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Fish Passage at Tobique-Narrows, Beechwood, and Mactaquac Hydropower Generating Facilities in the Saint John River System, New Brunswick.

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Executive Summary

Dams have long been a ubiquitous feature in rivers throughout the world and Canada. However, an understanding of fish passage at dam facilities has generally been inadequately addressed. Typically, only high value species such as salmonids in the northern hemisphere are managed for passage, but many challenges for effective passage persist even for these species. This report describes the configuration of the Tobique-Narrows, Beechwood, and Mactaquac hydropower generating and dam facilities highlighting the fish passage structures and operations. The objective of this report is to describe the existing dam structures, fish passage facilities, and fish passage operations. This report is a Final Deliverable of the NBP Project 2016-024, Fish Passage Report.

The Saint John River watershed supports 11 operational hydropower facilities and over 200 smaller dams or water control structures. The Mactaquac Generating Station (MGS) and Beechwood facilities are situated on the main stem of the Saint John River, whereas Tobique-Narrows is located on the Tobique River. All three dams provide some opportunity for upstream fish passage; however, the fish passage infrastructure was built to pass Atlantic Salmon. At the MGS, there is a fish collection facility that supports upstream passage for Atlantic Salmon and Gaspereau which are the only species actively managed. The fish collection facility utilizes a trap-truck-transport process that moves Atlantic Salmon and Gaspereau into the Mactaquac headpond and/or further up river. Other species can and occasionally are incidentally released into the Mactaquac headpond with Gaspereau transporting. The Beechwood fishway consists of a collection gallery, transportation channel, rest pool, and a skip hoist (elevator) that transports fish to the top of the dam (see diagrams in Ingram 1981). At the Tobique-Narrows generating station, fish passage is volitional (free swim) and occurs via a pool and weir fishway.

Currently, the Beechwood and MGS facilities do not have specific means to facilitate downstream passage. For fish moving downstream the only available route is to pass through the turbines or spillway infrastructure of the dams. In the fall of 2017, a downstream passage system for migrating smolts was installed in the fall of 2017 at Tobique-Narrows and is in the initial stages of operation.

With respect to fisheries management, NB Power is responsible for hydroelectric operations, whereas Fisheries and Oceans Canada and the Department of Energy and Resource Development manage fish and fish passage operations. Since the dams were constructed, the status of Saint John River Atlantic Salmon and other stocks have changed dramatically and new species have been introduced such as Muskellunge. Consequently, the original thinking about fisheries management has evolved. Fish species other than Atlantic Salmon and Gaspereau are mostly unmanaged for passage in either the upstream or downstream direction at all facilities.

A variety of fish passage studies have been conducted on Atlantic Salmon in the Saint John River such as downstream migration of juveniles (pre-smolt and/or smolt) and upstream migration of adults. Studies of other species in the Saint John River system rarely relate to fish passage, but some fish passage information may be gleaned from existing reports. Upstream fish passage issues at the three main facilities in the Saint John River include fishway mortality, fishway efficiency, and delayed migration each with unknown consequences for the populations. Downstream passage issues include direct and indirect mortality, stress, and disorientation during turbine or spillway passage, and delayed migration. There are unknown consequences for the populations as a result of existing downstream passage issues.

1. Introduction

1.1 Background

The Mactaquac Generating Station (MGS) was built in the late 1960s approximately 20km upstream of Fredericton, New Brunswick (NB) in the Saint John River. Alkali-aggregate reactions are causing expansion of the concrete used to build the dam. As a result, the MGS is projected to reach the end of its service life by 2030; for this reason, the concrete structures must be replaced or removed (New Brunswick Power Corporation 2014). In 2016, NB Power announced a decision to rebuild the MGS to its useful service life by 2030, referred to as *Life Achievement*. The Mactaquac Aquatic Ecosystem Study (MAES) which began in 2014 as a whole-river ecosystem study as part of the Mactaquac Life Achievement project, including fish passage considerations evolved in 2017 to also consider fish passage under the *Life Achievement* option.

1.2 Objective

The importance of fish passage at dams has long been recognized, but has not often been adequately addressed (e.g., Mallen-Cooper and Brand 2007). Where fish passage has been considered, often only high value species such as salmonids in the northern hemisphere, are targeted for upstream passage and monitoring (Thiem et al. 2013). Downstream passage typically occurs through the turbines or over the spillway, but some bypass systems exist (EPRI 2002). Dams also delay timing of fish migrations which depend on an evolved linkage to optimal environments (e.g., temperature and flow), and physiological conditions (e.g., smoltification in salmonids; Schilt 2007). The objective of this *Fish Passage at Tobique-Narrows, Beechwood, and Mactaquac Hydropower Generating facilities in the Saint John River System, New Brunswick* report is to describe the existing dam structures and fish passage facilities, as well as the operation of those fish passage facilities. The report will also describe the current knowledge of fish passage on the Saint John River to serve as a reference point to guide future fish passage research and to effectively and accurately evaluate fish passage success in the system. The report is one in a series in support of decisions for fish passage for the Mactaquac Project (NB Power 2016) and the complete river ecosystem.

1.3 Scope

The Saint John River has over 200 dams or water control structures scattered throughout its watershed (Kidd & Luiker, 2011). The majority of these structures are small, often derelict, originally built to drive mills or aid in log driving, and are no longer serving their original purpose (Kidd et al. 2010). Small structures can disrupt fish migrations; for example, 52% of the Williamette Basin is obstructed by 44 dams (Kuby et al. 2005), and dam removal in the Penobscot River increased fish community connectivity (Watson et al. 2018). However, characterization of the impacts of small dams or water control structures on the Saint John River is beyond the scope of this report.

This report describes the configuration of the Tobique-Narrows, Beechwood, and MGS facilities with an emphasis on fish passage structures and operations. What exists for fish capture data from each facility's fish passage structures are presented and trends discussed? Where possible, the data are used to assess fish passage. Fish passage efficiency and survival estimates based on telemetry and mark-recapture studies conducted on the Saint John River are summarized along with miscellaneous studies that have either assessed aspects of fish passage or delayed migration associated with the three hydropower facilities and their head ponds.

Most of the available data and past research activities associated with fish passage on the Saint John River focuses on Atlantic Salmon (*Salmo salar*). The studies provide insight into passage during different life history stages of the Atlantic Salmon and we follow the stages as described by Aas et al. (2011): upstream migrating adults that are returning from the sea in summer and fall; post-spawning adults known as "kelts" that migrating downstream in fall, winter, and spring; and, juveniles known as "parr" that are transitioning from life in fresh water to "smolts" which are migrating downstream to the sea.

2. Description of Hydropower Facilities and Dams in the Saint John River System

The Saint John River Watershed contains 11 operational hydropower facilities of which nine are located in New Brunswick and two in the State of Maine (Fig 2-1; Table 2-1). Three of the hydropower facilities are situated on the main stem of the Saint John River (MGS, Beechwood and Grand Falls; Fig 2-1). The Tobique-Narrows and Sisson facilities are located on the Tobique River, and the Hargrove Dam is on Monquart Stream. The Tinker and Caribou dams are on the Aroostook River; the Squapan Dam is on the Squapan River, a tributary of the Aroostook River (Fig 2-1, Table 2-1). Of these, the NB Power facilities considered in this report include, Tobique-Narrows, Beechwood, and MGS.

The Grand Falls facility and dam, the uppermost of the mainstem dams, was built on a natural barrier to fish passage (waterfall) that has historically defined the extent to which diadromous fish were able to ascend during their upstream migration (Curry 2007). The Grand Falls facility is not considered to have impeded upstream fish migrations. The hydropower facilities upstream of Grand Falls including the Madawaska Hydropower facility and dam on the Madawaska River, and the Second Falls Dam on the Green River (Fig 2-1) do not have upstream passage structures. These structures may represent barriers to local fish migrations such as the potamodromous White Sucker. The Sisson, Squapan, and Hargrove dams form complete barriers to upstream fish migration on the Tobique and Squapan rivers, and the Monquart Stream (Table 2-1). The Tinker and Caribou dams provide upstream fish passage (Table 2-1) though analysis of these dams is outside the scope of this report.

2.1 Tobique-Narrows

2.1.1 Background

The Tobique-Narrows hydropower generating station is located about 30 km upriver from the Beechwood facility and about 170 km from the MGS. The Tobique-Narrows facility was built in response to the need for electricity during the economic boom following the Second World War. Construction of the dam began in 1950 and the facility was completed three years later. Due to tendency of water levels to be low in late summer in this region, four storage lakes were built in the

Sisson (1953), Trousers (1952), Long (1952), and Serpentine (1953) sub-watersheds during the main dam's construction.

2.1.2 The Dam

The Tobique-Narrows facility is a concrete, gravity wing wall construction. The dam measures 6 m high and the dam's crest runs 244 m across the Tobique River. It has two Kaplan turbines which were both activated in 1953. The opening of the draft tube is 2 m high from the base of the dam.

2.1.3 Intake Structure

The generating system was built with a concrete gravity intake structure located 8 m off the bottom of the river. Two vertical lift gates measuring 5.2 m wide by 6.1 m high regulate water flow. A steel conduit encased penstock delivers water to each turbine. Conduits are 29.3 m long with a diameter of 4.6 m.

2.1.4 Spillway

The spillway is a concrete gravity structure. There are four vertical lift sluice gates and a single vertical lift gate for regulating overflow. The sluice gates are 12.2 m wide and 8.8 m high while the vertical lift gate is 4.9 m wide and 4.9 m high. The total discharge capacity for the spillway is 2,605 m^3/s.

2.1.5 Capacity

The capacity of the Tobique-Narrows Generating Station is 20 MW (megawatts), generated from the two Kaplan turbines (225 rpm). The total plant discharge capacity is 127.5 m^3/s.

2.1.6 Reservoir

Water level of the Tobique-Narrows head pond varies in volume because it is affected by annual and seasonal precipitation, evaporation, and snow melt rates, but the average headpond elevation level is measured as 95.5 m deep. During dry periods, discharge from water storage lakes (Sisson, Trousers, Long, and Serpentine) maintains water levels in the headpond. The hydraulic head, or distance measured between the water level upstream of the facility and the water level downstream of the dam is 21.5 m, and the tailrace depth during full capacity is 12 m. The total surface area of the headpond is typically 4.15 km^2. NB Power estimates that the useful storage volume (measured as the volume water from the average water level elevation to bottom of the intake structure) of the reservoir is 7.9×10^6 m^3. Total storage capacity of the reservoir is 2.0×10^7 m^3 (AMEC 2005). As it is a run of the river facility, the storage capacity of the Tobique-Narrows reservoir is limited.

2.2 Beechwood

2.2.1 Background

The Beechwood facility is located in Victoria County, about 135 kilometers upriver from the MGS and 30 km downstream of TN. Construction at the Beechwood site started in 1955 to meet growing power demands. In the fall of 1957, two of the Kaplan turbines came online. In March of 1962, a third turbine was activated bringing the dam to its intended capacity.

2.2.2 The Dam

The Beechwood dam is an earth filled embankment dam consisting of compacted earth and crushed rock with a clay core. The dam is 18 m high and spans 487 m across the Saint John River. The opening of the draft tube is 7.7 m high from the base of the dam.

2.2.3 Intake Structure

The Beechwood dam is built with a concrete, gravity intake structure. It is located at a depth of 2 m above the river bottom, rising to 3.2 m, and regulated by 3 vertical lift control gates for each turbine unit (9 control gates in total). The gates are 4.9 m wide and 11.6 m high. The concrete conduit is rectangular in shape (4.7 m wide and 10.1 m high) until it enters the scroll case; it is 14.6 m in length from the intake gate to the centerline of the unit where it is integrated with the powerhouse.

2.2.4 Spillway

The Beechwood spillway is a concrete gravity structure. Nine vertical lift sluice gates and two vertical lift gates regulate the flow of water. The sluice gates are 15.2 m wide and 1.8 m high, while the vertical gates measure 6.4 m wide and 7.6 m high. The spillway has a maximum discharge capacity of 9,910 m^3/s.

2.2.5 Capacity

Three Kaplan turbines (112.5 rpm) operate at Beechwood. When working at full capacity, the station can generate 112 MW of electricity. The total plant discharge capacity is 850 m^3/s.

2.2.6 Reservoir

Under typical conditions, the elevation of the Beechwood headpond is 74 m and the surface area is 11.5 km^2. NB Power considers the useful storage volume of the headpond to be 3.26×10^7 m^3, with a total storage capacity of 4.2×10^7 m^3 (Ruggles and Watt 1975). The depth of the tailrace during full capacity is 57.3 m, making the dam's hydraulic head 16.7 m. The storage capacity of the Beechwood reservoir is limited, *i.e.*, it is run of the river system.

2.3 Mactaquac

2.3.1 Background

Development of the MGS began in 1960 with dam construction starting in 1965. In 1968, Turbines 1, 2, and 3 began producing electricity. Another three turbines were installed; Turbine 4 in 1972, Turbine 5 in 1979, and Turbine 6 in 1980. In 1984, the headpond water level was raised 0.9 m (Jessop and Harvie 2003).

2.3.2 The Dam

MGS is a rock filled earthen dam, sealed with clay. The bulk of the dam structure is built of several compressed layers of compacted rock with a clay core. A crushed stone layer reduces erosion of the barrier facing the head pond. The crest of the dam runs 550 m and is 12.2 m wide at the top. The highest point of the MGS facilities is 55 m above the Saint John River. It has six Kaplan turbines. The opening of the draft tube is 6.7 m high from the base of the dam.

2.3.3 Intake Structure

The concrete gravity intake structure is located at a depth of 4 m from the river bottom, with two vertical lift gates per unit (total of 6 intakes and 12 control gates). Each gate is 4.9 m wide and 10.8 m high. A steel conduit encased penstock delivers water to each turbine. The conduit is 73.4 m long with a diameter of 4.6 m.

2.3.4 Spillway

MGS has two spillways both of which are concrete gravity structures. Each spillway has five vertical lift gates, which are raised to release water when necessary. Each of the 10 gates is 13.7 m wide and 16.2 m high with a total discharge capacity of 19,255 m^3/s.

2.3.5 Capacity

With the 6 Kaplan turbines working at full capacity, the MGS can produce 672 MW (112.5 rpm) of electricity. The plant is capable of discharging 2,294 m^3/s.

2.3.6 Reservoir

The size of Mactaquac headpond varies depending on precipitation, snow melt, ice accumulation, and temperature. Normally, the headpond elevation is 40.5 m with a surface area of 88.2 km^2 and useful storage of approximately 2.5×10^8 m^3, with a total storage capacity of 1.3×10^9 m^3. At full capacity, the tailrace depth is 6.4 m, making the dam's hydraulic head 34.1 m.

Table 2-1. Hydropower generation facilities located in the Saint John River system.

Dam	**Owner** (Jurisdiction)	**River**	**Built**	**Head (m)**	**Capacity (MW)**	**Historical Barrier**	**Fish Passage** (US = upstream; DS = downstream)	**References**
Mactaquac	NB Power (NB)	Saint John	1968	34.1	672	No	US: Collection gallery & trucking DS: Not provided	(Carr 2001, NB Power 2014)
Hargrove	Hargrove Hydro (NB)	Monquart	1963	21	0.5	No	US: Complete barrier DS: Not provided	(Smith 1969, NB Power 2015)
Beechwood	NB Power (NB)	Saint John	1957	16.7	115	No	US: Fish elevator DS: Not provided	(NB Power 2014)
Tobique-Narrows	NB Power (NB)	Tobique	1953	21.5	20	No	US: Pool-and-weir fishway DS: Fish bypass structure	(Smith 1969, Carr 2001, NB Power 2014)
Sisson	NB Power (NB)	Tobique	1953 (turbine installed in 1965)	41.0	9	Yes (Natural falls)	US: Complete barrier DS: Not provided	(Smith 1969, Carr 2001, NB Power 2014)
Tinker	Algonquin Power (NB)	Aroostook	1906 (rebuilt 1923)	25.9	34.5	Partial (Natural falls)	US: Fish trap & trucking DS: Not provided	(Warner 1956, Algonquin Power Co. 2016)
Caribou	Algonquin Power (ME)	Aroostook	1890	3.7	0.8	No	US: Fishway DS: Not provided	(Warner 1956, Maine DEP 2010)
Squapan	Algonquin Power (ME)	Squapan (tributary of Aroostook)	1941		1.5	No	US: Complete barrier DS: Not provided	(Maine DEP 2010)
Grand Falls	NB Power (NB)	Saint John	1928	39.9	63	Yes (Natural falls)	US: Complete barrier DS: Not provided	(Carr 2001, NB Power 2014)
Second Falls	City of Edmundston (NB)	Green River	1911 (turbine installed in 1920)	7.5	3	NA	US: Complete barrier DS: Not provided	(Carr 2001, Michaud and Gagnon 2011)
Madawaska	City of Edmundston (NB)	Madawaska	1917 (new turbine installed in 2011)	6.1	5.3 (1.5 Fraser; 3.8 Madawaska)	NA	US: Complete barrier DS: Not provided	(Carr 2001, Michaud and Gagnon 2011)

3. Fish Passage Facilities and Operation at Select Dams in the Saint John River System

Fish passage at the Tobique-Narrows, Beechwood, and MGS facilities have been studied to varying degrees. Each has some facility for upstream passage. Currently, only the Tobique-Narrows facility has a downstream passage structure, *i.e.*, a bypass (see Linnansaari et al. 2015 for various downstream passage technologies); testing of the downstream passage efficiency is currently ongoing. Therefore, the primary downstream migration routes consist of turbine passage and occasionally passage through spillways (if spilling occurs during the migration period of a target species) and the new bypass at Tobique-Narrows. All the three facilities provide opportunity for passing fish migrating upstream, though the fish passage infrastructure was largely built to pass Atlantic Salmon with little regard for the passage of other species (Jessop 1975).

3.1 Tobique-Narrows

Fish passage at the Tobique-Narrows generating station is volitional (free swim) and occurs via a pool and weir fishway. In this fishway, weirs separate a series of pools and each pool is elevated higher than the last. Water flows over the weirs and fish ascend by swimming or jumping (depending on water level) from one pool to the next. Lower water velocities in the pool sections allow fish to rest as needed before continuing their ascent of the fishway (Katopodis 1992).

Fish approaching a dam are often attracted to the highest flows which are typically coming from the draft tubes (Larinier 2002). The Tobique-Narrows fishway entrance is located above the draft tube exits, 3.8 m from the bottom of the dam, where fish enter through a 2 m tall x 0.8 m wide orifice (fixed, concrete) leading to a collection gallery (Smith 1979). In 1999, attraction pumps were added, and attraction flows increased from 0.6 m^3/s to 1.8 m^3/s (NASCO 2015). From the collection gallery, fish navigate 73 pools of the fishway which is 357 m long, 2.4 m wide, and is covered by metal grating (Francis 1984, Marshall et al. 2014). Four larger pools, located at each of four turns in the fishway, allow fish to rest before continuing their ascent (Francis 1984). Water levels in the fishway are maintained at a minimum of 1.5 m by a system of water-control gates and valves (Francis 1984).

From 1953 to 1968 and 1978 to 1980, a wooden fish trap was installed at the upper end of the fishway during the period of Atlantic Salmon migration (mid-May to late November; Smith 1979, Francis 1984). The trap had a floating floor that could be raised for fish identification and counting purposes. Gaps in the fish trap were designed to retain fish the size of 1SW salmon (grilse ~63 cm total length) and larger. The trap was checked daily (more during the run peaks) and salmon were counted before being released above the dam (Smith 1979). In 1981, the wooden trap was replaced by a metal trap and installed in the fourth resting pool, 75 m below the fishway exit (Francis 1984). This trap was fished daily and fish were released to the upstream end of the resting pool (Francis 1984). After 1989, all fish species found in the metal trap were recorded. The fishway operates year-round, 24 hours a day, but it is not monitored outside of the salmon migration period.

Downstream passage has been via spillways, turbines, or the fishway until 2017. The new bypass system guides fish through a 30 cm transport pipe invert, with a drop of 1.83 m to the bottom of a plunge pool. However, it is only 0.61 m from the pope to the typical water level. The plunge pool is oval in shape with dimensions of 9.14 m x 3.66 m x 1.66 m deep. In the plunge pool, fish can be assessed for biological characteristics. A screen at the end of the tank can be opened and fish crowded into a pipe (0.61 m diameter), which runs a horizontal distance of 44.81 m over a slope between 12.3% to 33.6%; emptying near the upstream passage entrance in the tailrace. If fish are to be retained (e.g., broodstock collection), a separate screen allows fish to swim through a 0.91 m wide, open flume leading from the plunge pool to a holding tank (3.05 m in diameter) with a water depth that varies between 0.72 m and 1.05 m deep. Fish can be loaded into transport trucks through a 0.61 m diameter pipe.

3.2 Beechwood

The Beechwood fishway consists of a collection gallery, transportation channel, rest pool, and a skip hoist (elevator) that transports fish to the top of the dam (see diagrams in Ingram 1981). The collection gallery is located over the draft tube exits and has six openings (fixed, concrete); only two are open at a time (Ingram 1981). During the Atlantic Salmon migration period, V-shaped, triangular entrance openings (1.8 m × 0.46 m; apex pointed down) are placed in entrance #3 and #6 and when possible, maintained at an average depth of 0.9 m below the tailrace level. The apexes of the V-shaped passages are directed towards the water flow to discourage fish from returning downstream (Ingram 1981). A weir was placed in entrance #1 of the collection gallery to attract and separate Gaspereau (Alewife and Blueback Herring) and other species of fish from Atlantic Salmon during the early part of the anadromous migration period (Ingram 1981). Gaspereau passage upstream of Beechwood dam has been negligible because the fish collection facilities are unable to begin operating effectively until after the spring freshet has subsided, (late May/early June), and because the fishway is not opened until mid-June to correspond with the first appearance of Atlantic Salmon (Jessop 2001). Depending on water temperature, the peak run of Gaspereau occurs in late May to early June.

The collection gallery contains a channel that leads to a rest pool and the skip hoist. Two, adjustable-vane, v-shaped openings (set at 20 cm) are located between the transportation channel, rest pool, and skip hoist to discourage downstream movement (Ingram 1981). The skip hoist is a solid metal box with sides 30.5 cm high and is separated into 4 parallel compartments for counting purposes. Above 30.5 cm, the skip hoist is screened to allow water to drain which facilitates lifting as well as identification, enumeration, and any necessary sampling. The skip hoist is suspended from metal rails and is lifted by a system of winches and cables (Ruggles 1980, Ingram 1981).

Water is supplied to the fishway at a rate of 1.55 m^3/s via the headpond and an auxiliary pump (installed in 1962) that extracts water from the tailrace (Ingram 1981). A 30.5 cm pipe delivers water from the headpond to a basin in the skip hoist pool and a 25.4 cm pipe supplies water to a diffuser pit located between entrance #2 and #3 in the collection gallery (Ingram 1981). It is speculated that the diffuser pit system supplies auxiliary water to the fishway structure in order to maintain hydraulic flows. The auxiliary pump supplies water to the basin in the skip hoist pool to increase the attraction flow (Ingram 1981).

Although the system is designed to transport fish automatically, in practice, an operator stops the hoist to identify and enumerate fish prior to releasing the fish into the headpond (Ingram 1981). Typically, four lifts are completed per day (8:30, 11:30, 13:30, 16:30), but during peak runs evening lifts are sometimes required. As the run slows during autumn, only two lifts per day are required (Ingram 1981). Since 1975, the fishway is has not been operated on weekends or holidays, except during peak Atlantic Salmon runs (Ingram 1981; Ross Jones, DFO, personal communication). On days when the skip hoist is not operating, a barrier gate prevents fish from entering the hopper. The fishway is not effective during high water (e.g., freshet) when water levels in the tailrace are above the walls of the water supply and skip hoist pools. As a consequence, the fishway typically operates only after the freshet has subsided in late May or early June (Ingram 1981). In recent years the fishway has begun operation in late June or early July to support early runs of Atlantic Salmon that have been transported upstream of MGS and released near Woodstock, NB. Fishway operations run until late October or early November.

3.3 Mactaquac

The MGS fish collection facility includes a collection gallery, a series of pools that allow fish to be concentrated, sorted, and counted, and a hopper that allows fish to be transferred to tanker trucks that transport fish to release sites upriver or to secondary sorting at the Mactaquac Biodiversity Facility (Ingram 1980) located across the river, just downstream of the MGS fish collection facility. Ingram's (1980) description of the MGS Fish collection facility and secondary sorting facility is summarized in the following paragraphs.

The collection gallery is located over the draft tube exits for Turbines #1, #2, and #3. There are three, 1.8 m wide and three, 0.6 m wide submerged entrance-weirs along on the collection gallery. Entrance-weirs adjust automatically with tailrace level (5.5 m fluctuation) such that an attraction flow of approximately 3.1 m^3/s is maintained (Rob Beaumaster, DFO, personal communication). Water is pumped to a water supply pool that feeds the collection gallery creating attraction flow using two large pumps (maximum 7.3 m^3/s each) and two small pumps (maximum 1.56 m^3/s each) that supply water to the crowder, brail, and hopper pools. The collection gallery leads to the water supply pool and crowder (holding) pool. A mechanized screen (the crowder), as deep and wide as the crowder pool, forces fish into the primary sorting facility. The primary sorting facility consists of two brail pools with movable floors and two hopper pools. Entrance to one brail pool is by a low weir, which creates a small attraction "waterfall" for Atlantic Salmon, effectively excluding all other fish species. Entrance to the other brail pool is by a v-shaped opening. The two brail pools are connected by a second weir that is seldom required. Fish are transferred to the hopper pool by raising the brail pool floor, causing the fish to be dumped through a gate into the hopper. The hopper is then raised, emptied into the tanker truck filled with water, and transferred to the secondary sorting facility located at the Mactaquac Biodiversity Facility (Ingram 1980). During the Gaspereau run, large fish (e.g., Atlantic Salmon) are removed and temporary held until transfer to the sorting facility at the Mactaquac Biodiversity Facility, while the remainder of the hopper load is trucked and released into the Mactaquac headpond (Ross Jones, DFO, personal communication).

The Mactaquac Biodiversity Facility contains a smolt migration channel which attracts a few returning Atlantic Salmon, a secondary sorting facility, as well as a variety of holding pools and hatchery related facilities that are outside the scope of this description and will not be discussed further. The smolt migration channel consists of a series of pools separated by weirs with a fish trap at the top to capture any salmon that make their way up the channel. Fish captured at the dam and the migration channel are released into one of two dumping pools at the secondary sorting facility. Brail floors in the dumping pools are raised to force fish into an inspection area where fish are examined, necessary sampling conducted, and sorted into one of three holding pools. Fish in holding pools can be transferred to tanker trucks for transport to release sites upriver.

4. Fisheries Management and Dams in the Saint John River System

Fisheries management for the Saint John River is a confusing assortment of activities that are shared between Fisheries and Oceans Canada (DFO) for diadromous species and NB Energy and Resource Development (ERD) for all other species. No management programs are currently in place for the river or individual species, however, there is active management activities for Atlantic Salmon, Gaspereau (Blueback Herring and Alewife), Atlantic Sturgeon, and American Eel. These include upstream passage processes for salmon and gaspereau at MGS, Beechwood, and TN. Passage activities are focused on Atlantic Salmon, and the passage facilities at the Tobique-Narrows, Beechwood, and MGS were built to pass this social and economic important species (Jessop 1975). However, since Tobique-Narrows was constructed over 60 years ago, the status of the Atlantic Salmon has declined dramatically as has the fish community in general. Gaspereau populations have increased and varied dramatically, particularly since the species have been managed by trucking them past the MGS. New species have been introduced such as Muskellunge and Rainbow Trout. These changes have concurrently instigated changes in management activities.
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4.1 Atlantic Salmon

The socio-economic importance of Atlantic Salmon and the dramatic decline of the Saint John River population since the start of hydropower development in the 1950s has resulted in a suite of changes in management actions over the years. It is beyond scope of this report to catalogue each change at each facility. Rather this report presents a general timeline of significant changes to management of the Atlantic Salmon population and fisheries providing a general description of current practices.

1954 – Tobique-Narrows was completed and its fishway was operational. First count of Atlantic Salmon returns to the area above Tobique-Narrows facility.

1957 – Beechwood was completed and its fishway was (mostly) operational. First count of Atlantic Salmon returns to the area above Beechwood facility.

1959-1962 – Some Atlantic Salmon collected at Beechwood were transported to the Tobique River (Smith 1979).

1963-1966 – Some Atlantic Salmon collected at Beechwood were retained as broodstock to mitigate the effect of the proposed MGS on salmon populations (Smith 1979).

1967 – MGS forms a complete barrier to migrating fish. A temporary fishway was installed and trap nets in the MGS tailrace were used to collect Atlantic Salmon which were transported to upstream release sites or retained as broodstock (Smith 1979).

1968 – MGS completed and fish collection facilities operational. First count of Atlantic Salmon returns to the area above MGS. Atlantic Salmon trucked to various upstream release sites (e.g., Woodstock, Arrostook and upstream of Tobique-Narrows) or retained as broodstock (Smith 1979).

1972-1980 –Commercial fishery for Atlantic Salmon closed for most of Salmon Fishing Area (SFA) 23 due to declining population (Pool and Stuart 1988).

1981-1983 – Limited (small quotas) re-opening of commercial fishery for Atlantic Salmon in SFA 23 (Pool and Stuart 1988).

1984 – Commercial fishery for Atlantic Salmon closed for entire SFA 23 due to declining population (Pool and Stuart 1988).

1998 – Complete closure of Aboriginal and recreational fishery (DFO 2008).

2001 – Captive-reared broodstock program begins with the first collection of more than 2,500 out-migrating juvenile salmon from the Tobique River (Jones et al. 2004).

2005-present – Atlantic Salmon captured at MGS before the end of June are either kept for broodstock or released at a site near Perth-Andover (instead of upstream of Tobique-Narrows), and salmon captured at MGS after June are released at a site just upriver of Woodstock where they can migrate upstream on their own. This follows the opinion of the existence of early and late run salmon migrating to these different locations (DFO 2008). There have been exceptions. For example, the Tobique-Narrows fishway was closed in 2009, and in 2010 salmon captured during the fall run at Beechwood were transported to the Tobique River (Ross Jones, DFO, personal communication). Atlantic Salmon are no longer transported to the Aroostook River, though some enter via the fishway at Tinker dam (Jones et al. 2014).

2006-2010 – Retention of returning adult Atlantic Salmon as broodstock was reduced and focused on early run fish known as the Serpentine Stock (DFO 2010). Broodstock mostly obtained from captive-reared program, primarily using out-migrating juveniles grown to adult (Jones et al. 2014). Returning Atlantic Salmon captured at MGS before the end of June are released at a site near Perth-Andover, and salmon captured at MGS after June are released at a site just upriver of Woodstock where they can migrate upstream on their own.

2012-present – Broodstock are obtained from captive-rearing program only, primarily using juveniles grown to adult (Jones et al. 2014). Returning Atlantic Salmon captured at MGS before the end of June are released at a site near Perth-Andover, and salmon captured at MGS after June are released at a site just upriver of Woodstock where they can migrate upstream on their own.

2017 – Tobique-Narrows downstream bypass facility becomes operational, but is still in a testing phase.

General Notes on Management Activities:

Prior to 2006, the management actions included releasing sea-run Atlantic Salmon captured at MGS in the Tobique River, Aroostook River, and occasionally other tributaries to the Saint John River (see Ingram 1980). During this period, adult salmon were also detected passing dams in the downstream direction and this was presumed to be a result of being transported farther upriver than their natal stream (DFO unpublished data).

The current management objectives for AS are to conserve and restore a declining resource through the captive rearing program (DFO 2015a), allow sea-run adults to freely migrate to their natal streams, and mitigate the negative effects of hydropower facilities on fish passage (especially in the downstream direction).

The captive-rearing program now collects out-migrating juveniles from the Tobique River and raises them to maturity at the Mactaquac Biodiversity Facility. As adults, most of these captive-reared fish are released back into the Tobique River to spawn. The motivation is an attempt to remove the mortality associated with passing hydropower facilities during migration and the mortality associated with the marine phase of their life history (DFO 2015b). The captive rearing program also provides fish for broodstock purposes, which reduces, and in some years eliminates, the need to retain sea-run adults (Jones et al. 2014). Broodstock are used to spawn and grow Salmon in captivity for river release (stocking) to compensate for production losses upriver of the dam.

Currently, there are no downstream passage facilities at either Beechwood or MGS facilities and passage occurs via the turbines or spillways. In the fall of 2017, downstream passage was installed at Tobique-Narrows. There are currently no downstream passage management actions.

4.2 Other Species

Fish species other than Atlantic Salmon are mostly unmanaged for passage throughout the Saint John River. At the Tobique-Narrows fishway and Beechwood fish-lift, most species are passed into the headpond; however, there are exceptions that have varied over time as noted below. At the MGS fish collection facilities, only Atlantic Salmon and Gaspereau are actively managed; however, species defined by DFO as “invasive” are destroyed when captured, this includes Muskellunge and Rainbow Trout. Other species may be incidentally released to Mactaquac headpond with Gaspereau transportation.

4.2.1 Gaspereau

After the MGS was constructed, the all Gaspereau were trucked upstream. The numbers at the MGS fishtrap and presumably the population size increased rapidly and this required a change in management to regarding passage of Gaspereau and to clear the fish collection facilities so that Atlantic Salmon did not experience unacceptable delays (DFO 2001). Prior to 1995, a period of active management resulted in a wide variation in escapement (Jessop 1990a, 2001). Since 1995, a target 800,000 Alewife and 200,000 Blueback Herring are passed over the dam each spring while remaining fish are harvested commercially to offset the trap and trucking costs (DFO 2001, Jessop 2001). Due to the density of Gaspereau during the peak of their run (late May – early June), incidental transport of other species (e.g., American Eel and Striped Bass) over the dam has occurred, but in relatively low frequency of occurrence (Smith 1979). Gaspereau are released in a cove a short distance upstream of MGS (Smith 1979).

4.2.2 Sea Lamprey

During 1953-6, Sea Lamprey were removed from the Tobique-Narrows fishway and destroyed (Smith 1979). Similarly, Sea Lamprey were removed from the Beechwood fish-lift and destroyed during 1957-9. In 1960, concerns about injury or mortality to Atlantic Salmon as a result of physical sorting, Sea Lamprey being passed into the Beechwood headpond, though the run had already been severely reduced (Smith 1979). From 1968-71 at the MGS, Sea Lamprey were removed from the collection facilities and destroyed, except for inadvertent releases with other species (Smith 1979).

The policy of culling Sea Lamprey may have been due to the perception that they have negative impacts on valued commercial and sport fisheries. Indeed, Sea Lamprey have caused considerable ecological damage in the Laurentian Great Lakes where they are an invasive species (Smith and Tibbles 1980). However, Sea Lamprey are native to the Saint John River and there is considerable evidence that Sea Lampreys benefit freshwater habitat and are an important part of healthy rivers (Kircheis 2004). Currently, there is no management/monitoring strategy for Sea Lamprey.

4.2.3 Muskellunge

From 1970-9, 6,250 Muskellunge were stocked in Lac Frontier, Quebec, a headwater lake located on the Northwest Branch of the Saint John River (Stocek et al. 1999). In the intervening 35 years, their range has steadily expanded downstream to the main-stem Saint John River (Stocek et al. 1999). Muskellunge are now captured at the MGS (312 since 1990) and Beechwood (80 since 1990) fish passage facilities, but the species hasn't been reported at the Tobique-Narrows Fishway (DFO, unpublished data). In 2015, young-of-the-year Muskellunge were found near Fredericton indicating reproductive success downstream of the MGS (K. Zelman et al., UNB, pers. comm.).

Fisheries and Oceans Canada (DFO) considers muskellunge an invasive species in the Saint John River. Muskellunge captured at the MGS are euthanized and specimens >100 cm in length are provided for research to the NB ERD (Kidd et al. 2010). The Beechwood fishway is operated exclusively by NB Power, where they encounter about one dozen individual Muskellunge annually. These fish are transported over the dam without being handled (Ross Jones, DFO, pers. comm.). Muskellunge have not been encountered at the Tobique fishway; however, if encountered, the fish would be euthanized. Some Muskellunge have also been tagged and released for research purposes (e.g., Canadian Rivers Institute, MuskiesNB) (Ross Jones, DFO pers. comm.).

4.2.4 Rainbow Trout

Rainbow Trout were introduced to New Brunswick in 1900 and have established self-sustaining populations (Carr 2006). In the Saint John River watershed, early reports found Rainbow trout in the Shikatehawk and Becaguimec Rivers (Carr 2006), but the species are now widely distributed between Grand Falls and the Mactaquac Reservoir (R. Curry, unpublished data). Rainbow Trout are encountered rarely at the Tobique-Narrows fishway (3 since 1990), infrequently at Beechwood (35 since 1990), and at MGS (16 since 1990; however, Rainbow trout are removed from the DFO Migration Chanel each year; DFO unpublished data). Rainbow Trout captured at the Tobique-Narrows, Beechwood, and MGS fish collection facilities on the Saint John River are considered invasive and euthanized.

5. Trends in Captures and Abundance at Select Dams in the Saint John River System

Since the construction of Tobique-Narrows, Beechwood, and MGS facilities, fish capture records have been kept with some exceptions. The data is used to inform fisheries management actions and monitoring programs, particularly for Atlantic Salmon. Below, fish capture records are summarized and trends in abundance are provided for select species. Additionally, and where data is available, fish capture records are evaluated to assess if hypothesized impacts of the hydropower development have occurred.

5.1 Atlantic Salmon

Tobique-Narrows, Beechwood, and MGS fishways offer the most complete record of fish capture for Atlantic Salmon (*Salmo salar*). However, in some cases fish capture records may not reflect true escapement, i.e., the number of fish released upstream to spawn or downstream migrating to the sea. Due to the importance of past Aboriginal, commercial, and recreational Atlantic Salmon fisheries, fish were often trucked from their point of capture (MGS or Beechwood) to some point further upstream to sustain fisheries and achieve spawning targets. For example, the number of salmon counted at the Tobique-Narrows fishway may not indicate escapement upstream of the dam after 1956 because in some years a proportion of salmon captured at Beechwood and MGS were transported above Tobique-Narrows (Smith 1979). Similarly, after MGS was completed in 1968 (and in 1967 when construction of the dam obstructed the river), a proportion of salmon captured at the MGS were transported above Beechwood and TN dams (to the Tobique River). As a result, the fish capture records do not indicate escapement above Tobique-Narrows and Beechwood for most years. A summary of the number of Atlantic Salmon captured at the Tobique-Narrows, Beechwood, and MGS fishways is presented in Figure 5-1.

The overall long-term trend in Atlantic Salmon fish capture records at all facilities is in decline. There are a myriad of potential factors contributing to declining Atlantic Salmon returns in the

Saint John River, including at-sea mortality/low return rates, overfishing, point source pollution (e.g., pulp mills), non-point source pollution (e.g., agriculture), pesticide use, aquaculture, and hydropower development. For example, there was extensive spraying of the pesticide, dichloro-diphenyl-trichloroethane (DDT), for spruce budworm in the Tobique River watershed in 1953 and 1955-8 which appeared to cause high juvenile salmon mortality, i.e., low juvenile densities in rearing areas (Elson 1967). Elson (1967) correlated the low numbers of juveniles for each spray year to the low adult returns observed four years later (1957 and 1959-62) at the Tobique-Narrows facility, but the construction of Beechwood during this period was acknowledged as an additional factor (Figure 5-1).

Six years after Beechwood was completed, Atlantic Salmon numbers in the Tobique River rebounded to levels observed prior to the construction the facility (Figure 5-1). This lasted for three years after which construction of MGS began and runs to the Tobique declined; however, the practice of trucking salmon captured at MGS and Beechwood to upstream of Tobique may account for this decline in numbers. At MGS, adult salmon returns increased for 10 years after construction of the facility in 1967, corresponding to a period of intense stocking with hatchery produced juveniles (Francis 1980) and the closure of the commercial fishery in 1972 (Pool and Stuart 1988). Salmon returns to the MGS were stable in the late 1980s and early 1990s, but starting in 1993, a concerning decline in returns began and has continued (Figure 5-1). The causes of this decline are uncertain.

5.1.1 Delayed Migration

Hydropower facilities may delay the upstream migration of salmon. Thorstad et al. (2008) indicates that prolonged delays in upstream migration may prevent salmon from reaching intended spawning areas resulting in decreased reproductive success. In the Loire River and tributaries, delayed migration increases the time that migrating salmon spend in the lower river where they are exposed to higher water temperatures for greater time periods which impacted their reproductive success (Baisez et al. 2011).

Tobique-Narrows fish capture records provide evidence of a delayed migration in the Saint John River as Beechwood and then MGS came online (Figure 5-2). After construction of the MGS, no salmon returned to the Tobique in May and few returned in June. Moreover, the proportion of salmon returning later in the season (September and October) has increased with the construction of Beechwood and MGS facilities. A 7-day moving average of counts at Beechwood and MGS shows a similar trend in later salmon returns to the river (Figure 5-3) was calculated to smooth the data. The results are presented in Figure 5-3. Early season (May and June) returns at Beechwood have been non-existent in recent years because early arriving salmon are transported and released upstream of Beechwood (Perth-Andover). The mid-September run peak in salmon numbers observed prior to MGS construction appears to have been reduced and shifted into October.

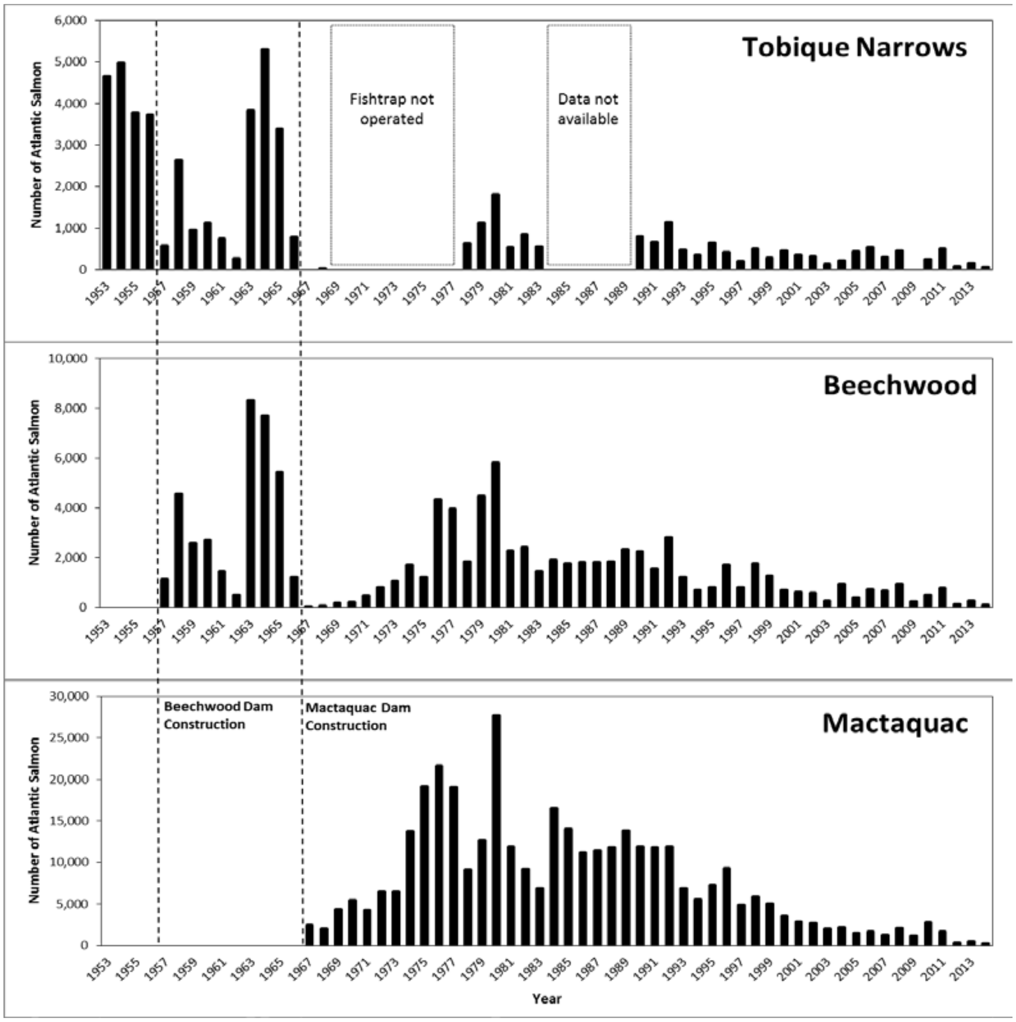

Figure 5-1. Number of Atlantic Salmon counted at Tobique-Narrows, Beechwood, and Mactaquac Generating Station fishways, 1953 to 2014.

Notes:

- The scale is different among panels.
- The number of salmon counted at the Tobique-Narrows fishway does not indicate escapement above the dam after 1956 because some in some years a proportion of salmon captured at Beechwood and MGS facilities were transported above the Tobique-Narrows facility directly.
- Similarly, a proportion of salmon captured at the MGS were transported above the Beechwood facility (to the Tobique River). The Tobique-Narrows Fishway was not operated in 2009.

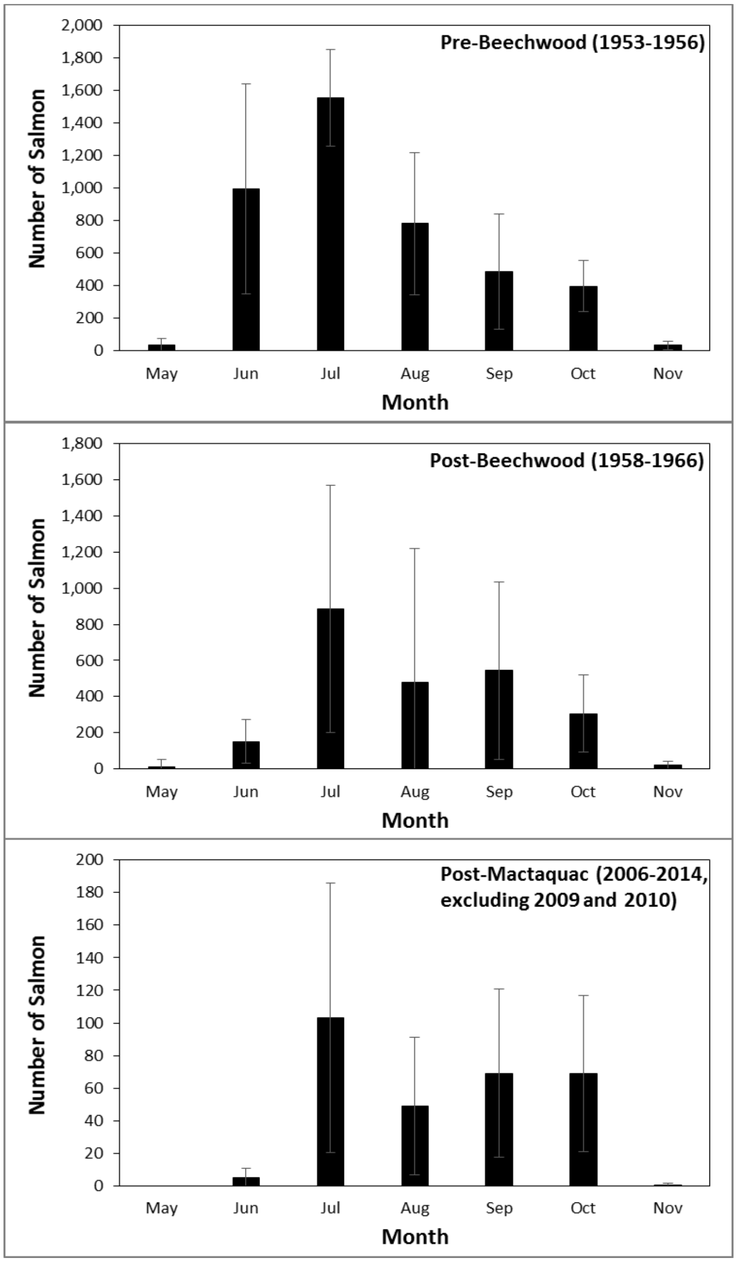

Figure 5-2. Timing of the Atlantic Salmon run (counts) to the Tobique-Narrows fishway before construction of Beechwood facility (1953 to 1956), after construction of Beechwood facility (1958 to 1966), and after construction of Mactaquac Generating Station facility (2006-2014).

Notes:

- The scale is different among panels.
- Error bars indicate standard deviation.
- The number of salmon counted from 1959 to 1966 was adjusted for trucked fish and broodstock removals using proportion of fish passed over Beechwood that ascended the Tobique-Narrows Fishway.
- The 2009 and 2010 data were excluded because salmon were trucked upstream of the Tobique-Narrows facility.

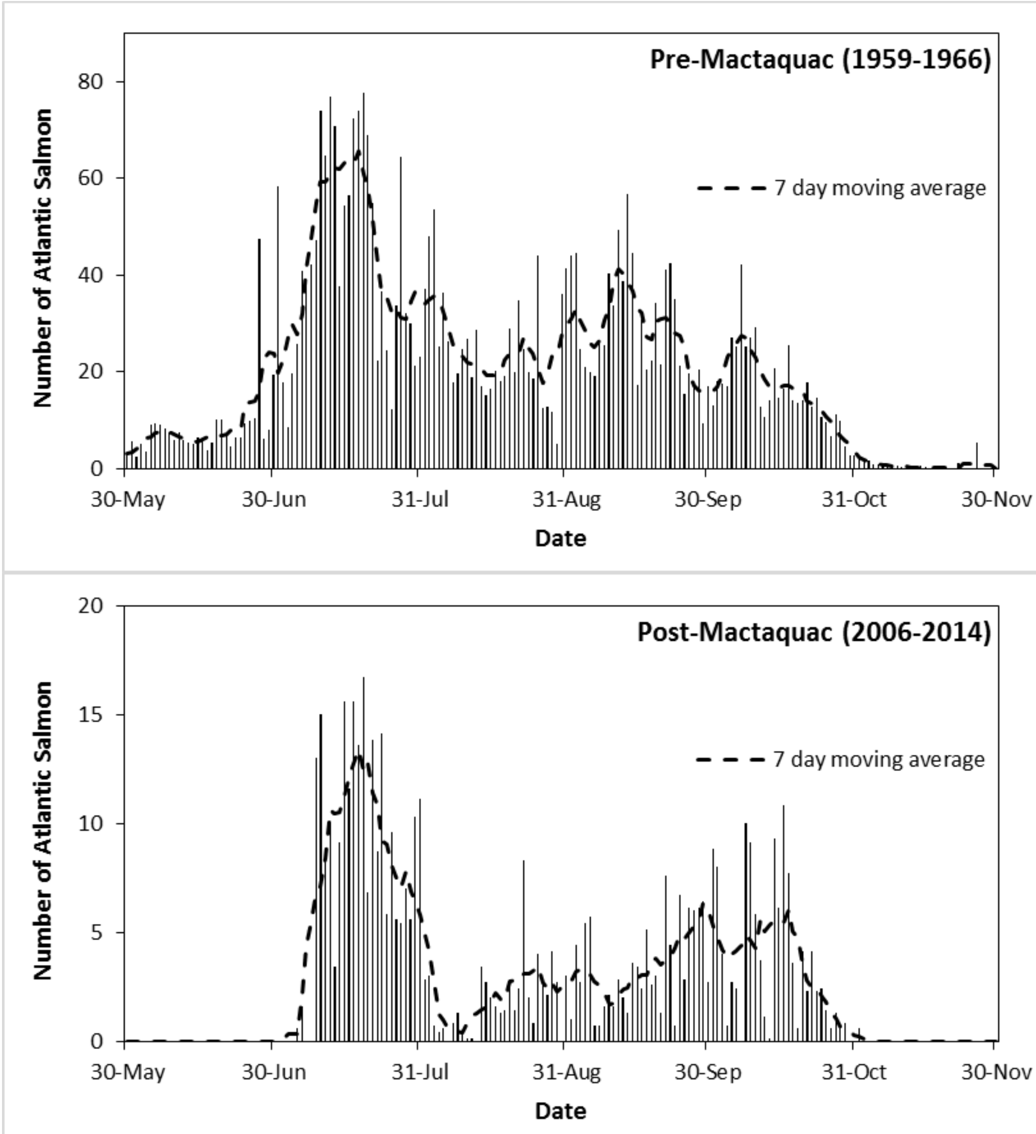

Figure 5-3. Timing of the Atlantic Salmon run (counts) to the Beechwood fishway before (1958 to 1966) and after construction of Mactaquac Generating Station facility (2006-2014).

Notes:

- The scale is different among panels.
- The 2009 and 2010 data were excluded because salmon were trucked upstream of the Tobique-Narrows facility.

5.2 Gaspereau (Alewife and Blueback Herring)

Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalls*; referred to collectively as Gaspereau or River Herring) populations were present in the river and assumed to be restricted downstream of the MGS location (Munkittrick et al. 2011). The Gaspereau numbers that were reported at Beechwood (Figure 5-4) rose from 47 in 1958 to 22,000 in 1966. After 2 years of low returns likely due to construction of MGS, Gaspereau numbers at Beechwood peaked at 60,000 in

1971 before declining to 100s of fish in the 1980s and 10s of fish in the 1990s with no fish being recorded after 2000. That decline hasn't been explained, despite maintaining annual escapement targets above MGS. After the MGS was completed, Gaspereau numbers in the fishtrap rose from 22,000 in 1969 to 4.4 million in 1978 and 6.4 million in 1988 (Figure 5-4). Gaspereau were so abundant that, at times, they hindered the effectiveness of the MGS fishway for passing Atlantic Salmon. Thus, a commercial harvest was initiated at the dam in 1974 in an effort to clear the fishway of Gaspereau and to limit subsequent returns (Jessop 2001). The large variation in Gaspereau returns to MGS from 1974 to 1994 was partially a result of management, i.e., changing escapement targets, and natural variability (Jessop 2001). A target escapement of 800,000 Alewife and 200,000 Blueback Herring was established in 1995 which was assumed to produce enough Gaspereau to maintain the commercial fishery while not overloading the fishway and interfering with Atlantic Salmon collection (Jessop 2001). Data from 2000 to 2014 was not available for the current analysis.

5.3 American Shad

Anecdotal records from the Tobique-Narrows fishway indicate that an American Shad run existed prior to the construction of Beechwood and MGS facilities. However, shad counts were not recorded (Smith 1979) and the fish did not readily use the fishway to pass the dam (Ruggles and Watt 1975). Smith (1979) indicated that shad runs to the Tobique in 1953 to 1971 had been either eliminated or greatly reduced after the construction of Beechwood and MGS facilities. After Beechwood was completed and the fishway became fully operational, a high of 1,490 shad were recorded in 1960 (Figure 5-5). Numbers declined to a few hundred fish in years following 1960, and only a few fish returned after completion of MGS (<20 per year; Figure 5-5). Similarly, shad recorded at the MGS fishway declined from 38,838 in 1968 to 7,363 in 1973 (Ruggles and Watt 1975; Figure 5-5). Under the Maritime Province Fisheries Regulations, shad captured as bycatch may be retained by the commercial Gaspereau fishery (Chaput and Bradford 2003). When the commercial fishery for Gaspereau began at MGS in 1974, the number of returning shad declined further. Difficulties obtaining independent data for both the number of shad released over the MGS and the number of shad retained by the Gaspereau fishery makes any assessment of the current number of shad returning to the MGS difficult. In recent years (2003 to 2009), estimates of shad released over the dam ranged from 12 to 272 fish (Figure 5-5). From 2010 to 2014 estimated shad released over the dam plus shad retained by the commercial Gaspereau fishery ranged from 123 to 645 fish (Figure 5-5). Fish capture records and information from the Gaspereau fishery suggest that a small shad run continues to return to the MGS each year, but returns have been reduced by 2 orders of magnitude since the late 1950s.

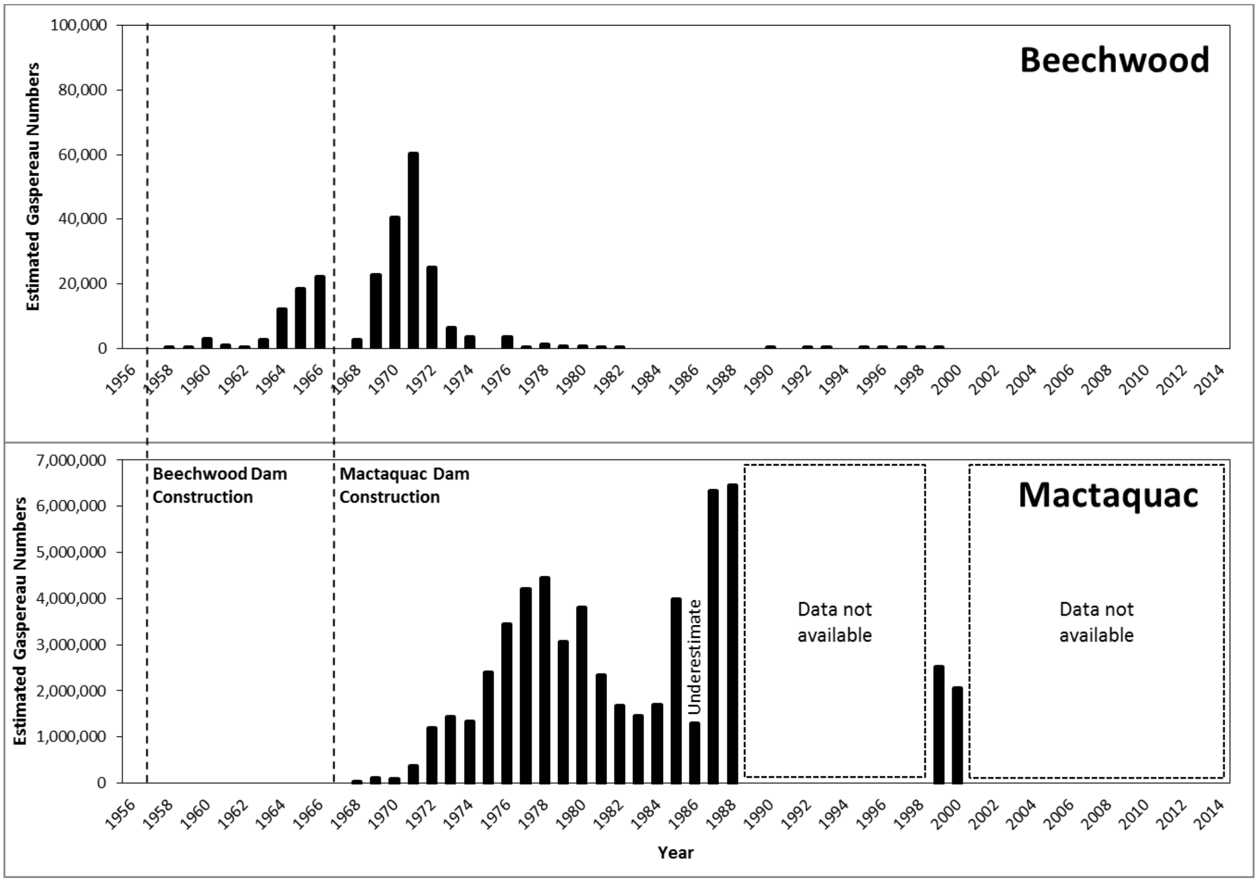

Figure 5-4. Gaspereau (Alewife and Blueback Herring) estimates (numbers) at Beechwood and Mactaquac Generating Station fishways, 1957 to 2014.

Notes:

- The scale is different among panels.
- Gaspereau numbers are estimates. Gaspereau numbers at MGS after 1974 are estimated from commercial catch (in tons) and escapement over the dam.
- See Jessop (2001) for graphical representation of 1989 to 1998 data. Data from 2001 to 2014 was not available. Jessop (2001) indicated that the 1986 Gaspereau run was underestimated.

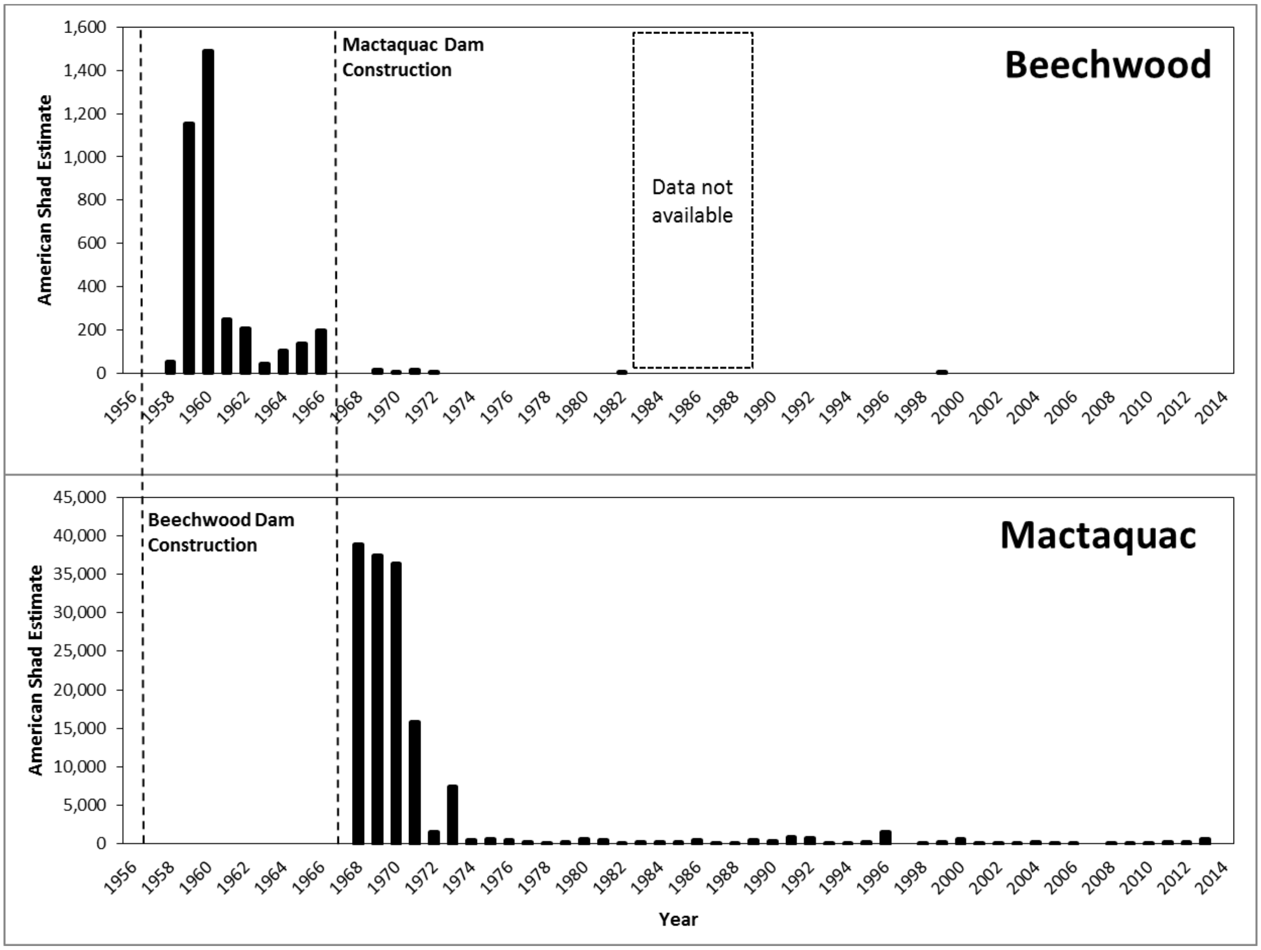

Figure 5-5. Estimated number of American Shad at Beechwood and Mactaquac Generating Station fishways, 1957 to 2013.

Notes:

- The scale is different among panels.
- Shad numbers are estimates of incidental releases with Gaspereau. Shad numbers from 1974 to 2009 reflect escapement over the dam. Shad numbers from 2010 to 2014 reflect escapement over the dam plus those retained as bycatch. See Ingram 1985 and 1990 for Shad retained as bycatch of the Gaspereau fishery (1977-1988). Data was not available for 1983 to 1989 at the Beechwood fishway and in 2007 at the MGS fishway.

5.4 Striped Bass

Striped Bass (*Morone saxatilis*) occurred upriver of Beechwood and potentially to Grand Falls (Munkittrick et al. 2011). Striped Bass were recorded at the Beechwood fishway prior to, and for a few years after the construction of MGS (Figure 5-6). Striped Bass sporadically enter the MGS fish lift, but they are only passed over the dam incidentally with Gaspereau. They are otherwise transferred to the sorting facility at the Mactaquac Biodiversity Facility, and subsequently released downstream. There is no record of Striped Bass using the Tobique-Narrows fishway.

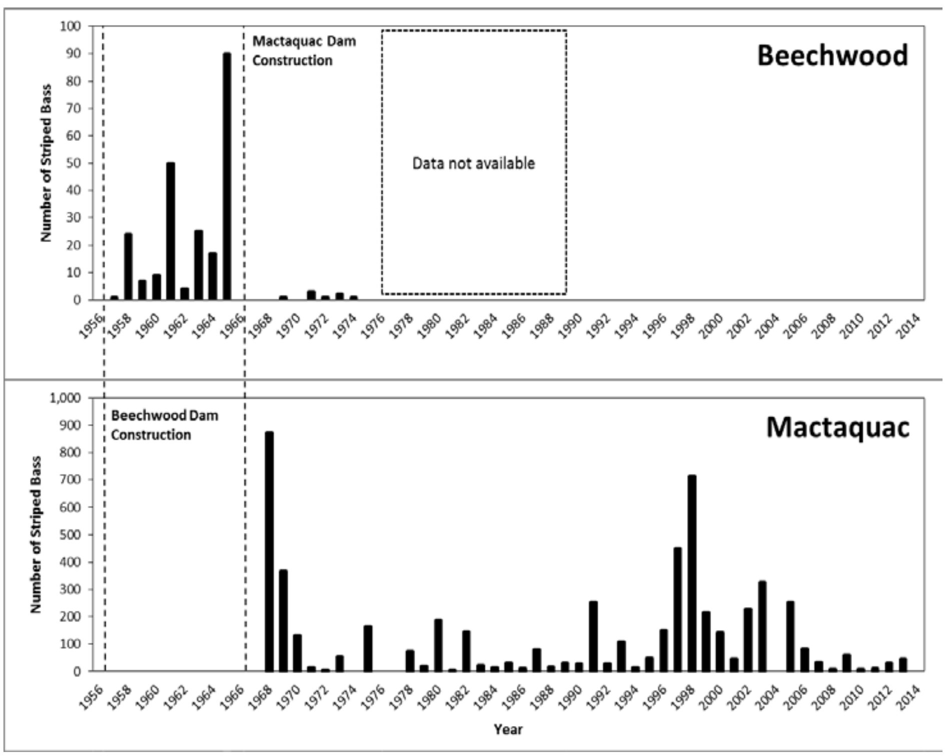

Figure 5-6. Number of Striped Bass at Beechwood and Mactaquac Generating Station fishways, 1957 to 2013.

Notes:

- The scale is different among panels.
- Data was not available for 1977 to 1989 at the Beechwood fishway and for 2004 at the MGS fishway.
- The Striped Bass data presented here is not intended and should not be used to infer trends in Striped Bass population.
- For the Beechwood fishway, it is assumed that counted Striped bass were passed upstream. At MGS, Striped Bass were only passed upstream incidentally with Gaspereau.

5.5 Sea Lamprey

After the construction of the Tobique-Narrows facility in 1953, Sea Lamprey (*Petromyzon marinus*) using the Tobique-Narrows fishway were removed and destroyed (Smith 1979). The actual counts of lampreys removed were not recorded; however, Smith (1979) reported that several thousands were removed and destroyed each year from 1953-6. When the fishway at Beechwood Dam became operational in 1957, lamprey were removed until 1959 and concurrently, they were not observed at the Tobique-Narrows fishway. The removal of lamprey at Beechwood ceased after 1959 (to reduce the chance of injury to Atlantic Salmon). The largest subsequent count at the Tobique-Narrows was 107 Lamprey in 1962. Prior to construction of the MGS facility, the lamprey numbers at Beechwood was variable, ranging from 386 in 1961 to 7,300 in 1964 (Figure 5-7). All lamprey are unable to pass MGS and most were removed from the MGS fishway from 1968 through 1971 (Smith 1979). Ingram (1980) reported that most lamprey were removed from the MGS fishway in the first years of operation, but did not specify what year the practice stopped. No lamprey were observed at Beechwood from 1966 through 1971, and afterwards only single lamprey has been observed. No Lamprey have been recorded at either Beechwood or MGS fishways since 1980 (Figure 5-7); however, occasionally juvenile lamprey are found attached to adult Salmon (Ross Jones, DFO, personal communication).

5.6 American Eel

Smith (1979) indicated that American Eel (*Anguilla rostrata*) used the Tobique-Narrows fishway prior to the construction of Beechwood and MGS facilities, but no counts were made. The reference states both adults and elvers were observed, but no biological data are provided. We assume "adult" refers to yellow eels (reference). Since 1990, only 33 yellow eels have been recorded at the Tobique-Narrows fishway. Prior to 1972, Ingram (1964) and Smith (1979) noted that thousands of yellow eels and elvers used the fishway, but they were not counted. The number of eels (assumed yellow eels) using the Beechwood fishway declined from over 30,000 in 1972 to 882 in 1982 (Ingram 1981, 1987; Figure 5-8). In the past 15 years, no more than 4 eels have been reported in each year. Eels were observed at the MGS fishway, but they were not counted because they were able to pass through the wire-mesh openings of the counting facility (Ingram and Ensor 1990). It is not clear if these numbers are yellow eels or elvers. In 1980, the MGS fishway operators noted that elvers and all eels had stopped using the fishway (Jessop and Harvie 2003). This coincided with the installation of 2 additional turbines at the MGS and changes in discharge patterns downstream of the dam. Jessop and Harvie (2003) presented evidence that the changes in discharge patterns created a potential barrier to elvers that could have prevented them from reaching the MGS fishway, but the authors acknowledged that there may be another explanation. A study in 2015-2017 observed American Eel elvers attempting to ascend the MGS (Brittany Dickson, UNB, unpublished data). This suggests that, in the contemporary period, the operation of the dam does not create a velocity barrier to migrating elvers. Elver presence within the near-dam vicinity was not randomly distributed and there were significantly more elvers on the left bank than found at comparable locations along the right bank. A possible explanation can be traced to the flow from the spillway and turbines as it crosses the width of the river and hits the right bank. As the right bank receives the majority of the water's force, the left bank remains relatively calm and elvers may encounter less resistance.

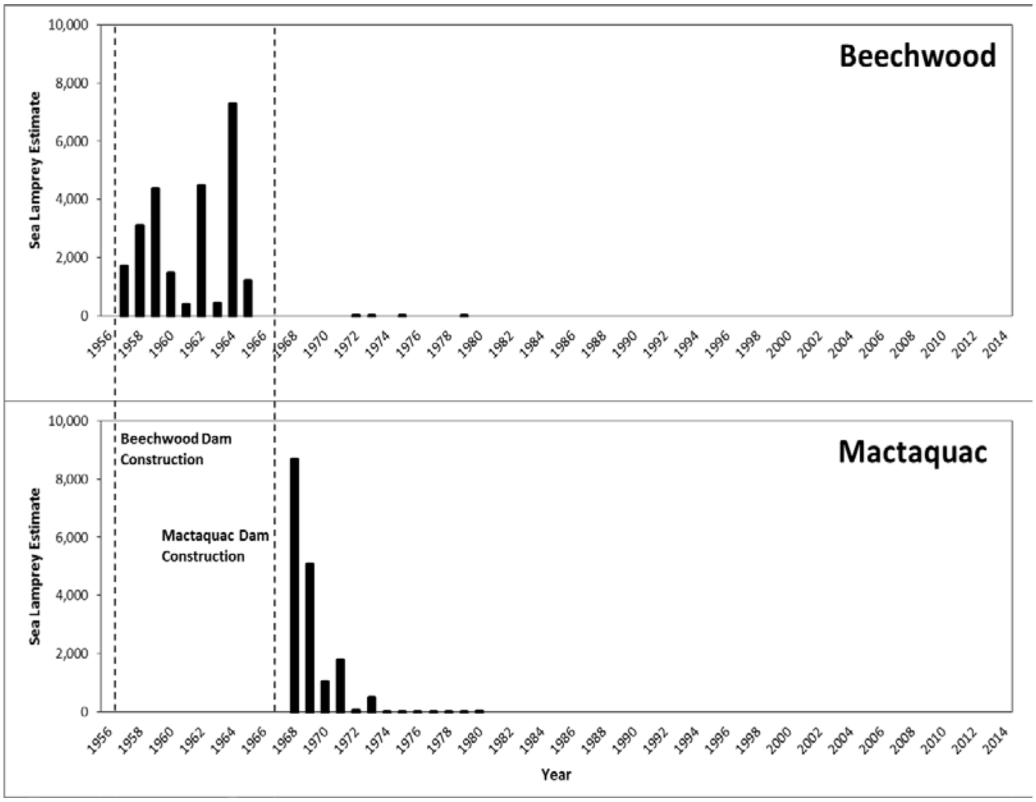

Figure 5-7. Estimated number of Sea Lamprey at Beechwood and Mactaquac Generating Station fishways, 1957 to 2014.

Notes:

- No count was conducted at Beechwood dam from 1966-1969. Smith (1979) reported a moderate run in 1966, no individuals in 1967, and few individuals in 1968 and 1969. Lamprey have not been reported at the Beechwood or MGS fishway since 1980.

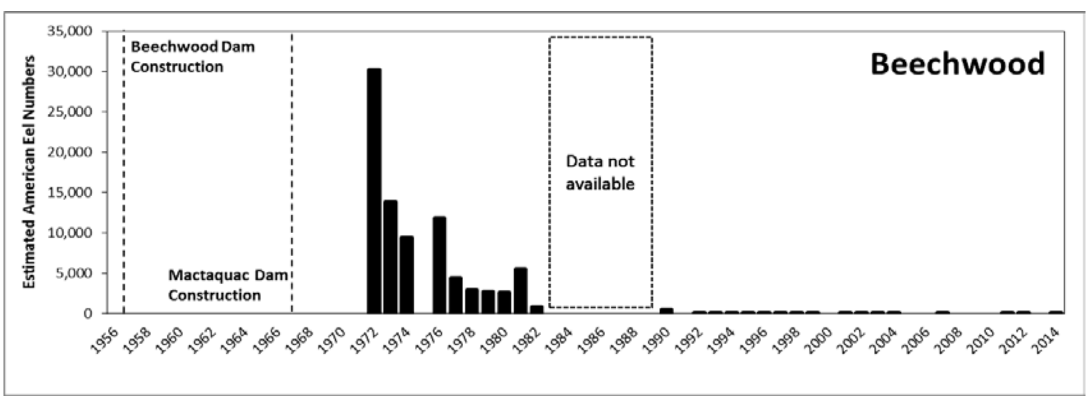

Figure 5-8. Estimated number of American Eel (probably elvers and yellow phase eels combined) at Beechwood Fishway, 1972 to 2014.

Notes:

- No count was conducted at Beechwood facility prior to 1972 and in 1975.

6. Fish Passage Studies in the Saint John River System

Numerous fish passage studies have been conducted to assess salmon migration success downstream as pre-smolt and smolt, and upstream as adults. Select studies are synthesized and evaluated below and a summary of relevant studies is presented in Appendix A, Table A-1. Fish passage studies of non-salmon species in the Saint John River system are limited; some information can be gleaned from existing reports (Table A-1). This information is summarized in Appendix A and discussed below.

6.1 Downstream Migration

6.1.1 Turbine and Spillway Passage

Atlantic Salmon: Downstream passage mortality of juvenile Atlantic Salmon has been studied four times at the Tobique-Narrows facility (Table 6-1). All studies assessed direct mortality of downstream passage, one study assessed delayed mortality, and one study assessed indirectly, a delayed mortality of downstream passage. Delayed mortality of downstream passage may occur due to sub-lethal effects of the passage, e.g., stress, injury, or disorientation, that increases the risk of physiological stress and mortality and/or predation. Predation can be exacerbated by the tendency of predators to congregate in the tailrace (Cada 2001, Budy and Thiede 2002, Ferguson et al. 2006). Downstream passage mortality of juveniles or adult Atlantic Salmon at Beechwood or MGS facilities has not been assessed.

MacEachern (1960) assessed the downstream passage mortality of small (8.9 - 14 cm) and large (14 - 18.6 cm) hatchery-reared smolts via turbines. This study was conducted while turbines at Tobique-Narrows were operating at maximum capacity (10,000 KW). The results indicated that small smolts mortality was 16.5%, and that delayed mortality for this size range was 2%. The author deemed 2% mortality insignificant and did not adjust the total estimate for this size class. The downstream passage mortality for larger smolts was 13.5%; however, an additional 12.0% died during the 8-day holding period used to assess delayed mortality. MacEachern (1960) adjusted the overall mortality for large salmon smolts to 23.7% to account for the observed delayed mortality. In this case, delayed mortality is a direct result of downstream passage because smolts were not exposed to predators during the holding period. Using data from MacEachern (1960), Bell (1981) calculated 18.3% mortality overall at Tobique-Narrows Dam.

In 1968, MacDonald (1969) conducted a mark-recapture study to assess the production of smolts upstream of the MGS. The study did not measure turbine or spillway mortality, but smolt mortality downstream of the MGS was observed. Dead smolts were observed in the gate wells and in the tailrace. Smolts in the gatewells had become trapped and while some fish found in the tailrace had obvious physical injuries others were unmarked. The author suggested that dead, unmarked smolts were likely killed by cavitation. In addition, MacDonald (1969) observed gulls feeding on small fish in the turbine discharge, though the fish species and status (alive, dead, stunned) was unknown. MacDonald (1969) planned to study smolt mortality at the MGS in the 1969, but no information on this study or whether it was conducted was found.

Over three years, Carr (2000) used acoustic tags to estimate the mean, downstream passage mortality of juveniles (pre-smolts and smolts) at Tobique-Narrows. The three year, mean mortality was 18.2% with annual mortality estimates of 10% in 1996 (pre-smolt), 25% in 1997 (pre-smolt), and 18.2% in 1998 (smolt). The study did not partition the route of passage (turbine or spillway) at Tobique-Narrows, but based on spilling records, a minimum 63.6% of tagged juveniles passed via the turbines. In the same study, Carr (2000) attempted to evaluate downstream passage mortality at Beechwood, however too few tagged fish passed the facility to obtain a reliable mortality estimate. Carr (2000) speculated that acoustic signals received in the region of dams may have been reduced due to predation, and those predators that had consumed a tagged fish may have been tracked assuming it was a salmon.

Jones and Flanagan (2007) reported that 79% of tagged pre-smolts descended Tobique-Narrows via the turbines and only 21% descended via the spillway. This result was surprising given that operating conditions during the study resulted in spilling more than 100 m^3/s of water for 8 days, the longest sustained period of spilling from 1994 through 2006. Turbine mortality for pre-smolts descending Tobique-Narrows was 10%, spillway mortality was 0%, and combined turbine and spillway mortality was 8% (Jones and Flanagan 2007). Jones and Flanagan (2007) also estimated delayed mortality with the caveat that some fish included in their estimate may have been overwintering, artificially inflating their estimate. Delayed mortality for pre-smolts descending Tobique-Narrows was estimated as 21% via the turbines, 18% via the spillway, and 20% combined (turbine and spillway; Jones and Flanagan 2007). Jones and Flanagan (2007) used the estimates of turbine, spillway, and delayed mortality to report total pre-smolt mortality at Tobique-Narrows as a range from 8% to 28% for combined (turbine and spillway) passage. However, the authors indicated that because of the high proportion of pre-smolts that pass the dam via turbines, the range in mortality could be closer to 10% to 31%.

During the fall of 2012, NB Power contracted AMEC (2013) to assess pre-smolt survival and passage routes (Turbine #1, Turbine #2, or spillway #5) at Tobique-Narrows under two different operating scenarios. During Scenario 1, 25% of daily discharge was released through Turbine #1, 25% through Turbine #2, and 50% through Spillway #5. During Scenario 2, 50% of daily discharge was released through Turbine #2, and 50% through Spillway #5. The number of tagged fish descending via each passage route was expected to be proportional to the amount of discharge passed through each route under each scenario. During Scenario 1, 22% of tagged pre-smolts passed via Turbine #1, 17% via Turbine #2, and 61% via Spillway #5, and the proportion of tagged fish descending via each route was not significantly different than expected ($p = 0.547$; see Table 6-1 for expected mortalities). During Scenario 2, 29% of tagged pre-smolts passed via Turbine #2, and 69% via Spillway #5, and the proportion of tagged fish descending via Spillway #5 was greater than those descending Turbine #2. The result was marginally insignificant ($p = 0.060$; AMEC 2013). Pre-smolt mortality for turbine passage was 12.0% (10.5% for Turbine #1, 12.9% for Turbine #2) and 11.1% for Spillway #5 (AMEC 2013). There was no statistical difference between the survival of tagged pre-smolts descending Tobique-Narrows regardless of their passage route (AMEC 2013). This result contradicts a previous study conducted at Tobique-Narrows (Jones and Flanagan 2007) and consensus that survival is greater for spillway passage compared to turbine passage (Schilt 2007).

American Shad: In Jessop's (1975) assessment of the decline of American Shad above hydropower development on the Saint John River, turbine mortality of adults and juveniles was cited as a probable contributing factor. No passage studies have been completed on adult or juvenile American Shad in the Saint John River; however, this species has survival challenges in fish passage facilities (e.g., Haro and Castro-Santos 2012).

Other Species: No detailed studies of the effects of spillway or turbine passage on adult salmon (fallbacks), post-spawning salmon, Gaspereau, American Eel, Sea Lamprey, or Striped Bass appear to exist.

Table 6-1. Juvenile Atlantic Salmon mortality estimates for Tobique-Narrows.

Source	Mark type	Life-Stage	Mortality Estimate	Delayed Mortality
MacEachern 1961	Red dye	Smolt	16.5-23.7%	2-12%
Carr 2000	Acoustic	Pre-smolt/smolt	18.2% over 3 years	Not assessed
Jones 2007	Acoustic	Pre-smolt	8-28% (turbine & spillway) 10-31% (turbine only)	21% (turbines) 18% (spillway) 20% (turbine & spillway)
AMEC 2013	Acoustic	Pre-smolt	Turbine 1 and 2 = 12.0% Turbine 1 = 10.5% Turbine 2 = 12.9% Spillgate 5 = 11.1%	Not assessed

6.1.2 Whole System Mortality Estimates

6.1.2.1 Theoretical Estimates

The cumulative mortality of downstream passing Atlantic Salmon smolts from upstream of Tobique-Narrows, through Beechwood and MGS by Washburn and Gillis Associates (1996). They used the empirical data for Tobique-Narrows and mortality estimates from Beechwood and MGS. A pooled mortality estimate of 18.3% (Bell 1981; MacEachern 1960) was used for the Tobique-Narrows (described in Section 6.1.1). Washburn and Gillis Associates (1996) reasoned that the turbine type (low speed Kaplan turbines) and configuration at Beechwood would decrease the risk of strike and damaging pressure drops. The authors used Bell's (1981) mortality estimates for smolt sized fish from McNary (7.8%) and Bonneville (7.5%) dams (Pacific salmon) which have similar turbine configurations as Beechwood and MGS: a 10% mortality rate was assumed for the Beechwood and MGS facilities (Washburn and Gillis Associates 1996).

Using the estimates above which also assume all fish pass via the turbines, the cumulative mortality of smolts passing the Tobique-Narrows, Beechwood, and MGS facilities would be 33.8% for fish originating above Tobique-Narrows, 19.0% for fish originating above Beechwood (post-Tobique-Narrows), and 10.0% for fish originating above MGS (post-Beechwood). There are many assumptions and therefore caveats with this estimates of smolt mortality, e.g., the estimates don't include sub-lethal impacts at each facility or spillway passage.

6.1.2.2 Empirical Estimates

The cumulative mortality effects of passing 0, 1, 2, or 3 dams on the Saint John River was assessed for Atlantic Salmon smolts with a coded wire tag (CWT) study conducted by Fisheries and Oceans from 1990 through 1992 (Washburn and Gillis Associates 1996, Carr 2001, and AMEC 2005). In the study, hatchery-reared smolts were implanted with a coded wire tag (CWT) prior to being released and their return to the MGS fishtrap as grilse was monitored. It should be noted that these survival estimates do not take into account maiden multi-sea winter (MSW) returns, thus underestimating smolt-to-adult survival. Estimates assume that mortality caused by factors below the MGS (*i.e.*, not related to passage) was equal among fish regardless of where they were originally released. The data is revisited such that the effects on survival of 3 dams (Tobique-Narrows, Beechwood, Mactaquac), 2 dams (Beechwood, Mactaquac), 1 dam (Mactaquac), or 0 dams (MGS tailrace) are reported in Table 6-2. These values are comparable to the estimated 1SW returns from hatchery-reared smolts released at Mactaquac between 1990 and 1992 (0.649%, 0.688%, and 0.406%; respectively) (Marshall et al. 1997). High inter-annual variability in the % return as grilse to the MGS fishway was observed and therefore, caution must be used when interpreting the results. Carr (2001) noted a number of factors such as handling, fish condition, release conditions, release times, water discharge, and water temperature that may account for much of the observed inter-annual variability.

Table 6-2. Results of the coded wire tag study for smolts released upstream of Tobique-Narrows, Beechwood, and Mactaquac Generating Station facilities.

Release Location	First Dam Encountered	Number of Dams	Smolts Released	Grilse Returns to MGS	Percent Return (%)	Freshwater Migration Survival Relative to 0 Dams (%)
1990-2						
Tobique River (Arthurette)	Tobique-Narrows	3	28,412	113	0.40	64.2
Saint John River (Grand Falls)	Beechwood	2	36,887	166	0.45	72.6
Saint John River (Grafton)	Mactaquac	1	14,273	76	0.53	85.9
Mactaquac Tailrace	-	0	26,136	162	0.62	100.0

6.1.3 Delayed Migration

Hydropower developments can delay the downstream migration of fish through reduced water velocities and artificial currents in headponds, difficulty passing the dam due to entrainment or trapping in dam forebays or gatewells, and delay in the tailrace caused by the stress or possibly disorientation of passing the dam (Schilt 2007). Delay at dams concentrates fish and can also attracts avian and piscivorous predators that congregate at dams (Schilt 2007).

A series of tests using tagged, hatchery smolts released approximately 2.4 km upstream of Beechwood Dam were conducted in 1960 and 1961 to determine the percentage of Atlantic Salmon smolts becoming trapped in the forebays (Ingram 1961a). During heavy spillage (mean = 2,750 m^3/s), less than 1% of smolts were trapped in the forebays, 3.3% to 8.8% during light spillage (mean = 50 m^3/s), and 16% to 17% during no spillage. A further test indicated that over 72% to 80% of trapped smolts were delayed for less than 24 hours (Ingram 1961a).

Ingram (1961) indicated that smolt migration was not seriously delayed by the Beechwood headpond because of a peak in smolts observed in the Beechwood forebays about a week after a peak in smolts were captured in gill nets above the Tobique-Narrows Dam in 1959. In addition, tagged, hatchery smolts arrived at Beechwood about a week after they were released above Tobique Dam (Ingram 1961a). These observations are supported by the 1970 study assessing the speed of migration of hatchery Atlantic Salmon smolts from Tobique River to Beechwood to Westfield (Semple 1971). The majority of salmon smolts (82%) travelled the 52 km from Trout Creek on the Tobique River to Beechwood Dam within 7 days and Semple (1971) concluded that smolts were not greatly delayed by the Tobique-Narrows or Beechwood headponds. The number of tags recovered at Westfield was insufficient to estimate further downstream migration time (Semple 1971).

Carr (2000) reported that downstream migration rates of tagged salmon smolts and pre-smolts in the Tobique and Mactaquac headponds were 21% of migration rates in natural flowing streams. While it is impossible to determine how far downstream pre-smolts intend to migrate, it is a fair assumption that smolts intend to migrate to the ocean. Therefore, of the smolts that reached the dams, on average 45.6% of tagged smolts did not migrate past the Tobique headpond, 64.2% did not migrate past the Beechwood headpond, and 100% did not migrate past the Mactaquac headpond. Holdover salmon smolts have been reported in the area of Kelly Creek and Mactaquac Arm, and salmon smolts were regularly caught in commercial eel traps in Mactaquac headpond (Washburn and Gillis Associates 1996). Jones and Flanagan (2007) reported 26% of tagged pre-smolts migrating past Beechwood Dam in 2006. Thus, it is not clear what proportion of juvenile Atlantic Salmon reported in the Mactaquac headpond were indeed smolt holdovers or simply pre-smolts.

In Jones and Flanagan's (2007) 2006 acoustic tagging study, the mean time for pre-smolts to migrate the 11.3 km from Three Brooks to Arthurette was 1.7 days, a rate of 6.6 km/day compared to the mean 10.2 days it took to migrate the 19.2 km from Arthurette to the Tobique-Narrows, a rate of 1.9 km/day (Table 6-3). Smolt migration rates decreased downstream of Arthurette once the slower moving waters of the Tobique-Narrows headpond were encountered. Despite a slower migration rate, 73% of tagged pre-smolts migrated past Tobique-Narrows compared to on average, 45.6% of pre-smolts that remained in the reservoir when Carr (2000) conducted a similar study (Table 6-3). It was suggested that the heavier tags used by Carr (2000) and the greater tag-to-body-weight ratio may have affected pre-smolt swimming behavior resulting in a lower number of pre-smolts passing the Tobique-Narrows Dam (Jones and Flanagan 2007).

Table 6-3. Results of two tracking studies investigating migration rates of pre-smolts along the Tobique River

Study	**Three Brooks to Arthurette**		**Arthurette to Tobique-Narrows**		**Smolts Remaining in Tobique-Narrows Reservoir**
	Migration Rate (km/day)	Delay days	Migration Rate (km/day)	Delay days	(%)
Carr 2000	12.1	0.93	2.6	7.4	45.6
Jones and Flanagan 2007	6.6	1.7	1.9	10.2	27.0

6.2 Upstream Migration

6.2.1 Fishway Mortality

Ingram (1980, 1985) tabulated mortality of adult Atlantic Salmon "before sorting" and "after sorting" at the MGS fishway from 1972 to 1982. Only the "before sorting" counts were used to assess incidental mortality associated with operating the fishway because the "after sorting" counts included fish sacrificed for experimental purposes and broodstock. The minimum, maximum, and mean annual "before sorting" mortality counts were 11, 76, and 27, respectively, or an overall mortality rate of <0.2%, although it likely underestimates the true mortality (Ingram 1980, 1985).

Adult salmon mortality in fishways at MGS, Beechwood, and Tobique are sometimes recorded from 1983 to 2005, and sometimes details are provided (e.g., Marshall et al. 1999; Jones et al. 2004, 2006). From 2009 to 2012, fishway mortality was reported for adult salmon at the MGS, Beechwood, and Tobique-Narrows fish passage facilities. Mortality as a percentage of salmon passing the dam was highest at the Beechwood (0.63 % to 3.88 %) and lowest at the Tobique-Narrows fishway (0 % to 0.41 %; Table 6-3). The cumulative fishway mortality (all dams) as a percentage of total returns to the MGS was 0.54 % to 2.73 % (Table 6-4). Fishway mortality for species other than Atlantic Salmon has not been reported beyond a few anecdotal accounts, e.g., American Shad mortality during collection, transport, and release at MGS (See section 6.2.2).

Table 6-4. Fishway mortality at Mactaquac Generating Station, Beechwood, Tobique-Narrows facilities, 2009-2012.

Year	Mactaquac		Beechwood		Tobique-Narrows		Combined Mortality		Source
	#	% of Total[1]	#	% of Total[1]	#	% of Total[1]	#	% of Total[2]	
2009	17	1.47	9	3.88	0	0.00	26	2.25	(DFO 2010)
2010	10	0.36	4	0.80	1	0.41	15	0.54	(DFO 2011)
2011	15	0.90	5	0.63	2	0.40	22	1.31	(DFO 2012)
2012	4	1.37	4	3.13	0	0.00	8	2.73	(DFO 2013)

[1] Percent of total passing the indicated dam
[2] Percent of total returns to MGS

6.2.2 Fishway Efficiency

Since the construction of Tobique-Narrows and Beechwood, passage by various species has been documented in the two fishways. The trap and truck operation at MGS captures and transports the targeted, three species for passage. However, the successful passage of individuals says little about a fishway's efficiency. In 1999, a tagging study was conducted on Atlantic Salmon to estimate the Tobique-Narrows fishway efficiency (Marshall et al. 2000); however, the results are unpublished and the data was unavailable for this report. There has been no published report of fishway efficiency for any species at the Tobique-Narrows, Beechwood, or the MGS fishways.

In the absence of direct study, examples from the literature can be useful to place limits on the passage efficiencies that can be expected. A recent review indicated that average upstream passage efficiency was 61.7% for salmonid species (n = 31 fishways) and 21.1% for non-salmonid species (n = 30 fishways; Noonan et al. 2012), though the range of passage efficiency was nearly 0 to 100% for both salmonid and non-salmonid species (Michael Noonan, personal communication). In addition, the type of fishway significantly affected passage efficiency, the most efficient being the pool and weir design (e.g., Tobique-Narrows fishway), where average passage efficiency was over 70% for salmonids (n = 21 fishways) and over 40% for non-salmonids (Noonan et al. 2012). Fish lift (Beechwood) and trap and truck (MGS) fishways were the second least effective fishways with average passage efficiencies less than 40% for salmonids and less than 15% for non-salmonids (Noonan et al. 2012).

Although no study of fishway efficiency has been reported for Saint John River facilities, some rudimentary fishway optimization studies were conducted at Beechwood. In the early years of Beechwood fishway operation, a number of deficiencies were identified and improvements were made to ensure the consistent operation of the fishway during high flows as well as enhancing the collection capacity by doubling water flow to the fishway (Ingram 1962). In addition, a variety of entrance orifice types and shapes were tested in an attempt to optimize fishway usage for Atlantic Salmon, though some consideration was also given to American Shad and Gaspereau (Ingram 1961b, 1962, 1964).

Ruggles and Watt (1975) followed by Jessop (1975) described the progressive collapse of the American Shad population upstream of hydropower development on the Saint John River. A small shad population existed in the Tobique River prior to the construction of Tobique-Narrows (Jessop 1975, Ruggles and Watt 1975) and while the presence of shad at the Tobique-Narrows fishway was noted in its first years of operation, the fish did not readily use the fishway to pass the dam and shad abundance rapidly declined in subsequent years (Ruggles and Watt 1975). After Beechwood was completed and the fishway became fully operational, a small shad run (maximum return = 1,490) returned to Beechwood until the MGS was built, after which few shad used the Beechwood fishway. Similarly, American Shad recorded at the MGS fishway declined from 38,838 in 1968 to 7,363 in 1973, with only a few hundred fish returning in recent years (see Section 5.3). An explanation for the collapse of the Saint John River American Shad populations is incomplete, but inadequate upstream fish passage has certainly had an impact (Meth 1973, Jessop 1975, Ruggles and Watt 1975). Jessop (1975) described problems with attraction flow at Tobique-Narrows and Beechwood fishways, and how the elevation and water velocities between pools in the Tobique-Narrows fishway were greater than optimal for shad. While American Shad mortality at the Beechwood fishway was minimal, at least 25% of shad using the MGS fishway were found dead in the headpond following release. This mortality was likely due to stress induced during capture and transport (Jessop 1975). In addition to problems with upstream passage, Meth (1973) concluded that incompatible spawning conditions in the headpond precluded a viable shad population above the MGS.

Striped Bass made upstream feeding excursions on the Saint John River at least as far as Aroostook (Warner 1956) prior to the construction of Beechwood and Mactaquac facilities (Meth 1973). Since the construction of these facilities, few Striped Bass have been observed in the Saint John River upstream of the MGS. The population downstream of the MGS is not understood well enough to know if non-passage at MGS has affected it current status (Andrews et al. 2017).

The upstream passage of Sea Lamprey has been studied on the Saint John River. Sea Lamprey can enter the MGS fishtrap and appear to be able to at least ascend through the fishways at Beechwood, and Tobique-Narrows. However, operational policies at the dams have often included removing and destroying Sea Lamprey (see sections 4.2.2 and 5.5).

Prior to 1980, American Eel elvers returned to the MGS fish collection facilities each year and some presumably passed the dam (in the trap and truck operations). Elver passage at the dam was probably not very efficient because their small size caused them to pass through the mesh gates at various points of the collection facility (Ingram 1980). After two additional turbines were installed in 1980, discharge patterns were altered downstream of the MGS and American Eel Elvers were no longer observed in the fish collection facilities (Jessop and Harvie 2003). This situation remains unresolved, though recently, an abundant number of elvers have been reported at the MGS (Brittany Dickson, UNB, unpublished data).

6.2.3 Delayed Migration

Smith (1957) described the 1957 Atlantic Salmon migration at Beechwood as being delayed and possibly reduced due to dam construction activities, excavation activities in the river, and inadequate operation/function of the fish lift. Salmon were observed at the dam on May 14th, though the fish lift was not operational until June 14th. Suckers and shad were also observed in the tailrace prior to the operation of the fish lift. Once the fish lift was operational, salmon and suckers were able to ascend the dam, though shad did not enter the hoist. Tagging operations indicated that at least 8% of tagged fish fell back below the dam and that 20.6% of salmon tagged at Beechwood, ascended the Tobique-Narrows fishway (Smith 1957).

From 1957 to 1962, tagging studies assessing the fallback of salmon released above Beechwood were completed for 5 of 6 years (Smith 1969). Over the 4 years when salmon were released immediately above Beechwood, 9.3% of tagged salmon fell back with annual fallback rates ranging from 5.7% to 11% (Smith 1969). In 1960, salmon were released 4 km upstream of Beechwood with only 0.6% of fish being recaptured below the dam (Smith 1969). The author noted that tagged fish may be more likely to fallback compared with untagged fish due to the increased handling during tagging and that some fish that fell back may not have been recaptured in the fishway or were caught by anglers. In addition, 37.7% of tagged fish and 62.6% of untagged fish from 1957 to 1960 were counted at Tobique-Narrows, indicating that tagged fish were less likely to ascend the Tobique-Narrows fishway, possibly because of the extra handling that may have increased the likelihood of delay, fallback, and mortality (Smith 1969). Of salmon tagged at Beechwood from 1957 to 1960, 47% had migrated the 29 km to the Tobique-Narrows fish trap within 1 week, and almost 85% had been counted within 3 weeks of release, though the overall range of migration times were variable and ranged from a minimum of 1 day to 96 days (Smith 1969).

In 1965, adult salmon tagged in Saint John Harbour and the Westfield area were used to assess the migration time between the Beechwood fishway and Tobique-Narrows fish trap; 86.2% of these fish made the trip in 1 week or less and 96.8% made the trip from Tobique-Narrows to Beechwood within 3 weeks (Smith 1969). These results were thought to be more indicative of the migration time for untagged fish compared to the estimates obtained in from 1957 to 1960 (Smith 1969). On average, salmon tagged in Saint John Harbour took 57.8 days to reach the Beechwood fishway and salmon tagged at Westfield took 54.1 days.

In 1973, a tagging study was conducted to determine whether the MGS and Beechwood headponds affected upstream migration of wild and hatchery adult Atlantic Salmon (Marshall 1975). Wild and hatchery salmon were trucked to three release points: Mactaquac headpond (0.4 km upstream of the MGS), Woodstock (75 km upstream of the MGS), and the Tobique River (195 km upstream of the MGS at the upper end of the Tobique-Narrows headpond). The study found that 5.8% of wild salmon and 12.5% of hatchery salmon released in the Mactaquac headpond fell back below the MGS and were recaptured in a fishway or trap oriented to catch fish moving in an upstream direction (Marshall 1975). This percentage likely underestimates the true fallback rate because it does not account for turbine or spillway mortality, though one dead hatchery salmon was found at McKinley Ferry just downstream of the MGS and was included in the statistic (Marshall 1975). Further, the correct interpretation of fallback numbers are confounded by salmon's tendency to return to their natal stream for spawning and the potential that wild salmon entered fishways seeking thermal refuge and were released further upstream than their natal stream. In the case of hatchery fish, their "natal stream" is the Mactaquac Biodiversity Facility (downstream) and this likely accounts for the higher proportion of hatchery salmon that fallback (Marshall 1975). Of salmon released at Woodstock, no wild salmon and only 1.3% of hatchery salmon fell back below the MGS. At Beechwood, 10.7% of wild salmon that ascended the fishway fell back below the Beechwood fishway and subsequently re-entered (Marshall 1975). From 1972 to 1976, the overall percentage of fallbacks at Beechwood Dam was 8% of 411 tagged salmon (Ingram 1981). From 1977 to 1981, the overall percentage of fallbacks at Beechwood Dam was 15% of 541 tagged salmon (Ingram 1987).

Of wild salmon released in the MGS headpond, only 22.3% were recaptured at Beechwood and 26.2% of those released at Woodstock arrived at Beechwood (Marshall 1975). Fewer hatchery salmon released in the Mactaquac headpond (2.8%) and at Woodstock (11.3%) were recaptured at Beechwood. The low proportion of wild adult salmon ascending the Beechwood fishway may indicate a significant delay in upstream migration, possibly a disruption of homing ability, or they went elsewhere. Since 2006, when trucking of fish upstream of Beechwood was reduced, barring exceptions in 2009 and 2010, approximately 50% of salmon released at Woodstock have ascended the Beechwood fishway. These results suggest that either migration conditions have improved or the tagged fish in Marshall's (1975) study were somehow impaired. Indeed, Marshall (1975) had concluded that tagging significantly increased the time required for a fish to migrate to Beechwood, though no caveat to the proportion of salmon ascending Beechwood was made. Alternatively, the higher proportion of salmon ascending Beechwood in more recent years could be explained by a changed salmon distribution within the upper Saint John River after years of preferentially trucking salmon to the Tobique River.

Marshall (1975) observed that salmon released later in the year were also less likely to move upstream. Whether these fish were less likely to continue upstream because of a physiological or behavioural cue to spawn, or because these 'late' run fish were destined for natal streams below Beechwood is unknown.

Observations of migration delay or conditions causing delay have been reported at times: more so in the earlier years of operation. For example, Ingram (1962) reported over 200 salmon below the Beechwood spillway during a period of no spill, and that fewer than 50 entered the fishway. On two separate occasions in 1963, spillage at Beechwood attracted salmon, delaying their entrance into the fishway by several days (Ingram 1963). This was indicated by a 429% and 478% increase in the number of salmon using the fishway during the 4 days after spillage stopped compared to the 4 days before spillage stopped (Ingram 1963). We do not know whether these conditions continue to affect upstream salmon passage or if they have been addressed through operational practices or other means.

Fallback of Gaspereau released 500 m upstream of the MGS was assessed in 1973 and 1977 (Jessop 1994). Less than 0.1% of 23,230 Gaspereau were recaptured at the MGS fishway and Jessop (1994) concluded that fallback was of Gaspereau was minor. The limited fishway capacity at the MGS causes delay when the Gaspereau migration peaks, affecting both Gaspereau and salmon (Jessop 1994). Based on acoustic tag data, Jessop (unpublished data in Jessop 1994) reported that salmon were delayed at the MGS fishway by 3 to 11 days when Gaspereau were abundant (late May to mid-June).

6.3 Gas Supersaturation – A Bidirectional Passage Issue

In 1968, an estimated 200 adult salmon and an unreported number of eels were found dead in the MGS tailrace with symptoms of gas bubble disease (MacDonald and Hyatt 1969). Penney (1987) summarized the results of MacDonald and Hyatt's (1969) investigation into whether turbine operation at MGS was the cause of dissolved gas-supersaturation that resulted in fish kills that occurred in 1968 and 1969. Dissolved oxygen and nitrogen gas saturation were measured at the turbine intake, in the turbine boils (outflow), and at various distances downstream under low (5 megawatt; MW) to high (105 MW) generating conditions. During low generating conditions, air was vented into the turbine to reduce damage to the turbines caused by cavitation. As a result, air was introduced into the water and formed tiny bubbles that were subsequently plunged up to 21 m below the surface where the increased pressure at this depth forced the additional gas into solution. As this water flowed from the depths of the plunge pool to shallower areas of the tailrace, nitrogen gas supersaturation occurred resulting in gas bubble disease in fish and subsequent mortality of fish (typically larger bodied fish) exposed for a significant time period (Penney 1987). Smaller fish were apparently not affected as no juvenile salmon mortalities were reported and salmon parr were subsequently observed in the area of the fish kill (MacDonald and Hyatt 1969). The issue of gas supersaturation due to air venting during periods of low generation levels was addressed by installation of a modified air valve system at MGS (Ruggles and Watt 1975). Gas supersaturation issues have not been reported from the Beechwood or Tobique-Narrows. Currently, there is no indication that gas supersaturation is a problem at any of the main stem dams on the SJR.

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Appendix A – Summary of fish passage and monitoring studies on the Saint John River

Table A-1 provides a condensed summary of research and monitoring of fish that applies to fish passage at dams on the Saint John River. The appendix is presented as a table, sub-divided by species, and for each source, a passage issue and study type are provided (where applicable) along with a brief description of the study and results. The focus of the summary is fish passage and each source may contain additional information. The list is not exhaustive, rather, it presents the published sources that have been most heavily relied upon for this report. Further, not every species encountered in the Saint John River, or even at the Tobique-Narrows, Beechwood, and Mactaquac fish passage facilities is included in the table. No fish passage information beyond the occasionally incomplete counts (and estimates) presented in (Smith 1979, Ingram 1980, 1981, 1985, 1987, Ingram and Ensor 1990) was identified for Landlocked Salmon, Brook Trout, Rainbow Trout, Smallmouth Bass, Suckers, Chain Pickerel, Lake Whitefish, Brown Trout, and others. The use of any information described in this appendix should be cross-referenced with the original source, and the original source cited.

Table A-1 – Summary of fish passage and monitoring studies on the Saint John River

Source	Passage Issue	Study Type	Description and Results
Atlantic Salmon			
(MacEachern 1960)	Turbine passage	Mark-recapture Mark type: red dye n = 40,000	**Description** - Turbine mortality of hatchery reared salmon smolts of different sizes (small: 8.9-14 cm; large: 14-21.6 cm). - Study included an 8 day holding period after recapture to assess delayed mortality in conjunction with a control group. **Results** - Turbine mortality for small salmon smolts was 16.5% with insignificant delayed mortality (2%). - Turbine mortality for large salmon smolts was 23.7% after accounting for delayed mortality (12%).
(Ingram 1961b)	Delayed migration	Mark-recapture Mark type: Unknown	**Description** Study assessing the percentage of Atlantic Salmon smolts becoming trapped in the forebays at Beechwood. **Results** - during heavy spillage, <1% of smolts trapped in the forebays, 3.3% to 8.8% during light spillage, and 16% to 17% during no spillage. - 80% of smolts trapped in forebays proceeded downstream within 1 day.

Atlantic Salmon (continued)			
(Ingram 1962)	Delayed migration	Observational	**Description** - Observational evidence of salmon delay due to spillage at Beechwood. **Results** -About 200 salmon appeared to be attracted to spillage and not the fishway entrance.
(Ingram 1962, 1963, 1964)	Passage efficiency	Observational	**Description** - Efficiency of salmon entrance to the Beechwood fishway using various fishway orifice shapes. **Results** - Inconclusive
(MacDonald 1969)	Turbine passage Spillway passage Predation	Mark-recapture Mark type: Pectoral fin clip n=6203	**Description** -Study designed to assess smolt production from the Upper Saint John River. -Smolts marked at Beechwood (collected from gatewells), released in the tailrace, and recaptured downstream of Mactaquac (at head of tide). **Results** -3043 smolts recaptured downstream of Mactaquac, of which 62 were marked. - Smolt run timing: began sometime before May 23 and most of the run had passed by mid-June. - No estimate of smolt mortality at Mactaquac but direct smolt mortality was observed and possible indirect/delayed mortality (predation of small fish by gulls in turbulent waters of the tailrace). -Observations of smolts trapped at top of head gates, turbine mortality, and mortality consistent with gas bubble disease.
(Smith 1969)	Fallback Delayed migration	Mark-recapture Mark type: metal (poultry) wing tag n = 2024	**Description** - Tagging study from 1957 to 1962 assessing fallback at Beechwood and migration time from Beechwood to Tobique-Narrows fishway **Results** - Fallback ranged from 5.7% to 11% for 4 different years with an overall mean of 9.3%. - When salmon were transported 4 km upstream of Beechwood, fallback was only 0.6%. - Salmon tagged at Beechwood dam were less likely to ascend the Tobique-Narrows fishway compared to untagged salmon. - 85% of tagged salmon migrated to the Tobique-Narrows fish trap within 3 weeks of release from Beechwood, a distance of 29 km.

Atlantic Salmon (continued)			
(Smith 1969)	Delayed migration	Mark-recapture Mark type: Carlin tag n = 6202	**Description** - Tagging study assessing migration times from Saint John Harbour and Westfield to Beechwood and Tobique 1965 to 1967. **Results** - Only 1965 data was used; tag recoveries in 1966 and 1967 were few and delayed. - Harbour to Beechwood: min 15 days, max 142 days, mean 57.8, 100 tagged fish counted. - Westfield to Beechwood: min 14 days, max 116 days, mean 54.1, 138 tagged fish counted. - Beechwood to Tobique: 86.2% made the distance within 1 week, 96.8% within 3 weeks.
(Semple 1971)	Delayed migration	Mark-recapture Mark type: Carlin tag n = 7721	**Description** - Tagging study assessing migration times of Atlantic Salmon smolts from Tobique River (Trout Brook) to Beechwood and to Westfield. **Results** - Over 82% of tagged smolt migrated 52 km from Tobique River tributary, Trout Brook, to Beechwood in 7 days (7.4 km/day). - Tag recoveries at Westfield were insufficient to make conclusions about smolt migration to Westfield.
(Marshall 1975)	Fallback	Mark-recapture Mark type: Carlin tag n = 1355	**Description** - Movements of tagged wild and hatchery salmon released upstream of Mactaquac (1972 and 1973). **Results** *Upstream migration* - Significantly more wild salmon moved upstream compared with hatchery salmon: Recaptures at Beechwood fishway were 24.3% (wild) and 3.5% (hatchery) for fish released just upstream of Mactaquac and 31.1% (wild) and 18.1% (hatchery) for fish released at Woodstock. - Recaptures above Tobique (angling) were 11.6% (wild) and 2.3% (hatchery). - Tagging increased the time required for salmon to migrate to the Beechwood fishway *Fallback* - Salmon falling back below Mactaquac was insignificant for fish released at Woodstock (1.3%) - Fish released just above Mactaquac (~1km upstream) fell back at rates of 5.8% (wild) and 12.5% (hatchery) in 1973 and 6.6% (wild) and 54.2% (hatchery) in 1972. - One tagged fish that fell back was found dead at McKinley Ferry (downstream of Mactaquac). - 10.7% of wild fish ascending Beechwood fell back below Beechwood and entered the fishlift a second time (no hatchery fish did this)
Atlantic Salmon (continued)			
(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities

Ingram 1980	Fishway mortality	Monitoring	- Counts and distribution records from Mactaquac fish collection facilities (1972-1976).
Ingram 1981	Fallback	Monitoring	**Description** - Counts and distribution records from Beechwood fish collection facilities (1972-1976). - Details of recapture of salmon at Beechwood from 1972-1976. **Results** -Overall fallback percentage was 8% for 411 tagged hatchery and wild salmon from 1972-1976.
Francis 1984	NA	Monitoring	- Counts of Atlantic Salmon ascending the Tobique-Narrows fishway 1978-1983.
Penney 1984	Dissolved gas supersaturation	Monitoring	**Description** - Study of dissolved nitrogen and oxygen gas saturation to assess the operational conditions that cause dissolved gas supersaturation and were responsible for previous fish kills at Mactaquac. - Evaluated the effectiveness of an installed engineering control as well as potential operational controls on dissolved gas supersaturation. **Results** - Nitrogen gas supersaturation occurred reliably at low generating capacity but was typically eliminated at higher generating capacity (>35 MW). - Turbine operation at low generating levels for extended periods likely caused observed fish kills in 1968 (adult Atlantic Salmon and American Eel). - Engineering controls that eliminate air intake to the turbines at generating levels of 15 MW or more reduced dissolved gas supersaturation. - Operation of turbines at 10 MW or below caused dissolved gas supersaturation regardless of the described engineering controls.
Ingram 1985	Fishway mortality	Monitoring	- Counts and distribution records from Mactaquac fish collection facilities (1977-1982).
Ingram 1987	Fallback	Monitoring	**Description** - Counts and distribution records from Beechwood fish collection facilities (1977-1982). - Details of recapture of salmon at Beechwood from 1977-1982. **Results** -Overall fallback percentage was 15% for 541 tagged hatchery and wild salmon from 1977-1982.
Ingram 1990	NA	Monitoring	- Counts and distribution records from Mactaquac fish collection facilities (1983-1988).

Atlantic Salmon (continued)			
(Jessop, unpublished data in Jessop 1994)	Delayed migration		**Description** - Anecdotal discussion of unpublished salmon tag study. **Results** - An ultrasonic tracking study of Atlantic salmon released downstream of the Mactaquac indicated that salmon could remain in the vicinity of the fishway for between 3 and 11 days before entering when Gaspereau were abundant.
(Washburn and Gillis Associates 1996)	Turbine passage Spillway passage Delayed migration	Mark recapture Mark type: coded wire tag n = 152,535	**Description** - Report on potential causes of smolt mortality during downstream migration. - Describes DFO coded wire tag study (1990-92) and calculates a survival for smolts migrating through 3, 2, 1, and 0 dams. Smolts released above 3 dams (Tobique-Narrows, Aroostook, Grand Falls), 2 dams (Beechwood, Hargrove), and 1 dam (Mactaquac) were pooled. **Results** - Theoretical estimate of mortality due to turbine passage using Bell's (1981; based on MacEachern 1960) pooled mortality of 18.3% of smolts at Tobique-Narrows and assumed 10% mortality for Beechwood based on the dam's similarity to Bonneville and McNary dams where mortality was 7.5% and 7.8%, respectively. Similarities were based on turbine type (low speed Kaplan) and the elevation of the turbine runner above the tailrace which affects mortality of smolt sized fish. Assumed 10% mortality for Mactaquac based on its similarity to Beechwood. - Mortality of smolts passing 3, 2, and 1 dams was 45.3%, 27.4%, and 16.9%, respectively, relative to smolts released downstream of Mactaquac Dam (smolts passing 0 dams). - Estimate of time required for smolts to travel through upper (32 km in 2 days), reservoir (125 km in 11 days), and tidal (135 km in 8 days) sections of the Saint John River to arrive in Saint John Harbour on June 10 (May 20 initiation of migration).

Atlantic Salmon (continued)			
(Carr 2000)	Turbine passage Delayed migration	Mark-recapture Mark type: Acoustic tag n=149	**Description** - Study conducted to determine emigration timing, migration rates, and turbine mortality of pre-smolts and smolts captured and released upstream of the Tobique-Narrows headpond. - 29 pre-smolts tagged in 1996, 60 pre-smolts tagged in 1997, 60 smolts tagged in 1998. **Results** *Delayed migration* - Rate of downstream movement in Tobique and Mactaquac headponds were 20% the rate in free flowing waters. Downstream fish movements in Beechwood reservoir were similar to fish movements in the free-flowing river. - No smolts made it past Mactaquac Dam (holdovers). *Turbine mortality* - Mean mortality over 3 years at Tobique-Narrows Dam was 18.2%.
(Marshall et al. 2000)	Passage efficiency	Mark-recapture Mark type: unspecified n=561	**Description** - 269 1SW and 292 MSW fish tagged at Mactaquac and released at Woodstock to assess the efficiency of the Tobique-Narrows fishway. **Results** - Not reported.
(Jones and Flanagan 2007)	Turbine passage Spillway passage Delayed migration	Mark-recapture Mark type: Acoustic tag n = 77	**Description** - Study conducted to monitor the downstream movement of pre-smolts captured and released upstream of the Tobique-Narrows headpond- 77 Tobique pre-smolts tagged in fall 2006 **Results** - 57 descended Tobique, 13 overwintered in Tobique headpond, 7 were not detected again (post-surgery mortality or predation). - Decreased migration rate in the Tobique headpond (1.9 km/day) compared to the free-flowing river (6.6 km/day). - 15 (26%) of the pre-smolts that passed the Tobique-Narrows also passed the Beechwood Dam. - Mortality for spillway passage was 0% (acute) and 18% (delayed). - Mortality for turbine passage was 10% (acute) and 21% (delayed). Estimated mortality was presented as a range: turbine and spillgate passage combined (8-28%) or turbine only (10-31%).

Atlantic Salmon (continued)			
(AMEC 2013)	Turbine Passage Spillway Passage Delayed Migration	Mark-recapture Mark type: Acoustic tag n = 120	**Description** - Study of pre-smolt passage under different operation (discharge) scenarios at Tobique. - Scenario 1: turbine 1 (25%)/Turbine 2 (25%)/spillway 5 (50%). Scenario 2: turbine 1 (0%)/Turbine 2 (50%)/spillway 5 (50%). - 120 pre-smolts tagged and released upstream, 19 released downstream of Tobique. **Results** *Mortality associated with different passage routes* - Turbines 1 and 2, combined = 12.0%. - Turbine 1 = 10.5%. - Turbine 2 = 12.9%. - Spillgate 5 = 11.1%.
Gaspereau (Alewife and blueback herring)			
(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities.
(Ingram 1980)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976).
(Ingram 1985)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
(Ingram 1987)	NA	Monitoring	- Counts from Beechwood (1977-1982).
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
(Jessop 1990a)	Delayed Migration	Observational	**Description** - Narrative account of Gaspereau returns to Mactaquac prior to the commercial Gaspereau harvest and active fishery management. **Results** - After the Gaspereau population had rapidly increased and prior to beginning the commercial Gaspereau harvest at Mactaquac (1971-1974), the Mactaquac fish collection facilities could not clear the fishway rapidly enough to avoid delays of Gaspereau (and Atlantic Salmon). - From 1971-1974 the Gaspereau run extended to mid-July when it was typically done before the end of June.

(Jessop 1994)	Fallback	Mark-recapture Mark type: Floy anchor n=23,230	**Description** - Fallback of Gaspereau below Mactaquac (1973 and 1977). **Results** - Fallback below Mactaquac dam estimated to be <0.1%. Release location 500m upstream.
Gaspereau (Alewife and blueback herring) - continued			
(Jessop 2001)	NA	Stock Management	**Description** - Gaspereau stock management and return history at Mactaquac. **Results** - Large variation in Gaspereau returns from 1974 to 1994 was partially a result of management (changing escapement targets) and natural variability.
American Shad			
(Jessop 1975)	Fishway passage	Monitoring	**Description** - length, weight, sex, age of American shad at SJR sampling locations (1972). - Estimated numbers of American shad passed at Beechwood and Mactaquac dams, 1957-1974). - Commercial catch statistics (1950-1974). **Results** - Problems with attraction flow at Tobique and Beechwood. - Elevation and water velocities between pools greater than optimal at the Tobique-Narrows fishway. - 25% mortality of Shad released to the Mactaquac headpond. - Decline in the number of American Shad returning to Mactaquac was likely accentuated by fishing pressure. However, the major causes appear to involve the biology of the population, the difficulties of fish passage at hydroelectric dams and the impact of adverse environmental conditions on the success of reproduction.
(Ruggles and Watt 1975)	Fishway passage	Effects	**Description** - Uses fishway counts of American Shad to demonstrate their rapid decline after Tobique-Narrows, Beechwood, and Mactaquac were built. **Results** - Presence of Shad at Tobique fishway noted for a few years after construction but a rapid decline after completion of Beechwood. - Beechwood fishway recorded 1,487 Shad in 1960 and 0 in 1967. - Mactaquac fishway recorded 38,838 Shad in 1968 and 7,363 in 1973. - Reasons for the collapse of Shad populations are unclear but inadequate upstream fish passage has had an impact.
(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities.

(Ingram 1980)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976).
(Ingram 1985)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
American Shad (continued)			
(Ingram 1987)	NA	Monitoring	- Counts from Beechwood Dam (1977-1982).
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
Striped Bass			
Smith 1979	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities.
Ingram 1980	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
Ingram 1981	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976).
Ingram 1985	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
Ingram 1990	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
Jessop 1990	Fish Passage	Status Report	**Description** - Describes current status of Striped Bass population in the Saint John River **.Results** - Partially attributes Striped Bass population decline to the construction of Mactaquac because of impact on spawning grounds. - Notes that Striped Bass no longer ascend Beechwood indicating inadequate fish passage.
Sea Lamprey			
(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities.
(Ingram 1980)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976).
(Ingram 1985)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
(Ingram 1987)	NA	Monitoring	- Counts from Beechwood (1977-1982).
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
American Eel			

(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976).
(Ingram 1987)	NA	Monitoring	- Counts from Beechwood (1977-1982).
American Eel (continued)			
(Jessop and Harvie 2003)	Fish Passage	Effects	**Description** - Analysis of change in discharge pattern downstream of Mactaquac after the installation of two additional turbines in 1980 and how these changes may have affected the migration of American Eel elvers **Results** - Changes in discharge patterns downstream of Mactaquac in 1980 correspond to the failed arrival of American Eel elvers after this year. - Analysis indicated that changed discharge patterns were capable of stopping American Eel elver migration to the dam, or delaying migration until the urge to swim upstream has passed and could account for the failed arrival of elvers since 1980.
Landlocked Salmon			
(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities.
(Ingram 1980)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976)
(Ingram 1985)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
(Ingram 1987)	NA	Monitoring	- Counts from Beechwood (1977-1982).
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
Rainbow Trout			
(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) fish collection facilities.
(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976)
(Ingram 1987)	NA	Monitoring	- Counts from Beechwood (1977-1982).
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
Smallmouth Bass			

(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities.
(Ingram 1980)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976)
(Ingram 1985)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
White Suckers			
(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities.
Suckers (continued)			
(Ingram 1980)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976)
(Ingram 1985)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
(Ingram 1987)	NA	Monitoring	- Counts from Beechwood (1977-1982).
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
Chain Pickerel			
(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities.
(Ingram 1980)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976)
(Ingram 1985)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
(Ingram 1987)	NA	Monitoring	- Counts from Beechwood (1977-1982).
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
Lake Whitefish			
(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities.

(Ingram 1980)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976)
(Ingram 1985)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
(Ingram 1987)	NA	Monitoring	- Counts from Beechwood (1977-1982).
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
Brown Trout			
(Ingram 1980)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
(Ingram 1985)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).
Brook Trout			
(Smith 1979)	NA	Monitoring	- Counts at Beechwood (1957-1971) and Mactaquac (1967-1971) fish collection facilities.
(Ingram 1980)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1972-1976).
(Ingram 1981)	NA	Monitoring	- Counts at Beechwood (1972-1974 and 1976)
(Ingram 1985)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1977-1982).
(Ingram 1987)	NA	Monitoring	- Counts from Beechwood (1977-1982).
Brook Trout (continued)			
(Ingram and Ensor 1990)	NA	Monitoring	- Counts from Mactaquac fish collection facilities (1983-1988).