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STATE OF FISH PASSAGE DESIGN FOR THE MACTAQUAC GENERATING STATION

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Intended use and technical limitations of the report, “State of Fish Passage Design for the Mactaquac Generating Station”. This report is a summary of reports and expert opinion regarding the current state of understanding of fish passage considerations for the Mactaquac Generating Station and specifically for the Life Achievement Option. The Canadian Rivers Institute does not assume liability for any use of the included data or analyses outside the stated scope.

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Executive Summary

The contemporary history of fish populations in the Saint John River (SJR) have been influenced by the development of several large hydropower generating stations in the watershed. The most downstream of these facilities is the Mactaquac Generating Station (MGS), which creates a complete barrier to upstream fish migration. Upstream passage is provided through a fish trap and lift, and truck transfer programme. Only Atlantic Salmon (*Salmo salar*) and Gaspereau (Alewife and Blueback Herring; *Alosa pseudoharengus, A. aestivalis*) are actively managed for passage upstream of the MGS. Downstream passage is not managed. In 2014, the Mactaquac Aquatic Ecosystem Study began in support of NB Power's decision-making for the end of life for the MGS. In 2016, NB Power announced that they would be refurbishing the current MGS; this is called the Life Achievement Option.

This report synthesizes four years of research (2014-8), incorporates the current state of fish passage knowledge globally, and provides a comprehensive description of the knowns, and unknowns related to considerations for species-specific passage at the MGS. The report also summarizes the results of workshops with global and local experts, regulators and First Nation organizations, and species-specific fish passage literature reviews and studies associated with the current operation of the MGS.

All fish species known from the SJR were considered in the various activities and reporting as part of the Mactaquac Aquatic Ecosystem Study (MAES). However, several species were identified as priority species for passage based on current scientific knowledge (i.e., local distributions, historic occurrences, the ecology of species, and status with COSEWIC - The Committee on the Status of Endangered Wildlife in Canada). In addition, First Nation communities identified that fish passage discussions should include all native species but agreed that a select number of species were collectively considered of high value by rightsholders. The MAES reports and the synthesis herein focus on these key species: Alewife (*Alosa pseudoharengus*), Blueback Herring (*Alosa aestivalis*), American Eel (*Anguilla rostrata*), American Shad (*Alosa sapidissima*), Atlantic Salmon (*Salmo salar*), Sea Lamprey (*Petromyzon marinus*), Striped Bass (*Morone saxatilis*), Rainbow Smelt (*Osmerus mordax*), and Atlantic and Shortnose Sturgeon (*Acipenser oxyrinchus* and *A. brevirostum*). Sturgeons and Striped Bass were not considered a high priority for passage consideration at the MGS given the likelihood that providing passage would cause harm to the populations in the SJR.

Consistently, the recommendation that would restore functional, multi-species fish passage in the SJR was to remove the dam. The next preferred option would be to rebuild the dam and thus allow for the creation of a new, comprehensive fish passage system, composed of several fish passage facilities built to accommodate the mix of species in the SJR. For the

chosen Life Achievement Option, the expert opinion consistently indicated that retrofitting a facility to add or alter fish passage structures has proven to be the least effective for improving passage solutions at large dams.

The Life Achievement option is going forward and the first-choice recommendation to achieve multi-species passage in the upstream direction is to create a new capture system downstream of the MGS that facilitates the capture and movement of multiple species based on holistic, ecosystem-based, adaptive management objectives. Successful downstream passage has a high degree of uncertainty because it has not been a management objective to date and therefore there are no downstream management activities and only one directed, efficiency study (smolts) with limited results. Efforts are underway to assess smolt and adult salmon passage with an emphasis on the Tobique Narrows Generating Station.

While there is a long history of fish passage applications globally, *functional* solutions are far from definitive. Many engineered systems can pass fish upstream and some can pass fish downstream, but functional solutions require passage that satisfies the biological requirements of each species as well as the fish community and the river ecosystem. In a system such as the SJR with a multi-species community, successful up- and/or downstream passage presents many challenges. Engineered solutions have been successful in passing certain species under specific circumstances; however, they perform poorly when attempting to pass a myriad of species. Passage challenges arise because of species-specific behaviour, swimming, and passage demands, plus other issues such as entering the lentic environment of a reservoir or finding a route out of a reservoir. As a result, reports arising from MAES all recommend that to begin to address the complex passage issues a comprehensive fish management plan is required. The plan must dictate how many of each species and life history stage must pass at each facility and thus, how to address the engineering challenges cost effectively.

Achieving fish passage up- and downstream at MGS is possible, as the current salmon and Gaspereau management programmes demonstrate. However, achieving functional fish passage begins with a requirement of population level targets for each species to be passed upstream which includes understanding efficiencies for the species downstream passage and the cumulative passage efficiencies among all dams and reservoirs. Local peoples and rightsholders also need to be engaged in the conversations to ensure that population management targets and decisions meet their expectations. Effective fish passage engineering begins with this collective knowledge and currently, we lack both the biological knowledge and engineering assessments to predict functional fish passage for the MGS and cumulatively along the SJR.

1. Introduction

In 2014, the Canadian Rivers Institute (CRI) and New Brunswick Power (NBP) initiated a collaboration to evaluate the potential impacts on the Saint John River (SJR) from three future development options of the Mactaquac Generating Stations (MGS). The three original options were: 1) complete dam removal, 2) repowering the station with a new powerhouse and spillway, 3) or rebuilding the spillway only (i.e., retain the reservoir but remove power generation capacity).

Subsequently, CRI established the Mactaquac Aquatic Ecosystem Study (MAES) which is a phased, multi-year observational and manipulative study to develop indicators and predict impacts on the SJR under each development option. The MAES program focused on three major project themes including whole river ecosystem studies, fish passage, and environmental flows. Between 2014 and early 2017, numerous projects were undertaken through the MAES program to understand and assess the latest advances in fish passage science, as well as species specific passage studies in the SJR between Reversing Falls near Saint John and the Tobique River. This work aimed to provide recommendations for multi-species fish passage with consideration of the cumulative passage issues under each of the original development options. In December 2016, a new option first introduced in 2015 called Life Achievement was selected by NBP. This option will see the current MGS facility refurbished. Building on the past work of MAES, in 2017 the program evolved to include an assessment of fish passage options under the Life Achievement option.

This report is a synthesis of the studies conducted by MAES related to fish passage in the SJR. Consistently, the recommendation for the Mactaquac Project since the first workshop on fish passage with local and international experts has been: the best option to restore functional, multi-species fish passage is to remove the dam. For the chosen Life Achievement Option, the expert opinion consistently indicates that retrofitting a facility to add or alter fish passage structures has low probability of improving passage solutions at large dams. To be the most effective while attempting to achieve comprehensive, functional fish passage, MAES proposed the creation of new capture system located downstream of MGS where each species could be captured and managed as desired.

It is evident that achieving fish passage up- and downstream at MGS in its current state is possible, as the current salmon and Gaspereau management programmes demonstrate. It is also probable that more species could be accommodated for capture at the MGS fish trap, and thus better upstream passage decisions for species management. However, achieving functional fish passage begins with a requirement of population level targets for each species to be passed upstream. Passage efficiencies must then be understood, both upstream and downstream, and critically, for all dams and their reservoirs. We currently lack both the biological knowledge and engineering assessments to predict functional fish passage for the MGS and the SJR.

2. Synopsis of MAES Fish Passage Projects

MAES fish passage projects have resulted in a thorough assessment of past and state of the art fish passage designs used around the world (Linnansaari et al. 2015a), a summary of expert advice on fish passage considerations globally and specific to the MGS (Linnansaari et al. 2015b), a science based assessment of species-specific passage needs including a list of recommended species for priority passage consideration (Linnansaari et al. 2016), and a review of the state of fish passage in the SJR (Chateauvert et al. 2018), all of which contributed to the recommendations provided to achieve functional, multi-species fish passage under the Life Achievement option (Curry et. al. 2018).

Further to the list of priority species for passage consideration developed by Linnansaari et al. (2016), CRI staff engaged with NBP and the Wolastoqey Nation in New Brunswick (WNNB) to refine the list based on cultural and economic criteria related to traditional use of the river's resources. These discussions resulted in four categories for fish passage consideration: 1) "green" - critical species for passage; 2) "blue" - passage not required for life-cycle purposes; 3) "red" - passage creates substantial risks to the species; and 4) "black" - passage may elevate risk to native species. Figure 1 illustrates the result of this process (originally presented at Kingsclear First Nation, 8 February 2018).

The MAES program also facilitated several *in situ* observational studies to understand important knowledge gaps related to key species spawning (Striped Bass - Andrews et al. 2017; Shortnose and Atlantic Sturgeon - ongoing; Muskellunge - ongoing) and migration behaviour (e.g., Atlantic Salmon - Babin et al. 2018; American Eel – ongoing and Dixon et al. 2018).

The following sections provide a summary of the MAES fish passage projects. The *in situ* field studies are summarized for each species in Section 4. The complete set of references cited in the reports are not repeated herein and can be accessed through the individual reports.

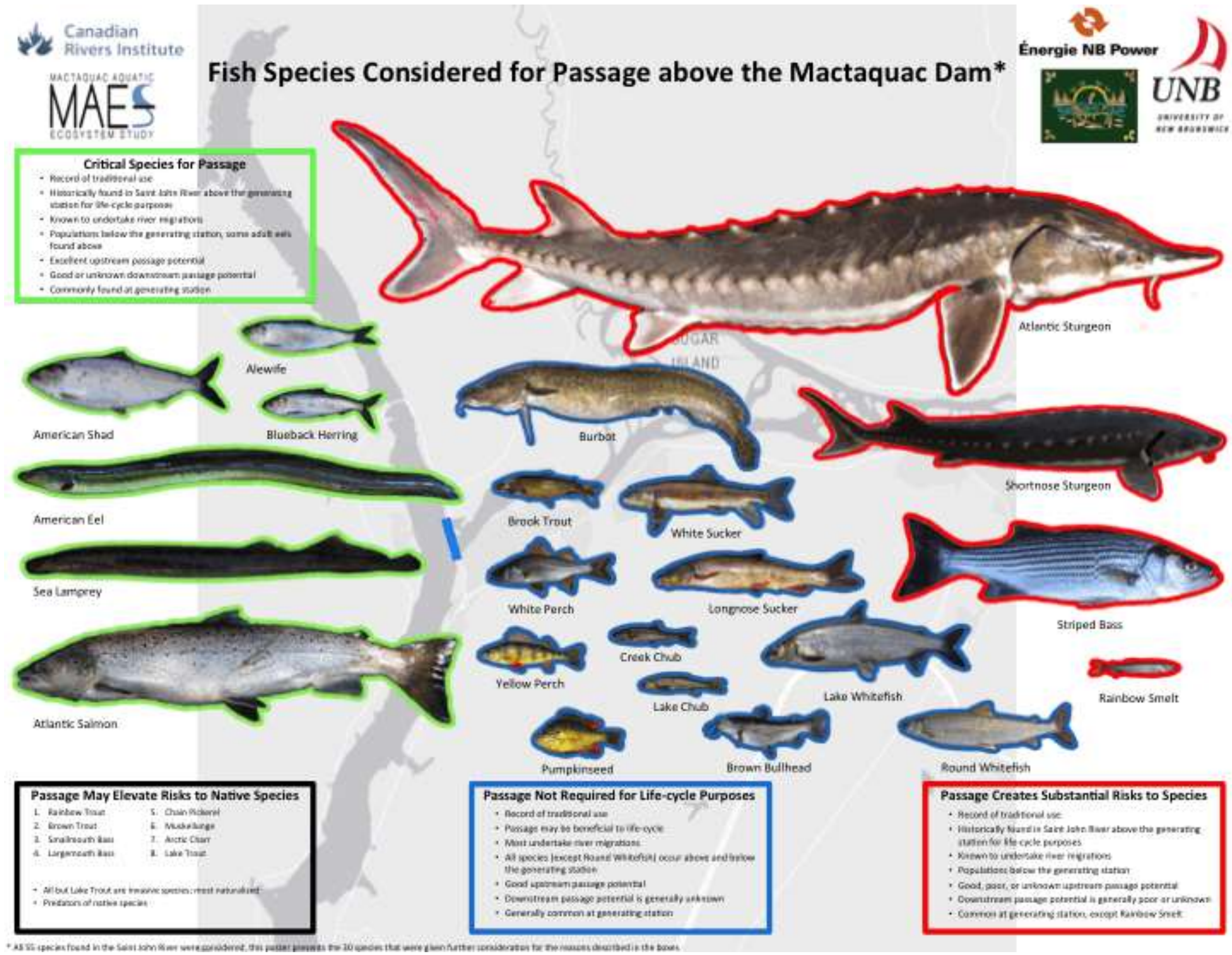

Figure 1: Fish species under consideration for passage above the Mactaquac Generating Station.

2.1 Fish Passage in Large Rivers: A Literature Review

Linnansaari et al. (2015a) provides a comprehensive summary of fish passage research, capturing both up and downstream considerations. This literature review evaluates both traditional (e.g., baffle and pool-weir fish ladders) and emerging technologies (e.g., flexible conduits to promote volitional upstream passage and fish friendly turbines). It provides a synthesis of estimated passage efficiency and mortality for various passage options and species. The report also reviews current fish bypass designs. The adoption of a "functional" fish passage definition is also introduced in this report. Functional fish passage is defined as: 1) passage must be safe causing minimal stress, injury or mortality, 2) passage must be effective based on a predefined target (e.g., 95%) of successful fish passed, and 3) passage must occur with minimal delay, i.e., fish movement is maintained within natural ecological, physiological, or ecologically important windows. The report finds that at large, high-head dams, non-volitional fish lifts or locks are the most common due to the logistical constraints of designing volitional options. Also, functional up- and downstream passage in a multi-species context will ultimately require more than one passage option and incorporate spillway passage, turbine passage, and/or a fish bypass structure(s).

Ultimately, the report finds that functional fish passage is associated with a great deal of uncertainty when passage is required in a multi-species context: there is no "miracle" fish passage facility which is more effective than any other. Therefore, a particular fishway type cannot be recommended or justified without careful consideration of the site (e.g., available attraction flow, placement of passage facility), the species-specific needs (e.g., swimming capabilities), and that adaptive management is vital to achieve success in any passage plan.

2.2 Proceedings of the Fish Passage Expert Workshop: Global Views and Preliminary Considerations for Mactaquac

In November 2014, CRI hosted a fish passage expert workshop in Fredericton. A group of local and internationally recognized experts attended to share best practices and lessons learned from their jurisdictions and experiences (Linnansaari et al. 2015b).
The experts, in addition to sharing their lessons learned, were asked a series of questions related to fish passage generically and specific to MGS: 1) what structures will the species require for successful up and downstream passage, 2) are there species for which it is unlikely that functional fish passage can be achieved, 3) are there structures/techniques or designs that will successfully pass multiple species currently present in the SJR, 4) what species would require specific passage structures, and 5) how might such structures or designs work in a new generating station?

The experts were unanimous that functional, multi-species fish passage at a large dam requires pre-definition of what "success" looks like and must incorporate cumulative effects and adaptive management considerations as well as accounting for species behaviour. They were also clear that achieving functional fish passage at the MGS could only be guaranteed by removing the dam, i.e., it should be expected that future engineered passage solutions will not provide 100%, functional fish passage. Assuming the MGS will remain as a hydroelectric generating facility within its current footprint, experts (while not in complete agreement) stated that the most likely solutions for functional, multi-species fish passage would need to include: multiple, upstream options including a fish lift, a technical fish ladder, and eel and lamprey ramps; whereas downstream passage may be accomplished with the installation of fish friendly turbines and designs that address bottom and surface oriented species movements. The experts largely agreed that a floating bypass collection facility for downstream passage is likely not suitable at the MGS. As well, the large reservoir may limit the effectiveness of any fish passage design if fish can't successful navigate or survive in the large lake-like conditions.

The experts agreed that functional fish passage is difficult to attain during a dam retrofit and that often a complete facility rebuild is required to make meaningful improvements to passage design and success. There was also agreement that volitional fish way options (i.e., fish actively move throughout the passage structure) may not be feasible at MGS given the logistical challenges of the size of the dam and potential impacts on delays in migration (a fish ladder designed for salmonids may need to be up to 640 m long). Whatever the passage option adopted, attraction flow is a vital consideration to draw fish to the passage structure. At many volitional fishway structures, facilities use 3-5% of one turbine units flow for this purpose, but the experts advised that 5-10% would be more effective. For example, approximately 140 m^3/s is used as attraction flow at the Bonneville Dam. It was generally agreed that upstream fish passage is most successful when attraction flow is situated adjacent to the powerhouse where flow is constant as opposed to adjacent to spillways where flow is intermittent.

2.3 Conceptual Considerations for Fish Passage for the Mactaquac Project

Linnansaari et al. (2016) used information and expertise gained through the first two years of MAES research to develop a list of 20 species for priority passage consideration. These species are thought to have the greatest potential for fish passage assuming the MGS reservoir is retained (Options 1 and 2). The species were chosen based on their known occurrence in the vicinity of the MGS and their known migratory behaviours, i.e., if any life history stage undertook migrations. This work was the precursor to the development of Figure 1 herein.

The report outlines specific passage considerations and assesses the suitability of technical solutions for a number of species at risk and species of commercial interest. In addition to the definition of functional fish passage outlined above (and in Linnansaari et al. 2015a) this report also incorporates in its definition that at the MGS specifically, functional fish passage requires a sufficient (scientifically derived) portion of fish from each managed species to be passed to ensure their long-term sustainability in the SJR.

The report finds that a fish lift system at the MGS would have the greatest likelihood of providing functional upstream passage to the majority of high priority species (with specific design considerations). However, American Eel and possibly Sea Lamprey would require separate, species-specific solutions. Realizing functional downstream passage for the priority species will be more difficult and costlier because several species-specific solutions will be required. This includes understanding the needs of surface and bottom migrants to ensure effective top and bottom by-pass entry structures. While turbine passage is the least desirable passage option, installation of "fish-friendly" turbines could improve passage for multiple species of varying body sizes.

The report concludes with two important findings. First, a comprehensive, adaptive fisheries management plan is required to ensure explicit passage targets are developed and evaluated, and second, that detailed management actions are identified to achieve targets and remedy situations when targets are not met. Finally, the report reiterates that removing the dam entirely has the highest likelihood of restoring functional fish passage versus retaining the dam due to structural and retrofitting limitations at the MGS.

2.4 Fish Passage at Tobique-Narrows, Beechwood, and Mactaquac Hydropower Generating Stations

A detailed synthesis of the history and current practices of fish passage at three hydropower facilities in the SJR, Tobique-Narrow GS, Beechwood GS, and the MGS, is provided in Chateauvert et al. (2018). The report provides an in-depth description of each dam's design and the structure of each dam's upstream passage facility, which includes a volitional pool and weir fishways (Tobique-Narrows), a skip hoist fish lift (Beechwood), and a fish lift/ trap and truck facility (MGS). Only Tobique-Narrows offers downstream passage in the form of a bypass which was installed in 2017; the bypass was designed for Atlantic Salmon smolts. At Beechwood and the MGS, downstream passage occurs only through the spillway or turbines. The report states that there is no existing published literature that evaluates the efficiency of any of the dams upstream passage structures. The species-specific population consequences of unknown upstream passage efficiency and lack of downstream passage are unknown.

At each dam, upstream passage facilities were designed for Atlantic Salmon. Other species were not considered in passage design considerations; however, Gaspereau have benefited significantly from the fish trap and truck program at the MGS and their abundance downstream of Beechwood has dramatically increased. The skip hoist at Beechwood allows movement of any species that can ascend the fishway. The hoist is typically operational during the Atlantic Salmon migration run (late May-early November) and while it can operate automatically, the operator often halts the hoist to allow fish identification and enumeration. Four hoists are usually completed per day. The Tobique-Narrows fishway operates 24 hours per day year round, but is only monitored during the salmon migration period.

The report provides a summary of theoretical and empirical estimates of downstream passage mortality (through turbines and spillways); estimates in the literature largely focus on Atlantic Salmon. The report also summarizes upstream passage challenges such as fishway mortality, efficiency, delayed migration, and gas supersaturation.

Chateauvert et al. (2018) examined the available fish capture data collected at each upstream passage facility since the 1950s. The data in that study shows a correlation between the decline of migratory species upstream of the MGS (other than Gaspereau) and the last turbine coming online at the MGS in the 1980's, although this does not indicate causation. The report also synthesizes numerous studies of other dams that document species-specific impacts as a result of one or more of the dams, including: direct and indirect mortality, delayed migration, and active exclusion from upstream waters (e.g., American Eel, Sturgeon, Sea Lamprey, Sturgeon and Striped Bass).

Finally, Chateauvert et al. (2018) synthesizes the historical and current fisheries management objectives and practices related to the movement of fish around the three generating stations in the SJR, as well as the known and speculated impacts of reduced, delayed or impeded migration for various species (e.g., Atlantic Salmon, American Eel, sturgeons). Currently, only Atlantic Salmon and Gaspereau are actively managed at the MGS with defined, albeit not well-articulated targets, and Atlantic Salmon are further managed for conservation and captive breeding objectives.

2.5 Options for Fish Passage in the Mactaquac Project: Life Achievement, Short-term Construction and Longer Term Final Solutions

Curry et al. (2018) outlines the necessary considerations for fish passage assuming the Life Achievement Option to refurbish the existing MGS facility. The authors discuss both temporary and long-term passage solutions because the existing fish lift may be unavailable for 1-2 years during construction. The report only considers upstream passage options because NBP was not considering the addition of new downstream passage options outside of existing spillway and turbine passage at the time of writing.

A potentially viable, temporary passage solution (e.g., during construction at MGS) is a modified trap and transfer system. This system would see fish selected for passage, i.e., currently managed Gaspereau and Atlantic Salmon, collected downstream of MGS and trucked upstream to release sites above MGS (as per current DFO management plans). The trapping method would involve a fyke or box trap net capable of withstanding SJR flows. Captured fish would be sorted and transported as per current DFO management plans. Sorting operations during the Gaspereau run would be challenging and significant resources would need to be dedicated to ensure passage and mortality targets are met. It is noted that this temporary solution is not ideal and will not address functional, multi-species fish passage. There are uncertainties associated with this solution as well as important operational challenges that suggest, while this solution may be feasible, it is far from ideal. Finally, this solution will not provide passage during the construction phase for migrating American Eel elvers which will require either a dedicated eel ladder or collection from the spillway where elvers are known to attempt ascent of the MGS (see Dixon et al. 2018).

In the longer term, because the MGS is a large structure and the SJR is a complex system, successful functional fish passage at the current facility may be difficult to obtain and has a high level of uncertainty. The authors reiterate the need for a fisheries management plan that dictates the targeted species and number of each species to be passed to guide the development of fish passage designs. Multiple components would be required to achieve functional fish passage and could include: trap and truck facility, a fish lift, a possible volitional fishway, and dedicated structures for Sea Lamprey and American Eel. It may be difficult or impossible to achieve all of the ideal passage options within the confines of retrofitting the existing MGS facility.

One solution for a permanent, long-term upstream fish passage option is a comprehensive trap and truck option that would be developed downstream of the existing MGS (Curry et al. 2018). The trap mechanism would involve a permanent, directional fence (e.g., low head dam) installed in the river that forces fish towards a free-swim automated sorting and transfer facility. The sorting facility would be automated based on species detection and would count and bin species to appropriate transport systems (e.g., back into the downstream section of the river, or onto trucks for movement above the MGS). American Eel and Sea Lamprey specialized structures would also be included in the sorting facility. The authors provide details on design considerations for both the low-head dam/weir and fish collection facility.

The report suggests that a comprehensive trap and truck facility will capture a larger diversity of fish species moving upstream than a single passage/retrofitting option installed at the MGS. A new facility could also avoid obstacles and uncertainties associated with traditional passage options. The nature of the sorting facility will also greatly advance our understanding of the fish communities and population structure of fishes in the SJR, i.e., directly benefitting future management decisions. Furthermore, the comprehensive trap and truck program could address both temporary and long-term fish passage needs related to the retrofitting of the MGS, but there are still logistical design and construction considerations to address in addition to undertaking important discussions with local First Nation communities and DFO. After completion of this report, an engineering design review of this option was undertaken by NBP and their fish passage design engineering consultant (Kleinschmidt, Maine, USA) determined the option not feasible.

3. Synthesis of Passage Recommendations

The following sections summarize our current state of understanding of passage considerations for the six species collectively identified as priority for passage consideration (see Section 2 and Appendix 1). Full descriptions and more species-specific considerations are discussed in Linnansaari et al. (2016).

3.1 Alewife (*Alosa pseudoharengus*) and Blueback Herring (*A. aestivalis*)

Both Alewife and Blueback Herring (collectively Gaspereau) are currently managed by DFO at the MGS. Spawners are captured in the trap/lift and trucked to the reservoir where they complete spawning, adults return downstream via turbine passage (there is rarely spilling in the period post spawning), juveniles rear over the summer, and juveniles head to sea via turbine passage from August to October. Since 1995, the spawner escapement targets have been 800,000 Alewife and 200,000 Blueback Herring. The smaller proportion of Blueback Herring relates to their later run timing which was speculated but not proven to impact the early run of Atlantic Salmon via crowding and potentially delay salmon entry to the MGS fish lift. The Gaspereau population has increased 200-fold from returns of 22,000 in 1968 to >4.4 million in 1987 because of the added habitat provided by the reservoir. Some uncertainty of the maximum yield and production capacity of the reservoir exists; its estimated carrying capacity is approximately 10 t / km^2, but the carrying capacity is not assumed to have been reached.

The current management and operations at MGS are successful in arranging upstream passage for these species within numbers determined by the current fisheries management plans. However, neither upstream (adults) nor downstream (adults and juveniles) efficiencies have been assessed, e.g., the impacts of management's selective effects on spawning population composition annually, or turbine mortality rates for adults and juveniles.

For the Life Achievement Option, management of the Gaspereau population will be important to successfully achieve functional fish passage at the MGS. Crowding in the passage facilities by Gaspereau may be an issue for salmon and other species. Future upstream passage solutions must be adequately sized to address the issues, or management plans developed to regulate Gaspereau numbers during capture and transportation. Downstream passage efficiencies will need to be assessed to appropriately manage the juvenile production of the reservoir and upstream reaches. Further study of the reservoir capacity and the ecosystem scale impacts of Gaspereau juveniles and potentially adults (e.g., Hanson and Curry 2004) are critical before upstream passage targets are altered.

Upstream passage considerations (Adults):

- The upstream passage solution must be scaled to effectively capture large numbers of Gaspereau without compromising passage of other species, e.g., the physical and operational capacity at current MGS fish lift may not be adequate in a multi-species management scenario.
- Management plans must be developed to address potential impacts of delays on Gaspereau and other species.
- Fish lifts are the most likely technical solution to be successful for upstream passage for Gaspereau; assuming the maintenance of the status quo of passing 800,000 alewife and 200,000 blueback herring above the MGS.

Downstream passage considerations (Post-spawned Adults; Young-of-the-Year):

- Both Alewife and Blueback Herring are iteroparous capable of undertaking multiple reproductive migrations over their lifetime, and thus timely and efficient downstream passage will be important for post-spawned adults.
- Current passage efficiencies for post-spawned adults and juveniles are unknown.
- Adults and juveniles are most probably best managed by surface-spill or guidance (e.g., booms or louver arrays) to a surface-oriented by-pass.
- Studies are required to understand paths travelled by adults and juveniles in the reservoir and approaches to the facility.
- Turbine passage efficiency is predicted to be higher in modern, fish-friendly turbine units.

3.2 American Eel (*Anguilla rostrata*) – Threatened (COSEWIC 2012)

American Eel are catadromous, migrating to freshwater as juveniles from the Sargasso Sea. In freshwater, the eels can inhabit the main river, tributaries, or headwater lakes where they grow and mature for up to 20 years before returning to the sea to spawn. Eels are prevalent in downstream tributaries, e.g., Nashwaak River has 16 years of abundances 1-2 eels per 100 m^2 (DFO 2014). Eels are not actively managed at the MGS, e.g., eels are not actively moved upstream and thus 46% of the SJR watershed is unavailable (Pratt et al. 2014). Their numbers upstream of MGS have declined since the installation of the MGS in 1968 (Ellis et al. 2017). However, reports of adult eels being captured above the MGS occur (e.g., Gautreau et al. 2018) suggesting some migrating juvenile eels are either being transported in the Gaspereau transfers or are finding ways through or over the MGS, albeit in very low numbers. Dixon et al. (2018) observed thousands of juvenile eels attempting to ascend the MGS spillway throughout the summer 2016 and 2017 (average size 10-15 cm) even though DFO had reported that no more elvers reach MGS (Jessop and Harvie 2003).

American Eel are considered a priority species for passage consideration because they meet the ecological criteria assessed throughout the MAES program and the species has food, social, and ceremonial value to local Indigenous communities (WNNB 2018).

Emerging issues complicate the decision on whether or not to pass American Eel above MGS. First, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has proposed that the species be listed as Threatened under the Federal Species At Risk Act, 2002 (SARA). This decision is based on the status of the global, panmictic population. Listing the species will result in the prohibition of activities that results in harm: passing eel above the MGS may fall in this category where no safe downstream passage is assured. A local discussion to allow a portion of juvenile eels attempting to ascend the MGS to pass upstream would require further consultation with SARA officials.

Ultimately, there is a great deal of uncertainty with respect to how to achieve functional passage for American Eel under the Life Achievement option for MGS. For the Life Achievement Option, the current MGS fish trap/lift may not be suitable for functional upstream passage of juvenile American Eel. Arranging upstream passage for juveniles appears to be achievable based on experiences at other hydroelectric generating facilities, e.g., elvers could be easily captured and manually transferred upstream. Downstream passage of adults will be difficult and costly. Arranging upstream passage is not recommended at this time. Specifically passage considerations should be withheld until the implications for the eel population are known, including the impact of an emerging parasite issue in the SJR downstream of the MGS, and the opinions and needs of Indigenous communities are better understood.

Upstream passage considerations (Juveniles):

- The current population status and implications for upstream passage require study.
- If upstream passage is determined to be acceptable, the numbers passed will depend predominantly on the population status and opinions and needs of the Indigenous communities.
- For high-head dams, eel climbing ramps and specialized lifts are recommended. These solutions are deemed feasible at MGS; alternatively, simple trapping and manual transport is feasible and may be an option that better engages local Indigenous communities in the management of the species (Dixon et al. 2018).
- A swim bladder parasite has been identified in downstream resident eels and the risk of moving it upstream is uncertain at this time.

Downstream passage considerations (Adults):

- Efficient (low mortality) downstream passage for American Eel under the Life Achievement Option is unlikely without extensive and expensive engineering solutions. Specialized facilities and devices will be required to exclude adults from turbine passage.
- The installation of seasonal trash racks to prevent turbine entry and a bottom-oriented bypass system are recommended, but such options are likely limited at the current MGS.
- Passage has been provided using a bypass tunnel that moves fish and eels from the forebay through the facility and ejects them into the tailrace at Chaudière Falls, Ontario (https://www.hatch.com/en/Projects/Energy/Chaudiere-Falls-Hydroelectric-Redevelopment-Project). The bypass system at Chaudière Falls became operational in 2018 and studies are ongoing to determine its effectiveness at reducing eel injury and mortality.
- Passage may be provided through opportunistic flow and power management actions (e.g., spilling water); however, effective passage using spill and guidance requires specific knowledge of American Eel migration timing and behavior, e.g., approach to the dam, all of which is not known for the SJR.

3.3 American Shad (*Alosa sapidissima*)

Currently, American Shad is not actively managed. Shad are not passed upstream of the MGS and individuals that are encountered in the MGS fish trap are returned to the downstream area or included as bycatch during gaspereau escapement season. Numbers of American Shad passed in the MGS fish trap have drastically declined from 30,000s annually to a few shad in recent years. This is assumed to be a Gaspereau crowding problem entering and in the fish trap. As is the case for other fish species encountered in the fish trap at MGS, the numbers of shad captured does not represent the actual population status (see Striped Bass review by Andrews et al. 2016).

Passing American Shad upstream in the Life Achievement Option has the potential to be successful, e.g., a trap-and-truck solution. The existing issues at MGS have been overcome with trap-and-truck techniques used in the Connecticut and Merrimack rivers, i.e., there are design and operating improvements that can accommodate shad behaviour in the trap and trucks (A. Haro, Conte Anadromous Fish Research Laboratory, USGS, pers. comm.).

Downstream passage of both post-spawned adults and juveniles is required. In high latitude populations such as the SJR, populations consist of a high proportion of repeat spawners and therefore, downstream passage for adults is critical (e.g., Stich et al. 2018). It is predicted that passage will be via turbines because no spill is generally occurring during the downstream migration periods. No efficiency or mortality estimates exist for the current MGS, but literature values for turbine passage mortality suggest 10-25% for adults (Kaplan units) and ~5% for juveniles.

If adults are passed upstream, it is possible that they may spawn successfully and usable habitats may increase as much as 68% from the pre-Beechwood and Mactaquac dam construction. The estimated numbers of adults that could successfully reproduce in the reservoir ~12,000 based on studies in the 1970s. As with Gaspereau, additional studies of the reservoir capacity and the ecosystem scale impacts of American Shad juveniles and potentially adults are critical before upstream passage targets are implemented.

Upstream passage considerations (Adults):

- Large technical fishways have provided passage for large numbers of American Shad in the Columbia River system.
- American Shad will not migrate through orifices and overflow passage must be provided, e.g., full Ice-Harbour pool and weir ladder.
- American Shad lack the stamina and motivation to swim through long technical ladders (e.g., high head dams) if areas of unsuitable hydraulics are encountered. Attempts to downscale large technical ladders used in the Columbia River to smaller versions in Atlantic Coast rivers have generally failed to pass shad efficiently, e.g., the Cabot Fishway, Connecticut River.
- Technical pool and weir ladders must have streaming rather than plunging flows and avoid turbulence, air entrainment, hydraulic jumps, upwelling, and eddies.

- Turning basins are problematic for shad. Openings between sections must be lighted (not dark) and wide enough to accommodate shad schooling behaviour.
- Fish lifts will require large hoppers with adequate water flow (velocities and directionality) and where handling is avoided.
- For attraction flows, significant consistent, streaming flows are required.

Downstream passage considerations (Adults and Juveniles):

- Downstream passage is generally poorly understood for American Shad adults and juveniles. Large numbers of juveniles in the Columbia River suggest passage can be achieved, but the same results are equivocal in eastern rivers
- Shad adults and juveniles tend to migrate in the top of the water column and therefore, surface spill and by-pass are preferred passage options, and these must employ a uniform, accelerating flow structure. Rapidly accelerating velocities in the entrance of a by-pass must be avoided.
- Behavioural exclusion techniques have produced inconclusive results, although juvenile shad may be attracted to surface by-pass entrances with light.
- Louvers can be somewhat effective for guiding juvenile and post-spawned adults towards the entrance of by-pass structures.
- Turbine passage efficiency is predicted to be higher in modern, fish-friendly turbine units.

3.4 Atlantic Salmon (*Salmo salar*) – Endangered (COSEWIC 2010)

Atlantic Salmon is a species selected as high priority for passage consideration because of its importance for Indigenous peoples and the general public. The species has declined significantly since 1990's and is currently listed as Endangered under the New Brunswick SARA and is being considered for listing as Endangered federally. Many factors have been implicated in the declining population size including fish passage associated with the hydropower facilities in the SJR and their associated reservoirs (COSEWIC 2010). The hydropower facilities are considered a significant issue because important and extensive spawning, nursery and rearing areas are located upstream of the MGS.

For the Life Achievement Option, the current upstream passage structure for capture and trucking is successful in moving adult Atlantic Salmon upstream, but the efficiency is unknown and similarly, the impacts on the population are unknown. Issues with the current management actions include efficiency of trapping, i.e., the proportion of total salmon approaching MGS that successfully enter the fish trap, or if all captured fish at MGS have upstream origins. Mark-recapture studies in 1990's measured downstream smolt passage success at the MGS (and the Beechwood and Tobique facilities – results are reviewed in Chateauvert et al. 2018). There is no study that converts these estimated efficiencies into an assessment of functional fish passage.

Upstream passage considerations (Adults only):

- Both volitional (free-swim) using multiple designs of technical fish ladders, including pool-and-weir, and vertical slot designs, and non-volitional (fish lifts) solutions can be effective for passing salmonids upstream. At MGS, such a fishway would be longer than anything engineered for Atlantic Salmon to date.
- A key requirement is attraction flow which can be difficult to achieve in retrofitting situations.
- Choice between volitional and non-volitional passage solutions also depends heavily on the migration success in the reservoir. If reservoir migration doesn't cause a delay or straying of individuals, then volitional passage typically allows fish to migrate with some delays (depending on the facility efficiencies). However, if reservoir migration is a bottleneck, then a trap-and-transport method (physical transport of passed fish to more upstream locations via trucking or other means) may be the more effective passage solution. The reservoir migration efficiency for Atlantic Salmon adults is currently under study in the MAES research programme.

Downstream passage considerations (Post-spawn Adults; Smolts):

- The downstream passage issues are both the passage efficiency at a facility and the successful migration through the reservoir. The reservoir migration efficiency for smolts and adults as well as the downstream approaches and current success rates via spillways and turbines at MGS are currently under study in the MAES research programme.
- High survival of downstream passage for salmon smolts is most probably achieved by arranging well-timed, surface spill from the top of the water column. Biologically relevant spill schedules are critical. Both preliminary hydrodynamic modeling and studies of migration timing by smolts and adults are currently under study in the MAES research programme.
- Surface by-pass systems that direct smolts and post-spawning adults to a preferred spill-way route will be the most effective, e.g., surface guidance systems to deflect smolt and adults away from turbine intakes.
- Bar racks with narrow bar spacing can create a physical barrier to prevent smolts and adults entering the turbine units.
- Fish-friendly turbine units are increasingly recommended.

3.5 Sea Lamprey (*Petromyzon marinus*)

The ecology and migrations of Sea Lamprey are poorly known in the SJR. Adult Sea Lamprey were commonly observed at the Tobique-Narrows and Beechwood dams, e.g., >7,000 in some years prior to construction of MGS. They were numerous at the MGS fish lift in the years following its construction (> 8,000), but due to the management strategy to remove and destroy adult lamprey at MGS, the stock rapidly declined, and lamprey are rarely captured in the MGS trap. They do occur and reproduce in the tributaries downstream of the MGS (e.g., Munkittrick et al. 2011). Sea Lamprey don't form river-specific natal populations and thus they are predicted to appear at the MGS. Their absence may be related to juvenile pheromones because the stream-dwelling larvae release a migratory, bile acid-based pheromone considered crucial in guiding adults to watersheds for spawning. These chemical cues will be missing from tributaries upstream of the MGS, i.e., arranging upstream passage will require a management plan that establishes new spawning locations for returning adults.

It is not known how adult Sea Lamprey or juveniles returning to the sea would behave in the MGS reservoir. The Sea Lamprey is semelparous and adults die after spawning, thus downstream passage is not required for adults. Adults would migrate past the MGS reservoir seeking flowing waters (likely tributaries) for spawning, i.e., passage may be important at both Beechwood and Tobique-Narrows dams where passage efficiencies are unknown. Spawning sea lamprey provide marine-derived nutrient (MDN) subsidies at a critical period whereby rising water temperatures and increasing photoperiod stimulates primary productivity (Samways et al. 2015, Samways et al. 2018). These MDN subsidies coincide with the emergence of young-of-the-year fish (e.g., Atlantic salmon fry), which benefit from these nutrient subsidies (Samways et al. 2017).

For the Life Achievement Option, both up- and downstream passage designs and efficiencies will be constructed with a high level of uncertainty of success. In general, passage for most ladder/lift designs are poorly documented for Sea Lamprey. As with Gaspereau and American Shad, additional studies of the upstream, ecosystem scale impacts of Sea Lamprey juveniles are critical before upstream passage targets are implemented.

Upstream passage considerations (Adults):

- The adult Sea Lamprey is highly rheophilic (attracted to flow), have unique swimming and climbing behaviour in fishways, migrate at night, and these behaviours will have to be accommodated in an engineered solution.
- Pool and weir, vertical slot ladders, and fish lifts efficiencies are poor or not known.
- The Pacific Lamprey (*Lampetra tridentata*) can use pool and weir fish ladders and other specialized design structures, but an average efficiency of ~50 % was reported in the Columbia River system over a 10-year period (Keefer et al. 2014; Moser et al. 2011).

Downstream passage considerations (Juveniles):

- The seaward migration of juvenile Sea Lamprey (tranformers) is not well understood in the SJR. In other systems, transformer migration is bimodal occurring at night with high flows both in autumn and spring.
- Transformers are particularly vulnerable to entrainment and impingement in screens and bar racks designed to protect juvenile salmonids.
- Transformers are bottom-oriented during downstream migration.
- Pre-transformation ammocoetes (pre-transformers) may also exhibit downstream migrations which are poorly understood.
- Currently, there are no downstream passage guidance or exclusion technologies developed specifically for Sea Lamprey (A. Haro, Conte Anadromous Fish Laboratory, USGS, pers. comm.)

4. Conclusion

There is a long history of fish passage engineering applications globally; however, *functional* solutions are far from a definitive guarantee of effectiveness at a population level. In a system such as the SJR with a multi-species community, successful up-and/or downstream passage presents many challenges. There are many technologies that have successfully passed certain species under specific circumstances, however, they tend to perform poorly when attempting to pass a myriad of species because each has specific behaviour, swimming, and passage demands.

At the MGS, the functionality of the existing lift is not well understood and assessing its passage efficiency is paramount under the Life Achievement Option. Aside from no efficiency studies being conducted to date, our poor understanding the needs and specific behaviour of each of the species to be passed greatly increases the difficulty in achieving functional fish passage, i.e., there is a high degree of uncertainty and past experiences with retrofitting for fish passage are equivocal. In the absence of such data, engineers must rely on the previous passage projects that may or may not be similar to the MGS and attempt to integrate them into a passage structure(s) that is at best, a guess at meeting all species-specific needs.

Achieving fish passage up- and downstream at MGS is possible, as the current salmon and Gaspereau management programmes demonstrate; however, achieving functional fish passage begins with a requirement to know the population level targets for each species that requires a passage solution. Passage efficiencies must then be understood, both up-and downstream, and critically, cumulatively among all dams and their reservoirs. Effective passage engineering begins with this knowledge and currently, we lack both the biological knowledge and engineering assessments to predict functional fish passage for the MGS and the SJR. NBP, through MAES Phase II and ongoing discussions and partnerships with DFO, the Wolastoqey Nation, and stakeholders, is currently attempting to fill these data gaps in support of their fish passage planning and engineering of solutions.

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Appendix 1. Summary of Passage Considerations Based on Biological and Engineering Knowledge Included in the Report

Species	Life History Stage	Priority	Population Status Upstream	Population Status Downstream[1]	Beyond MGS Population Connectivity[2]	Predicted Minimum Number Passing Upstream Annually at MGS in 2012[3]	Upstream Passage Potential	Peak Upstream Movement	Technical Solution – Upstream (order of potential effectiveness)	Downstream Passage Potential	Peak Downstream Movement	Technical Solution – Downstream (order of potential effectiveness)	Special Considerations	Reference
American Shad	Adult	High	Unknown	Uknown	Required	123-645[4]	Possible	May - July	1. Ladder 2. Trap and Truck	Unknown	Unknown	1. Bypass / Collection 2. Spillway	1. Mortality associated with trap and truck	Chateauvert et al., 2018 Linnansaari et al., 2016
American Shad	Juvenile	High	Uknown	Uknown	Required	Unknown	N/A	N/A	N/A	Unknown	Unknown	1. Bypass / Collection 2. Spillway 3. Turbine		
Alewife	Adult	High	Unknown	Stable	Not required	740,728[5]	Excellent	May-June	1. Lift 2. Ladder 3. Trap and Truck	Good	June-July	1. Bypass / Collection 2. Spillway 3. Turbine	1. Size of capture / lift facility 2. Escapement targets	Dobson-Edge et al., 2018; Linnansaari et al., 2016; Munkittrick et al., 2011;
Alewife	Juvenile	High	Stable	Stable	Not required	Unknown	N/A	N/A	N/A	Good	August-October	1. Bypass / Collection 2. Spillway 3. Turbine		
Blueback Herring	Adult	High	Unknown	Stable	Not required	934,501[5]	Excellent	June	1. Lift 2. Ladder 3. Trap and Truck	Good	June-July	1. Bypass / Collection 2. Spillway 3. Turbine	1. Size of capture / lift facility 2. Escapement targets	Dobson Edge et al., 2018; Linnansaari et al., 2016; Munkittrick et al., 2011
Blueback Herring	Juvenile	High	Stable	Stable	Not required	Unknow	N/A	N/A	N/A	Good	August-October	1. Bypass / Collection 2. Spillway 3. Turbine		
Atlantic Salmon	Adult	High	Unstable	Unstable	Required	209	Excellent	June-October	1. Lift 2. Ladder 3. Trap and Truck	Good	December-January	1. Bypass / Collection 2. Spillway 3. Turbine	Reservoir conditions	Babin et al., 2018
Atlantic Salmon	Kelt	High	Unstable	Unstable	Required	N/A	N/A	N/A	N/A	Good	April-May	1. Bypass / Collection 2. Spillway 3. Turbine	Reservoir conditions	Babin et al., 2018
Atlantic Salmon	Smolt	High	Unstable	Unstable	Required	N/A	N/A	N/A	N/A	Good	April-June	1. Bypass / Collection 2. Spillway 3. Turbine	Reservoir conditions	Babin et al., 2018
American Eel	Adult	High	Unstable	Unstable	Unknown	0	N/A	N/A	N/A	Poor	Late fall	1. Spillway 2. Bypass / Collection 3. Fish friendly turbine	SARA designation	DFO 2014; Linnansaari et al., 2016.
American Eel	Elver - Juvenile	High	Stable[6]	Stable[6]	Unknown	0	Excellent	June-August	1. Climbing ramp 2. Collection from Spillway at night	N/A	N/A	N/A	Swim bladder parasite	DFO 2014[6]; Dixon et al., 2018; Campbell et al., 2013
Sea Lamprey	Adult	High	Unstable	Stable	Unknown	0	Good	May-July	1. Climbing ramp	N/A	N/A	N/A		Linnansaari et al., 2015; Linnansaari et al., 2016
Sea Lamprey	Juvenile	High	Unstable	Stable	Unknown	0	N/A	N/A	N/A	Good	May-November	1. Bypass / Collection 2. Spillway 3. Turbine	1. High mortality from impingement	Linnansaari et al., 2015; Linnansaari et al., 2016
Atlantic Sturgeon	Adults (>1 m body length)	Passage creates substantial risk to species	Unknown	Known	Not Required	0	Poor	Unknown	1. Fish Lift	Poor	Unknown	1. Bypass / Collection		
Atlantic Sturgeon	Sub-Adults (<1 m body length)	Passage creates substantial risk to species	Unknown	Known	Not Required	0	Poor	Unknown	1. Fish Lift	Poor	Unknown	1. Bypass / Collection		
Atlantic Sturgeon	Larvae / young-of-the-year	Passage creates substantial risk to species	Unknown	Known	Not Required	0	Possible	Unknown	1. Fish Lift	Good	Unknown	1. Bypass / Collection 2. Spillway		
Shortnose Sturgeon	Adult	Passage creates substantial risk to species	Unknown	Known	Not Required	0	Poor	Unknown	1. Fish Lift	Poor	Unknown	1. Bypass / Collection		
Shortnose Sturgeon	Subadults	Passage creates substantial risk to species	Unknown	Known	Not Required	0	Poor	Unknown	1. Fish Lift	Poor	Unknown	1. Bypass / Collection		
Shortnose Sturgeon	Larvae / young-of-the-year	Passage creates substantial risk to species	Unknown	Known	Not Required	0	Possible	Unknown	1. Fish Lift	Possible	Unknown	1. Bypass / Collection 2. Spillway		
Striped Bass	Adult	Passage creates substantial risk to species	Unknown	Unknown	Not Required	33	Good	July/October	1. Ladder 2. Lift 3. Trap and Truck	Unknown	Unknown	1. Bypass / Collection 2. Spillway	1. Unknown adult origin 2. Limited understanding of population status	Andrews et al., 2017; Linnansaari et al., 2016
Striped Bass	Juvenile	Passage creates substantial risk to species	Unknown	Unknown	Not Required	Unknown	Unknown	July/October	N/A	Unknown	Unknown	1. Bypass / Collection 2. Spillway		

[1] Known state of population in the downstream of MGS reaches: Stable, Unstable, Unknown

[2] Known state of population connectivity across the MGS "boundary": Required, Not Required, Unknown

[3] Current knowledge of number of individuals captured at the MGS Fish Trap (DFO provided data up to 2012)

[4] Based on estimates from 2010-2014 for shad retained in Gaspereau fishery and those passed over MGS

[5] Average numbers of Alewife and Blueback Herring passed between 2003-2018 are 783,092 (max. 1,326,644; min 200,023) and 1,676,623 (max 3,545,610; min 461,618) respectively