Aquatic Connectivity and Aquatic Invasive Species:

A Decision-Making Framework for Fish Passage Projects in Nova Scotia

Clean Annapolis River Project

Nova Scotia Salmon Association's Adopt a Stream Program

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Preface

As watershed restoration advocates and practitioners, unimpeded access for migratory fish and other aquatic organisms is generally a clear goal with obvious benefits. However, spread of aquatic invasive species, particularly chain pickerel and smallmouth bass in Nova Scotia has given those actively involved in watershed restoration and especially in aquatic connectivity improvement cause for serious concern. The purpose of this document is to provide managers with guidance and a decision framework to assess the risks and benefits to improving fish passage in proximity to aquatic invasive species.

There are many other considerations that go into decisions to undertake fish passage improvements, particularly fishway constructions or barrier removals that affect water levels, expose previously submerged ground, and/or require excavation.

We live and work in Mi'kma'ki, the ancestral and unceded territory of the Mi'kmaq People. Locations where fish passage work is being considered may very well be in areas of high cultural and traditional significance. Environmental decision-making and undertakings are well served by taking a Two-Eyed seeing approach, utilizing both western science and Mi'kmaq ways of knowing and requires actively engaging with and seeking guidance from Mi'kmaq communities and Indigenous-led conservation organizations.

Watershed restoration, ecological recovery, and human reconciliation require effective collaboration, careful consideration, and committed effort.

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Technical expertise was provided from a multi-organizational technical review committee formed to oversee and contribute to the development of this guide.

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Section One: Introduction

Aquatic habitat connectivity improvement projects are a very popular and widely encouraged fish habitat restoration activity in Canada. In Nova Scotia, aquatic connectivity has been embraced by community-based watershed stewardship groups as a fundamental step in the restoration process. Between 2013 and 2019, over 80 fish passage improvement projects were completed in Nova Scotia by the Adopt a Stream program and affiliate groups alone, improving access to approximately 755 kilometers of rivers and streams.

In watersheds without aquatic invasive species (AIS), improvement of aquatic connectivity at anthropogenic barrier sites (dams, culverts, etc.) is considered almost always beneficial to fish. These projects decrease the risks of isolation to resident species and increase the range of habitat for migratory species. Unfortunately, with increasing distribution of AIS in Nova Scotia, decisions to improve connectivity to expand habitat for both resident and migratory species and consequentially increase the risk of invasion by AIS have become complex.

Since 2010, the Clean Annapolis River Project (CARP) and the Nova Scotia Salmon Association's (NSSA) Adopt a Stream Program have collaborated on several initiatives to develop tools, techniques, and training programs to assist community-based watershed stewardship groups in addressing aquatic habitat fragmentation. Coincidentally, the threat of AIS, mainly chain pickerel (*Esox niger*) and smallmouth bass (*Micropterus dolomieu*), and their distribution in Nova Scotia has grown substantially in recent years.

In an effort to address the growing threat of AIS in the context of fish passage improvement initiatives, CARP, in partnership with the NSSA through its Adopt a Stream Program, has developed this decision-making framework to guide managers in the planning and prioritization of aquatic connectivity improvement projects in the Nova Scotia context. The aim of this framework is to have a practical way of assessing the risk of isolation (i.e. maintaining, improving, or developing fish exclusion barriers) vs. invasion (i.e. providing or improving fish passage at current anthropogenic barrier sites) at current barrier sites.

1.1 Aquatic Connectivity

In Nova Scotia, the most common barriers to fish movement are the 30,000+ road-stream crossings; particularly, improperly designed, installed, or maintained culverts. Additionally, the ~586 dams in Nova Scotia (Fielding, 2011), active and inactive, can cause fragmentation of aquatic habitat.

Culvert fish passage assessments show that most culverts are barriers to some species or age class of native fish during fish passage flows. Many culverts deemed "full barriers" or "partial barriers" can have negative impacts on fish populations due to intermittent fish passage. While barrier culverts will prevent the passage of most fish, under most flow conditions, culvert sites are usually not 100% impenetrable. Many culverts have some degree of permeability to AIS and native species.

Aquatic connectivity is important to fish and fish habitat. A connected stream network allows fish access to spawning areas, seasonal habitat, cold-water refuge, water-quality refuge, food sources, and predator escapement. When habitat is more connected, where AIS are not present, fish populations are generally larger, healthier, and less susceptible to threats such as habitat degradation.

1.2 Fish Passage Improvements

Fish passage improvements are generally considered an integral part of watershed restoration in impacted or degraded watersheds. In systems absent of AIS, these types of projects are commonly acknowledged as one of the first steps to a watershed restoration project. As AIS become more common globally, this becomes a more complex decision for managers.

NSSA Adopt a Stream Program has worked to develop, improve, and promote new and previously existing fish passage improvement devices that are low cost and feasible for community groups to implement to improve habitat connectivity in local watersheds. To date, over 80 of these small and medium scale projects have been completed in Nova Scotia, and the popularity of these projects continues to grow.

Commonly used fish passage improvement techniques in Nova Scotia include outflow chutes, low-flow barriers, step pool construction, tailwater control modification, fiberglass box pool-weir ladders, and steep pass denil-style fishways. For more information on these devices contact the Adopt a Stream Program.

Figure 1: An example of a culvert retro-fit fish passage improvement that utilized an outflow chute and baffles to slow water velocities and increase depth.

1.2.1 Selective Fish Passage – American Eel (Anguilla rostrate) and Lamprey (Petromyzontidae spp)

Typically, fish passage improvements are meant to improve connectivity for native species; however, this will inherently improve passage for AIS species and increase the risk of introduction and/or establishment of AIS in new habitats. There is, however, one notable exception where fish passage improvements can be completed and be selective to eel and eel-like species.

Eels are uniquely able to overcome very steep slopes if appropriate substrate conditions are provided. Eel ladders, commonly used at hydroelectric dams, are constructed by incorporating climbing medias such as mussel-spat rope, frayed lines, pegboards, AstroTurf, and patterned concrete. These projects do not currently risk new introductions/establishments of AIS species in Nova Scotia, and so can be excluded from the risk assessment framework outlined in this document.

1.3 Aquatic Invasive Fish Species in Nova Scotia

1.3.1 Chain Pickerel (*Esox niger*)

The chain pickerel was introduced to Nova Scotia in 1945 starting with three lakes near Meteghan in Western NS (Mitchell et al, 2010). Since then, the number of introductions and establishments of the species has grown to over 100 lakes and watercourses in 12 of the province's 46 primary watersheds (NSDFA, 2019). The increasing range of this species continues through species movement through stream corridors and across catchment boundaries via human introductions. The main motivation for the spread of chain pickerel by humans is increased recreational angling opportunities. There are other potential but unconfirmed vectors of intra-catchment movement such as birds and brackish waters during floods.

On average, chain pickerel is currently being introduced to approximately four new waterbodies in Nova Scotia annually. On average, three of these introductions are the result of species free movement within a watershed, and one via illegal, deliberate human introduction (Leblanc, personal comm, 2020).

Chain pickerel is known as a voracious predator, capable of consuming fish that are similarly sized using ambush style hunting strategies (Rand et al, 1981; Crossman, 1996). Chain pickerel is a generalist species capable of surviving in many aquatic habitats common to Nova Scotia. However, chain pickerel prefers shallow, slow-moving, or stagnant water with weedy or woody structures to use in ambushing prey (Crossman, 1996). It prefers warm water and can tolerate high levels of acidity down to 3.8 pH (Lee et al, 1980). Chain pickerel can tolerate salinity levels as high as 22ppm for short periods (Lee et al, 1980). In lake habitat, chain pickerel can out-compete most, if not all, native species in Nova Scotia. These effects have been documented by Sean Mitchell (2010) with his research through the Nova Scotia Freshwater Fisheries Research Cooperative: "Impact of Introduced Chain Pickerel (*Esox niger*) on Lake Fish Communities in Nova Scotia, Canada". In this study, Mitchell states that chain pickerel presence in Nova Scotia lakes tend to have the following impacts: "(1) simplify fish communities in lakes (significantly lower richness and diversity in pickerel versus non-pickerel lakes), (2) reduce overall fish abundance in lakes [catch per unit effort] two orders of magnitude greater in non-pickerel lakes than in pickerel lakes), and (3) truncate fish size distribution in lakes (absence of small bodied fishes in pickerel lakes)." Chain pickerel in some cases can eradicate all other fish species within a lake (Feener, 2018). The chain pickerel's effect is less known in riverine habitats. Surveys on the LaHave River completed by Coastal Action Foundation confirm that chain pickerel consume salmon smolts in large quantities when given the opportunity (Feener, 2018).

1.3.2 Smallmouth Bass (*Micropterus dolomieu*)

The smallmouth bass was first introduced to Nova Scotia by the provincial government in 1942 as a new recreational sport fishing opportunity (Leblanc, personal comm, 2020). Distribution of smallmouth bass has grown exponentially since then. From 1942 to 1971 the distribution grew from a few lakes to over 30. From 1971 to 1995 the distribution approximately doubled (MacNeil, 1995). In 2008, there were 188 waterbodies with established smallmouth bass populations (LeBlanc, 2010) indicating another approximate doubling from 1995. From 2008 to 2020, the distribution of the species has again approximately doubled to approximately 300 waterbodies with established smallmouth bass populations in Nova Scotia (NSDFA, 2019). On average, smallmouth bass is currently being introduced to approximately eight new waterbodies in Nova Scotia annually. On average, seven of these introductions are the result of the species' free movement within a watershed, and one via illegal, deliberate human introduction (LeBlanc, personal comm, 2020).

Smallmouth bass can now be found in 26 of the 46 primary watersheds in Nova Scotia and its range continues to expand (NSDFA, 2019). Smallmouth bass, like chain pickerel, mainly spread across catchment boundaries by humans (LeBlanc, 2010), largely motivated by increased angling opportunities.

The smallmouth bass is a generalist species with a preferred habitat consisting of cool water temperatures with low turbidity to support its visual predation strategy (Brown et al, 2009, Edwards, 1983). Although smallmouth bass growth rates are much faster in lakes (Edwards, 1983), the species often inhabit rivers and streams with low gradients and a large percentage of pool habitat (Brown et al, 2009). When smallmouth bass inhabit rivers, it is most commonly found in rivers and streams >10.5m wide with very low gradients from 0.00075%-0.0047% (Edwards, 1983). It prefers complex rocky bottoms with slow or still water flow (Brown et al., 2009). Smallmouth bass, like chain pickerel, is capable of tolerating some salinity for short periods (Brown et al., 2009).

The smallmouth bass is known to have an impact on native species. The risk to native species posed from smallmouth bass is less in riverine habitats compared to lake habitats (DFO, 2009). Smallmouth bass is capable of out competing most native species in Nova Scotia under the correct habitat conditions. The Department of Fisheries and Oceans (DFO) risk assessment report on smallmouth bass' impact on Atlantic salmon (2009) states, "when smallmouth bass are introduced into a water body, they prey heavily on smaller fish, can out-compete other fish species, and can become a dominant component of the food web."

1.3.3 Brown Trout (*Salmo trutta*) and Rainbow Trout (*Oncorhynchus mykiss*)

Although chain pickerel and smallmouth bass are the most known AIS in Nova Scotia, there are other AIS present. Rainbow and brown trout have generally had less of an overall impact on native fish communities relative to chain pickerel and smallmouth bass in Nova Scotia (Madden et al, 2010); however, they should remain a consideration when connecting habitat where these species are present.

The brown trout is native to Europe; it was introduced to Nova Scotia in 1924 when it was stocked by the provincial government to increase recreational angling opportunities (NSDAF, 2005). It has since become established in many rivers in Nova Scotia. Brown trout has strong established populations in the Stewiacke River, Cornwallis River, River John, Salmon River, and many others (NSDAF, 2005). Brown trout can be either residential or anadromous. Generally, the brown trout is tolerant of a wider range of habitat conditions (degradation, warm water, etc.) than brook trout (*Salvelinus fontinalis*) (NSDAF, 2005). Brown trout is longer lived than brook trout and is a popular fish for anglers because of its larger size and difficulty to catch (NSDAF, 2005). Brown trout is still stocked by the Inland Fisheries Division of the Nova Scotia Department of Fisheries and Aquaculture. Stocking records show that brown trout have been stocked in select locations within Annapolis, Guysborough, Antigonish, Pictou, Richmond, Halifax, and Inverness Counties (NSDFA, 2018). The brown trout is considered an AIS by DFO. In rivers on the Northumberland Strait, brown trout is thought to have a more significant impact on native brook trout and Atlantic salmon than smallmouth bass and chain pickerel (LeBlanc, personal comm, 2020).

The rainbow trout is native to the west coast of North America. The species was introduced by the provincial government to Nova Scotia in 1899 (MacLean, 2011). Rainbow trout is actively stocked in Nova Scotia and historically it has been stocked in almost every county in the province. Mixed-sex rainbow trout were stocked in the past, but from 2007 to the present (2020), the province has been stocking either female or sterile fish only, eliminating the risk of reproduction/establishment of those fish in stocked lakes and rivers (Madden et al, 2010). Rainbow trout is not considered an AIS in Nova Scotia by DFO as the species does not, by DFO's definition, cause ecological harm, economic harm, or impacts to human health (LeBlanc, personal comm., 2020). Other than some Bras D'or Lakes tributaries, there are no known reproducing populations of rainbow trout in the province. The few established populations in Cape Breton were likely the result of escapees from aquaculture operations (Madden et al., 2010).

1.3.4 Other Aquatic Invasive Species

1.3.4.1 AIS Identified in Nova Scotia

Other AIS known to be present in Nova Scotia include the goldfish (Carassius auratus), koi fish (Cyprinus rubrofuscus), and the Chinese mystery snail (Cipangopaludina chinensis). These species are not discussed at length in this framework as these species currently have localized distributions and small abundances. If any AIS species are known to be present in the watershed of a proposed fish passage improvement site, they should be considered in the risk assessment.

1.3.4.2 Potential Future AIS Threats

AIS distribution is increasing globally. The threat of new AIS introductions in Nova Scotia is real. Several AIS species have been identified as potential threats to Nova Scotia's aquatic ecosystems but are not currently known to be present: largemouth bass (Micropterus salmoides), muskellunge (Esox masquinongy), walleye (Sander vitreus) and, Asian carp (Cyprinus carpio). Established populations of these species are geographically close to Nova Scotia and are expected to potentially propagate well here if introduced (Leblanc, personal comm, 2020). If feasible, regular eDNA and electrofishing surveys are potential methods of monitoring for early detection of AIS. Early detection can help in preparing management strategies to mitigate potential impacts.

Section Two: Decision Making Framework

2.1 Decision-Making Framework Overview

This guide is intended to aid managers tasked with making decisions regarding fish passage actions at anthropogenic barrier sites, with respect to the spread of AIS. This document outlines a risk-assessment framework that managers can utilize to weigh associated risks and make effective strategic decisions.

This risk assessment framework assesses the risk of two opposing alternatives: **"invasion" vs. "isolation"**; in other words, enhancing fish passage vs. restricted fish passage. This framework breaks down these two alternatives into multiple risk factors. By evaluating individual risk factors using available data, the overall cumulative risk of both alternatives can be weighed.

Risk of invasion refers to risks from AIS associated with enhancing fish passage at a barrier site and thus potentially increasing the likelihood that AIS could become introduced, established, and impact native species dwelling in the upstream habitat. This alternative is broken down into three risk categories: risk of introduction, risk of establishment, and risk of impact.

Risk of isolation refers to risks and opportunity costs associated with deliberately not improving or actively restricting fish passage in effort to thwart the spread of AIS. This alternative can be broken down into two risk categories: risk of extirpation and opportunity cost.

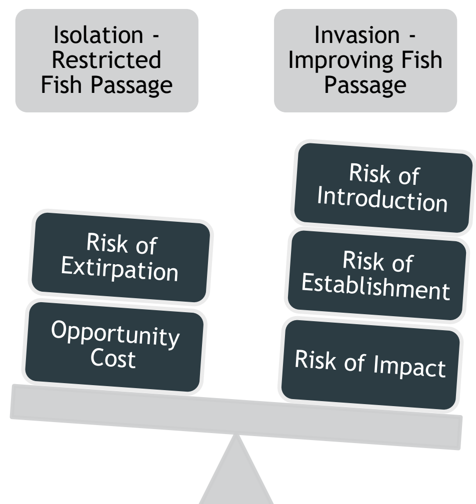


Figure 2: Risk assessment framework model

This guide is not a substitute for proper remediation techniques and procedures. If the construction of a fish passage project is expected to alter the watercourse or surrounding landscape, then additional consideration into the effect of those changes must be considered. In some cases, fish passage projects require site specific ecological, and/or archaeological assessments before they commence.

2.1.1 Site Appropriateness for Framework

The exclusive use of this framework is **<u>not</u>** suitable for sites that meet the following conditions:

- Projects involving upstream catchment areas greater than 25 square kilometers.
- Projects where aquatic or amphibious species listed under the *Species at Risk Act* (SARA)[1] are present upstream of a proposed project site (e.g. Atlantic whitefish).

[1] https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html

- Projects where upstream areas are located partially or entirely within a designated protected area[2] or an area of significant cultural and/or social value.

Higher risk associated with projects matching the above criteria justify more in-depth study, investigation, and stakeholder engagement. These projects should include input from provincial, federal, Indigenous, and other applicable stakeholder groups.

The framework was developed with chain pickerel and smallmouth bass as the focus AIS as these two species currently hold the greatest threat to aquatic ecosystems in Nova Scotia. The framework, however, can easily be used and adapted for other AIS species.

2.2 Risk Assessment Worksheet

The risk assessment framework outlined in this guide utilizes a worksheet for managers to organize and present the risk assessment and coupled decision in a user-friendly way. By completing the worksheet using the suggested risk values (Section 3), managers can be assured that they have considered and weighed the associated risks to make a strategic decision. The worksheet provides a written record of the decision and the various criteria and data used to come to that decision to be referenced and re-evaluated over time.

The suggested risk values provided are based on past research, peer reviewed articles, grey literature, and expert opinion from a technical committee. Values are suited to conditions typical to Nova Scotia. Discretion should be taken by managers using the suggested values to ensure that the values suit the specific conditions of the potentially unique site.

If sufficient data is not available to confidently assess risk, then data should either be collected or that risk factor should be assessed as "unknown". If many of the risk factors are assessed as "unknown" then fish passage restoration projects should be postponed until data deficiencies are addressed.

At the end of the worksheet, managers are asked to summarize risk associated with each risk category (i.e. invasion, establishment, impact, extirpation and opportunity cost) and then to summarize the cumulative risk for each alternative (i.e. Invasion and Isolation). When summarizing risk, managers should take a comprehensive approach. Risk values should not be averaged. Instead, managers should reflect on all risk factors and their relative importance/weight when summarizing risk values. The alternative with the least risk, either enhancing fish passage (invasion) or restricted fish passage (isolation), is the recommended course of action.

If both alternatives (invasion and isolation) have similar risk levels, then it is recommended that a fish passage improvement be cancelled. This is in keeping with a precautionary approach to fish passage improvement projects that is advocated within this framework.

[2] https://novascotia.ca/parksandprotectedareas/plan/interactive-map/

2.2.1 How to Use the Risk Assessment Worksheet

Step 1: Fill in site information for the barrier site.

- Site Name/Identification #: List the common name that the site is referred to or the site identification # used in the organization's geodatabase.
- Watercourse Name: Enter the watercourse name that the barrier is situated upon.
- Organization: Enter the name of the representing organization that is completing the risk assessment worksheet.
- Watershed: Enter the name of the watershed that the barrier is situated within.
- Assessment Completed By: Enter the name(s) and position(s) of the manager(s)/reviewer(s) that is completing the risk assessment worksheet.
- Latitude/Easting: Enter the latitude or UTM Easting of the barrier site.
- Longitude/Northing: Enter the longitude or UTM Northing of the barrier site.
- Aquatic Invasive Species: List the AIS species present within the watershed.
- Native Species: List native species of concern within the watershed.

Step 2: Assess risk for each risk factor using the information provided in Section 3 or by referencing the quick reference sheet in Appendix C and provide commentary and justification.

- Use discretion when using suggested risk values. Ensure values suit specifics of a potentially unique site. Suggested values can be disregarded if conditions warrant deviation.
- The commentary/justification column is to be completed with descriptive text explaining why a certain risk level was assigned. Maps, data, reports, watershed plans, or other resources used should be cited.
- If data is not available to confidentially assess risk levels, then more data should be collected or that risk factor should be assessed as "unknown."

Step 3: Compile the risk levels for risk factors under introduction, establishment, impact, extirpation risk, and opportunity cost risk categories.

- The compilation of risk is not an average of risk levels. Managers should use their own discretion to compile risk in consideration of all risk factors and their importance/weight.
- Some risk factors may impact the weight of others and this should be taken into consideration by managers. ***For example**: If the downstream connectivity risk factor is assessed as "No Risk" (i.e. one or more impenetrable barriers between AIS source population and a proposed project site) then it may be warranted to weigh the AIS proximity risk factor as less important while compiling risk levels due to the impossibility for AIS to access the site regardless of proximity as a result of the impenetrable barrier.*

Step 4: Compile risk levels for risk categories to evaluate the overall cumulative risk of enhancing fish passage (invasion) and restricted fish passage (isolation) alternatives.

- The compilation of risk is not necessarily an average of all risk levels from the risk categories. Managers should use their own discretion to compile risk here.

2.2.2 Risk Assessment Worksheet Example

The following page is a fictional example of a completed risk assessment worksheet. Blank worksheets are available in the Appendix of this document. An electronic version is available; contact the Clean Annapolis River Project or Adopt a Stream for copies.

Site Information			Date: 15/03/2020
Site Name/Identification #	CAR002	Watercourse	Unnamed Caribou Lake Tributary
Organization	Trout River Watershed Stewardship Association	Watershed	Trout River
Assessment Completed By	John Doe, Jane Smith	Barrier Site Catchment Size (km^2)	2.39
Latitude/Easting	44.58126	Longitude/Northing	-64.50496
Aquatic Invasive Species	chain pickerel, smallmouth bass	Native Species	brook trout, American eel, white suckers

Risk Assessment - Improving Fish Passage (Invasion)

Risk Category	Risk Factor	Section Reference	Risk Level (High, Mod, Low, None, Unknown, N/A)	Commentary/Reasoning
Risk of Introduction	**Downstream Connectivity:** How isolated is the proposed project site from AIS?	3.1.1.1	Moderate	The site has one full barrier 0.6km downstream of the proposed project site. This is the only barrier between the proposed project site and AIS.
	Upstream Connectivity: How exposed is the upstream habitat to AIS if the proposed project site were breached?	3.1.1.2	Moderate	There is 3.9km of linear stream habitat and 0.4km of lake perimeter upstream of the proposed project site.
	AIS Proximity: How close are AIS to the proposed project site?	3.1.1.3	High	AIS are known to be present in Caribou Lake downstream of the site and within the same sub-catchment. This data was collected in 2018 from angling and electro-fishing surveys completed by Trout River Watershed Association. EDNA samples confirm that AIS species are not present upstream of the proposed fish passage site.
	Degree of Fish Passage Improvement: To what degree will the proposed project improve fish passage for AIS?	3.1.1.4	Moderate	The proposed fish passage project is to install an outflow chute and baffles through the culvert. This project would improve fish passage to AIS species, but it is possible that without the fish passage project AIS could pass the site under flow conditions.
Risk of Establishment (CP & SMB Only)	**Upstream Habitat Gradient:** Is the upstream habitat gradient of riverine habitat suitable for establishment of AIS?	3.1.2.1	Moderate	The average gradient of the upstream habitat is within the tolerance range of smallmouth bass and chain pickerel but above preference range for smallmouth bass.
	Upstream Presence of Lake Habitat: Is there lake, pond, or stillwater habitat upstream of the proposed project site?	3.1.2.2	High	There are two small ponds in the headwaters of the watercourse.
Risk of Impact	**Displacement Potential:** To what degree could AIS displace native species in the upstream habitat?	3.1.3.1	Moderate	It is likely that AIS would displace native species if established in the upstream habitat. Extirpation is unlikely.
	Upstream Species of Conservation Value: Are there aquatic species of significant conservation value upstream of the proposed project site?	3.1.3.2	None	There is no species of significant conservation value upstream of the proposed project site.
	Pathogen/Disease/Hybridization Potential: Is there potential of hybridization, pathogen, or disease transfer from AIS to native species?	3.1.3.3	None	There is no known risk of transfer of pathogens or diseases and hybridization is not possible.

Risk Assessment - Restricted Fish Passage (Isolation)

Risk Category	Risk Factor	Section Reference	Risk Level (High, Mod, Low, None, Unknown, N/A)	Commentary/Reasoning
Risk of Extirpation to Residential Species	**Upstream Habitat Quantity:** How much habitat is available to native residential species upstream of the proposed project site?	3.2.1.1	High	Upstream habitat is quite small with less than 5km of linear habitat.
	Upstream Habitat Quality: What is the quality of habitat for native residential species?	3.2.1.2	Low	Upstream habitat quality is very good based on habitat and water quality surveys.
	Proposed Project Site Fish Passage Status: What is the current permeability of the proposed project site to native residential species?	3.2.1.3	Moderate	This site is expected to be passable to native species at some flows.
Opportunity Cost to Diadromous Species	**Diadromous Species Presence:** Are there diadromous species that would/could utilize the habitat upstream of the proposed project?	3.2.2.1	None	Large hydro dam approximately 25km downstream of the proposed project site prevents access to this site from diadromous species
	Quality of Spawning/Rearing Habitat: What is the quality of spawning and rearing habitat upstream of the proposed project site for diadromous species present in the watershed?	3.2.2.2	N/A	No access to diadromous species due to hydro dam downstream of proposed project site.
	Quantity of Spawning/Rearing Habitat: What is the quality of the spawning/rearing habitat available upstream of the proposed project site for diadromous species present in the watershed?	3.2.2.3	N/A	No access to diadromous species due to hydro dam downstream of proposed project site.

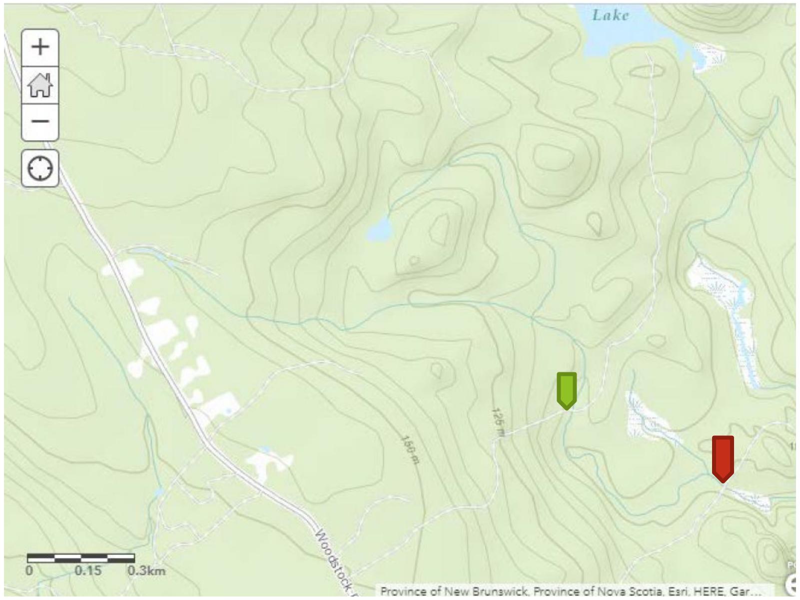
Risk Assessment Summary - Invasion vs. Isolation

Risk Category	Risk of Introduction	Risk of Establishment	Risk of Impact	Extirpation Risk	Opportunity Cost
Select/Circle One for Each Category	Very High	Very High	Very High	Very High	Very High
	High	**High**	High	High	High
	Moderate	Moderate	**Moderate**	Moderate	**Moderate**
	Low	Low	Low	Low	Low
	Very Low	Very Low	Very Low	Very Low	Very Low
	None	None	None	**None**	None

Overall Risk of Fish Passage Improvement (Invasion)					
None	Very Low	Low	Moderate	**High**	Very High

Overall Risk of Restricted Fish Passage (Isolation)					
None	**Very Low**	Low	Moderate	High	Very High

Proposed Fish Passage Improvement Project Decision	Proceed with Fish Passage Improvement Project	Postpone Fish Passage Project to Collect More Data	**Cancel Fish Passage Improvement Project**	Augment Barrier Using Fish Exclusion Barrier Device

Decision Summary and Notes	Site Map
The proposed fish passage project site (green arrow) is a double steel circular culvert located on an unnamed logging road near Walden. The site is very close to Caribou Lake where there is known established populations of both chain pickerel and smallmouth bass. There is just one full barrier between the known AIS source population and the proposed project site. Additionally, although there is not a large quantity of upstream habitat for residential population persistence, the habitat is of very good quality. Also, there is potential for genetic transfer and re-population because the proposed project site is likely passable to residential species at some flows. Fish passage improvement at this site has been canceled indefinitely due to the proximity of AIS source populations downstream of the site and the low risk associated with extirpation of residential species and due to the impassable dam ~25km downstream there is no additional opportunity cost to diadromous species.	
Site Image - Upstream	**Site Image - Downstream**
	

Section Three: Risk Factors

3.1 Risk of Invasion

When an AIS invades a new area, it will go through three stages of invasion. First, it is **introduced**; this can be via unauthorized human introductions, passing of a previously impenetrable barrier, or simply by moving through a stream corridor. After introduction to new habitat, AIS can become **established** within a new habitat if habitat conditions are suitable for its survival, growth and reproduction. In the last stage, the AIS can have an **impact** on native species and either displacement or co-existence will take place.

Risk of invasion refers to the overall risk from AIS if a barrier site were to have fish passage improved. In this framework, risk of invasion is broken down into three **risk categories** employing these three stages of invasion: risk of introduction, risk of establishment, risk of impact. The summation of these risk categories compiles the overall invasion risk assessment for a proposed fish passage improvement.

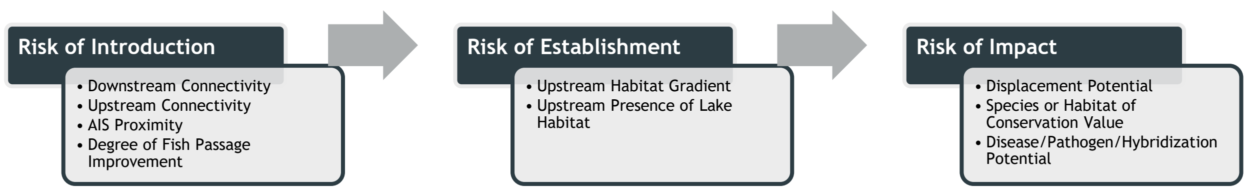


Figure 3: Risk categories and risk factors for risk of invasion.

3.1.1 Risk of Introduction

Risk of introduction is the likelihood that AIS could reach and breach a proposed project site. This section considers barriers preventing AIS from reaching and breeching a barrier site and to what degree a fish passage project would potentially improve AIS ability to access upstream habitat. This risk category has the following risk factors: downstream connectivity, upstream connectivity, AIS proximity, and degree of fish passage improvement.

3.1.1.1 Downstream Connectivity

Downstream connectivity refers to the number and severity of barriers between an AIS source population(s) and a proposed project site. Anthropogenic and natural barriers such as dams, waterfalls, culverts, etc. can prevent AIS from reaching a proposed project site entirely. Risk of introduction decreases with greater number and severity of barriers isolating a potential project site from AIS source populations.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
One or more impenetrable barriers between AIS and proposed project site*.	Several (>3) full barriers between AIS and proposed project site*.	A few (1-2) full barriers between AIS and proposed project site*.	No barriers between AIS and proposed project site.
*Completely impenetrable barriers (i.e. a barrier that passes no age class of fish at all flow levels up to a 1:100-year flood) are much less common than "full barriers". Although full barriers are severe, they are not the same as impenetrable. Most culverts have some degree of permeability to AIS and native species over long timescales.			

If there are one or more impenetrable barriers between a proposed project site and an AIS source population then it is possible that AIS proximity (section 3.1.1.3) may have less importance. If this is the case, consider the weighting for that risk factor accordingly.

3.1.1.2 Upstream Connectivity

Upstream connectivity depends on the location and severity of barriers located upstream of a proposed project site. The connectivity of habitat upstream of a proposed project site contributes to the amount of habitat immediately available to AIS if a proposed project site were breached.

This risk factor is assessed using the linear stream length and perimeter of lakes accessible upstream of a proposed project site before reaching an impenetrable barrier. For streams and rivers, measure length in kilometers; for lakes or ponds, measure perimeter in kilometers. Use the sum of the two values to evaluate the quantity of habitat accessible (refer to example below).

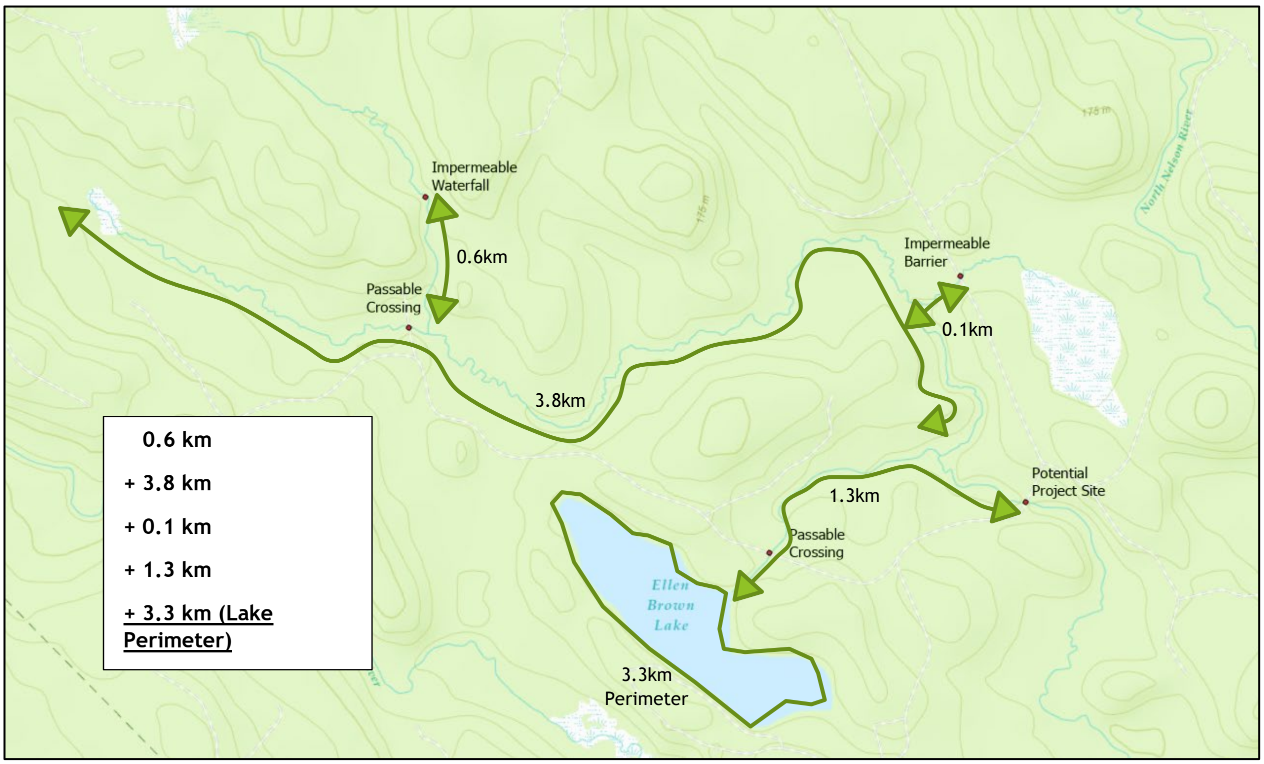


Figure 4: Example of the measuring technique used to measure upstream connectivity for the purposes of this framework.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
N/A	< 0.5 km of linear stream and/or lake perimeter accessible.	0.5-2 km of linear stream and/or lake perimeter accessible.	>5 km of linear stream and/or lake perimeter accessible.

3.1.1.3 AIS Proximity

AIS proximity refers to the relative proximity of an AIS source population to a potential project site. The relative proximity of an AIS source population to a proposed project site contributes to the risk that AIS will be able to access a site and potentially breach it. When

AIS are within the same primary or sub-catchment there are risks that over long timescales AIS will reach a proposed project site.

This risk factor is measured by determining if AIS are present in the same primary catchment, sub-catchment, or immediately downstream of a proposed project site. "Primary catchment" in this framework does not refer to the provincial watershed inventory's "primary watershed"; this inventory sometimes combines more than one river system in a primary watershed. Refer to the glossary of terms for a definition of primary catchment.

If there is an established AIS population upstream of a proposed project site, there is no risk of introduction as AIS already have been introduced. In this case, a fish passage improvement project is likely justified.

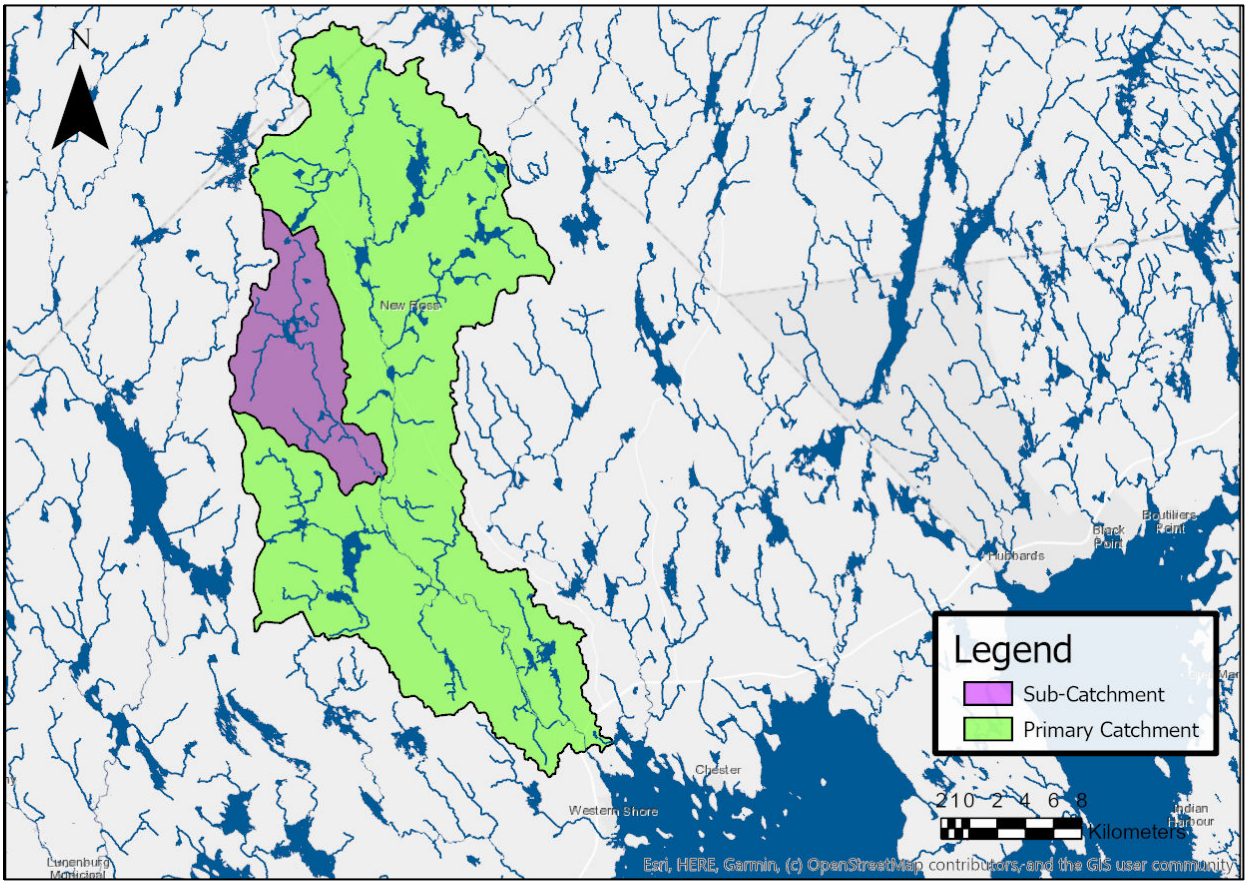


Figure 5: A map displaying the differences between primary catchments and sub-catchments for the purposes of this framework.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
AIS species are not present in primary catchment **OR** AIS already established upstream of proposed project site.	AIS are present in the same primary catchment as a proposed project site.	AIS are present in the same sub-catchment as a proposed project site.	AIS are present immediately downstream of the barrier.

This guide does not consider the risk of intra-catchment movement of AIS (i.e. movement across watershed boundaries by humans or other). This should remain a consideration to managers planning large-scale fish passage projects in watersheds adjacent to or in proximity of established AIS populations. In addition, in some instances, primary watersheds can be connected to other primary watersheds by headwater lakes or marshes. This should be considered if AIS are in adjacent primary watersheds.

If possible, in watersheds where AIS establishments are geographically close, completing fish passage improvements that are removable/reversable could be a good strategy to hedge against the risk of invasion from AIS.

3.1.1.4 Degree of Fish Passage Improvement

Degree of fish passage improvement refers to the anticipated change to fish passage status that a proposed fish passage improvement project will have for AIS species.

Sites under consideration for fish passage improvement projects may not present a substantial barrier to AIS species but still negatively impact native species. Energetic loses, intermittent passage, or potential for fish injury are all good reasons for a fish passage improvement project at sites that are only partial barriers. In these cases, fish passage improvements may be warranted due to the inconsequential impact the project may have on AIS movement over long timescales.

This risk factor is assessed using the predicted change to fish passage status for AIS that an improvement project will have.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
The fish passage project is expected to have no effect on the passage of AIS species.	The proposed fish passage improvement project will marginally improve the passage of AIS species.	The proposed fish passage improvement project will improve the passage of AIS species.	The proposed fish passage project will greatly improve the passage of AIS species.

In some situations, where the permeability of the barrier to AIS is high and the invasion risk outweighs the isolation risk, the installation of a fish-exclusion barrier or enhancing the current barrier may be warranted.

3.1.2 Risk of Establishment (Chain Pickerel and Smallmouth Bass Only)

Risk factors presented for the risk of establishment section of this framework are specifically for chain pickerel and smallmouth bass only. Other AIS will need separate establishment criteria and risk factors, or this section could be skipped altogether with the assumption of successful establishment.

Risk of establishment is the likelihood that upon introduction of an AIS, they will successfully establish a self-sustaining population. For establishment to be successful, AIS must be able to complete its life cycle (survival, growth, and reproduction) within the given habitat conditions. Risk factors considered for this risk category include upstream habitat gradient and upstream presence of lake habitat.

3.1.2.1 Upstream Habitat Gradient (Chain Pickerel and Smallmouth Bass Only)

This section is to be completed for chain pickerel and smallmouth bass only. For other species assume that the risk of establishment is high.

Upstream habitat gradient refers to the slope of the rivers and streams (i.e. the drop in river elevation over its length) upstream of a proposed project site. Stream gradient is an important habitat variable for establishment of fish species. Species tend to prefer different gradients ranging from the fast-moving water in high gradient step pool and cascading habitat to slow-moving water in still waters. Generally, chain pickerel and smallmouth bass prefer lower gradient stillwater and lake habitat; however, both species can establish in riverine-type habitat.

When considering this risk factor, any significant length of stream with a slope within the below suggested risk values should be considered as a potential area where smallmouth bass or chain pickerel could establish. Average upstream gradient should not be used to represent upstream habitat and instead the full range of gradients present should be considered.

Stream gradient can be difficult to obtain reliably with topographic maps or currently available digital elevation models. Best practice is to obtain stream gradients by completing a field-based surveys of the stream.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
N/A	>1% gradient throughout upstream habitat.	Mostly 1%-0.5% gradient.	Mostly < 0.5% gradient.

3.1.2.2 Presence of Lake Habitat (Chain Pickerel and Smallmouth Bass Only)

This section is to be completed for chain pickerel and smallmouth bass only. For other species assume that the risk of establishment is high.

Presence of lake habitat refers to the presence or absence of lake, pond, or stillwater habitat in the stream network upstream of a proposed project site that would be available to AIS if a proposed project site were breached (i.e. not upstream of an impenetrable barrier).

Although chain pickerel and smallmouth bass can establish populations in both lake and riverine habitats, they are primarily lake-dwelling species. Chain pickerel and smallmouth bass tend to thrive and have greater potential for explosive growth in these habitats. The presence of lake, pond, or stillwater habitat upstream of a barrier can be an indicator of potential establishment success for both chain pickerel and smallmouth bass.

For this risk factor, determine if there is lake, pond, or stillwater habitat upstream of a proposed project site. The suggested risk assessment values for this risk factor are either high or low based on the presence or absence of the above-mentioned habitat types.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
N/A	No lake, pond, or stillwater habitat present.	N/A	Lake, pond, or stillwater habitat present.

3.1.3 Risk of impact

Risk of impact refers to the projected severity of the impact that an established AIS population could have on native species with overlapping habitat. Upon establishment AIS can impact native species in a variety of ways (predation, competition for food, occupation of critical habitat, etc.). The impact of AIS on native species is dependent on numerous factors, including species biology and habitat characteristics. Understanding the impact of a successful AIS invasion to native species is important in understanding the overall risk of invasion. The risk factors associated with this risk category are displacement potential, upstream species or habitat of conservation value, and disease/pathogen/hybridization potential.

3.1.3.1 Displacement Potential

Displacement potential refers to the potential for AIS to outcompete or predate upon a native species resulting in either reduced population size or complete extirpation. The severity of native species displacement is determined by species biology (both native and invasive) and habitat characteristics.

Chain pickerel and smallmouth bass are known to significantly displace salmonids and other native species and can alter native fish community structure. Chain pickerel likely has the greatest potential impact on native fish species due to its voracious predatory behavior, explosive population growth, and ability to withstand a wide range water quality, temperature, and habitat conditions. Smallmouth bass has a negative impact on native fish species in Nova Scotia. When smallmouth bass is established in a new habitat they prey heavily on smaller fish and can outcompete native species (DFO, 2009). Both species, upon establishment, typically will become a dominant component of the food web.

One way to estimate the potential impact AIS will have is to use an example site as a case study. Identify an area where the AIS species in question has become established that has similar habitat characteristics to the proposed project site. Using this example area, evaluate the impact AIS had on native species, and extrapolate to the potential project site.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
N/A	Displacement possible	Displacement likely	Extirpation possible or likely

If the potential displacement impact of native species is unknown, assume that extirpation of native species is possible or likely in adherence to the precautionary approach.

3.1.3.2 Upstream Species or Habitat of Conservation Value

Upstream species or habitat of conservation value refers to the presence or absence of aquatic and amphibious species or habitat of significant conservation value upstream of a proposed project site. When a species of conservation value is present in upstream habitat, there is more risk associated with improving fish passage at a proposed project site. Species of conservation value can be defined as species that have significant evolutionary, ecological, or socio-economic value (Fausch et al., 2006). Species that meet these criteria demand greater caution.

In addition to species of conservation value, it is possible that an assemblage of species, sensitive areas, or rare habitat could represent an area of conservation value. Areas with high biodiversity or valuable habitat could warrant increased caution.

As noted in Section 2.1.1, if there are species present upstream of a proposed project site listed as species at risk or if an area of the upstream catchment is a designated protected area or an area of significant cultural/social value, this framework should not be used exclusively, and more in-depth investigation and stakeholder engagement is required.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
No species and/or habitat of conservation value located upstream.	Species and/or habitat of low conservation value present upstream.	Species and/or habitat of moderate conservation value present upstream.	Species and/or habitat of high conservation value present upstream.

3.1.3.3 Disease/Pathogen Transfer and Hybridization

Disease, pathogens, and hybridization between AIS and native species is not a common issue in Nova Scotia. If these issues occur within the same watershed as a proposed project site, they need to be considered during the risk assessment.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
Disease, parasites and/or hybridization not possible.	Disease, parasites, and/or hybridization possible, but unlikely and their potential impact limited.	Disease, parasites, and/or hybridization possible and their potential impact moderate.	Disease, parasites, and/or hybridization likely and their potential impact significant.

3.2 Risk of Isolation

Aquatic habitat connectivity benefits two classes of fish: diadromous and resident fish species. Resident fish species are threatened by isolation due to potential genetic bottleneck and random environmental events causing extirpation without opportunity to re-populate. Diadromous species spend part of their life in the marine environment and may only use freshwater habitat for part of their life history. Choosing not to improve fish passage or actively blocking passage may have opportunity costs for these species.

Isolation risk is presented in this framework in two main categories: **extirpation risk to residential species** and **opportunity cost to diadromous species**. The risks and costs are associated with not improving, or purposely blocking fish passage, thus fragmenting aquatic habitat, are considered in this section.

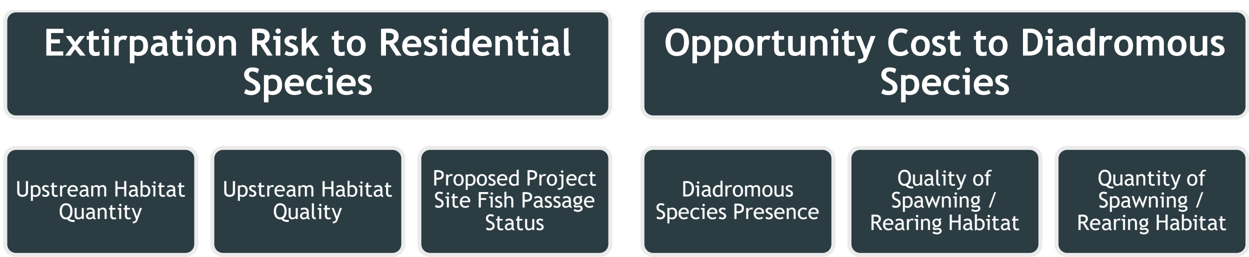


Figure 6: Risk categories and risk factors for risk of isolation.

3.2.1 Risk of Residential Species Extirpation

Extirpation risk to residential species refers to the likelihood that resident fish populations upstream of a proposed project site are sustainable over long timescales as an isolated population. Isolated populations of fish species are at a higher risk of extirpation than those connected to larger populations. Risk of extirpation increases with smaller carrying capacity and adult survival rates that isolated habitat provides. Higher carrying capacity and adult survival can buffer the population from random environmental events that may otherwise cause extirpation (Morita, 2002). May be worth while to mention rescue effect: the presence of a source population nearby can allow for emigration and avoid extirpation through rescue effect. In absence of aquatic connectivity there is no chance for individuals to re-occupy the habitat.

To assess the severity of the risk associated with resident species extirpation, consider the following risk factors: upstream habitat quantity, upstream habitat quality, and proposed project site fish passage status.

3.2.1.1 Upstream Habitat Quantity

Upstream habitat quantity refers to the carrying capacity of the upstream habitat (i.e. the number of individuals that a given habitat can support). Carrying capacity of isolated habitat is the main predictor of probability of population persistence over long time scales (Morita, 2002). An isolated population has a greater chance of long-term population persistence in habitat with a large carrying capacity than a population in a habitat with a small carrying capacity. The larger carrying capacity acts as a buffer from random environmental events.

Carrying capacity of habitats is correlated to the amount of linear stream habitat upstream of a barrier. For this risk factor, measure the total amount of linear habitat available to residential species upstream of a proposed project site.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
> 10km	10-5km	5-2km	< 2km

3.2.1.2 Upstream Habitat Quality

Upstream habitat quality refers to the condition of habitat upstream of a proposed project site for adult survival of resident native species. Adult survival (i.e. the percent of juveniles that reach reproductive age in a given habitat) is a strong predictor of the probability of population persistence over long timescales (Morita et al, 2002).

The quality of upstream habitat impacts the risk of residential species extirpation. With higher quality habitat, and high adult survival, the risk of population extirpation decreases. Adult survival correlates to upstream habitat quality. Water quality (pH, DO, metals, etc.), physical habitat characteristics, temperature regime, and flow regime as they relate to the habitat requirements for native species can be considered in determining the quality of the upstream habitat.

One option to evaluate the quality of habitat for brook trout is the Nova Scotia Fish Habitat Assessment Protocols (NSFHAP)[3] and the accompanying Habitat Suitability Index (HSI). These tools can help determine the quality of habitat in an objective way. Other habitat suitability index models may be available for other native species as well.

Suggested Risk Assessment Values			
No Risk	**Low Risk**	**Moderate Risk**	**High Risk**
N/A	Good Quality OR >0.8 HSI Index Value.	Moderate Quality OR 0.45-0.8 HSI Index Value	Low Quality OR <0.4 HSI Index Value

3.2.1.3 Proposed Project Site Fish Passage Status

Proposed project site fish passage status refers to the current pre fish passage improvement fish passage status of a proposed project site to native resident species. As mentioned in Section 3.1.1.4, fish passage improvement projects are not always directed towards impenetrable or even full barrier sites. Many fish passage improvement projects in Nova Scotia are aimed at improving fish passage at partial barrier sites where fish passage may be blocked during only some flow levels. These projects are beneficial to prevent energetic loses, intermittent passage, or potential for fish injury to native species.

If the barrier allows for some sporadic passage of native species, then there will opportunity for re-colonization and gene flow, lowering the overall risk of isolation.

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[3] http://adoptastream.ca/training/habitat-suitability-assessment

Suggested Risk Assessment Values			
No Risk	Low Risk	Moderate Risk	High Risk
Mostly passable for native resident species.	Passable at some flows for native resident species (partial barrier).	Rarely passable at some flows for native resident species (full barrier).	No permeability at all flows for native resident species (impenetrable barrier).

When "no risk" or "low risk" is selected for this risk factor, quality of upstream habitat (Section 2.3.1.1) and quantity of upstream habitat (Section 3.2.1.2) may be weighed as less important as there will be opportunity for repopulation of extirpated habitat and genetic flows.

3.2.2 Opportunity Cost

The term 'opportunity cost' refers to the missed potential benefit(s) from an alternative(s), that is not selected in favor for an opposing alternative.

The opportunity cost of not improving fish passage in favor of preventing invasion is the benefit of potential spawning and/or rearing habitat for diadromous species that could have been realized.

To assess the opportunity cost of not improving fish passage the following factors are considered in this framework: diadromous species presence, quality of spawning/rearing habitat, and quantity of spawning/rearing habitat.

3.2.2.1 Diadromous Species Presence

Diadromous species presence refers to the presence or absence of diadromous species within the watershed, and whether those species have access to a proposed project site.

If diadromous species are likely to utilize upstream habitat if passage were provided, then the opportunity cost of not improving fish passage would be the benefits provided by the upstream habitat to the diadromous species. There are many native diadromous species in Nova Scotia. Diadromous species that migrate into freshwater and require upstream migration for their life histories in Nova Scotia include alewife/river herring (gaspereau), Atlantic salmon, sea trout, American shad, sea lamprey, rainbow smelt, Atlantic sturgeon, shortnose sturgeon, and American eel.

For this risk factor, estimate the likelihood that diadromous species would utilize the upstream habitat for spawning and/or rearing. Circumstances affecting the likelihood of habitat usage by diadromous species include diadromous species presence and connectivity with the ocean.

Suggested Risk Assessment Values			
No Risk	Low Risk	Moderate Risk	High Risk
Diadromous species would not utilize upstream habitat OR no diadromous species present OR proposed project site does not pose a significant barrier to diadromous species.	A diadromous species unlikely to utilize upstream habitat OR proposed project site is passable at some flow levels by diadromous species.	A diadromous species likely to utilize upstream habitat if fish passage is to be improved.	Multiple diadromous species likely to utilize upstream habitat if fish passage is to be improved.

If there are no diadromous species present, or access to diadromous species is blocked by a downstream barrier, then quality of upstream spawning/rearing habitat (Section 3.2.2.2) and quantity of upstream spawning/rearing habitat (Section 3.2.2.3) should not be considered and the risk value assigned to those risk factors should be “no risk”.

3.2.2.2 Quality of Upstream Spawning/Rearing Habitat

Quality of upstream spawning/rearing habitat for anadromous species considers how well upstream habitat conditions meet the spawning and rearing habitat requirements for the diadromous species present in the watershed.

Part of the opportunity cost of not improving fish passage is the benefit that accessing the upstream spawning/habitat could have to diadromous species.

Different species have very different habitat requirements for successful spawning. Based on the spawning/rearing habitat requirements for the anadromous species present in the watershed, estimate spawning/rearing habitat quality and then estimate risk using the suggested risk values below. For information on spawning and rearing habitat requirements for common diadromous species in Nova Scotia refer to Appendix A.

Suggested Risk Assessment Values			
No Risk	**Low Risk (Cost)**	**Moderate Risk (Cost)**	**High Risk (Cost)**
No suitable spawning or rearing habitat.	Low quality spawning/rearing habitat for diadromous species	Moderate quality spawning/rearing habitat for diadromous species.	High quality spawning/rearing habitat for diadromous species.

3.2.2.3 Quantity of Spawning/Rearing Habitat

Quantity of spawning/rearing habitat for diadromous species refers to the amount of spawning and rearing habitat available to diadromous species present in the watershed.

For this risk factor consider the habitat upstream of a proposed project site and determine if there is suitable spawning/rearing habitat for diadromous species present in the watershed and what quantity is available.

Suggested Risk Assessment Values			
No Risk	**Low Risk (Cost)**	**Moderate Risk (Cost)**	**High Risk (Cost)**
No suitable spawning or rearing habitat.	Insignificant amount of spawning/rearing habitat available to diadromous species.	A moderate amount of spawning/rearing habitat available to diadromous species.	Significant amount of valuable spawning/rearing habitat available to diadromous species.

Closing Statement

Aquatic Invasive Species are a growing threat in Nova Scotia; smallmouth bass and chain pickerel’s distributions are expected to continue to expand. Strategic, risk-based decision making using reliable data can help to contain this threat. This framework steers managers through the important considerations and guides them to a strategic decision regarding aquatic connectivity improvements with concern for AIS. This will help to ensure that organizations working to improve fish habitat and overall watershed ecosystem health will not unintentionally contribute to the spread of aquatic invasive species.

Glossary of Terms

Adult Survival: The percentage of juvenile fish that reach reproductive age in each habitat.

AIS Source Population: A location where AIS have become established that individuals may migrate out from.

Anadromous Species: Species that spawn in fresh water but complete other parts of their life history in the marine environment (i.e. Atlantic salmon).

Aquatic Connectivity: The degree of connectiveness of a watershed's river and stream network for abiotic and biotic flows.

Aquatic Invasive Species (AIS): Fish, invertebrate, plant species introduced to a new habitat outside of their native range.

Barrier: An obstacle within a waterbody that hinders the free passage of aquatic organisms.

Carrying Capacity: The number of species that a specific habitat area can support indefinitely given the resources that the habitat can supply.

Diadromous Species: Species that spend parts of their life history in both fresh water and marine environments (i.e. American eel).

Displacement: The full or partial replacement of one species with another within a habitat through predation or via outcompeting for food resources.

Energetic Loses: When an individual fish uses energy (fat lipids) to overcome an obstacle on their way upstream. The energy used will no longer available for spawning and will decrease the individuals chances for spawning success.

Extirpation Risk: The risk that a species will become locally extinct within an isolated habitat.

Fish Exclusion Barrier: A human-made structure designed to stop the movement of AIS to locations upstream of the barrier.

Full Barrier: A culvert where there is an outflow drop from the culverts outflow to the tailwater control of greater than 0 or where the culvert is greater than 25m in length and is not backwatered with 15cm of depth at the inflow at low flows.

Gene Flow: The movement of individual species and their genes from one population to another.

Generalist Species: Species capable of surviving and thriving in a wide variety of environmental conditions.

Genetic Bottleneck: When a population is significantly reduced in size limiting the genetic diversity of the population. This can lead to increased susceptibility to disease, environmental disasters, and unfavorable genetic traits.

Impenetrable Barrier: A barrier where the target fish species cannot pass the site up to or beyond a 1:100 year flow.

Isolated Habitat: Habitat that has been fully or partially separated or cut off from the larger network by a barrier.

Manager: A person who makes decisions regarding the management of natural resources on behalf of their organization.

Native Species: A naturally occurring species within their native range that co-evolved with the other native species that share its habitat.

Opportunity Cost: The benefits lost from an alternative not chosen. In this case opportunity cost refers to the benefits of aquatic connectivity that would be passed on if a potential fish passage project were not completed.

Partial Barrier: A culvert that is not backwatered with 15cm of depth at the inflow at low flows.

Passable: A culvert that does not hinder the movement of aquatic organisms.

Primary Catchment: An area of land where the water is collected based topography which through a network of streams flows into a singular river that flows into the ocean.

Rearing Habitat: Habitat with characteristics suitable for rearing of the target species.

Residential Species: Species that complete its life cycle within the freshwater environment.

Risk Category: A sub-set of risk factors summarized into one overall risk assessment.

Risk Factor: A variable that can increase or decrease risk or susceptibility.

Risk of Establishment: The risk that upon introduction into a new habitat, an AIS will establish a self-sustaining population within the habitat through survival, growth, and reproduction.

Risk of Impact: The risk of potential impacts that AIS pose to native species throughout-competing, predation, hybridization, pathogen transfer, or disease transfer.

Risk of Introduction: The likelihood that an AIS will access a new habitat area.

Risk of Invasion: The overall risk to native species associated with the introduction, establishment, and impact of AIS.

Risk of Isolation: The overall risk and opportunity cost to native species if a fish passage improvement project were not completed.

Spawning Habitat: Habitat with characteristics suitable for spawning of the target species.

Specialist Species: Species that have adapted to a narrow range of environmental conditions. Specialist species thrive and outcompete within niche habitat conditions.

Species at Risk: A species that is listed as threatened under the Canadian *Species at Risk Act*.

Stream Gradient: The slope of the stream or the change in elevation of a stream over its length.

Sub-Catchment: An area of land where the water is collected based topography which through a stream or a network of streams flows into a main stem river (i.e. a main stem river is a river whose confluence is with the ocean).

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Appendix A: Spawning and Rearing Habitat Requirements

Rearing Habitat Requirements for Native NS Diadromous Species				
Species	**Physical Characteristics**	**Lake vs. Riverine and/or Stream Gradient**	**Optimal Water Quality***	**Notes**
Alewife and Herring (Alosa pseudoharengus and Alosa aestivalis)	• Substrate not important. Submerged aquatic vegetation is important (Greene, 2009).	• Prefer lake and pond habitat. Can rear in brackish water (Greene, 2009).	• 15°C-20°C, >3.6mgl DO, pH unknown (Greene, 2009).	• 3-9 months in freshwater as juveniles (Greene, 2009).
Atlantic Salmon (Salmo salar)	• 0.5-1.5% stream gradient. In-stream cover is important. Gravel-cobble substrate (Bowlby et al., 2014).	• Primarily riverine habitat (Bowlby et al., 2014).	• 15°C-25°C, >5.4 pH (Bowlby et al., 2014).	• 1-4 years (avg 2) in freshwater (Bowlby et al., 2014).
American Shad (Alosa sapidissima)	• Substrate not important (Greene, 2009).	• Riverine habitat (Greene, 2009).	• 5mgl DO, 10°C-25°C, pH Unknown (Greene, 2009).	• Spend ~80 days in freshwater as juveniles. (Greene, 2009)
American Eel (Anguilla rostrate)	• Prefer soft bottom. • (Greene, 2009)	• Unknown	• 5mgl DO (Greene, 2009)	• Very little is known about American eel habitat requirements. (Greene, 2009)
*Water quality tolerance ranges given in this table are generally true but do not account for episodic spikes or for watercourses with high concentrations of metals (i.e. Aluminum) or other toxins.				

Spawning Habitat Preferences by Species				
Species	**Physical Characteristics**	**Lake vs. Riverine and/or Stream Gradient**	**Water Quality***	**Notes**
Alewife and Herring (Alosa pseudoharengus and Alosa aestivalis)	• Alewife spawn in sand, pebble, and cobble substrates while herring prefers hard bottoms. • Vegetative cover is important for spawning to both species. (Greene et al., 2009) (Pardue, 1983)	• Generally, prefer lake/pond habitat or low gradient slow moving water. • Minimum depth of 15-30cm for spawning. • Prefer headwater ponds. (Greene, 2009) (Pardue, 1983).	• A pH of 5 to 8.5 suggested for egg viability* (Greene, 2009).	• Alewife and Herring can spawn in brackish waters and often spawn behind barrier beaches. They also prefer habitat with vegetative cover. • (Pardue, 1983) (Greene, 2009).
Atlantic Salmon (Salmo salar)	• Gravel Cobble Substrate with very few fines. (Bowlby et al., 2014)	• Riverine habitat with a gradient of 0.5% to 1.5%. (Bowlby et al., 2014)	• pH of greater than 5.0*. • >4.5mg/L Dissolved Oxygen. • Large temp fluctuations and or extreme cold periods can be problematic. (Bowlby et al., 2014).	• Generally, Atlantic salmon prefer to spawn in 2nd to 3rd order streams (citation required)
American Shad (Alosa sapidissima)	• Eggs released in water column, substrate not important. • (Greene, 2009).	• Riverine, Water Vel of 0.3-0.7m/s. • Prefer run habitat. • (Greene, 2009).	• Optimal water temp 14-20C. • >5mg/L DO. • pH of 5.5-9.0*. (Greene, 2009).	• Shad can spawn in brackish water and are tolerant of turbulent waters. (Greene, 2009).
*Water quality tolerance ranges given in this table are generally true but do not account for episodic spikes or for watercourses with high concentrations of metals (i.e. Aluminum) or other toxins.				

Site Information	Date:
Site Name/Identification #	Watercourse
Organization	Watershed
Assessment Completed By	Barrier Site Catchment Size (km^2)
Latitude/Easting	Longitude/Northing
Aquatic Invasive Species	Native Species

Risk Assessment - Improving Fish Passage (Invasion)

Risk Category	Risk Factor	Section Refer-ence	Risk Level (High, Mod, Low, None, Unknown, N/A)	Commentary/Reasoning
Risk of Introduction	**Downstream Connectivity:** How isolated is the proposed project site from AIS?	3.1.1.1		
	Upstream Connectivity: How exposed is the upstream habitat to AIS if the proposed project site were breached?	3.1.1.2		
	AIS Proximity: How close are AIS to the proposed project site?	3.1.1.3		
	Degree of Fish Passage Improvement: To what degree will the proposed project improve fish passage for AIS?	3.1.1.4		
Risk of Establishment (CP & SMB Only)	**Upstream Habitat Gradient:** Is the upstream habitat gradient of riverine habitat suitable for establishment of AIS?	3.1.2.1		
	Upstream Presence of Lake Habitat: Is there lake, pond, or stillwater habitat upstream of the proposed project site?	3.1.2.2		
Risk of Impact	**Displacement Potential:** To what degree could AIS displace native species in the upstream habitat?	3.1.3.1		
	Upstream Species or Habitat of Conservation Value: Are there aquatic species of significant conservation value upstream of the proposed project site?	3.1.3.2		
	Pathogen/Disease/Hybridization Potential: Is there potential of hybridization, pathogen, or disease transfer from AIS to native species?	3.1.3.3		

Risk Assessment - Restricted Fish Passage (Isolation)

Risk Category	Risk Factor	Section Reference	Risk Level (High, Mod, Low, None, Unknown, N/A)	Commentary/Reasoning
Risk of Extirpation to Residential Species	**Upstream Habitat Quantity:** How much habitat is available to native residential species upstream of the proposed project site?	3.2.1.1		
	Upstream Habitat Quality: What is the quality of habitat for native residential species?	3.2.1.2		
	Proposed Project Site Fish Passage Status: What is the current permeability of the proposed project site to native residential species?	3.2.1.3		
Opportunity Cost to Diadromous Species	**Diadromous Species Presence:** Are there diadromous species that would/could utilize the habitat upstream of the proposed project?	3.2.2.1		
	Quality of Spawning/Rearing Habitat: What is the quality of spawning and rearing habitat upstream of the proposed project site for diadromous species present in the watershed?	3.2.2.2		
	Quantity of Spawning/Rearing Habitat: What is the quality of the spawning/rearing habitat available upstream of the proposed project site for diadromous species present in the watershed?	3.2.2.3		

Risk Assessment Summary – Invasion vs. Isolation

Risk Category	Risk of Introduction	Risk of Establishment	Risk of Impact	Extirpation Risk	Opportunity Cost
Select/Circle One for Each Category	Very High	Very High	Very High	Very High	Very High
	High	High	High	High	High
	Moderate	Moderate	Moderate	Moderate	Moderate
	Low	Low	Low	Low	Low
	Very Low	Very Low	Very Low	Very Low	Very Low
	None	None	None	None	None

Overall Risk of Fish Passage Improvement (Invasion)					
None	Very Low	Low	Moderate	High	Very High

Overall Risk of Restricted Fish Passage (Isolation)					
None	Very Low	Low	Moderate	High	Very High

Proposed Fish Passage Improvement Project Decision	Proceed with Fish Passage Improvement Project	Postpone Fish Passage Project to Collect More Data	Cancel Fish Passage Improvement Project Indefinitely	Augment Barrier Using Fish Exclusion Barrier Device

Decision Summary and Notes	Site Map
Site Image - Upstream	**Site Image - Downstream**

Suggested Risk Values – Quick Reference Sheet

Enhancing Fish Passage (Invasion) Suggested Risk Values

Risk Factor	No Risk	Low Risk	Moderate Risk	High Risk
AIS Risk of Introduction				
Downstream Connectivity	One or more impenetrable barriers** between AIS and proposed project site.	Several (>3) full barriers between AIS and proposed project site. *	A few (1-2) full barriers between AIS and proposed project site.	No barriers between AIS and proposed project site.
Upstream Connectivity	N/A	< 0.5 km and/or linear stream and/or lake perimeter accessible.	0.5-2km of linear stream and/or lake perimeter accessible.	>2km of linear stream and/or lake perimeter accessible*.
AIS Proximity	AIS species are not present in primary catchment **OR** AIS already established upstream of proposed project site.	AIS are present in the same primary catchment as the proposed project site.	AIS are present in the same sub-catchment as the proposed project site.	AIS are present immediately downstream of the barrier.
Degree of Fish Passage Improvement	The fish passage project is expected to have no effect on the passage of AIS species.	The proposed fish passage improvement project will marginally improve the passage of AIS species.	The proposed fish passage improvement project will improve the passage of AIS species.	The proposed fish passage project will greatly improve the passage of AIS species.
AIS Risk of Establishment				
Upstream Habitat Gradient	N/A	>1% gradient throughout upstream habitat.	Mostly 1%-0.5% gradient.	Mostly < 0.5% gradient.
Upstream Presence of Lake Habitat	N/A	No lake, pond, or stillwater habitat present.	N/A	Lake, pond, or stillwater habitat present.
AIS Risk of Impact				
Displacement Potential	N/A	Displacement unlikely	Displacement likely	Extirpation possible
Upstream Species or Habitat of Conservation Value	No species and/or habitat of conservation value located upstream.	Species and/or habitat of low conservation value present upstream.	Species and/or habitat of moderate conservation value present upstream.	Species and/or habitat of high conservation value present upstream.
Pathogen/Disease/Hybridization Potential	Disease, parasites and/or hybridization not possible.	Disease, parasites, and/or hybridization possible, but unlikely and their potential impact limited.	Disease, parasites, and/or hybridization possible and their potential impact moderate.	Disease, parasites, and/or hybridization likely and their potential impact significant.

Restricted Fish Passage (Isolation) Suggested Risk Values

Risk Factor	No Risk	Low Risk	Moderate Risk	High Risk
Risk of Residential Species Extirpation				
Upstream Habitat Quantity	Greater than 10 km	10-5 km	5-2 km	<2 km
Upstream Habitat Quality	N/A	Good Quality OR >0.8 HSI Index Value.	Moderate Quality OR 0.45-0.8 HSI Index Value	Low Quality OR <0.4 HSI Index Value
Proposed Project Site Fish Passage Status	Mostly passable for native resident species.	Passable at some flows for native resident species (partial barrier).	Rarely passable at some flows for native resident species (full barrier).	No permeability at all flows for native resident species (impenetrable barrier).
Opportunity Cost to Diadromous Species				
Diadromous Species Presence	Diadromous species would not utilize upstream habitat OR no diadromous species present OR proposed project site does not pose a significant barrier to diadromous species.	Diadromous species unlikely to utilize upstream habitat OR proposed project site is passable at some flow levels by diadromous species.	Diadromous species likely to utilize upstream habitat if fish passage is to be improved.	Multiple diadromous species likely to utilize upstream habitat if fish passage is to be improved.
Quality of Spawning/Rearing Habitat	No suitable spawning or rearing habitat.	Low quality spawning/rearing habitat for diadromous species	Moderate quality spawning/rearing habitat for diadromous species.	High quality spawning/rearing habitat for diadromous species.
Quantity of Spawning/Rearing Habitat	No suitable spawning or rearing habitat.	Insignificant amount of spawning/rearing habitat available to diadromous species.	A moderate amount of spawning/rearing habitat available to diadromous species.	Significant amount of valuable spawning/rearing habitat available to diadromous species.

*For watersheds where AIS are present and the linear habitat above a barrier is >25km, in depth study, investigation, and stakeholder engagement beyond this decision-making guide framework should be completed before any action on fish passage is taken as risk is inherently greater.

** Completely impenetrable barriers (i.e. a barrier that passes no age class of fish at all flow levels up to a 1:100-year flood) are much less common than "full barriers". Although full barriers are severe, they are not the same as impenetrable. Most culverts have some degree of permeability to AIS and native species.