Mactaquac Aquatic Ecosystem Study
Report Series 2016-034

CONCEPTUAL CONSIDERATIONS FOR FISH PASSAGE FOR THE MACTAQUAC PROJECT

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8 May 2017

TABLE OF CONTENTS

Correct citation for this publication:

Linnansaari, T., Yamazaki, G. and Curry, R.A. 2017. Conceptual Considerations for Fish Passage for the Mactaquac Project. Mactaquac Aquatic Ecosystem Study Report Series 2016-034. Canadian Rivers Institute, University of New Brunswick. vi + 40 pp.

DISCLAIMER

Intended Use and Technical Limitations of this report: This report was first provided to NB Power August 31, 2016. It subsequently underwent a peer-review with appropriate revisions applied in this final version. This report is intended to: 1) Provide a conceptual overview of fish passage solutions and other related passage considerations that may be important for different options currently evaluated in the Mactaquac Project; and 2) Provide professional opinion on differentiating among the options presented for the future of MGS by NB Power. The opinion is strictly related to probability of providing successful and functional fish passage, and does not consider any cultural, social or economic aspects that are inherently linked to the future options. The information presented in this report provides generic information, and is not in any way intended as an alternative to proactive consultation with regulatory authorities. The information contained herein does not necessarily represent the opinion of the Canadian Rivers Institute, University of New Brunswick.

LIST OF ACRONYMS

AAR	Alkali-Aggregate Reaction
CRI	Canadian Rivers Institute
DFO	Fisheries and Oceans Canada
MAES	Mactaquac Aquatic Ecosystem Study
MGS	Mactaquac Generating Station
NBP	New Brunswick Power
SJR	Saint John River
UNB	University of New Brunswick

ACKNOWLEDGEMENTS

The original report completed in August 2016 was subject to a full peer-review by Dr. Alex Haro, Conte Anadromous Fish Research Laboratory, USGS. We are grateful for very productive comments and additions provide by Dr. Haro.

EXECUTIVE SUMMARY

This report provides an overview of fish passage considerations for the Mactaquac Project options for removal or renewal of the Mactaquac Generating Station (MGS). The report uses our existing understanding of the river and site along with our best understanding of the concepts of functional fish passage: functional implies sufficient passage to sustain a population, i.e., it is safe, effective, and without migration delay.

The Saint John River has a diverse fish fauna that consists of multiple migratory species (anadromous, catadromous, and potamodromous) with varying fish passage requirements. The species are examined based on their probable need for passage at the MGS location, i.e., being common near the MGS during some part of the year and being known to undertake directed migrations during one or more life history stages.

Several species under consideration are "listed" species or support fisheries. Accordingly, the suitability of various technical solutions is discussed for Atlantic Salmon (*Salmo salar*), Alewife (*Alosa pseudoharengus*), Blueback Herring (*A. aestivalis*), American Eel (*Anguilla rostrata*), American Shad (*Alosa sapidissima*), Atlantic and Shortnose Sturgeons (*Acipenser oxyri*nchus and *A. brevirostrum*), Sea Lamprey (*Petromyzon marinus*), and Striped Bass (*Morone saxatilis*).

Functional, upstream passage will require multiple components and the final design and efficiency will vary among the options for the MGS. A fish lift system has the greatest probability of providing a good basis for functional upstream passage at the site. A fish lift can pass a variety of species, but it is a non-volitional solution and therefore, passage is limited to operational schedules and requires sustained maintenance. Many species-specific details will have to be considered for a functional fish lift. American Eel will require a separate, species-specific solution. As part of the overall passage solution, a technical fish ladder, i.e., volitional or free-swim passage cannot be ruled out. A technical fish ladder will be very large (long) due to the high vertical head. There is high uncertainty regarding species other than adult salmonids that will successfully use such a ladder, e.g., issues with motivation and stamina in long, technical fish ladders.

Arranging functional downstream passage will be equally, if not more challenging. Efficient and safe passage will require multiple routes, i.e., via spillways, a by-pass structure, and turbine passage. Technical details are species-specific and must consider both surface and bottom migrants, i.e., directed to various levels within the water column. Turbine passage is the least preferred option. Including "fish-friendly" turbines provides the most promising option for multiple species and body sizes.

Additional passage considerations include the role of the reservoir as a barrier for up- and downstream migrants, winter fish ecology, related operational considerations of constructed passage solutions, and the ecological consequences of reconnecting the up- and downstream reaches of the river ecosystem that has changed post-MGS.

Minimizing impacts on the river's fish community will depend on a ***comprehensive and adaptive, long-term fish management plan*** for the Saint John River. Such a plan does not exist, but it is critical for achieving the overall goal of a healthy river ecosystem. The plan will include explicit fish passage targets, i.e., species and numbers or maximum mortality rates, that are related to the cumulative effects of multiple passage structures used by certain species. The plan will dictate the design requirements needed to produce the most effective ecological and economical solutions among options.

The likelihood of achieving functional fish passage varies among the options for a future MGS. Returning the river to a natural, free flowing state has the highest likelihood for functional fish passage. There is greater uncertainty for functional fish passage with a new facility that sustains the current dam and reservoir. In a new facility, passage structures can be designed to best meet species-specific requirements. The lowest likelihood for functional fish passage is the Life Achievement Option because retrofitting the existing infrastructure to achieve targeted efficiencies will be challenging.

In summary: 1) Removing a dam and its reservoir is always the best solution for achieving the most effective fish passage. This does not guarantee a return to the historical fish communities, i.e., a new ecosystem state is predicted; 2) Existing fish passage technologies are not well developed, especially for downstream passage. Consequently, expectations for engineered solutions should be realistic and not overestimated; 3) Retrofitting an existing structure has the lowest probability of achieving necessary or desired fish passage efficiency noting that some species can be partially accommodated in a retrofit scenario; 4) Developing functional fish passage will be an iterative and long-term process based on an adaptive management approach; 5) A critical, early goal must be ***a comprehensive and adaptive, long-term fish management plan*** for the SJR that has identified species and numbers that must be passed.

1 INTRODUCTION

1.1 PROJECT BACKGROUND

The Saint John River (SJR) is managed for hydropower production by a provincial owner-operator, the New Brunswick Power Corporation (NBP). NBP operates several hydropower facilities in the SJR system, and the four largest are the Mactaquac Generating Station, Beechwood Generating Station, Tobique-Narrows Generating Station, and Grand Falls Generating Station (Figure 1)

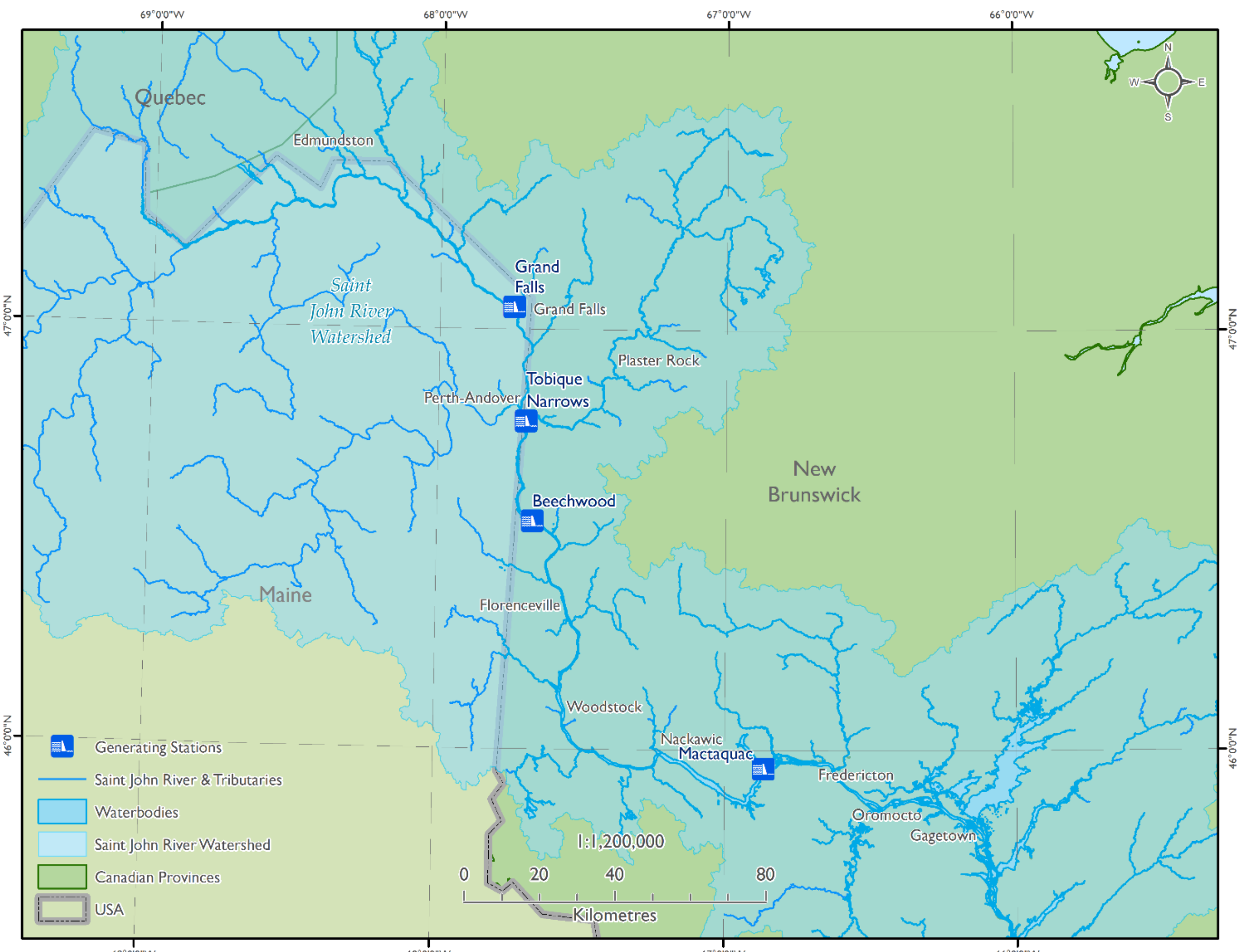

Figure 1. The location of the major NB Power generating stations on the main stem of the Saint John River.

The first facility in the system (farthest downstream) is the Mactaquac Generating Station (MGS) located 18 km upstream from the city of Fredericton and 150 km upstream of the Bay of Fundy on the mainstem of the SJR (Figure 2). The station began operating in 1968. The dam structure is 1,100m long with a hydraulic head 34 m under typical operating conditions (Note: the highest point of the dam is 55 m above the Saint John River). It has the capacity to generate 670 megawatts of energy using six Kaplan turbines. The MGS supplies 12 % of the electric power production for New Brunswick.

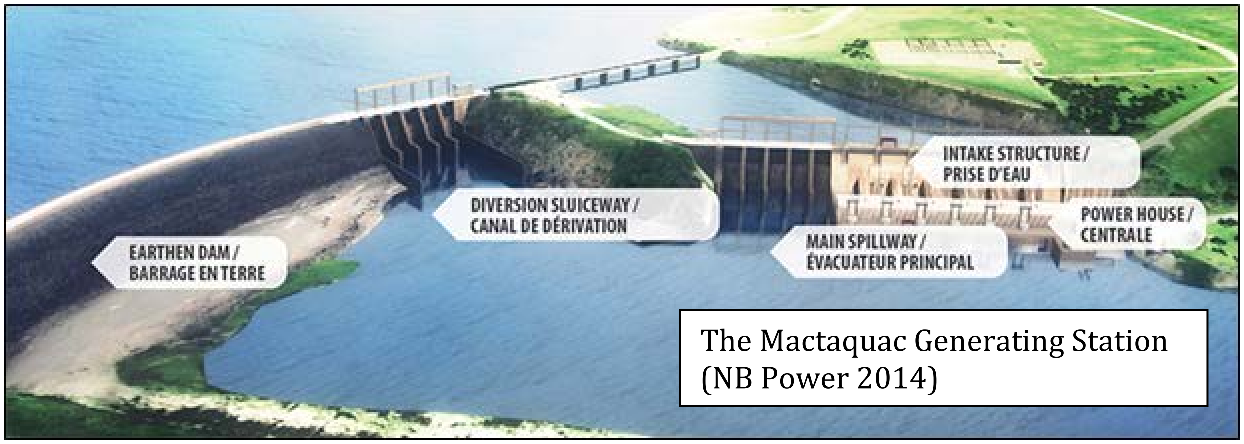

Figure 2. Current configuration of the Mactaquac Generating Station.

The concrete portions of the MGS, 300 m which include the diversion sluiceway, spillway and the powerhouse, may reach the end of service life in 2030 because of problems with concrete expansion known as Alkali-Aggregate Reaction (AAR). AAR occurs when concrete paste reacts with silica in the sand and gravel mix of the concrete. The reaction causes the concrete to swell and crack over time. The earthen dam is a rock-filled structure sealed with clay; it is not affected by AAR and remains secure.

NBP has started a process to evaluate the future options for the MGS known as the Mactaquac Project (www.mactaquac.ca). In parallel with the options consideration, NBP continues to review the feasibility of achieving the original design life (100 years) from the existing facility. The future options are:

Option 1: Repower by building a new generation facility;
Option 2: Retain the reservoir (commonly known as the headpond), but with no hydropower;
Option 3: Remove the dam and restore the river to a free-flowing state at the site;
Life Achievement: Replace AAR affected concrete and retain the functionality of the current generation facility, but make provisions for improved fish passage. This option was added in 2016.

The options and their technical details are described in Stantec (2015) and online at www.mactaquac.ca.

NBP has engaged the Canadian Rivers Institute (CRI) at the University of New Brunswick (UNB) to design an extensive, multidisciplinary aquatic ecosystem study to support an informed, science-based decision for a preferred option. The CRI initiated the Mactaquac Aquatic

Ecosystem Study (MAES) which is a planned, whole-river ecosystem study and manipulation (CRI 2015). MAES has three key components: 1) Whole Ecosystem Studies; 2) Fish Passage; and 3) Environmental Flows.

1.2 FISH PASSAGE CONTEXT

The Fish Passage theme is a main objective of the MAES: three of four future scenarios include up- and downstream fish passage as major consideration for the Mactaquac Project. The Fish Passage component consists of *in situ* field studies examining six different species for which important ecological knowledge gaps were identified related to spawning (Striped Bass, Shortnose Sturgeon, Atlantic Sturgeon, Muskellunge) or migrations (Atlantic Salmon, American Eel). The objectives of these studies are described at http://canadianriversinstitute.com/research/mactaquac-aquatic-ecosystem-study/. The detailed results are being compiled in several reports and M.Sc. and Ph.D. theses at the UNB and will be available in the future. The CRI has undertaken several additional activities to address fish passage:

1) The state-of-the-art in fish passage engineering and science world-wide has been reviewed (published literature) along with direct input of expert advice from jurisdictions where fish passage solutions have been attempted in large rivers and/or in multi-species situations. [Project NBP 2.1.1; Linnansaari et al. 2015a]
2) The organizing of a Fish Passage Expert Workshop where world experts in the field of fish passage science had an opportunity to comment on the current status of fish passage in their jurisdictions and provide lessons learned that may be applied to the Mactaquac Project. [Project NBP 2.1.2; Linnansaari et al., 2015b]
3) The provision of recommendations for conceptual design options for fish passage for multiple fish species for future scenarios at the MGS site. [Project NBP 2.1.3; this report]
4) Conducted site visits to rivers with large hydropower dams or restored rivers - Columbia River (OR), Cowlitz River (OR), White River (OR), Elwha River (WA), Exploits River (NFLD), West Salmon River (NFLD), Connecticut River (MA), Merrimack River (MA), Penobscot River (MN), and numerous regulated rivers in Norway;
5) Compiled the most recent advances in fish passage science from relevant conferences; and
6) Interacted with local/regional fish ecology and passage experts in workshops and meetings, i.e., with Maliseet communities and their organizations, Fisheries and Oceans Canada (DFO), the Province of New Brunswick (NB), local fishers, and non-government agencies (NGOs).

This report was a Final Deliverable of the NBP Project 2.1.3, Conceptual Considerations for Fish Passage for the Mactaquac Project. It provides advice for arranging functional fish passage for the MGS under the original options and the Life Achievement Option introduced in 2016. The advice is based on a review of existing information regarding functional fish passage and current understanding of the river and the options for the MGS. Importantly, the advice is our best conceptual understanding. The report does not provide details of final fish passage solutions for any option.

Functional fish passage is defined herein as “passing a sufficient portion of fish population of each managed species to ensure their long-term sustainability” as described in detail in Linnansaari et al. (2015a; and references therein). “Sustainability” has yet to be defined for the Mactaquac Project by the regulatory agencies, e.g., level of successful reproduction, targets for effective population sizes, etc. Regardless, three conditions must be achieved:

1) Passage must be safe; passed fish experience minimal stress, injury, and mortality;
2) Passage must be effective - a large enough proportion of fish to sustain a population must be passed; and
3) Passage must occur with minimal delay - fish must be able to reach their destination within necessary windows of ecological, reproductive, and physiological requirements.

Functional fish passage for the MGS does not consider the potential overall effects of the system-wide, hydropower facilities and other factors affecting fish passage that may or may not affect fish populations that have migrations influenced by multiple barriers. An example is the Atlantic Salmon (*Salmo salar*) for which significant portions of historic spawning and nursery habitats are located upstream of three hydropower facilities: MGS, Beechwood and either the Tobique-Narrows in the Tobique River or Tinker Dam in the Aroostook River which represent 15.8 % and 12.3 % of the total suitable habitat, respectively for all Outer Bay of Fundy rivers (Marshall et al. 2014). The status of fish passage at these facilities is provided in Chateauvert and Linnansaari (2016). The ***cumulative efficiency*** among facilities and the consequences for fish populations in the SJR are not considered in this report, but will be very important in achieving system-wide, functional fish passage and determining suitable passage targets for fish at MGS.

The remainder of this report briefly discusses the fish community in the vicinity of the MGS and the conceptual requirements for functional fish passage for these species. Selected species-specific details are discussed to provide some context regarding how holistic fish passage may be arranged. Both up- and downstream passage are discussed as fundamental to functional fish passage. Additional fish passage considerations are discussed and a conceptual ranking of the different options based on likelihood of obtaining functional fish passage is presented.

This report assumes that returning the river to a free-flowing state at the location of the current MGS is the best possible fish passage solution, i.e., there is no barrier to movement up- and downstream. A future free-flowing state does not imply a return to historic river conditions at the MGS site either physically, e.g., the hydraulics, or biologically, e.g., the fish passage efficiencies and community structure. For the dam renewal options, it was assumed that the current dam height, the reservoir’s physical and chemical characteristics, and the reservoir’s management regime (e.g., surface level control) are retained as in thee existing conditions.

2 FISH COMMUNITY IN THE SAINT JOHN RIVER

2.1 FISH SPECIES AND MIGRATION REQUIREMENTS

The fish community of SJR consists of 55 native or introduced species (Appendix 1; Munkittrick et al. 2011; Curry and Gautreau 2010; and CRI, unpublished data). Fourteen species are diadromous and of these three species have freshwater resident populations, but may also include an anadromous component, or at least make excursions to estuary (the presence of migratory contingents of these species are not confirmed; Appendix 1); six are considered marine/estuarine; three that only occupy lacustrine (lake) habitats; and 32 that are resident in the freshwater parts of the SJR.

Of these 55 fish species, 12 are not present in the project areas of MGS: 11 are considered uncommon, but may be encountered at MGS on occasion; 30 are known to be, or are presumed common, in the area at some time of the year; and two migratory species for which presence around MGS cannot be reliably confirmed with existing data (Appendix 1). The species that are not present in the project area are not further considered in this report.

We developed a list of species with potential requirements for fish passage at the MGS location. The criteria were: 1) commonly present near the MGS at least during some part of the year; and 2) known migrations for one or more life history stages (Table 1). Nine species are diadromous; nine species are river resident and migratory; two species may have separate or a combination of river resident and anadromous forms.

Table 1. Species[1] of consideration for fish passage at the MGS site (listed in alphabetical order within groups). Green = highest probability of need. Yellow = lower probability of need. Brown = uncertain and assumed low probability of need.

Status at MGS	Life history	Group	Common Name	Scientific Name	River migrations
Common	Diadromous	River Herrings	Alewife	*Alosa pseudoharengus*	Yes
Common	Diadromous	Lampreys and eels	American Eel	*Anguilla rostrata*	Yes
Common	Diadromous	River Herrings	American Shad	*Alosa sapidissima*	Yes
Common	Diadromous	Salmonids	Atlantic Salmon	*Salmo salar*	Yes
Common	Diadromous	Sturgeons	Atlantic Sturgeon	*Acipenser oxyrinchus*	Yes
Common	Diadromous	River Herrings	Blueback Herring	*Alosa aestivalis*	Yes
Common	River resident [Anadromous]	Salmonids	Brook Trout	*Salvelinus fontinalis*	Yes
Common	River resident	Catfishes	Brown Bullhead	*Ameiurus nebulosus*	Yes
Common	River resident	Cods	Burbot	*Lota lota*	Yes
Common	River resident	Carps and Minnows	Creek Chub	*Semotilus atromaculatus*	Yes
Common	River resident	Carps and Minnows	Golden Shiner	*Notemigonus crysoleucas*	Yes
Common	River resident	Pikes	Muskellunge	*Esox masquinongy*	Yes
Common	River resident [Anadromous]	Salmonids	Rainbow Trout	*Oncorhynchus mykiss*	Yes
Common	Diadromous	Lampreys and eels	Sea Lamprey	*Petromyzon marinus*	Yes
Common	Diadromous	Sturgeons	Shortnose Sturgeon	*Acipenser brevirostrum*	Yes
Common	River resident	Perches and Sunfishes	Smallmouth Bass	*Micropterus dolomieui*	Yes
Common	Diadromous	Perch	Striped Bass	*Morone saxatilis*	Yes

Status at MGS	Life history	Group	Common Name	Scientific Name	River migrations
Common	River resident	Perches and Sunfishes	White Perch	*Morone americana*	Yes
Common	River resident	Suckers	White Sucker	*Catostomus commersoni*	Yes
Common	River resident	Perches and Sunfishes	Yellow Perch	*Perca flavescens*	Yes
Uncommon	River resident [Anadromous]	Salmonids	Brown Trout	*Salmo trutta*	Yes
Uncommon	River resident	Salmonids	Lake Whitefish	*Coregonus clupeaformis*	Yes
Uncommon	River resident	Suckers	Longnose Sucker	*Catostomus*	Yes
Unknown	Anadromous	Cods	Atlantic Tomcod	*Microgadus tomcod*	Yes
Unknown	Anadromous	Salmonids	Rainbow Smelt	*Osmerus mordax*	Yes
Common	River resident	Killifishes	Banded Killifish	*Fundulus diaphanus*	Not known
Common	River resident	Carps and Minnows	Blacknose Dace	*Rhinichthys atratulus*	Not known
Common	River resident	Pikes	Chain Pickerel	*Esox niger*	Not known
Common	River resident	Carps and Minnows	Common Shiner	*Notropis cornutus*	Not known
Common	River resident	Carps and Minnows	Fallfish	*Semotilus corporalis*	Not known
Common	River resident	Sticklebacks	Fourspine Stickleback [2]	*Apeltes quadracus*	Not known
Common	River resident	Carps and Minnows	Lake Chub	*Couesius plumbeus*	Not known
Common	River resident	Sticklebacks	Ninespine Stickleback [2]	*Pungitius*	Not known
Common	River resident	Perches and Sunfishes	Pumpkinseed Sunfish	*Lepomis gibbosus*	Not known
Common	River resident	Sticklebacks	Threespine Stickleback [2]	*Gasterosteus spp.*	Not known

[1] Species that are absent from MGS vicinity or those that are both uncommon and do not make river migrations are not included in this table (See Appendix 1).

[2] Can have estuarine populations.

3 SPECIES-SPECIFIC CONSIDERATIONS

Arranging functional fish passage requires species-specific information related to migration timing and motivation, general behaviour, e.g., schooling, interactions with competitors and predators, and swimming capabilities. For some species, such as Atlantic Salmon, site or river specific passage requirements have been studied, but the information for many other species, especially non-salmonids, is vague or with variable results across studies (Bunt et al. 2012; Noonan et al. 2012; Hatry et al. 2013). In this report, we focus on the specifics for SJR species and conceptual fish passage relevant for the proposed MGS scenarios. Repeated studies have demonstrated that achieving functional fish passage is a very challenging task made more complex as systems increase in size and with numbers of species requiring passage (e.g., Williams et al. 2012; Katopodis and Williams 2012). The MGS is a large structure and the SJR a complex ecosystem. Original fish passage considerations for the MGS (and all other stations) was for Atlantic salmon adults only. Overall, there have been few peer-reviewed studies regarding fish passage for the SJR and thus very little is certain regarding passage efficiency.

The report focuses on conceptual, up- and downstream technical solutions that may be suitable for MGS, but other relevant species-specific considerations are discussed. Such considerations are from lessons learned from history (other facilities and studies), local knowledge, and ongoing MAES studies. It is anticipated that additional biological and engineering studies specific to the MGS will occur once a preferred option is selected.

3.1 ATLANTIC SALMON (*Salmo salar*)

Atlantic Salmon is a species of high socio-cultural importance for both the First Nations and the general public. The species has suffered a tremendous decline since 1990's and is currently considered for listing as Endangered under the Federal Species-At-Risk Act (SARA) and has already been listed under the New Brunswick SARA. There are many potential causes of the decline (e.g., salmonid aquaculture operations and shifts in oceanic conditions caused by changes in climate), but issues relating to fish passage associated with the hydropower facilities in the SJR and their associated reservoirs is among the most serious factors affecting the freshwater production of Atlantic Salmon (Clarke et al. 2014).

The hydropower facilities are considered a significant issue because important and extensive spawning, nursery and rearing areas are located upstream of the MGS (Marshall et al. 2014), i.e., passage for Atlantic Salmon is critical to complete their life cycle. Many technical solutions for fish passage specifically suited for salmonids have been developed. The potential passage issues are the actual location of the barrier, the dam structures, the characteristics of the reservoir, and equally, the up- and downstream migration efficiency.

The Atlantic Salmon is one of only three species included in fish passage management and operations at the current MGS. The current upstream passage structure for capture (MGS Fish

Trap with its lift) and trucking is successful in moving adult Atlantic Salmon upstream, but the efficiency is uncertain, e.g., salmon successfully enter the fish lift/trap and are trucked upstream, but the proportion of the actual upstream migrants transported or if all captured fish are from upstream origins ("straying" from downstream rivers to MGS) is not known. Mark-recapture studies in 1990's have measured downstream smolt passage success at the MGS (and the Beechwood and Tobique facilities – results are reviewed in Linnansaari et al. 2016). There is no study that converts these efficiencies into an assessment of functional fish passage.

Upstream passage considerations (Adults only):

- Both volitional (i.e., free-swim; 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. Key requirements are attraction (to the passage facility) and efficiency (successful overall passage) which depend on detailed flow analysis (attraction flows are required as salmon are rheophilic) to ensure the entry is correctly placed. Designs may require computational fluid dynamic (CFD) modeling and construction of down-scaled, physical models to ensure proper hydraulic environments that are attractive to fish and promote entry into and retention in the passage structure.
- The choice between volitional and non-volitional passage solution 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 without delays, but dependent 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.]
- Effective upstream passage is contingent on appropriate structure and hydraulic scaling and flow dynamics. This includes consideration of potential crowding by other species (see Section 3.2). [The number of species and abundances migrating to the current MGS location is currently being studied in the MAES research programme.]

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

- The potential issues regarding downstream passage are both the successful migration in the reservoir and the passage efficiency at a facility. [The reservoir migration efficiency for Atlantic Salmon smolts and adults as well as the downstream approaches and current success rates via spillways and turbines are currently under study in the MAES research programme.]
- High survival and efficiency of downstream passage at a dam for downstream migrant salmon smolts are most probably achieved by arranging well timed, surface spill from the top of the water column. This can be voluntary, i.e., spilling to promote fish passage or natural discharge related spilling. Top-spilling gates can be constructed or retrofitted, e.g.,

surface passage weir (BPA 2013). Selection of appropriate locations for surface passage and the engineering designs require defining migration routes and points of concentration of smolts near a dam and CFD modeling. Biologically relevant spill schedules are critical. [Both preliminary hydrodynamic modeling and studies of migration timing by Atlantic salmon smolts and adults are currently under study in the MAES research programme.]

- Surface by-pass systems that direct smolts and postspawning adults to the preferred spill-way route are critical. The entrance flows are critical (Haro et al. 1998) and require CFD modeling, i.e. the use of uniform acceleration weirs has proven successful, e.g., constant acceleration of ~1m/s/m (Gregory Allen, Alden Research Laboratory, pers. comm.).
- Surface guidance systems to deflect smolt and adults away from turbine intakes are critical. These structures can be partial depth guidance booms, e.g., boom, or partial depth louver systems, e.g., similar to louvers installed at Bishop's Falls, Exploits River, Newfoundland.
- Bar racks with narrow bar spacing (< 2 cm clear opening) are a physical barrier to prevent smolts and adults entering the turbine units
- Fish-friendly turbine units are increasingly recommended (Hogan et al. 2014).
- Turbine passage efficiency for smolts may be higher in modern, fish-friendly turbine units.

Reservoir passage considerations:

The reservoir migration efficiency for Atlantic Salmon smolts (downstream) and adults (up- and downstream) are currently under study in the MAES research programme (Babin et al., CRI, unpublished data). Preliminary results indicate some straying of migrants in up- and downstream directions as well as some delays. Preliminary analysis of the smolt migration and spill timing indicated that the main smolt migration doesn't coincide with the current timing of spilling at the MGS. Current MAES work is combining a hydrodynamic model and smolt/adult movements to fully understand the mitigation opportunities that may be available (e.g. well-timed surface spill) to improve reservoir transit efficiency.

One mitigation action, flow augmentation, has improved the success rate of migration through large reservoirs in the Columbia River system (BPA 2013). Flow augmentation involves a strategic release of water from storage reservoirs which increases water velocity in the reservoir, increases the migration speed of smolts, reduces the delay experienced in the reservoir, and has been shown to result in concurrent improvements in survival (BPA 2013). Timing of the smolt migration, i.e., arriving in estuarine or marine waters when smolts are physically adapted to make the freshwater-seawater transition, is a key to smolt survival (Scheuerell et al. 2009).

If the reservoir or the dam passage itself creates significant impediments for smolts or adults, then one option for consideration is upstream trapping of downstream migrating fish, e.g., at the Tobique-Narrows Dam, and transporting the fish downstream of the MGS. The merits of trap-and-transport downstream strategy are uncertain. In the Columbia River system, the results have varied between studies and between fish of wild and hatchery origin (BPA 2013). [The MAES programme is currently conducting a first assessment of the trap-and transport strategy during downstream migration of smolts, i.e., from the Tobique River to downstream of the MGS - Babin et al., Unpublished data.]

3.2 ALEWIFE (*Alosa pseudoharengus*) AND BLUEBACK HERRING (*A. aestivalis*)

Both alewife and blueback herring, commonly referred to as gaspereau (collectively, both species), are currently managed by DFO at the current MGS. Spawners are captured in the lift/trap and trucked to the reservoir where they complete spawning and juveniles are reared. Since 1995, the spawner escapement targets are 800,000 Alewife and 200,000 Blueback Herring (Jessop 2003). Gaspereau are two species that have benefited from a vast expansion of spawning habitat created when MGS became operational in 1968: The gaspereau population has increased 200-fold (returns of 22,000 in 1968 to >4.4 million in 1987; Jessop 2003). Some uncertainty of the maximum yield and production capacity of the Mactaquac reservoir exists; its estimated carrying capacity is approximately 10 t / km^2 (Gibson and Myers 2003), however, the carrying capacity is not assumed to have been reached (Jessop 1990a). Currently, gaspereau are the most abundant anadromous species in the SJR system. The current management and operations at MGS are successful in arranging upstream passage for these species within numbers determined by the current fisheries management plan.

The smaller proportion of Blueback Herring transported to the Mactaquac reservoir is due to their later run timing to the MGS which was speculated to overlap with the early run of Atlantic Salmon. A crowding effect that may delay Atlantic Salmon entry to the MGS fish lift was suggested, e.g., Jessop (1990b). This relationship has not been proven, but consequently a lower proportion of Blueback Herring are collected and transported to the reservoir.

The management of the gaspereau population is a key factor for functional fish passage at the MGS. Gaspereau were not considered when MGS was constructed and this led to complications for passage for other species such as the American Shad (see section 3.4). Crowding by gaspereau will be an issue for functional upstream passage including impacts on other species. Future upstream passage solutions must be adequately sized to address the issue, or management plans developed to regulate gaspereau numbers being transported.

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 capacity at current MGS fish lift is not adequate in a multi-species management scenario.
- The capacity of the passage facility will need to be designed to address fisheries management for gaspereau, i.e., escapement numbers to the reservoir, timing of runs to accommodate both species, and other species needs.

- Fish lifts are the most probable, successful technical solution for upstream passage for gaspereau (ASMFC 2010); again, the capacity will depend on fisheries management goals

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

- Both Alewife and Blueback Herring are iteroparous and are an important contingent of downstream migrants; timely and efficient downstream passage will be important for both juveniles and post-spawned adults. Current efficiencies for juveniles and post-spawned adults are unknown. Both species remain abundant at the MGS during upstream migrations and during downstream, out-migration by young-of-the-year (YOY), but downstream passage efficiencies are unknown.
- Post-spawned adults are most probably best managed by surface-spill or guidance to a surface-oriented by-pass. Surface guidance structures, e.g., guidance booms or floating louver arrays, may enhance the efficiency. Studies are required to understand paths travelled by downstream migrants in the reservoir, e.g., hydraulics, operations, depth, light conditions, and approaches to the facility (see also Jessop 1990c).
- Turbine passage efficiencies and injury/mortality for juveniles and post-spawners in existing operational conditions is not known.
- Turbine passage efficiency is predicted to be higher for these species in modern, fish-friendly turbine units.

3.3 AMERICAN EEL (*Anguilla rostrata*)

American Eels have not been actively transported upstream of the MGS since it was constructed and abundances upstream have declined to near zero (Chateauvert and Linnansaari 2016). As a catadromous species, the requirement for upstream passage is not related to spawning, but to access to rearing habitats. The amount of suitable rearing habitat for eel upstream of MGS is very abundant (e.g., Francis 1980). American Eel has historically been present throughout the river as reported in the Mi'kmaq and Maliseet culture and diet, and continues to be an important food source (MNCC 2014).

Regarding upstream passage, the MGS appears impassable for juvenile eels, or elvers, i.e., <150mm in body length and likely age 1+. In addition, elvers were reported as near absent at the MGS tailrace since 1980 (Jessop and Harvey 2003). MAES has implemented studies to better understand the elver migrations to the MGS (Dixon et al., Unpublished data). High numbers of elvers, 80 – 140 mm, showing typical upstream migratory tendencies, e.g., rheotactic, show climbing behaviour, were found in spillway locations at the MGS in 2015 and 2016 (Britany Dixon, CRI, unpublished data). This study will provide essential information for arranging upstream passage for elvers.

Eel passage is being studied for many situations (ASMFC 2013). In general, upstream issues are less complicated than downstream passage, and both are more complicated for high-head dams such as the MGS.

Upstream passage considerations (Juveniles):

- Upstream passage of juvenile American Eel can be arranged in most cases, but it will require eel-specific, technical solutions for the site and facility, and possibly multiple passage facilities at various locations at the site.
- The best technical solutions for high-head dams are eel climbing ramps/traps, or lifts, and functional designs exist (ASMFC 2010, ASMFC 2013).
- Siting the passage structure in a location where young migratory eels naturally aggregate is the most key factor in arranging functional upstream passage for eels. Structures should be placed in a location that is determined to be a point of eel concentration/attraction by biological and flow surveys (Dixon et al., CRI, unpublished data).
- Upstream passage is best designed adaptively; it requires monitoring of attraction, passage rates, and escapement. Once passage structure performance is confirmed to be effective, passes can be modified to allow eels to pass the barrier without monitoring.

Downstream passage solutions (Adults or silver-phase):

- Downstream passage is required for silver-phase eels, >50 cm in body length, migrating to the sea. Downstream passage technologies are not well developed for silver-phase eels including poor success with behavioural guidance devices (e.g., light, sound, electricity), thus this life stage will require specific technical solutions and an adaptive flow management regime.
- Silver eels migrate tend to spend considerable time migrating near the bottom and are often insensitive to velocity changes until they encounter an obstruction, e.g., a physical guidance or exclusion device (Gosset et al. 2005, Russon et al. 2010). Deep by-passes tend to be more effective than surface by-passes for downstream migrant eels. The potential effects of barotrauma must also be considered, i.e., moving eels from areas of high pressure at depth to low surface pressures downstream.
- Functional downstream passage solutions for eel are being studied elsewhere and similar studies are most probably required for the MGS site. Silver eels can suffer high turbine mortality. Turbine passage efficiency is predicted to be higher in modern, fish-friendly turbine units, but the best solution is preventing eels from entering turbines.
- Turbine exclusion can be achieved by installing narrow gap bar racks, but impingement of eels occurs for steep vertical slope racks with water approaching normal to the rack, and with flows exceeding 1 m/s (Richkus and Dixon 2003). Improvements in downstream passage of silver eel have been achieved in smaller river systems by using low-sloping, narrow (10 – 25 mm) gap bar racks and low approach velocities (Calles et al. 2013).

- Effective downstream passage may require adaptive flow and power production management during key downstream migration periods. This involves periods of controlled night time (bottom) spill, periods of limited (or no) power generation at night, generation of power using only fish-friendly units during eel migration, e.g., installing narrow gap overlay bar-racks in front of turbines with high mortality probability during a designated eel protection period. Other jurisdictions employ various tactics to monitor and manage for eel protection periods. The feasibility of such mitigation is related to the predictability of migration and its duration. These biological characteristics are currently unknown for the SJR.
- Adaptive management is critical - Monitoring and assessment of eel downstream passage is required and adjustments are presumed.
- Capturing migrating eels upstream and moving them downstream of MGS location may be a possible mitigation strategy, but would require considerable and long-term effort and commitment.

3.4 AMERICAN SHAD (*Alosa sapidissima*)

Numbers of American Shad arriving into the fish trap/lift at the MGS have drastically declined (Chateauvert and Linnansaari 2016). As is the case for many other fish species encountered at the MGS, the numbers of shad captured at the current fish trap/lift do not represent the actual stock status (Andrews et al. 2016).

The annual captures in the fish lift in the years following the construction of MGS were between 36,000 and 39,000 indicating that the trap/lift did attract. The ability of the MGS fish lift to attract American Shad was interrupted by the expanding size of gaspereau populations (See section 3.2), which led to significant de-scaling and abrasions of shad due to crowding and caused significant delays in the approach to the trap/lift for several days (Jessop 1975). The fish lift's hoist mechanism (hopper) at MGS also causes vibrations during the lifting that excites shad causing thrashing and additional abrasions, scale loss, and stress. Trucking was also conducted in a small, dark, confined truck tank with no flow for orientation, causing further extreme activity, stress and injuries. Successful trap-and-truck techniques have been further developed and such are successfully used elsewhere, e.g., Connecticut and Merrimack rivers.

Downstream passage of both post-spawned adults and juveniles is through the turbines because no spill generally occurs during the downstream migration periods. No efficiency or mortality estimates exist for American Shad for the current MGS, but literature values for turbine passage mortality suggest 10-25% for adults (Kaplan units) and ~5% for juveniles (e.g., Taylor and Kynard 1985; Haro and Castro-Santos 2012). There was also a drastic reduction in the proportion of repeat spawners reaching MGS (Carscadden and Leggett 1973) since construction of the facility. The high mortality rates led to a decision to discontinue passage of adult American Shad upstream of MGS in late 1970's (exact year is not recorded; B. Jessop, DFO Maritimes [retired], pers. comm.). Currently, American Shad is not actively passed upstream of the MGS and the individuals that are encountered in the MGS fish lift are returned to the downstream area.

Overall, suitable habitat for shad is estimated to be reduced by 67.7% from the pre-dam (Beechwood and Mactaquac) conditions (Jessop 1975), but the estimated escapement numbers that could be supported upstream is ~12,000 (Jessop 1975). Successful American Shad reproduction upstream of the MGS may be possible (Jessop 1975).

The current, general understanding of up- and downstream passage for American Shad has been compiled by Larinier and Travade (2002) and Haro and Castro-Santos (2012), including details related to sizing of technical structures and their functionality. These details are not repeated herein, but the main conclusions include:

Upstream passage considerations (Adults):

- Large technical fishways have provided passage for American Shad in the Columbia River system, but efficiencies remain unknow (Alex Haro, Conte Anadromous Fish Research Laboratory, USGS, pers. comm.). American Shad will not migrate through orifices and overflow passage must be provided, e.g., full Ice-Harbour pool and weir ladder. In high head dams, technical fish ladders become long because the vertical head must be partitioned into many pools, which increases the total time required for fish to pass. Attempts to downscale large technical ladders from Columbia River to smaller versions in Atlantic Coast rivers have generally failed to pass shad efficiently, e.g., the Cabot Fishway, Connecticut River. American Shad lack the stamina and motivation to swim through long technical ladders if areas of unsuitable hydraulics are encountered and fish that do not pass the fishway during the day tend to fall back downstream through the fishway during night (Haro and Kynard 1997).
- 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 open (not dark) and wide (>45 cm) to accommodate shad schooling behaviour (USFWS 2016).
- Fish lifts may be suitable for passing shad over high dams efficiently; however, injuries can be incurred unless they are lifted in large hoppers with adequate water flow and handling is avoided.
- Significant streaming attraction flows are required for maximizing attraction efficiencies.

Downstream passage considerations (Adults and Juveniles):

- Downstream passage and survival through turbines is poorly understood for American Shad. However, arranging effective downstream passage is critical in high latitude populations such as the SJR where populations consist of a high proportion of repeat spawners.

- Shad tend to migrate in the top of the water column and therefore, surface spill and by-pass are preferred passage options. Typical surface by-pass entrances employ uniform accelerating flow structure (Haro et al. 1998). However, rapidly accelerating velocities in the entrance of a by-pass may also lead to hesitation to enter the by-pass; entrances should be specifically engineered to solve similar transition avoidance problems.
- 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.
- Passages through traditional turbines can incur relative high mortalities, especially for postspawning adult American Shad. Turbine passage efficiency is predicted to be higher in modern, fish-friendly turbine units.

Future management of American Shad (i.e., as is relevant to Options 1, 2 and Life Achievement) must consider the habitat loss that has been caused by the creation of the reservoir. American Shad is a lotic spawner, requiring stable flows for spawning (e.g., Greene et al. 2009) and although reservoir environment and its tributaries are not suitable habitats (Jessop 1975), their success at reproduction is unknown upstream. Upstream functional passage at Beechwood generating station is uncertain because of lengthy delays and be highly inefficient in attracting American Shad (see review in Chateauvert and Linnansaari 2016).

The questions posed by Jessop (1975) remain unanswered yet still formulate the foundation for effective decisions regarding the future of American Shad in relation to the MGS. From Jessop (1975):

1) Determination of whether all (or what percentage of) shad approaching Mactaquac Dam use the collection facility, and whether there is significant delay in passing them above the dam.
2) Investigation of methods to reduce handling and trucking mortality, such as determining the optimum number of fish per truck, and the possible use of a saline transporting medium.
3) Assessment of adult and juvenile shad mortalities resulting from passage through turbines.
4) Investigation of the feasibility of using turbine gate wells at Mactaquac for collecting juvenile shad and avoiding turbine passage.
5) Investigation of the location of spawning areas and subsequent spawning success.
6) Assessment of the impact of the commercial shad fishery at the mouth of the river on the numbers returning to Mactaquac Dam.
7) Development of a management program specifically designed for those shad populations resident below the Mactaquac Dam.

3.5 STURGEONS (*Acipenser spp.*)

Two species of sturgeon are present in the SJR: the Atlantic Sturgeon (*Acipenser oxyrinchus*) and the Shortnose Sturgeon (*Acipenser brevirostum*). Anecdotal evidence suggests that sturgeons historically migrated as far upstream as the Grand Falls, but the historical numbers and potential for critical habitats, e.g., reproduction, are unknown. Shortnose Sturgeon reproduces in the downstream vicinity of the MGS (Washburn and Gillis Associates 1980; Usvyatsov et al. 2012; 2013); the exact location is being sought in current MAES studies (Arluison et al., Unpublished data). Similarly, Atlantic sturgeon reproduces in the lower SJR (juveniles are present) and the exact spawning locations are being determined within the MAES programme (Arluison et al., Unpublished data). In rivers with hydropower facilities, spawning of sturgeon spp. often occurs in the downstream vicinity of the generating stations (e.g., Kynard 1997; Bruch and Binkowski 2002; Labadie 2012).

Current mark-recapture population estimates for Atlantic Sturgeon suggest that population size is similar to its pre-European level of 17,000 – 20,000 individuals, and the population is reproducing and is stable in the area downstream of the MGS, i.e., there are multiple age classes including juveniles (Dadswell et al. 2017). The population size of Shortnose Sturgeon is unknown, but in one specific overwintering location there was an estimate of 5,000 individuals (Li et al. 2007).

The presence of suitable spawning habitat upstream of the MGS has not been assessed. Because no sturgeon have been passed since the MGS was constructed, movement and spawning behaviour upstream of MGS for either Shortnose Sturgeon or Atlantic Sturgeon is completely unknown, i.e., success rates for navigating the reservoir to the next dam. There is some risk that upstream passage to the large reservoir may place sturgeon into an “ecological trap” if effective downstream passage cannot be arranged (Brown et al. 2013). Currently, the passage of sturgeon would end at Beechwood Dam which is not equipped to pass sturgeons upstream. Shortnose Sturgeon may become a landlocked population over time in the reservoir, as was the case for the Connecticut River above Holyoke Dam.

Arranging passage for sturgeons is very challenging. In a recent review, Jager et al. (2016) listed no examples of passage success for Atlantic Sturgeon because of its large body size. The details of the review are not repeated herein, but the main conclusions drawn from Jager et al. (2016) include:

Upstream passage considerations (Adults and Sub-Adults):

- Sturgeons generally swim along the bottom and select energy-inexpensive routes with steady flow (McElroy et al. 2012). Their swimming performance follows unique body size-swimming performance relationships (Katopodis and Gervais 2012).

- A technical passage solution, e.g., a ladder, would require large pool sizes and baffle spacing. Wide technical fishways have had some success in passing other sturgeon species, e.g., at the Dalles Dam, Columbia River (White Sturgeon) and St. Ours Dam, Richelieu River, Quebec, (Lake Sturgeon; Theim et al. 2011).
- Fish lifts are used for passing sturgeon, although the overall success has been poor in other jurisdictions, and would be uncertain in MGS, e.g., the fish lift at the Holyoke Dam, Connecticut River passed 97 Shortnose Sturgeon over 22 years of operation.
- The entrance to a fish lift or technical fishway must accommodate the benthic behaviour and large size of sturgeon, i.e., it will require a large entry that gradually leads to the entrance of the fish facility and provides a swift attraction flow.
- The trap-and-transport method may be effective for providing upstream passage for sturgeon (McDougall et al. 2013). Trapping may require appropriate capture techniques and correctly sized transport vehicles. This may be more effective than a technical passage (ladder or lift).

Downstream passage considerations (Adults, Sub-Adults, Young-of-the-Year):

- If upstream passage is provided, it is of utmost importance to arrange an effective downstream passage solution for both passed adults and juveniles (YOY and sub-adults) that arise from spawning upstream. Sturgeons are extremely long lived, iteroparous spawners and may undertake 10+ spawning runs during their lifetime. Repeat-spawners are invaluable for the population. Downstream passage must occur; it is a priority for sturgeon.
- YOY and sub-adult sturgeon can pass through turbines, but not without mortalities.
- Large-bodied, adult sturgeon must be excluded from turbines as turbine blade strike mortality is unacceptably high in traditional turbines. Turbine passage remains complicated for intermediately-sized sturgeon that are small enough to pass through bar-racks, but large enough that blade-strike probability is increased. Effective guidance or exclusion will be required to direct sturgeons away from turbine passage.
- Downstream guidance structures must be focused on the river bottom and entrance to the by-pass must be sufficiently deep to accommodate sturgeon. Both mechanical and behavioral guidance structures are not well developed for sturgeon.
- Turbine passage efficiency of sturgeon is predicted to be higher in modern, fish-friendly turbine units, but these units still must be adequately large to accommodate the large bodies of sub-adult and adult sturgeon.
- Bottom draw spillways (by-passes) have been shown to produce some success and acceptable survival rates for sturgeon (McDougall et al. 2014).

3.6 SEA LAMPREY (*Petromyzon marinus*)

The ecology and migrations of Sea Lamprey are among the most poorly known of the anadromous species in 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 (Chateauvert and Linnansaari 2016). They were numerous at the MGS fish lift in the years following its construction (> 8,000), but due to the management strategy at the time, i.e., removal and destruction of adult lamprey at MGS, the stock rapidly declined and lamprey are no longer encountered at the MGS (Chateauvert and Linnansaari 2016). They do occur and reproduce in the tributaries downstream of the MGS (e.g., Munkittrick et al. 2011). As Sea Lamprey is considered to be panmictic, i.e., does not form river-specific natal populations (Waldman et al. 2008), it is difficult to explain why adult lamprey are not appearing at the MGS. One explanation may be related to juvenile pheromones, i.e., stream-dwelling larvae release a migratory, bile acid-based pheromone (Bjerselius et al. 2000) considered crucial in guiding adults to watersheds that are successful as spawning and nursery areas for larvae (Hansen et al. 2016). 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. For spawning, Sea Lamprey require steady, unidirectional water flow (0.5–1.5 m/s), and suitable sand and gravel (0.9–5.1 cm diameter), and depths < 2 m (Manion and Hanson 1980), and thus, the MGS reservoir is considered unsuitable for spawning. They would have to migrate upstream to complete their life cycle including possible passage at both Beechwood and Tobique-Narrows dams is possible (with unknown efficiency and delay; Chateauvert and Linnansaari 2016). In general, passage efficiencies for most ladder/lift designs are poorly documented for Sea Lamprey.

Upstream passage considerations (Adults):

- The adult Sea Lamprey is highly rheophilic (attracted to flow; Moser et al. 2011) and migrate primarily at night (Hansen et al. 2016). Any passage structure must be operated during the hours of darkness for good efficiency and minimum delay.
- Adult Sea Lamprey use ‘‘burst-and-attach’’ locomotion to ascend technical ladders (Quintella et al. 2009). In areas of fast water velocity, they use their oral disc to attach to substrate and rest between bouts of swimming and thus ascending is characterized by a combination of intermittent burst swimming and periods of rest (Haro and Kynard 1997).
- In technical fishways, e.g., pool and weir, vertical slot ladders and fish lifts, efficiency is poor (Pereira et al. 2016) or not known (Travade et al., 1998).
- The Pacific Lamprey (*Lampetra tridentata*) can use pool and weir fish ladders, 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). Pacific lamprey can climb steep sloped surfaces (e.g., Bonneville Dam uses short sections of 45^o ramps) or even vertical surfaces using bursting axial undulations (Reinhart et al. 2008). Inclined aluminium ramps with interspersed rest boxes have been designed and shown to be effective: 90–100% efficiency, 40% attraction (Moser et al. 2011). However, our understanding of the Sea

Lamprey in fish passage structures is poorly understood (Pereira et al. 2016; (Mary Moser, Northwest Fisheries Science Center, NOAA, pers. comm.).

Downstream passage considerations (Juveniles):

- The Sea Lamprey is semelparous and adults die after spawning, thus downstream passage is not required for adults.
- The seaward migration of juvenile Sea Lamprey (i.e., juveniles that have transformed to the parasitic phase from the ammocoete phase and termed "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 (Hansen et al. 2016). The migrations are nocturnal and appear to concentrate in the thalweg near the bottom where current velocity is greatest for the Pacific lamprey (Moser et al. 2015).
- Downstream migrating transformers are particularly vulnerable to entrainment and impingement in screens and bar racks designed to protect juvenile salmonids (e.g., Moser et al. 2015), given their elongate body form and relatively poor swimming performance. Although thought to be bottom-oriented during their downstream migration, the effects of barotrauma are presumed to be less for Sea Lamprey than most teleost fishes, as this species does not have a swim bladder.
- Pre-transformation ammocoetes may also exhibit downstream migrations and may be subject to impingement, but probably to a lesser degree than the juveniles, due to their smaller size (Moser et al. 2015).
- Currently, there are no downstream passage guidance or exclusion technologies developed specifically for Sea Lamprey (Alex Haro, USGS, pers. comm.)

3.7 STRIPED BASS (*Morone saxatilis*)

Historically, one of the important, main-stem spawning locations for Striped Bass is believed to have existed in the downstream vicinity of MGS (Andrews et al., 2016). The SJR Striped Bass population consists of a variety of genetically distinct populations that includes strains from the Atlantic seaboard (USA), Shubenacadie River (NS), and a recently identified SJR group (Sam Andrews, CRI, unpublished data). Some adults migrate to the MGS tailrace to feed and return to downstream reaches or to their natal spawning rivers. Successful spawning in the SJR has not been documented for over 40 years, although Striped Bass are considered common and juveniles are becoming more frequently observed in the SJR. The enigma surrounding Striped Bass in SJR, as well as the possibility of a creating a land-locked population upstream of the MGS is discussed in detail in Andrews et al (2016) and is not repeated here.

An important consideration in terms of fish passage for Striped Bass in SJR is related to the motivation of the fish to pass upstream of MGS; the incentive may be low given that at least some proportion of the population are migrants from other populations and the abundance of food provided by migrating gaspereau stalled at the MGS and the reservoir's out-migrating, YOY gaspereau. Rare occurrences of adult Striped Bass are reported in the reservoir (Allen Curry, CRI, unpublished data) and these are likely trapped and trucked inadvertently. There is no record of spawning in the reservoir or upstream since the MGS was completed. Historical habitats upstream of the MGS are unknown.

Upstream passage considerations (Adults and Juveniles):

- Fish lift and/or trap-and truck options may be viable for upstream passage of juveniles and adults of this species.
- Adult Striped Bass have been passed in large, technical ladders.
- Adult Striped Bass arrive to the MGS and enter in the existing fish lift/trap; however, we don't yes understand the motivation for this behaviour beyond feeding.
- Until we understand why adults and juveniles are captured at the MGS, it is difficult to assess potential passage requirements but it is most probably that the key feature will be motivation to enter structures.

Downstream passage considerations (Adults and Juveniles):

- Adults are large-bodied, iteroparous spawners. Repeat-spawners are extremely important for a healthy population and safe, non-turbine passage route is mandatory. Exclusion structures preventing entrainment to turbines may be required; performance of behavioural guidance structures for Striped Bass is unknown.
- Migration timing and depth are not well known and will require additional study to establish appropriate spill regimes and location (top, mid-column or bottom), by-pass location, and guidance structures.
- Juvenile migration timing and behaviour are currently unknown. Assuming successful spawning upstream, juveniles will require spillway and by-pass passage.
- Turbine passage efficiency is predicted to be higher in modern, fish-friendly turbine units, but these units still must be adequately large to accommodate large adult Striped Bass.

3.8 OTHER SPECIES

The SJR is home to 55 species of which at least 30 are regularly encountered in the upstream or downstream vicinity of the MGS (see Table 1 and Appendix 1). The non-diadromous species most probably migrating near, and thus likely impacted by the future MGS include common fish species, e.g., Golden Shiner, Creek Chub, Smallmouth Bass, Yellow Perch, White Perch, Muskellunge, Burbot, White Sucker, Brown Bullhead, Brook Trout, and Rainbow Trout.

The ability to move along the longitudinal gradient in rivers is important for non-diadromous fish species because of access to additional spawning areas or other life history stage-specific habitats that sustain healthy populations, e.g., genetic diversity. In addition, such connectivity supports the health of the broader river ecosystem, e.g., provision of nutrient subsidies, inter-species requirements of freshwater mussels (Vaughn and Taylor 2000).

In a natural, barrier-free river system, movements of individuals along the river continuum is believed to occur on a continuous basis in all fish species. Even in the absence of directed migrations, genetic stability along rivers is predicted over time. Dams disrupt this river continuum resulting in genetic decoupling and sub-populations are created. If the sub-populations form isolated reproducing populations both up-and downstream of the migration barrier these populations may become self-sustaining, or may also become extinct due to inbreeding or are otherwise genetically deficient because of small population size. If connectivity of populations of a fish species exists between up- and downstream areas of a dam, the risk of river specific, sub-population extinction is reduced. In the case of MGS, all the river resident species that are common near the project area currently have viable populations both up- and downstream of the dam (Appendix 1), noting that many have no assessment of population status.

Many freshwater species in SJR also undertake directed migrations, for example, during spawning (Appendix 1). Interruptions of spawning runs will negatively affect a population, but may also have indirect effects on the river ecosystem, e.g., by interrupting nutrient flows. Catostomids (i.e., the Sucker family) often dominate the abundance and biomass at fishways in North America (Schwalme et al. 1985; Bunt et al. 2001). Many Catostomids are obligate freshwater migrants (potamodromous) and both the White and Longnose Sucker can undertake large scale directed spawning migrations in the SJR (Doherty et al. 2010; Allen Curry, CRI, unpublished data). Recent evidence unequivocally shows that Catostomids, although iteroparous, provide very important nutrient subsidies in their spawning tributaries, and thus can enhance stream productivity. For example, Childress et al. (2014) documented elevated phosphorous (P) and nitrogen (N) concentrations of three- to five-fold relative to reference reaches and Jones and Mackereth (2016) measured 84% and 78% of annual N and P subsidies, respectively, were derived from spawning runs of Catostomids. Similar ecological functions are believed to be also provided by other potamodromous species.

In the case of the MGS and its reservoir, nutrient subsidies provided by potamodromous fish may have been eliminated, but possibly compensated by large runs of gaspereau that enter the reservoir. However, the nutrient transport and nutrient budgets are a function of spatial scales; for example, the fish species moving from the main river and destined to the tributaries of the SJR above Mactaquac, e.g., spawning migrations of White Sucker (Doherty et al. 2010), and dispersal of eel and lamprey as indicated by historic records (Francis 1980). This contrasts with the marine-derived nutrient subsidies introduced by the Alewife and Blueback Herring that mostly remain in the main stem and current reservoir.

In the past, focus has been placed in North America on fish passage design solely for diadromous species (see Linnansaari et al. 2015a and 2015b). Designing passage solutions for one or a few species without understanding the complete ecosystem with its complex interactions among species and their habitats is not advisable. There are few developed passage technologies that accommodate non-diadromous species and passage of these species is often serendipitous. Passage technologies for freshwater-resident fish fauna will have to be studied and developed to meet species specific behaviours, swimming capabilities, attraction requirements, etc. (e.g., Peake 2008).

In general, for upstream passage an effective fish passage solution for the river resident, native fish fauna is a nature-like fishway that allows year-around, volitional passage for all species (e.g., Turek et al. 2016). However, because of the high vertical head at the MGS site, i.e., it would require an extremely long, low slope nature-like fishway, the technical feasibility and biological performance of such a passage structure was not positively viewed in the Fish Passage Experts Workshop (Linnansaari et al. 2015b). A passage solution with a high, vertical head will most probably include a fish lift and/or trap-and-truck solution.

Downstream passage effectiveness for resident fishes are largely lacking. Downstream passage for residents would most probably be partially achieved opportunistically via structures designed for the diadromous species, including via spillways. Various technical solutions have been attempted for certain groups of fish, e.g., Catostomids, Percids, and Cyprinids (see CanFishPass database; Hatry et al. 2011), but evaluation data are minimal.

4 CONCEPTUAL UPSTREAM PASSAGE CONSIDERATIONS

The key considerations relevant for successful, upstream fish passage at the future MGS location are as follows:

- The most effective upstream passage is a return to a free-flowing state (Linnansaari et al. 2015b) noting that this doesn't ensure a return to historical fish community complexes or population states, and most probably introduces 2-3 species that are currently abundant upstream into downstream reaches, e.g., Rainbow trout, Brown trout, and Muskellunge.
- An effective fish passage solution for the MGS site requires first and foremost, a ***comprehensive, long-term fish management plan*** for the SJR that has identified species and numbers that must be passed now and potentially in the future. The plan will dictate the design requirements necessary to produce the most effective ecological and economical solution.
- World-wide experience dictates that successful fish passage depends on a developing a plan that continually monitors performance of passage and that can adapt strategies and tactics in response to passage challenges that will be discovered, i.e., success depends on an ***adaptive fish passage management plan***.
- A fish lift system is likely to provide relatively functional upstream passage at the MGS site. The design of a lift will have to accommodate the requirements for species in the

adaptive fish management plan, e.g., size/shape/capacity, entrance, including the potential for more than one lift to address different species-specific needs, e.g., sturgeons vs. American Shad. A lift is not a complete solution. Challenges in scale and multi-species functionality can be addressed with careful design and operational plans, e.g., effective fish lift operations will have to consider the timely passage of species that preferentially migrate outside normal, human-operator hours of work (e.g., nighttime). Timely operations including maintenance and repairs will be a critical component of the overall ***adaptive fish management plan***.

- A trap-and-transport option may still be required as part of the overall fish passage strategy in an ***adaptive fish management plan***. The current "trap-and-truck" process at the MGS has several issues that would require modifications to be successful in a future fish passage programme.
- A recently introduced technology for tube, pressure-differential fish passage should be explored noting that solutions for high vertical head dams are unproven.
- Very large, technical fishways providing passage over high-head dams have been constructed in the Columbia River system where they pass Pacific salmon species with measurable successes. Such a fishway could be designed for Atlantic Salmon and most probably concurrently provide upstream passage for other species, e.g., gaspereau, American Shad, American Eel. However, efficiencies for Atlantic Salmon including delay in migration impacts, e.g., length of time delayed in ladder related to hydraulics and/or competition for access and space with migrating gaspereau, are unknown. Efficiencies for other species are similarly unknown.
- Attraction flows for any technical passage solution are critical, particularly for large facilities and if there are multiple passage structures, e.g., lifts and trap-and-truck operations. The entrance to upstream passage structures is often the key determinant of successful upstream passage (reviewed in Linnansaari et al. 2015a). Design critically depends on modeling downstream flows near the facility, both existing and proposed, and under a variety of river flow and generation conditions, e.g., building appropriate, downscaled physical models, modeling downstream computational fluid dynamics, and understanding the species to be passed and their behavior on approach to and at the facility.
- Diverting flow for fish passage will most probably result in a loss of power-generation.
- American Eel will require a separate, species-specific solution. A combination of juvenile eel ramps and lift(s) are most probably required and these would be specifically designed for the MGS location and its physical structures. Retrofitting an existing structure (e.g., spillway, turbine bay) for effective upstream passage of eels has also been successful at other facilities. The MAES programme is currently assessing eel approaches and ramp designs at the existing MGS.
- Within the ***fish management plan***, it is important to establish clear and regular monitoring and assessment of the upstream fish passage efficiency (FPE; BPA 2013) for

each species and passage structure. The adaptive management plan will be designed to address actions to minimally sustain targeted the species-specific and cumulative FPEs.

5 CONCEPTUAL DOWNSTREAM PASSAGE CONSIDERATIONS

The key considerations relevant for successful, downstream fish passage at the future MGS location are as follows:

- Again, the most effective downstream passage is a return to a free-flowing state (Linnansaari et al. 2015b) noting that this doesn't ensure a return to historical fish community complexes or population states, and most probably introduces 2-3 species that are currently abundant upstream into downstream reaches, e.g., Rainbow trout, Brown trout, and Muskellunge.

- As with upstream passage considerations, an effective fish passage solution for the MGS site requires first and foremost, a ***comprehensive, long-term, adaptive fish management plan*** for the SJR. The plan will dictate the design requirements required to produce the most effective ecological and economical solution.
- Downstream passage will be species-specific and thus require multiple structures/options which are traditionally provided via: 1) spillway passage; 2) by-pass passage; and 3) turbine passage.
- Within the ***fish management plan***, it is important to establish clear and regular monitoring and assessment of the downstream fish passage efficiency (FPE; BPA 2013) for each species and passage structure. The adaptive management plan will be designed to address actions to minimally sustain targeted the species-specific and cumulative FPEs.

5.1 SPILLWAY PASSAGE

- Spillway passage can occur either as top or bottom spill depending on the facility and species-specific requirement: for Atlantic salmon smolts and juvenile Alosids, spilling from the surface of the water column is the preferred solution; for bottom migrating species, e.g., eel, lamprey, and potentially sturgeons, a bottom spill may be more effective. Construction of spill facilities at multiple levels provides options for passage of a variety of species.
- Bottom spill from deep waters has the potential to inflict barotrauma. These effects must be considered in design of deep by-pass entrances (see Linnansaari et al. 2015a).
- Spilling water can generate elevated levels of dissolved gases downstream. This is a known issue for fish and such conditions should be avoided or mitigated for in the design process. The ***adaptive fish management plan*** will be designed to address actions to assess and adapt operations to minimize potential impacts of barotrauma.

- Spilling water can also create poor hydraulic conditions in the tailrace of the dam that may affect upstream passage efficiency or increase predation risk for fish passed downstream. The ***adaptive fish management plan*** will be designed to address actions to assess and adapt operations to minimize potential impacts of poor hydraulic conditions and predation risk.
- Diverting flow for fish passage will most probably result in a loss of power-generation.

5.2 BY-PASS PASSAGE

- By-pass systems are the best among constructed options for effective downstream passage because structures are designed specifically for fish passage.
- The entry point of a by-pass system must consider species-specific entrance and exit points to address known issues (see Section 5.1).
- Physical guidance structures are typically required to guide fish to by-pass structure; these are species-specific. Partial-depth (floating and not penetrating to the bottom of the water column) guidance booms, guide walls, and louvers can be effective for surface migrating species. Best results are achieved when booms, guide walls, and louvers are installed at shallow angles relative to forebay flow direction, e.g., 15° across forebay or entry canals. Full-depth guidance structures can potentially guide all species regardless of migration depth.
- Rapid flow acceleration at the entry of the by-pass can be problematic. Fish detect abrupt changes in water velocity and can be repelled from areas with significant changes in velocity, i.e., a by-pass entrance with a uniform acceleration flow field is required and can be achieved through appropriate design.
- Exit of the by-pass must allow a safe plunge into the tailrace, e.g., adequate plunge pool depth, appropriate hydraulic conditions, and an area of low predation. The ***adaptive fish management plan*** will be designed to address actions to assess and adapt operations to minimize potential impacts of by-pass passage.

5.3 TURBINE PASSAGE

- Turbine passage is the least preferred option for downstream passage because; for conventional turbines, it can result in the greatest levels of mortality and injury for all fish.
- Currently, "fish-friendly" turbine designs provide the most promising technology for mitigating turbine passage for multiple species and body sizes (Hogan et al. 2014; Cada 2001). The Alden and Minimum Gap Runner (MGR) Kaplan fish-friendly turbine designs appear to improve survival rates of small-bodied fish, although research is still ongoing (e.g., Hogan et al. 2014). Including one or more fish-friendly turbines where downstream migrating species are directed has the potential to maximize FPE.
- Turbine passage is not preferred for large-bodied fish and alternative passage options are required.

- The ***adaptive fish management plan*** will be designed to address actions to assess and adapt operations to minimize potential impacts of turbine passage.

5.4 OTHER DOWNSTREAM PASSAGE CONSIDERATIONS

- Within the ***fish management plan***, it is important to establish clear and regular monitoring and assessment of the downstream fish passage efficiency (FPE; BPA 2013) for each species and passage structure. The adaptive management plan will be designed
- The FPE assessment will include evaluations of downstream passage routes, delays, mortality and injury via direct assessment (e.g., telemetry, mark-recapture) are required to accurately assess effectiveness of downstream passage. FPE includes indirect effects of passage such as stress recovery from passage and susceptibility to predation may occur downstream (e.g., Colotelo et al. 2016).
- A trap-and-transport method for downstream passage has been used at other locations at both near-facility and farther upstream locations and requires further assessment regarding applicability for the SJR situation.

6 OTHER CONSIDERATIONS

In addition to the actual technical solutions to achieve effective up- and downstream passage for multiple species at the MGS, there are other important considerations regarding the fish and the river ecosystem to be considered in the decision-making process for the future of the MGS facility.

6.1 WHAT CONSTITUTES "FUNCTIONAL" FISH PASSAGE?

This report discusses ***functional fish passage*** for the MGS under the proposed options, where functional is defined as passing a sufficient portion of the population to ensure the long-term sustainability of the population. Functional includes a measure of the facility's efficiency which is defined as the proportion of a species that successfully passes a facility in relation to the number that approach and attempt to pass a facility location. Worldwide, there are many engineered solutions and management actions that are achieving some level of positive passage efficiency for fish travelling up- and downstream of barriers in rivers. Understanding and maximizing passage efficiency at a barrier is critical, but only in the context of system-wide or cumulative efficiency in multi-barrier systems: a facility may pass 50% of an approaching species attempting to access their only reproductive habitats, but if the approaching group is the last 5% of the total population, then 100% (not 50%) of these fish will most probably require successful passage.

Achieving functional fish passage requires first and foremost a ***comprehensive, long-term fish management plan*** for the SJR that has identified species and numbers that must be passed, now and potentially in the future. The plan will dictate the design requirements necessary to produce the most effective ecological and economical solution. Operationally this requires a) a high-level of understanding of the fish species, their behavior, ecology and physiology, e.g., constraints for engineered structures and their operations; b) the population structure and dynamics and community interactions; c) the functional role of the fish in the ecosystem, e.g., nutrient transfers, sustaining co-dependent species; d) the hydraulic environment of up- and downstream approaches for fish; and, e) the engineering constraints for passage options at a specific locations. In addition, biological systems and engineered structures are dynamic, i.e., they change over time. Because of these many biological, physical, engineering, and management complexities, including habitat interconnectedness and population dynamics, ensuring functional fish passage is dependent on an ***adaptive management approach***. Without a multi-stakeholder willingness to support or a regulated adaptive management plan, there is very low probability that fish populations can be sustained over time in a river system with human-built barriers.

6.2 EFFECTS OF THE RESERVOIR

The reservoir created by the current facility at MGS is large; its area is 88.2 km^2 at a typical reservoir elevation of 40.5m and extending 96 km in length (Chateauvert and Linnansaari 2016). The effects of a created reservoir environment, particularly in large hydro-regulated rivers, are increasingly recognized as problematic for the native fish fauna that has evolved in fluvial ecosystems (Pelicice et al. 2014). Large reservoirs change habitats from riverine to lacustrine and in addition, can create an ecological barrier added to the physical barriers of the dam, i.e., complicating the river connectivity impacts. The reservoir has a gradient of hydrological and limnological conditions that creates a gradual transition of lotic (flowing water), semi-lentic (slow-moving/standing water) and lentic environments between upstream and downstream reaches (Pelicice et al. 2014). This can create a significant migration obstacle for rheophilic fish species particularly when moving downstream (Pelicice et al. 2014), as a flowing water cue for downstream orientation and movement becomes lost.

The potentially problematic role of reservoir passage is recognized in the MAES programme, but MAES Phase 1 can only evaluate effects for three life stages of one species, Atlantic Salmon: smolts, returning adults, and kelts, post-spawning (A. Babin, Unpublished data). These studies focus on smolt and kelt navigation downstream to and through the MGS reservoir and adult salmon migration upstream. Preliminary results indicate that reservoir passage is causing some delay, straying and swimming-direction reversals (A. Babin, Unpublished data). The role of the MGS reservoir may be as a barrier, sink, or to induce possible positive impacts on its multi-species community (e.g., Munkittrick et al. 2010; Freedman et al. 2012).

The change from a riverine to lacustrine habitat experienced in the SJR with the creation of the MGS has not been assessed as it relates to the fish community and the river's ecosystem; nor has the option of a return to a free-flowing river at the MGS site. The MAES project is examining the reservoir's current fish community and limnological characteristics, e.g., water quality and plankton communities as well as modeling a projected return to a free-flowing river, i.e., predicted new riverine habitats. These studies will be useful for understanding how the changes with the reservoir, past and proposed future, have or could impact the fish and river ecosystem.

6.3 EFFECT OF DAM AND THE RESERVOIR AS A BARRIER FOR INVASIVE SPECIES

One consideration not yet addressed in the SJR is the barrier created by the MGS reservoir and dam that inhibit expansions of some non-native species that may be considered invasive or threatening to native fauna or the river ecosystem. One species that appears restricted to a distribution upstream of the MGS reservoir is Rainbow Trout (*Oncorhynchus mykiss*). Comprehensive electrofishing surveys in the tributaries upstream of the reservoir indicate that the Rainbow Trout is reproducing and becoming more common (Allen Curry, CRI, unpublished data). While adult Rainbow Trout are annually observed downstream of the MGS (Ross Jones and John Whitelaw, DFO Maritimes, unpublished data), juveniles are rare in the tributaries downstream of the MGS. It is uncertain how the Rainbow Trout would re-distribute if fish passage was improved at a rebuilt/retrofitted MGS or the MGS reservoir was returned to a free-flowing river.

Another non-native species, the Muskellunge (*Esox masquinongy*) is now established upstream of the MGS and adults are more common downstream of the MGS. The MGS may have dampened the colonization rate of this large predator downstream, i.e., after 30 years of observations, MAES studies have only recently shown that Muskellunge are successfully spawning downstream of the MGS (Kaleb Zelman, CRI, unpublished data). The impacts of expanding the access up- and downstream of the MGS site for other non-native species including aquatic macrophytes (plants) and parasites as well as disease are uncertain.

6.4 FISH PASSAGE DURING WINTER CONDITIONS

Fish passage operations are typically undertaken during the open water conditions, i.e., spring, summer, and fall. Ice and freezing conditions may prevent operation of many technical up- and downstream fish passage facilities. Fish passage requirements in winter are poorly understood, but for certain species winter may be the most important migration season. Burbot (*Lota lota*) is active in winter including spawning migrations. Burbot is present both up- and downstream of the MGS, but no data exists regarding its migration requirements in SJR. Transformer lamprey may be emigrating in late fall and winter as do Atlantic Salmon pre-smolts. More ecological research for the winter period is required (e.g., Harrison et al. 2016).

6.5 REQUIREMENT FOR MONITORING AND ADAPTIVE MANAGEMENT

Despite detailed planning, modeling exercises and use of best available technologies, the experience worldwide indicates that arranging functional fish passage is not simple nor easy; nor is it a static process (as discussed above and see also Linnansaari et al. 2015b). A robust and continuous ***monitoring program*** assessing fish passage will always be required throughout the lifetime of a fish passage project. Meaningful monitoring and willingness to commit to an ***adaptive management*** strategy are critical for successful, functional, long-term fish passage. Monitoring and quick, adaptive responses are key philosophies of the necessary ***comprehensive, long-term fish management plan***.

7 DIFFERENTIATING AMONG THE OPTIONS: LIKELIHOOD OF ACHIEVING FUNCTIONAL FISH PASSAGE

Providing functional fish passage in a multi-species context is a challenging task despite advancements in passage technology as well as in the biological and ecohydrological information regarding habits and behaviour of various fish species. It is necessarily complex and success usually cannot be guaranteed. Realizing functional fish passage for the MGS site will be an iterative and long-term project based on an adaptive management approach to achieve the goals laid out in a ***comprehensive, long-term fish management plan*** for the SJR that has identified species and numbers that must be passed. Consequently, predicting fish passage success for the options of the Mactaquac Project is a conceptual exercise.

Predicting success of fish passage mitigation is often a modeling exercise based on experience and opinion. For this reason, the MAES programme invested significantly in developing a conceptual vision for successful fish passage by: (1) reviewing the relevant, available information regarding the distribution and status of SJR fishes (see above discussions); (2) reviewing technical solutions for fish passage from around the world (Linnansaari et al. 2015a); (3) soliciting world-wide expert opinions (Linnansaari et al. 2015b); (4) studying species-specific issues (as discussed herein); (5) conducting site visits to rivers with large hydropower dams or restored rivers - Columbia River (OR), Cowlitz River (OR), White River (OR), Elwha River (WA), Exploits River (NFLD), West Salmon River (NFLD), Connecticut River (MA), Merrimack River (MA), Penobscot River (MN), and numerous regulated rivers in Norway; (6) gathering the most recent advances in fish passage science from relevant conferences (the new and unpublished knowledge); and (7) consulting with local/regional fish ecology and passage experts in workshops and meetings, i.e., with Maliseet communities and their organizations, DFO, the Province of NB, local fishers, and NGOs. From this collective knowledge, the following conceptual fish passage discussion is presented. Importantly, the discussion makes no provisions for other aspects of fish passage in the SJR such as the regulatory management objectives, federal and provincial Species at Risk Acts, First Nation interests, social or economic factors, technical or economic feasibility, the energy grid, or other physico-ecological aspects. The following discussion of uncertainty among options in the Mactaquac Project is bound by our best understanding of the science at the time of this report.

7.1 HIGHEST LIKELIHOOD FOR FUNCTIONAL FISH PASSAGE:

Option 3 – Return to a natural, free-flowing river

Assessment – Removing the dam in its entirety will be the best and only solution to guarantee functional fish passage at the current site of MGS. Option 3 is also the only option that removes the ecological effects of the large reservoir. This option will have the most significant effect on fish habitats which are predicted to be positive for most species, e.g., Atlantic Salmon and American Shad, and potentially negative for other species, e.g., Alewife and Blueback Herring.

Assumptions –

- The current site of MGS will become readily navigable for the local fish fauna following the removal of dam structures, i.e., unobstructed passage is provided.
- "Readily navigable" assumes the site will be re-engineered because of the existing dam footing structures; a restoration plan for the site is not yet determined. The re-engineering may include restoration of the historic conditions of rapids or some alternative physical (flow) conditions that <u>may</u> create a less restrictive passage environment.
- The removal and engineering at the site doesn't imply or ensure 100% of fishes will traverse the location, i.e., there is no guarantee a return to historical fish community complexes or population states. In addition, this option most probably introduces 2-3 species that are currently abundant upstream into downstream reaches as well as creating new habitats that may keep species from moving past the site, e.g., if suitable spawning locations are encountered for Striped Bass or sturgeons as an example.

7.2 GREATER UNCERTAINTY OF FUNCTIONAL PASSAGE:

Option 2 – Retain dam structures and reservoir without turbines.

Assessment – Retaining the dam and reservoir with a spillway only and no power generation is conceptually a more benign option than a similar structure with power generation. First, no turbine mortality will be incurred. Spilling of water during important migration periods would not come at economic cost and therefore abundant water is available to manage for passage of fish. Water for attraction and technical ladders would be available. The uncertainty of the reservoir as an ecological barrier remains unresolved, but sufficient spilling during key migration times could have a positive effect on reducing delays and straying in the reservoir, e.g., Atlantic Salmon smolts (see also BPA 2013). With a dam and reservoir still in place however, some delays in migrations and impacts on populations will be incurred.

Assumptions –

- The operating water elevation range, and therefore headpond storage, will remain the same as present-day regimes.
- Upstream passage will be successfully arranged for the multi-species fish community.
- Sufficient attraction and auxiliary flows will be available for upstream passage structures.
- Maximum downstream passage survival for all species will be achieved via combination the necessary design of controlled surface and bottom spill and by-pass technologies, noting that this will be a challenge for some species, e.g., American Eel and adult/sub-adult sturgeons.
- Reservoir effects will remain the same as the present-day MGS situation, although spill timing will be adjusted to meet the demands of migrating fish and may therefore mitigate both delay and straying. For example, relatively high flows can be provided during the period between dawn and dusk during salmon and eel downstream migration periods.
- An appropriate environmental flow regime will be achieved downstream;
- Monitoring, adaptive management and adjustment to the passage structures are planned and will be implemented if the initial installations are shown to be unacceptably ineffective.
- The financial means to continue adaptive fish passage management will exist for the life of the dam and reservoir.

7.3 MOST UNCERTAINTY FOR FUNCTIONAL PASSAGE:

Option 1 – Retain dam structures and reservoir with a new power house

Assessment – Building a new generating station and associated spillway and sluiceway structures provides the opportunity to build new and appropriate fish passage facilities (and associated management plans) using the best available technology, and thus is a better option than a retrofitting of the existing facility (Section 7.4). The uncertainty of the reservoir as an ecological barrier or source of delay or migratory failure would remain unresolved.

Assumptions –

- There will be enough capacity and a variety of upstream passage structures to match the appropriate, species-specific specifications are created and managed accordingly for the life of the new facility.
- Fish-friendly turbine units will be utilized to reduce downstream mortality.
- Downstream exclusion methods and by-pass options with sufficient flow for both surface and bottom migrating fish will be adopted and operated to maximize fish passage.
- Surface spill / bottom spill will be arranged to maximize fish passage.

- Monitoring, adaptive management, and adjustment to the passage structures will be planned and will be implemented if the initial installations are shown to be unacceptably ineffective.
- The financial means to continue adaptive fish passage management will exist for the life of the dam and reservoir.

7.4 LOWEST LIKELIHOOD FOR FUNCTIONAL FISH PASSAGE:

Life Achievement – Retrofitting the existing facility

Assessment – Conceptually, retaining the existing facility at MGS is the option least likely to provide functional fish passage. The current fish passage solution at the MGS, i.e., the structures, operations, and management plans cannot be considered functional for the full range of species in the river. Improvements are possible; however, retrofitting existing hydroelectric generating stations and their facilities has been attempted in many locations and situations worldwide and the effectiveness for improving passage varies widely, i.e., achieving an improvement to existing facilities are uncertain. In addition, costs can be significant for the incremental retrofitting often required in continuing attempts to improve efficiencies. The uncertainty of the reservoir as an ecological barrier or source of delay or migratory failure would remain unresolved.

Assumptions –

- Improvements to fish passage at the current facility through retrofits will be constrained by existing infrastructure and installation of certain structures may be more difficult or could be impractical.
- Refurbished existing turbine unit designs will not be as fish-friendly as other options.
- Monitoring, adaptive management, and adjustment to the passage structures will be planned and will be implemented if the initial installations are shown to be unacceptably ineffective.
- The financial mean s to continue adaptive fish passage management will exist for the life of the dam and reservoir.

7.5 CONCLUSION

a) Removing a dam and its reservoir is always the best solution for achieving the most effective fish passage. In large, multi-species rivers, the ecosystem will have adjusted to the barrier and reservoir effects and thus removing these structures does not guarantee a return to the historical fish communities or ecosystem and most probably redistributes the post-dam, fish species of the community as well as the other system components, i.e., a new ecosystem state is predicted.

b) Existing fish passage technologies are not well developed, especially for downstream passage. Consequently, expectations for engineered solutions should be realistic and not overestimated.
c) Retrofitting an existing structure has the lowest probability of achieving necessary or desired fish passage efficiency noting that some species can be partially accommodated in a retrofit scenario, e.g., upstream migrating American Eel juveniles.
d) Developing functional fish passage at the MGS site will be an iterative and long-term process based on an adaptive management approach to achieve the goals laid out in a ***comprehensive, long-term fish management plan*** for the SJR that has identified species and numbers that must be passed. It is imperative that all stakeholders, regulators, and fish passage facility operators create and understand a comprehensive fish management plan that defines species to be passed up- and downstream and the efficiencies to be achieved at a future facility, e.g., proportion of the population or facility-specific mortality rate.

8 ACKNOWLEDGEMENTS

The authors would like to recognize the funding for this project that is received from NBP and NSERC's Collaborative Research and Development programme (CRDPJ: 462708-13). We also thank the personnel of Fisheries and Oceans Canada (R. Jones, J. Whitelaw, R. Bradford and B. Jessop [retired]) for discussions regarding the various aspects of fish populations and their trends over time in the Saint John River. Many individuals in our workshops provided very useful information on the fish and river, their histories and socioeconomic, cultural, and Aboriginal importance.

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Appendix 1. Fish species of the Saint John River (N = 55; CRI 2011 and more recently, Allen Curry, CRI, unpublished data). Listed in the table are all species that have been encountered in the river*. US = upstream and DS = downstream

Common Name	Scientific Name	Group [1]	Status at MGS [2]	Life history / Generic habitat	River migration[3]	Population US and DS [4]	Introduced
Alewife	*Alosa pseudoharengus*	River Herrings	Common	Anadromous	yes	DS	
American Eel	*Anguilla rostrata*	Lampreys & eels	Common	Catadromous	yes	DS [5]	
American Shad	*Alosa sapidissima*	River Herrings	Common	Anadromous	yes	DS	
Atlantic Salmon	*Salmo salar*	Salmonids	Common	Anadromous	yes	US and DS	
Atlantic Sturgeon	*Acipenser oxyrinchus*	Sturgeons	Common	Anadromous	yes	DS	
Banded Killifish	*Fundulus diaphanus*	Killifishes	Common	River resident	yes	US and DS	
Blacknose Dace	*Rhinichthys atratulus*	Carps & Minnows	Common	River resident	no	US and DS	
Blueback Herring	*Alosa aestivalis*	River Herrings	Common	Anadromous	yes	DS	
Brook Trout	*Salvelinus fontinalis*	Salmonids	Common	River resident [6]	yes	US and DS	
Brown Bullhead	*Ameiurus nebulosus*	Catfishes	Common	River resident	yes	US and DS	
Burbot	*Lota*	Cods	Common	River resident	yes	US and DS	
Chain Pickerel	*Esox niger*	Pikes	Common	River resident	no	US and DS	yes [7]
Common Shiner	*Notropis cornutus*	Carps & Minnows	Common	River resident	yes	US and DS	
Creek Chub	*Semotilus atromaculatus*	Carps & Minnows	Common	River resident	no	US and DS	
Fallfish	*Semotilus corporalis*	Carps & Minnows	Common	River resident	yes	US and DS	
Fourspine Stickleback	*Apeltes quadracus*	Sticklebacks	Common	River resident	no	DS	
Golden Shiner	*Notemigonus crysoleucas*	Carps & Minnows	Common	River resident	yes	US and DS	
Lake Chub	*Couesius plumbeus*	Carps & Minnows	Common	River resident	no	US and DS	
Muskellunge	*Esox masquinongy*	Pikes	Common	River resident	yes	US and DS	yes
Ninespine Stickleback	*Pungitius*	Sticklebacks	Common	River resident	no	US and DS	
Pumpkinseed Sunfish	*Lepomis gibbosus*	Perches & Sunfishes	Common	River resident	no	US and DS	
Rainbow Trout	*Oncorhynchus mykiss*	Salmonids	Common	River resident [6]	yes	US and DS	yes
Sea Lamprey	*Petromyzon marinus*	Lampreys & eels	Common	Anadromous	yes	DS	
Shortnose Sturgeon	*Acipenser brevirostrum*	Sturgeons	Common	Anadromous	yes	DS	
Smallmouth Bass	*Micropterus dolomieui*	Perches & Sunfishes	Common	River resident	yes	US and DS	yes [7]
Striped Bass	*Morone saxatilis*	Perch	Common	Anadromous	yes	DS	

Threespine Stickleback	*Gasterosteus aculeatus*	Sticklebacks	Common	River resident	no	US and DS	
White Perch	*Morone americana*	Perches & Sunfishes	Common	River resident	yes	US and DS	
White Sucker	*Catostomus commersoni*	Suckers	Common	River resident	yes	US and DS	
Yellow Perch	*Perca flavescens*	Perches & Sunfishes	Common	River resident	yes	US and DS	
Blacknose Shiner	*Notropis heterolepis*	Carps & Minnows	Uncommon	River resident	no	DS	
Brook Stickleback	*Culaea inconstans*	Sticklebacks	Uncommon	River resident	no	DS	
Brown Trout	*Salmo trutta*	Salmonids	Uncommon	River resident [6]	yes	US and DS	yes
Fathead Minnow	*Pimephales promelas*	Carps & Minnows	Uncommon	River resident	no	US and DS	yes
Finescale Dace	*Chrosomus neogaeus*	Carps & Minnows	Uncommon	River resident	no	US and DS	
Lake Whitefish	*Coregonus clupeaformis*	Salmonids	Uncommon	River/Lake	yes	DS	
Longnose Sucker	*Catostomus*	Suckers	Uncommon	River resident	yes	US and DS	
Northern Redbelly Dace	*Chrosomus eos*	Carps & Minnows	Uncommon	River resident	no	US and DS	
Pearl Dace	*Semotilus margarita*	Carps & Minnows	Uncommon	River resident	no	US and DS	
Redbreast Sunfish	*Lepomis auritus*	Perches & Sunfishes	Uncommon	River resident	no	DS [8]	
Slimy Sculpin	*Cottus cognatus*	Sculpins	Uncommon	River resident	no	US and DS	
Arctic Char [9]	*Salvelinus alpinus*	Salmonids	Absent	Lake resident	yes	DS	
Atlantic Menhaden	*Brevoortia tyrannus*	Herrings	Absent	Marine	no	DS	
Atlantic Silverside	*Menidia*	Silversides	Absent	Marine	no	DS	
Blackspotted Stickleback	*Gasterosteus wheatlandi*	Sticklebacks	Absent	Estuarine	no	DS	
Central Mudminnow	*Umbra limi*	Mudminnows	Absent	River resident	no	UP and DS	yes
Goldfish	*Carassius auratus*	Carps & Minnows	Absent	River resident	no	DS	
Lake Trout [10]	*Salvelinus namaycush*	Salmonids	Absent	Lake resident	yes	UP	
Largemouth Bass	*Micropterus salmoides*	Perches & Sunfishes	Absent	River resident	no	UP	yes
Mummichog	*Fundulus heteroclitus*	Killifishes	Absent	Estuarine	yes	DS	
White Hake	*Urophycis tenuis*	Cods	Absent	Marine	no	DS	
Yellowtail flounder	*Limanda ferruginea*	Flounders	Absent	Marine	no	DS	
Atlantic Tomcod	*Microgadus tomcod*	Cods	Unknown	Anadromous	yes	DS	
Rainbow Smelt	*Osmerus mordax*	Salmonids	Unknown [11]	Anadromous	yes	DS	
Round Whitefish	*Prosopium cylindraceum*	Salmonids	Unknown	River resident	yes	UP	

[*] CRI (2011) lists 53 fish species for SJR. The list has been updated by addition of two species, Goldfish and Largemouth Bass, that have been confirmed since 2011 (Allen Curry, CRI, unpublished data).

[1] The various fish species are grouped based on generalized, morphological characteristics.

[2] Common = Encountered commonly at MGS; Uncommon = Encountered rarely at MGS; Absent = Not encountering at MGS; Unknown = No data for these species.

[3] River migrations = Migrations are known either within the SJR (CRI 2011 and unpublished data) or from the published literature (e.g., Scott and Crossman 1973).

[4] The presence of self-reproducing populations upstream (US) or downstream (DS) of the MGS.

[5] American Eel are reported rarely in stream surveys upstream - most probably from inadvertent trucking during the Gaspereau Fishery.

[6] These species are known to form both resident and anadromous populations.

[7] Species that are now considered "naturalized", i.e. established as a part of natural fish fauna in New Brunswick.

[8] Reported but not yet confirmed in the Mactaquac Reservoir.

[9] Most probably Aquaculture escapees.

[10] Known in two lakes only upstream of MGS.

[11] Recorded in the Mactaquac Reservoir in 2016.