.htm#P0_0. Accessed 2020.

Ledwin, S. 2018. Fish Passage at Woodland and Grand Falls Dams: Background for Discussion. Presentation at the International St. Croix River Watershed Board and Partners Meeting. Calais, ME. Presented by S. Ledwin, Director Sea-run Fisheries and Habitat Division, Augusta, ME.

Linnansaari, T., B. Wallace, R.A. Curry, and G. Yamazaki. 2015. "Fish Passage in Large Rivers: A Literature Review." *Mactaquac Aquatic Ecosystem Study Report Series 2015-16*. Canadian Rivers Institute, University of New Brunswick, v + 55 p.

Marshall, T. L. 1976. Historical Perspectives of Resource Development Branch Activities in Restoring Anadromous Fishes to the St. Croix River, New Brunswick-Maine. Department of Fisheries and the Environment, Canada. Internal Report Series No. MAR/I-76-2. Halifax, Nova Scotia.

Maine Department of Environmental Protection. 2010. "Maine Lakes: Geographic & Woodlands Flowage." Maine Department of Inland Fisheries and Wildlife, Maine Office of Geographic Information System, Augusta, ME. http://www.gulfofmaine.org/kb/2.0/record.html?recordid=9680. Last updated March 2015.

MDIF (Maine Department of Inland Fisheries and Wildlife and Division of Parks and Public Lands). 2012. Spednic Lake / Upper St. Croix River Management Plan. https://maine.gov/dacf/parks/get_involved/planning_and_acquisition/management_plans/spednic_lake_upper_stcroix.html. Accessed 2020.

Maine Department of Inland Fisheries and Wildlife. n.d. "Grand Falls flowage Bathymetry." https://www.maine.gov/ifw/docs/lake-survey-maps/washington/grand_falls_flowage.pdf. Accessed 2020.

Maine Department of Inland Fisheries and Wildlife. n.d. "Grand Falls Flowage." https://www.lakesofmaine.org/data/maps/7437.jpg. Accessed June 2020.

Ministère du Développement de l'Énergie et des Ressources. 2018. Last updated April 2019. Woodland Flowage. https://www2.gnb.ca/content/dam/gnb/Departments/nr-rn/pdf/en/Fish/lake_depths/woodland_flowage.pdf. Accessed June 2020.

National Marine Fisheries Service (NMFS). 2008. "Anadromous Salmonid Passage Facility Design." NMFS, Northwest Region, Portland, OR. http://scholar.google.com/scholar_url?url=https://repository.library.noaa.gov/view/noaa/4045/noaa_4045_DS1.pdf&hl=en&sa=X&scisig=AAGBfm30gKnA9dxQMH9Hj-asKkK62jOilw&nossl=1&oi=scholarr. Accessed 2020.

National Oceanic and Atmospheric Administration Fisheries. 2019. "Juvenile Downstream Passage on the West Coast." https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/juvenile-downstream-passage-west-coast. Accessed 2020.

NBP (New Brunswick Power Corporation). 2020. Environmental Impact Assessment (EIA) Registration (1553): Milltown Generating Station Decommissioning Project, Milltown, New Brunswick. https://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/environmental_impactassessment/1553.html. Accessed 2020.

Nestler, J. M. G. R. Ploskey, J. Pickens, J. Menezes, and C. Schilt. 1992. "Responses of blueback herring to high-frequency sound with implications for reducing entrainment at hydropower dams." *North American Journal of Fisheries Management.* 12: 667-683.

Nestler, J. M. and G. R. Ploskey. 1996. "Sound Way to Save Fish." *Civil Engineering.* 66: 58-61.

Nestler, J. M. and L. T. Schneider. 1998. "An integrated structural and behavioral barrier for fish protection at a major pumped-storage hydropower dam." Proceedings of Hydrovision98: Exploring Our New Frontiers. 28-31 July 1998, Reno, NV. *HCI Publications, Inc*. Kansas City, Missouri.

Nestler, J. M., D. Dennerline, M. Weiland, G. Weeks, D. Degan, S. Howie, and J. Sykes. 1998. "Richard B. Russell Phase III Completion Report: Impacts of Four-unit Pumpback Operation." Technical Report EL-99-1, U.S. Army Engineer Engineering Research and Development Center, Vicksburg, Mississippi.

Nestler, J. M., W. Lynch, and J. A. Sykes. 1999. "Pumped Storage and the Fishery: Insights from Richard B. Russell Dam." *Hydro Review XVIII*: 18-26.

Nislow, K. H. and B. E. Kynard. 2009. The Role of Anadromous Sea Lamprey in Nutrient and Material Transport between Marine and Freshwater Environments. American Fisheries Society Symposium. 69:485-494, 2009.

NOAA. 2020. Juvenile Downstream Passage on the West Coast: Migrating juvenile salmon and steelhead in the Columbia and Snake Rivers pass up to eight dams on their way to the ocean. https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/juvenile-downstream-passage-west-coast. Accessed November 2020.

Noonan MJJ, Grant JWA, and Christopher DJ. 2012. A quantitative assessment of fish passage efficiency. *Fish and Fisheries.* 13: 450–464.

Northwest Fish Passage Training and Facilities Workshop. 2011. https://www.ferc.gov/EventCalendar/EventDetails.aspx?ID=5904&CalType=%20&CalendarID=116&Date=&View=Listview. Accessed 2020.

Northwest Power and Conservation Council. 2016. "Review of Fish Passage Technologies at High Head Dams." https://www.nwcouncil.org/sites/default/files/2016-14.pdf. Accessed 2020.

OTA (U.S. Office of Technology Assessment). 1995. *Fish Passage Technologies: Protection at Hydropower Facilities, OTA-ENV-641 (Washington, DC: U.S. Government Printing Office, September 1995).*

Paul, A. 2018. The St. Croix Watershed: Exploring Past and Present Fisheries Related Activities along the Waterway. New Brunswick Power, Draft Report. January 18, 2018. https://passamaquoddypeople.com/system/files/atoms/file/2018-01-18_Report_Austin_Paul_(Skutik_Fishing_Activities).pdf. Accessed 2020.

Pereire, E., B. R. Quintella, C. S. Mateus, et al. 2016. Performance of a Vertical-Slot Fish Pass for the Sea Lamprey *Petromyzon marinus L*. and Habitat Recolonization: Performance of a Fish Pass for Sea Lamprey. *River Research and Applications*. 33(1).

Rajaratnam, N., G. Van der Vinne, and C. Katopodis. 1986. "Hydraulics of vertical slot fishways." *Journal of Hydraulic Engineering, American Society of Civil Engineers.* 112. 909-927.

Rizzo, B., H. Jansen, and K. Beland. 1989. Report to the St. Croix Steering Committee on Proposed Fish Passage Improvements at the Woodland and Grand Falls Projects on the St. Croix River, Maine/New Brunswick. Report from the Fish Passage Subcommittee. November 1989.

Ruitenberg, A.A., and A. Ludman. 1978. "Stratigraphy and tectonic setting of early Paleozoic sedimentary rocks of the Wirral-Big Lake area, southwestern New Brunswick and southeastern Maine." *Canadian Journal of Earth Sciences.* v. 15, no. 1, p. 22-32.

Salmon Recovery.gov. n.d. "Surface Passage Systems and Removable Spillway Weirs: Lower Columbia and Snake River Dams." https://www.salmonrecovery.gov/Files/Fact%20sheets/Surface%20Passage%20Systems%20and%20Removable%20Spillway%20Weirs.pdf. Accessed 2020.

Saunders, R. M., A. Hachey, and C. W. Fay. 2006. Maine's Diadromous Fish Community: Past, Present, and Implications for Atlantic Salmon Recovery. *Fisheries*. Vol. 31 No. 11.

Selinger, C. and B. Zeiringer. 2018. River Connectivity, Habitat Fragmentation and Related Restoration Measures (Chapter 9) in: River Ecosystem Management: Science for Governing Towards a Sustainable Future (S. Schmultz and J. Sendzimir, Eds). Springer Nature.

Schilt, C. R. and J. M. Nestler. 1999. "Blueback herring respond to brief ultrasonic stimulus sounds." *Journal of the Acoustical Society of America.* 106. DOI: 10.1121/1.427425.

Scruton, D. A., C.J. Pennell, C.E. Bourgeois, R.F. Goosney, L. King, R.K. Booth, W. Eddy, T.R. Porter, L.M.N. Ollerhead, and K.D. Clarke. 2008. Hydroelectricity and fish: A synopsis of comprehensive studies of upstream and downstream passage of anadromous wild Atlantic salmon, *Salmo salar*, on the Exploits River, Canada. *Hydrobiologia.* 609, 225–239.

Someah, K. 2011. CWA 316(b) Update: Fish guidance and protection. Power Magazine. https://www.powermag.com/cwa-316b-update-fish-guidance-and-protection/. Accessed 2020.

SED (Sipayik Environmental Department). 2017. Fish conveyance and migration in the International St. Croix River. March 2017. Prepared by Sipayik Environmental Department, Passamaquoddy Tribe at Pleasant Point for the IJC. https://www.ijc.org/sites/default/files/2018-12/IWI_Fish_Conveyance_Migration_Final_Report_2016-17.pdf. Accessed 2020.

Silva. A. T., M. C. Lucas, T. Castro-Santos, C. Katopodis, et al., 2017. The future of fish passage science, engineering, and practice. *Fish & Fisheries*. November 2017. DOI, 10.1111/faf.12258.

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.

USACE (U.S. Army Corps of Engineers). 2014. "Pacific Lamprey Passage Improvements Implementation Plan 2008–2018: 2014 Revision." http://pweb.crohms.org/tmt/documents/FPOM/2010/Task%20Groups/Task%20Group%20Lamprey/10%20Year%20Lamprey%20Plan%20update%20final%202015.pdf. Accessed 5 May 2020.

USFWS (U.S. Fish and Wildlife Service). 2014. National Marine Fisheries Service Endangered Species Act Biological Opinion. Funding of Passamaquoddy Tribal Research on Alewife Migration Behavior and Food Web Interactions in the St. Croix River and Estuary. NER-2014-11886. National Marine Fisheries Service Greater Atlantic Region Fisheries Office.

USFWS. 2019. "Fish Passage Engineering Design Criteria." USFWS, Northeast Region R5, Hadley, MA.

Wabanaki – a. Undated (UD). Salmon Falls, Milltown Dam and Fishway. http://www.wabanaki.com/wabanaki_new/images/Dams/MilltownDam/Milltown%20Dam%20Info.pdf. Accessed 2020.

Wabanaki – b. UD. Woodland Dam and Fishway History. http://www.wabanaki.com/wabanaki_new/documents/Woodland%20Dam%20and%20Fishway%20History.pdf. Accessed 2020.

Wabanaki – c. UD. Some history of the Grand Falls Dam and Fishway in the St. Croix River. http://www.wabanaki.com/wabanaki_new/documents/Grand%20Falls-Some%20HistoryV2.pdf. Accessed 2020.

WIDNR (Wisconsin Department of Natural Resources). 2018. Fish Passage at Dams Strategic Analysis. Wisconsin Department of Natural Resources. February 5, 2018.

Willis, T. V. 2009. How Policy, Politics, and Science Shaped a 25-Year Conflict over Alewife in the St. Croix River, New Brunswick–Maine. American Fisheries Society Symposium. 69:793–811, 2009.

Wippelhauser, G S., J. Sulikowski, G. B. Zydlewski, M. A. Altenritter, M. Kieffer, and Michael T. Kinnison. 2017. Movements of Atlantic Sturgeon of the Gulf of Maine Inside and Outside of the Geographically Defined Distinct Population Segment*, Marine and Coastal Fisheries.* 9:1, 93-107, DOI: 10.1080/19425120.2016.1271845.

Wippelhauser, G.S. 2020. Personal communications with Doug Bradley (LimnoTech), December 2020. Provided population estimates included in table as average production values for alewife assuming 400 fish/acre.