Lower Churchill Hydroelectric Development
Freshwater Fish Habitat Compensation Plan
Muskrat Falls

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1 BACKGROUND

Nalcor Energy (Nalcor) has proposed to develop the remaining hydroelectric potential of the lower Churchill River by developing hydroelectric generating facilities at Muskrat Falls and Gull Island with a combined capacity of over 3,000 MW (**Figure** 1.1). Interconnecting transmission lines will be installed between these generating sites and the Upper Churchill Falls Generating Station. Gull Island and Muskrat Falls are approximately 100 km and 30 km southwest of Happy Valley-Goose Bay, respectively. The Muskrat Falls portion of the project will result in the creation of a reservoir with a surface area of 101km^2. The total area to be inundated will be 41km^2, representing a 65-70 percent increase in the existing waterbody surface area.

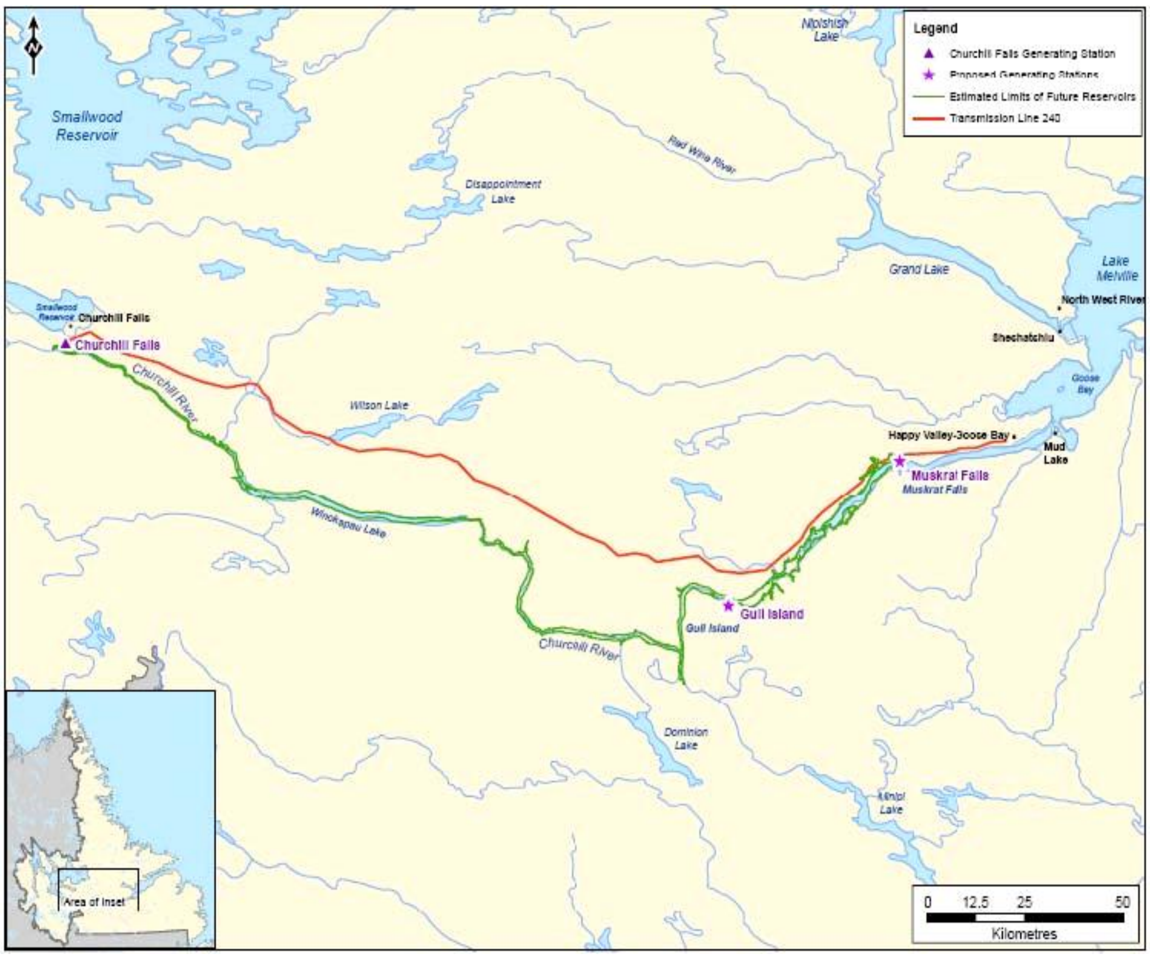


Figure 1.1 The lower Churchill River and proposed Muskrat and Gull facility locations.

As part of the Environmental Assessment and permitting process, Nalcor has been developing a Freshwater Fish and Fish Habitat Compensation Plan since 2006. The stages of Plan development included the completion and submission to Fisheries and Oceans Canada (DFO) of a Fish Habitat Compensation Framework ("Framework") in 2009 and the completion and submission to DFO of a Fish

Habitat Compensation Strategy ("Strategy") in May 2010. Both documents underwent review by DFO and their consultants as well as stakeholders through a series of Technical Workshops held in St. John's and Goose Bay. Comments, clarification and edits were incorporated and final documents submitted to DFO. These documents were also submitted to the Panel Hearings as Information Requests (IRs). Specifically, the Framework was submitted under IR JRP.107 and the Strategy was submitted under JRP.153. All Panel Hearing Information Requests referenced in this document can be located in a compendium of additional information (AMEC 2012).

The current construction schedule has Muskrat Falls being built first, followed by Gull Island. The timing of construction between the two facilities is such that two separate fish habitat compensation plans are being developed. This document addresses Fish Habitat Compensation for only the Muskrat Falls portion of the Lower Churchill Hydroelectric Generation Project. This allows the required level of engineering to be completed for Muskrat Falls in a timely manner and also allows results of initial monitoring to be incorporated into ongoing planning. This Plan has been prepared by a team of fisheries biologists and design engineers and is based on extensive fisheries surveys, fish habitat compensation expert experiences, other relevant studies, consultation with DFO, and consultation with stakeholders.

Existing baseline data collected since the 1970s as well as site/project-specific data collected since 1998 is included in the development of this Fish Habitat Compensation Plan. Nalcor has engaged Fisheries and Oceans Canada (DFO) from the beginning of this process, and will continue to integrate their review comments and to draw on their expertise throughout compensation planning, implementation of compensation works, and monitoring/management programs.

The Lower Churchill Hydroelectric Generation Project has been under consideration since the construction of the Churchill Falls Generating Station in 1971. Since that time, baseline studies have been conducted to characterize and quantify the aquatic habitat within and near the project footprint. Studies have intensified since 1998, not only for habitat characterization and species utilization, but also for post-project predictions on habitat stability and utilization once the project is completed, particularly within the areas of the reservoirs. Habitat quantification has been completed and a Harmful Alteration, Disruption or Destruction (HADD) determination provided by DFO. The size of the project and the multi-species composition has necessitated the formation of a Fish Habitat Compensation Strategy that incorporates an adaptive management approach. The approach includes extensive quantitative and qualitative analysis, modeling, baseline data, and monitoring to maximize compensation effectiveness. It also includes physical compensation works to allow for more rapid stabilization and increased utilization/function of important habitat types within the lower Churchill River drainage. Physical compensation works offset a portion of the losses resulting from the HADD of fish habitat and will also augment and enhance post-Project habitat.

While monitoring for **Environmental Effects (EEM)** such as mercury accumulation, turbine entrainment, and downstream effects will be included in the *Fisheries Act* Authorization application, it is not strictly associated with Fish Habitat Compensation and is therefore provided in a separate document.

It should be noted that two major tributary delta habitat construction areas are described within the Plan; however, based on existing data, Pinus River delta is the primary physical works associated with delta construction as it will be the delta used by most species. Because of the adaptive and cautious nature of the plan, Edward's Brook is being constructed as an adaptive investment (i.e., a habitat bank) of additional habitat beyond what is considered required. It is included so that it is available to fish, and its results applied to the offset of the HADD determination, should the Pinus River delta habitat underperform. This is a conservative approach as once the reservoir is created, additional delta habitat construction will be impossible.

1.1 PROJECT CONSTRUCTION SCHEDULE

Overall construction timeframe for Muskrat Falls has been estimated at seven years (IR response JRP#165 - CEAA 2011) with full inundation being completed in the final year (end of year seven). The construction schedule has changed considerably since the quantification of existing aquatic habitat and the Fish Habitat Compensation Strategy were submitted. The project schedule has been revised to now begin with the construction of Muskrat Falls, followed by Gull Island which will change the timing of habitat inundation. In terms of overall effects, they were determined to be relatively unchanged regardless of construction sequence (see IR response JRP#165 - CEAA 2011). The order of fish habitat compensation works has been re-arranged to match the reservoir construction sequence (i.e., Muskrat Falls first); however, the overall approach remains the same. It should be noted that if there is delay in construction between Muskrat Falls and Gull Island, the monitoring for Muskrat Falls will continue and inform on the ongoing success of various compensation options and will allow opportunity for further adaptation and/or modification of ongoing planning for Gull Island. Construction at the Muskrat Falls site (i.e. bulk excavation) is scheduled to begin in January 2013. The river will be diverted through the spillway structures, to allow for construction of the main dam, at the end of the 2015 season (i.e., September 2015).

1.1.1 Reservoir Preparation

An overview of reservoir preparation timing and methods are provided in IR response JRP#148 (CEAA 2010 – see AMEC 2012). Generally, Muskrat Falls reservoir preparation (timber removal) will begin in 2013 for the Muskrat Falls facility. Work will begin near the Muskrat Falls facility location (i.e., at Muskrat Falls) and continue upriver toward Gull lake which is the upper extent of the Muskrat Falls reservoir.

1.1.2 Diversion Head Pond Formation

Conditions at Muskrat Falls (water velocity and temperature) have the potential to form frazil ice in and around the Muskrat Falls construction area. Frazil ice typically backs up against stable ice cover conditions just downstream of Muskrat Falls and forms a hanging dam below the falls. In some winters this ice can back up to the base of the falls such that the falls can be flooded out when water levels rise upstream (more the 20 m asl in some years). This was identified as a serious concern for construction because if this were to happen, the construction site would be flooded and possibly washed away. The issue was identified within the Environmental Assessment process however, little detail was provided. Since that time, construction design strategies have been advanced. As a result, a portion of the Muskrat Falls reservoir will be inundated once the spillway structure is constructed. That is, the water level within the reservoir will be increased to 25m elevation in September 2015 and will remain at that elevation until full inundation in mid-July 2017. The Diversion Head Pond (Head Pond) will allow a stable ice cover to form upriver of the Muskrat Falls construction site and prevent frazil ice from forming. The water surface elevation of 25m was chosen as the height needed to slow the water velocity to a point where a stable ice cove forms. The formation of the Head Pond is incorporated into the Fish Habitat Construction Works described within the Plan as well as the overall monitoring schedule. Using GIS, approximately 30-35% of the total HADD associated with Muskrat Falls reservoir would be within the Diversion Head Pond. For example, a total of 234.6ha of fast velocity main stem and 3.8ha of stream habitat would be included (**Figure** 1.2).

2 ENVIRONMENTAL PROTECTION AND MITIGATION

The intent of the Fish Habitat Compensation Plan is to offset losses of fish habitat/function associated with the project. This is accomplished by utilizing appropriate mitigation methods during construction and by compensating for any habitat losses or alterations, after mitigations have been applied. Provided below are outlines of mitigation methods associated with many of the project and Fish Habitat Compensation construction activities. Additional details are provided in the referenced documents, particularly the Environmental Protection Plan (EPP).

2.1 MUSKRAT FALLS FACILITY CONSTRUCTION METHODS

Provided below are construction summaries of aspects related to Muskrat Falls that will interact with fish and fish habitat; reservoir preparation and impoundment. Where possible, the reader is referred to applicable Information Request responses or other documents that further describe these processes.

2.1.1 Reservoir Preparation

The scope of reservoir preparation is described in IR JRP#148 and includes:

- Mechanical operations to clear approximately 2,000 ha of area in the Muskrat Falls Reservoir. Clearing will consist of the cutting, to within 15 cm or less of the ground, of brush, merchantable and non-merchantable timber and debris, the removal of fallen trees, and the cutting, removal and stockpiling of merchantable timber within identified areas.
- Construction of approximately 130 km of forest access roads. Several access points will commence directly from the Trans Labrador Highway or other existing roads to the area designated for clearing. Shorter sections of access road east and west will be constructed along the bank of the reservoir.

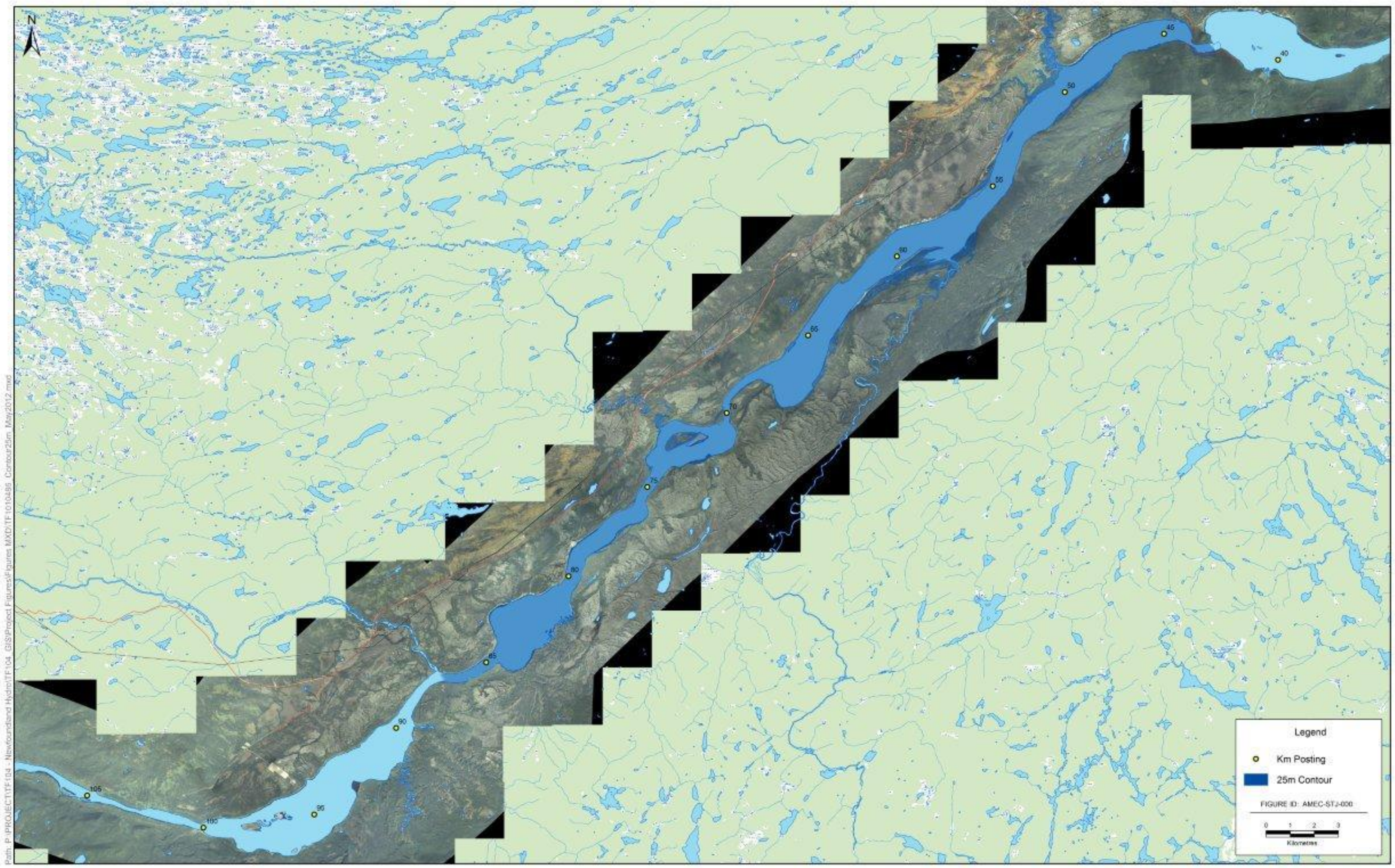


Figure 2.1. GIS delineation of 25m Diversion Head Pond, Muskrat Falls reservoir.

- Design, supply and installation of short and long span panel bridges.
- Supply and installation of pipe culverts.
- Clearing and preparation of approximately 20 storage yards to stockpile processed wood.
- Merchantable wood will be felled full-tree, skidded to roadside and processed at roadside to the tree-length form. (Note: Tree-length wood is the complete tree with the limbs and top removed). Merchantable wood consists of sound trees with a top diameter of not less than 9.1 cm. All merchantable wood shall be salvaged.
- Merchantable wood will be trucked to storage yards and piled.
- Non-merchantable wood will be felled and skidded to roadside.
- When possible, dead falls (wind thrown trees) will be skidded to roadside as non-merchantable wood.
- Non-merchantable wood (including dead falls) and slash from processing merchantable wood will be mulched and the mulched fibre left at roadside.
- Areas of dead falls not skidded and shrub alder and willow will be mulched wherever they occur within the ice and stickup zones and the mulched fibre will be left.
- Mulching of brush, slash from processing, non-merchantable timber and debris is the only acceptable method of disposal. The Burning of any material, for the purpose of disposal, will not be permitted within the project area. The mulched material will be spread evenly throughout cleared areas.
- Maintenance of vegetated buffer zones around water courses.
- Rehabilitate access roads and remove stream crossing structures upon completion and demobilization of cleared areas.

2.1.2 Reservoir Impoundment

The reservoir impoundment process will have potential effects on both downstream and within-reservoir fish and fish habitat. Upon completion of the spillways and other powerhouse infrastructure, the water level behind the facility will be raised to offer ice and debris protection for the remaining construction. Increasing the water level will provide a stable ice cover in winter creating the Head Pond. As currently designed, the water level will be raised to an approximate elevation of 25m in September 2015. Therefore the diversion head pond will be needed for the last two years of construction (full inundation will occur in mid-July 2017). Once formed, the head pond will be maintained until final reservoir impoundment, as drawdown between each winter would require create increased risk of bank instability and slumping. This would in turn increase TSS/turbidity and reduce habitat suitability for those final years of construction.

2.2 ENVIRONMENTAL PROTECTION PLAN

Nalcor has an Environmental Protection Plan (EPP) that is not only applied to all activities associated with the construction at the hydroelectric facilities, but activities that are associated with the Project at other locations. The provisions of this EPP will also be applicable to all works with respect to Fish Habitat Compensation as described in this document. This will eliminate or reduce environmental effects of many project activities on the aquatic environment during both construction and operation. The detailed protection and mitigation measures applicable to freshwater fish habitat are provided in the EPP and summarized as follows:

- Implement a "no fishing policy" for employees while working on the Project;
- Where discharge occurs into freshwater, it will undergo treatment and compliance with applicable regulations;
- Limiting, where practicable, project activities within the lower Churchill River watershed (as well as all other watersheds where construction and Fish Compensation works are to occur);
- Consolidation of facilities and reduction of areas of disturbance;
- Minimize alteration of surface water and groundwater patterns and flow;
- Compliance with the Environmental Protection Plan (EPP) for sediment control, road grading and drainage, blasting, excavation and dredging, and road de-icing;
- Education and training of personnel and protection of fish habitat with regards to best practice;
- Adherence to applicable federal and provincial regulations and policies;
- Design of any forest harvesting to control erosion;
- Design of stream crossings to reduce habitat alteration and facilitate fish passage;
- Limit/monitor construction and project operations near waterways during sensitive periods for fish (e.g., avoidance of spawning/incubation periods);
- Completion of all annual instream compensation works between June 15 and September 30;
- Water intakes to include appropriate fish screens; and
- A Relocation Plan to remove fish from areas of construction, and/or de-watering when there is the potential for them to become stranded (e.g., during reservoir filling).

3 FISH HABITAT LOSSES

Freshwater habitat losses are related to the loss of habitat within the footprint of the Muskrat Falls Hydroelectric Facility as well as the harmful alteration of fish habitat, as determined by DFO, within the Muskrat Falls reservoir.

As summarized in the Habitat Quantification Report (AMEC 2007), many studies have been conducted in order to document aquatic habitat and habitat utilization in the Project area. The results from these studies provide a quantification of aquatic habitat and describe its utilization in terms of fish species and life stages. In order to properly describe the habitat losses and harmful alterations, a description of the existing fish assemblage and all fish habitat that will be affected by the Muskrat Falls facility and reservoir is presented in the section below. Baseline data continues to be collected on fish habitat utilization and fish health for incorporation into the Adaptive Management portion of this Fish Habitat Compensation Plan (see **Section** 5.3).

3.1 EXISTING AQUATIC HABITAT

The proposed Muskrat Falls portion of the Project is located within the lower reaches of the Churchill River, Labrador. In order to put post-Project fish habitat utilization in context, a description of the existing fish habitat and utilization is necessary. The following section provides a general description of the existing environment in the lower Churchill River within the location of the Muskrat Falls facility and reservoir. This section is a summary of the many reports and readers are referred to the individual baseline and component studies for further details. AMEC (2012) presents a complete digital air photo series of the lower Churchill River and the aerial extent of the proposed reservoirs.

3.1.1 Flow Regime

The existing range of flow downstream of Muskrat Falls is presented in **Figure** 3.1. As part of the Churchill Falls generating facility, the Naskaupi and Kanairiktok Rivers were partially diverted into the Smallwood reservoir and hence the Churchill River valley. This effectively increased the drainage area of the watershed by 14% and hence the Mean Annual Flow (MAF). Current MAF through the Churchill Falls powerhouse is 1,365m^3/s (typically ranging between 1,092m^3/s in June and 1,743m^3/s in January). All water is discharged back into the lower Churchill River once passed through the turbines. The Churchill Falls Generating facility controls 69,267km^2 (i.e. the upper Churchill drainage basin), which is 75% of the total drainage area of the Churchill River. Inflows in the upper basin are stored and released from the Smallwood and Ossokmanuan reservoirs for hydroelectric generation.

As a result, the outflow from the upper Churchill drainage basin is higher in winter (when energy demand is higher) and lower in late spring and summer when compared to flows prior to the development. This has resulted in a less variable flow regime over the course of the year, both seasonally and monthly. This dynamic of flow moderation has been in operation and influencing the lower Churchill River for close to 40 years. Despite the overall moderation in flows, high spring runoff still occurs partly as a result of the many large tributaries that feed the lower Churchill River downstream of the Churchill Falls tailrace.

The lower Churchill drainage basin is characterized by steep tributary slopes and little natural storage such as lakes and bogs when compared to the upper basin. The MAF is estimated at 1,840m^3/s at Muskrat Falls. The hydrology of the lower Churchill River drainage basin is affected by the operation of the existing Churchill Falls facility and regional climate. The climate results in a seasonal runoff with inflows being highest in the spring (typically peaking in May or June) and lowest in late winter. Inflows in the remaining lower 23,088km^2 (i.e. the lower Churchill drainage basin) are not controlled, and follow this natural runoff pattern.

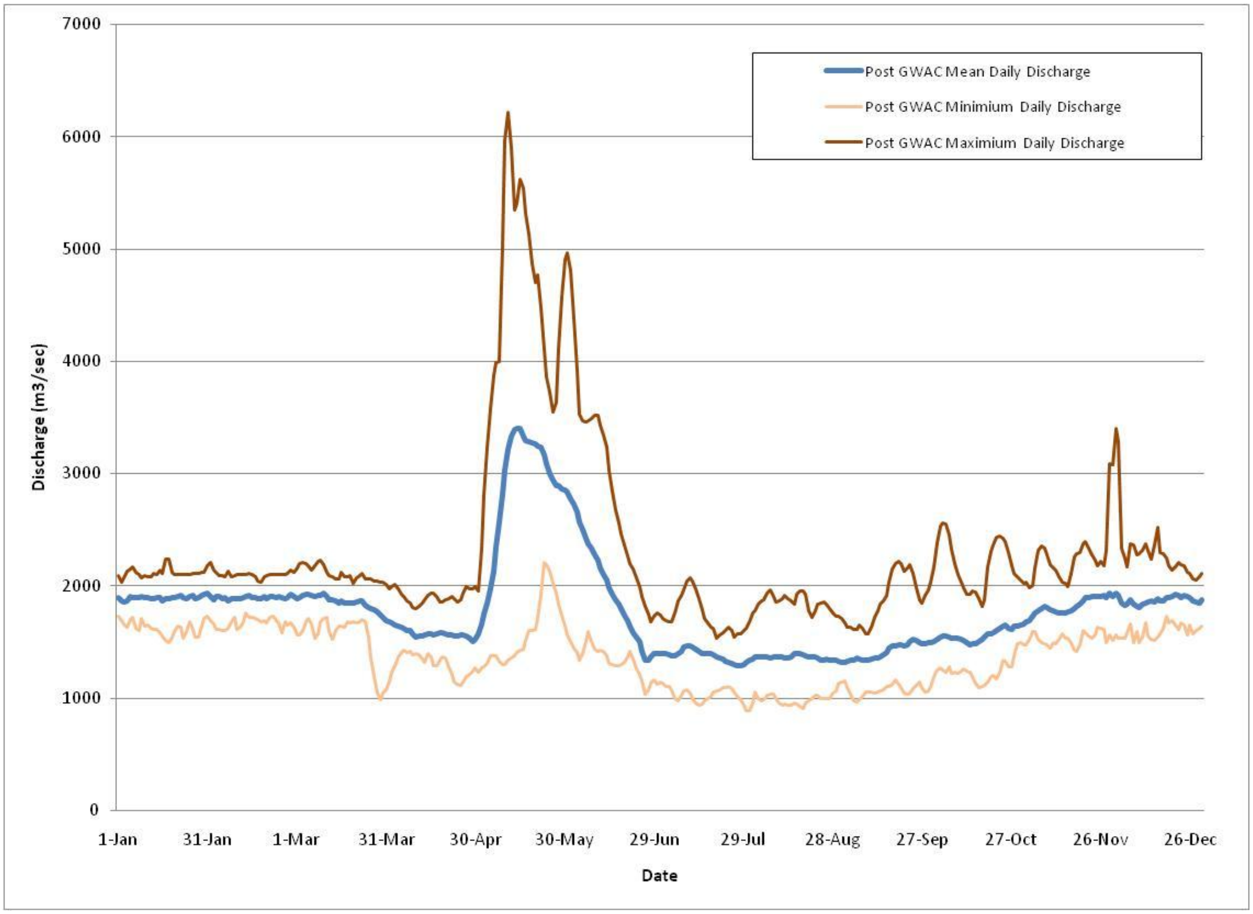


Figure 3.1. Mean daily flow at Muskrat Falls – existing flow range, 1998-2009. GWAC=1999 Guaranteed Winter Availability Contract.

3.1.2 Habitat

The lower Churchill River refers to that overall stretch of river below the existing Churchill Falls Generating Facility (see **Figure** 1.1). The Churchill River is the largest river in Labrador; it is approximately 856km long, from its headwaters at the boundary of the Labrador/Quebec border, running in a general west to east orientation to Lake Melville, which flows into the Labrador Sea.

The headwaters of the Churchill River are located along the western boundary of Labrador, occurring within the upland plateau of interior Labrador before dropping sharply at Churchill Falls. The geological substructure of Labrador is primarily Precambrian bedrock of the Canadian Shield. With the retreat of ice sheets following the last glaciation, the land mass previously underneath the ice sheets has been slowly rising. The valley of the Churchill River is deeply incised into the surrounding upland. The lower stretches, including the vicinity of Muskrat Falls, are characterized by marine sediments including clays and silts in terraces and deposits above current sea level. Extensive deltaic sand deposits occur in the vicinity of Happy Valley-Goose Bay and the outflow at Lake Melville.

As the land slowly became exposed following glaciation, plant species extended their ranges northward. The terrestrial, freshwater and marine ecosystems that subsequently developed in the Churchill River valley and watershed are the result of biological colonization, geography and climate. Many freshwater species have extended into the Churchill River valley from the East as glaciers retreated (Black *et al*. 1985). The climate in the Upper Lake Melville area tends to be relatively moderate, with temperatures at the mouth of the Churchill River, in Happy Valley-Goose Bay, ranging from a daily average of -17.3°C in January to 15.5°C in July. Temperatures become cooler upriver of the Upper Lake Melville area, and at higher elevations. The Churchill River valley typically receives approximately 1,000mm of precipitation annually, 45 percent of which falls as snow.

Most studies conducted within the lower Churchill River as part of the assessment and baseline data collection have been conducted with the river divided into large segments based on river morphology and aspects of the Projects. **Figure** 3.2 provides the five basic segments of the main stem of the lower Churchill River.

The Muskrat Falls reservoir is located entirely within the section of river defined as Section Two. Detailed descriptions of the other sections are provided in the Fish Habitat Compensation Strategy (AMEC 2010). **Section Two** of the river includes the main stem between Muskrat Falls and Gull Island (i.e. the proposed Muskrat Falls reservoir location). This section is relatively slow flowing (estimated mean water velocity of 1.3m/s) compared to other river sections, shallow (estimated mean water depth of 6.0m), and wide (mean width estimated at 1.0km) with a bottom substrate composition dominated by sand and finer material (80% sand). **Figure** 3.3 presents typical shoreline and substrate conditions in this section of river. Similar to habitat below Muskrat Falls, this river section is also rich in suspended sediments compared to those further upriver; concentrations have been recorded from <5 to 77mg/L within this area, with a mean of approximately 18mg/L. Highest concentrations are measured during spring when runoff from the watershed typically increases (Minaskuat 2007). The higher composition of finer substrates results in naturally increased turbidity. While the majority of the river segment is shallow, a small portion of Gull Lake is relatively deep (bathymetric mapping indicates a maximum depth of 58m). The deeper portion of Gull Lake is maintained by the same frazil ice process as that which maintains the deep pool below Muskrat Falls.

The most complex ice processes in the Churchill River generally occur between Gull Island and Goose Bay. The portion of the lower Churchill River downstream of Gull Island to Muskrat Falls typically has enough water velocity to prevent a complete ice cover from forming, except for border ice, and stationary ice covers that form in the slow-flowing stretches at Sandy Island Lake and Gull Lake. The open fast-flowing water generates large amounts of frazil, slush and pan ice, which are then carried downstream.

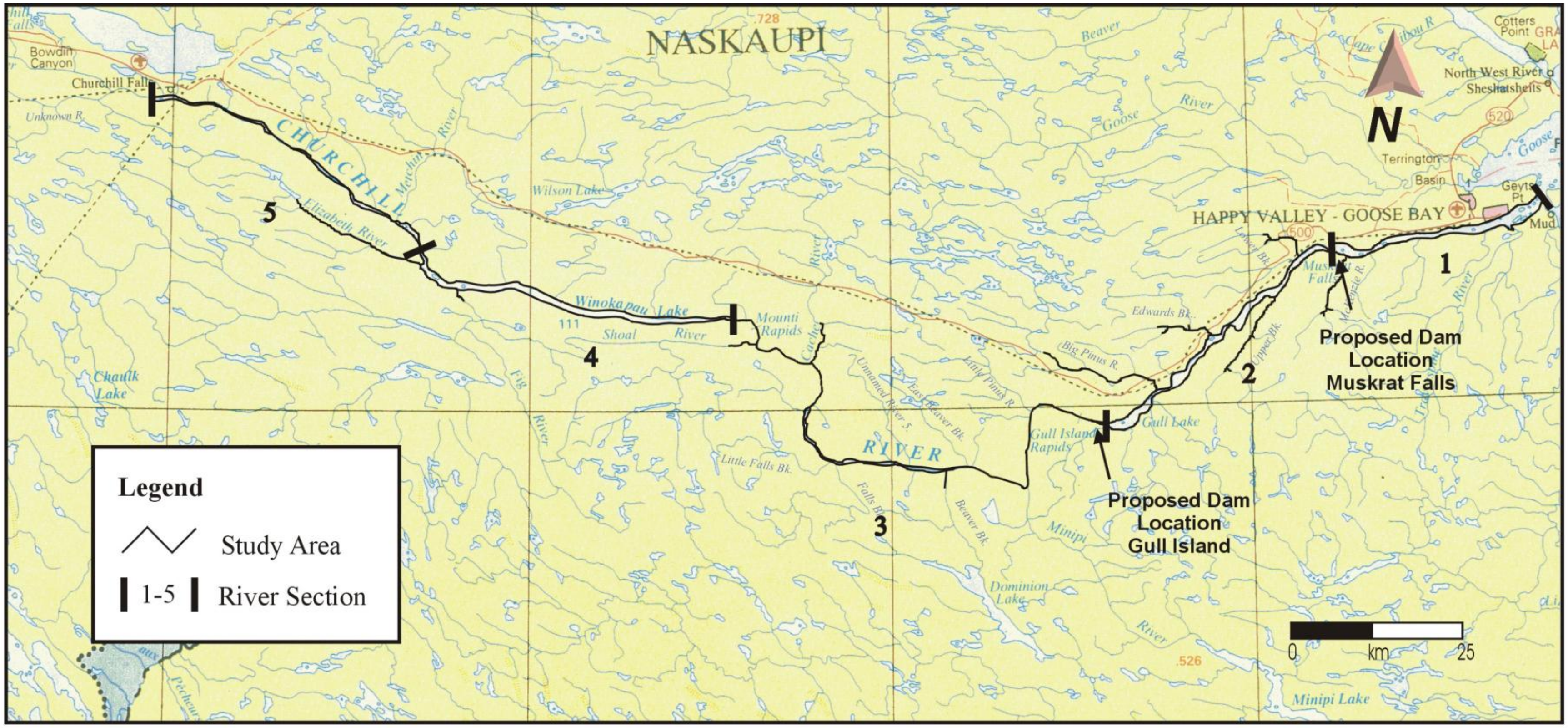


Figure 3.2.General Project area with outlined river sections.

Figure 3.3. Typical shoreline and bottom substrate, Section Two Churchill River.

Larger tributaries emptying into this main stem section include Edward's Brook, Lower Brook, Upper Brook and Pinus River.

3.1.3 Classification, Availability and Distribution

A description of the distribution and quantity of each aquatic habitat type in the main stem and tributaries of the proposed Muskrat Falls reservoir area is presented in **Figure** 3.4. Furthermore, a complete series of digital air photos is provided in AMEC (2012). Fish habitat was classified in the lower Churchill River using physical characteristics that are typically used to describe the biological suitability of aquatic habitat; that is water velocity, substrate composition, and water depth. The key variable in the classification of the habitat types is water velocity because it is easily measured and affects other characteristics such as bottom substrates and shape of the river (Newbury and Gaboury 1993). The habitat types within the lower Churchill River have been sub-divided into five general classifications; main stem riverine, tributary riverine, tributary stream, main stem lacustrine and estuarine. AMEC (2007) provides additional details regarding the habitat quantification method. Mean physical characteristics of tributary and each main stem habitat type, as described using the available transect/HECRAS model results, are provided in **Table** 3.1. Substrate compositions are also provided.

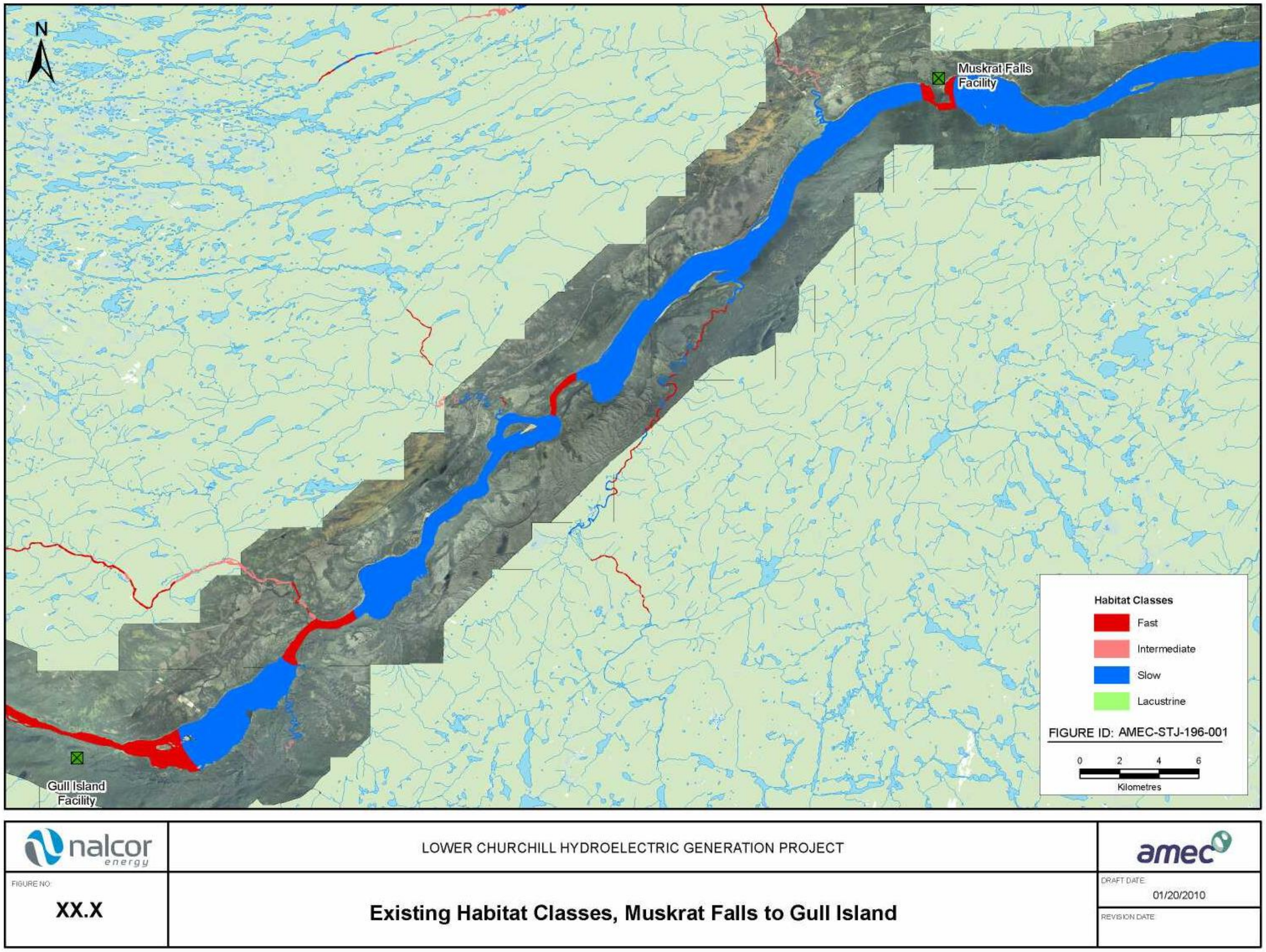


Figure 3.4.Existing Habitat Classification, Muskrat Falls to Gull Island (Muskrat Falls reservoir).

Table 3.1. Summary of existing habitat within Section Two (Muskrat Falls reservoir area), lower Churchill River. Range of measures provided in parentheses.

Section	Habitat Classification	Existing Habitat (ha)	Mean Water Velocity (m/s)[1]	Mean Water Depth (m)[1]	Mean Substrate Composition (%)						
					Bedrock	Boulder	Rubble	Cobble	Gravel	Sand	Mud/ Organic
Section Two (Muskrat Falls Reservoir: Muskrat Falls to Gull Island Rapids)	Slow	5,590.41	**0.65** (0.04 - 2.37)	**9.6** (1.9 - 57.7)	0.0	0.0	9.3	10.0	0.0	80.7	0.0
	Fast	774.26	**2.23** (0.71 - 12.04)	**6.4** (2.8 - 13.5)	2.1	12.5	25.1	39.9	5.3	15.1	0.0
Tributary	Slow	112.39	**0.60** (0.15 – 1.04	**0.84** (0.2 – 2.0)	0.0	12.7	28.3	50.9	4.8	3.3	0.0
	Intermediate	26.42	**1.00** (0.12 – 1.81)	**0.81** (0.3 – 2.50)	0.0	26.1	33.6	37.1	3.0	0.3	0.0
	Fast	11.78	**1.46** (0.54 – 3.23)	**1.01** (0.3 – 2.5)	0.3	20.0	21.3	31.6	20.4	6.7	0.0

[1] Values from established transects and HECRAS modeling at Mean Annual Flow (MAF).

3.1.4 Fish Assemblage

There have been extensive fish and fish habitat investigations within the Lake Melville area and the lower Churchill River by various investigators over the last four decades. These extensive surveys provide the data used to describe existing as well as predicted post-Project habitat and fish utilization. Summaries of fish species present within the Lake Melville area and general life history information have been compiled from several DFO documents such as *The Rivers of Labrador* (Anderson 1985), the *Life History Characteristics of Freshwater Fishes Occurring in Newfoundland and Labrador, with Major Emphasis on Lake Habitat Requirements* (Bradbury et al. 1999) and the *Life History Characteristics of Freshwater Fishes Occurring in Newfoundland and Labrador, with Major Emphasis on Riverine Habitat Requirements* (Grant and Lee 2004). Other key information sources include the surveys completed on the lower Churchill River for previous environmental assessments (Beak 1980 and Ryan 1980), the aquatic studies conducted between 1998 and 2012 for this Project and others (AGRA 1999, AMEC 2000; 2001; 2007; 2009; Black et al. 1986; Scruton 1984). These various surveys and review works present a picture of the fish species distribution through the watershed as well as their habitat utilization. In order to put the Churchill River in a regional context, a summary of fish species within the Lake Melville and lower Churchill River system has been described in the Fish Habitat Compensation Strategy (AMEC 2010).

There have been twenty-one species listed within the freshwater habitat of the Lake Melville area by Anderson (1985). They include longnose sucker (*Catostomus catostomus*), lake whitefish (*Coregonus clupeaformis*), white sucker (*Catostomus commersoni*), round whitefish (*Prosopium cylindraceum*), longnose dace (*Rhinichthys cataractae*), rainbow smelt (*Osmerus mordax*), brook trout (*Salvelinus fontinalis*), lake chub (*Couesius plumbeus*), lake trout (*Salvelinus namaycush*), Atlantic salmon (*Salmo salar*), northern pike (*Esox lucius*), burbot (*Lota lota*), mottled sculpin (*Cottus bairdi*), slimy sculpin (*Cottus cognatus*), threespine stickleback (*Gasterosteus aculeatus*), pearl dace (*Semotilus margarita*), ninespine stickleback (*Pungitius pungitius*), American eel (*Anguilla rostrata*), Arctic charr (*Salvelinus alpinus*), Atlantic sturgeon (*Acipenser oxyrhynchus*) and northern redhorse (*Moxostoma aureolum*). This listing includes those species captured in the Churchill River upstream and downstream of Muskrat Falls as well as those recorded from other rivers draining into Lake Melville.

While distributed widely throughout North America (Scott and Crossman 1998), four of these species; the lake chub, longnose dace, pearl dace and mottled sculpin have only been found in the Hamilton Inlet region within Labrador (Anderson 1985). Anadromous migrations of species such as brook trout and Atlantic salmon are not found above Muskrat Falls as it is a barrier to upstream migration (Anderson 1985; IR JRP 52 – AMEC 2012). Four other species listed above are not found above Muskrat Falls; northern redhorse, American eel, rainbow smelt and Atlantic sturgeon. Common French and English names of all species are provided in AMEC (2012).

Table 3.2 presents a summary of the fish species that have been captured/sampled from the main stem of the lower Churchill River, by river section, as well as Goose Bay Estuary and Lake Melville since 1998.

The number of species not withstanding; total standing stock and productivity are generally low and typical of northern watersheds, reflecting low nutrient input (JWEL 1999b). Many of the fish species present are at the extreme distribution of their range, meaning that specific adaptations may be necessary to cope with stresses imposed by the natural environment. **Figures** 3.5 and 3.6 provide a summary of catch-per-unit effort (CPUE) from both gillnets and fyke nets upriver, within, and downstream of the Muskrat Falls reservoir. The fish assemblage specific to the Muskrat Falls reservoir is the focus of any predicted change caused by the Project and this Compensation Plan.

Table 3.2. Summary of fish species captured/sampled in lower Churchill River, Goose Bay Estuary and western Lake Melville since 1998

River Section (going west)	Species Captured
Lake Melville	American Plaice, Arctic Cod, Arctic Staghorn Sculpin, Atlantic Poacher, Tomcod, Capelin, Greenland Cod, Rainbow Smelt, Snakeblenny, Thorny Skate, Threespine Stickleback, Winter Flounder, Brook Trout
Goose Bay Estuary	Longnose Sucker, American Plaice, Sand Lance, Arctic Cod, Atlantic Poacher, Tomcod, Longnose Dace, Lake Chub, Lake Whitefish, Dwarf lake Whitefish, Round Whitefish, Greenland Cod, Rainbow Smelt, Rock Cod, Snakeblenny, Threespine Stickleback, Winter Flounder, Brook Trout
Section #1 (Goose Bay to Muskrat Falls)	Longnose Sucker, White Sucker, Brook Trout, Lake Whitefish, Dwarf Lake Whitefish, Northern Pike, Lake Chub, Lake Trout, Burbot, Ouananiche/Atlantic Salmon, Threespine Stickleback, Sculpin, American eel
Section #2 (Muskrat Falls reservoir – Muskrat Falls to Gull Island Rapids)	**Longnose Sucker, White Sucker, Brook Trout, Lake Whitefish, Round Whitefish, Northern Pike, Longnose Dace, Lake Chub, Burbot, Ouananiche, sculpin, threespine Stickleback, Pearl Dace (Pinus River)**
Section #3 (Gull Island Rapids to Winokapau Lake)	Longnose Sucker, Longnose Dace, White Sucker, Brook Trout, Ouananiche, Lake Trout, Northern Pike, Lake Whitefish, Lake Chub, Round Whitefish, Burbot, Mottled Sculpin, Slimy Sculpin, Threespine Stickleback
Section #4 (Winokapau Lake)	Longnose Sucker, White Sucker, Brook Trout, Ouananiche, Lake Whitefish, Lake Chub, Dwarf Lake Whitefish, Round Whitefish, Lake Trout, Longnose Dace, Burbot
Section #5 (Winokapau Lake to Churchill Falls tailrace)	Longnose Sucker, Longnose Dace, White Sucker, Brook Trout, Ouananiche, Lake Whitefish, Round Whitefish,

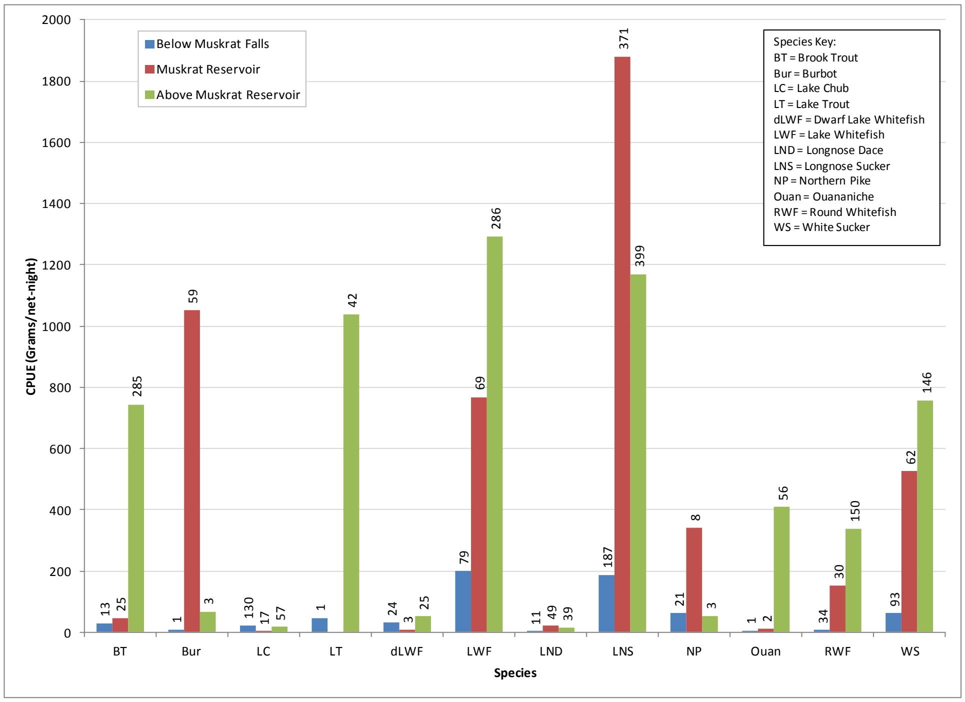


Figure 3.5. Catch-per-unit effort (CPUE) of fish species biomass captured by gillnet since 1998. Total numbers of fish captured are provided in brackets above each.

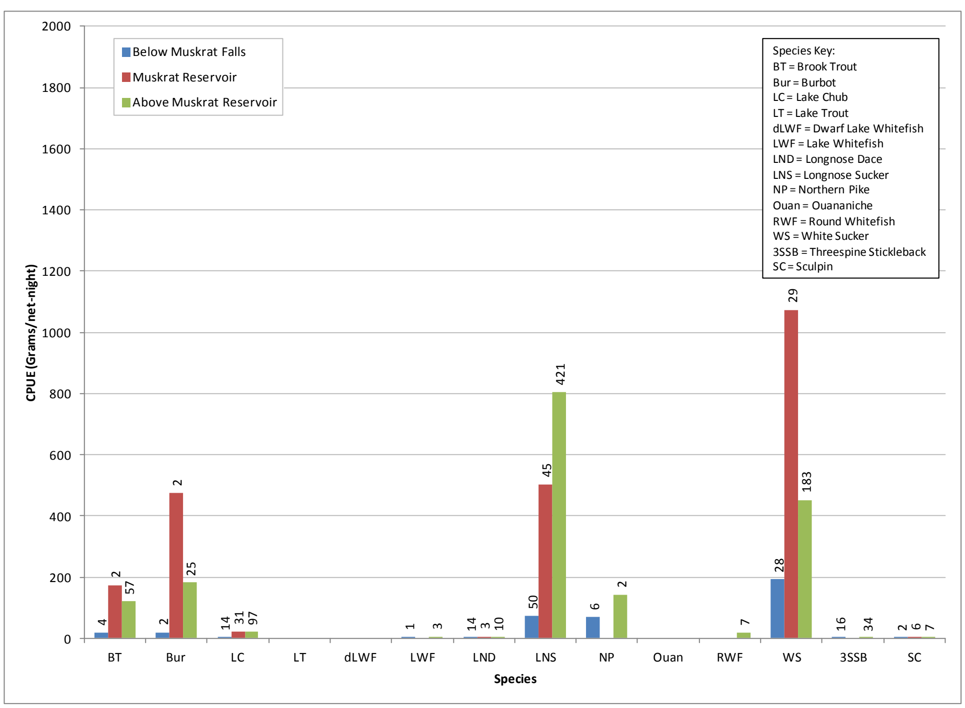


Figure 3.6. Catch-per-unit effort (CPUE) of fish species biomass captured by fyke net since 1998. Total numbers of fish captured are provided in brackets above each.

4 DETERMINED HABITAT LOSSES AND HARMFUL ALTERATION

From the outset of Project assessment and compensation planning, data has been collected to assist in achieving a *Fisheries Act* Section 35(2) Authorization. Section 35(1) of the *Fisheries Act* protects fish habitat in Canada by prohibiting its harmful alteration, disruption or destruction (HADD). Under Section 35(2) of the *Fisheries Act* the Minister of Fisheries and Oceans can allow a HADD to occur. A proponent is required to describe its project and quantify any habitat that could be affected by the proposed Project. This information assists Fisheries and Oceans Canada (DFO) in determining whether HADD will occur. If necessary, the information can also be used to provide a base for developing a fish habitat compensation (FHC) plan (DFO 2004).

In May 2008, DFO presented its HADD determination. The habitat within the determination is sub-divided into two categories; habitat that will be destroyed (i.e. will no longer have any productive capacity as fish habitat) and habitat that will be altered in terms of its characterization and hence its utilization/productive capacity. The Project includes the construction of both the Muskrat Falls and Gull Island Facilities; however, as stated previously, the Fish Habitat Compensation Plans have been separated. Provided below is the HADD determination for the Muskrat Falls portion only.

The habitat that will be destroyed includes that under the direct footprint of the Muskrat Falls generating facility; determined as 7.30 hectares (ha). This is the full aerial extent of the facility footprint.

Due to the predicted lag in stabilization and concern related to future habitat utilization within newly formed reservoirs at the time, DFO considered any altered fish habitat (in this case, existing Intermediate, Fast, Stream and Littoral habitat types) within the footprint of the reservoirs to constitute a portion of the determination. While DFO has recognized that post-project habitat will be utilized and hence to be included in the compensation planning, the determination is considered cautionary. The habitat equivalent units of these habitat types determined to be altered includes:

- 724.63 ha of riverine fast velocity habitat within the Churchill River Main Stem due to inundation/reservoir creation;
- 5.02 ha of riverine intermediate velocity habitat within the Churchill River Tributaries due to inundation/reservoir creation;
- 3.81 ha of riverine fast velocity habitat within the Churchill River Tributaries due to inundation/reservoir creation; and
- 11.57 ha of stream habitat due to inundation/reservoir creation.

The habitat distribution is shown in **Figure** 3.4. This document outlines Nalcor's plan to offset these losses through a series of physical habitat creations and enhancements that will be added to the predicted use of the reservoir by resident fish (with a detailed adaptive monitoring program to measure function, effectiveness, and to direct any required mitigations).

5 MUSKRAT FALLS FISH HABITAT COMPENSATION

Options assessment and discussions with DFO and stakeholders have determined that the more applicable compensation is that which remains within, or as close to, the ecological habitats being affected. This is also consistent with the Practitioner's Guide to Habitat Compensation (DFO 2004). On that basis, the riverine and delta options as outlined in the FHC strategy (AMEC 2010) have been pursued.

The Plan presents habitat-specific suitability criteria for each species present and demonstrates how these criteria will be met through existing post-Project habitat and habitat creation/enhancement. The intent of this approach is to conserve, to the extent possible, the existing and natural patterns of fish habitat utilization. The specific objectives and goals of this Fish Habitat Compensation Plan are:

1. *To maintain the predicted post-Project habitat within the Muskrat Falls reservoir area;*
2. *To maintain the existing species diversity within the Muskrat Falls reservoir area; and*
3. *To maintain the existing health of those fish species within the Muskrat Falls reservoir area*.

Inherent in the approach is the use of the reservoir by resident fish species. The plan follows the three-tier approach outlined within both the Fish Habitat Compensation Framework (JRP IR 107 – AMEC 2012) and Strategy (JRP IR 153 – AMEC 2012), previously submitted to DFO, submitted during panel hearings for review and discussion, and presented in stakeholder workshops. The tiers outline; the use of the reservoir by fish species, habitat creation to increase habitat function for specific life stage success, and a monitoring program that verifies predicted changes in habitat and its use by fish and lays out a process to adapt if unanticipated changes occur. All tiers of the approach require adequate baseline data for comparisons, including sampling within the Diversion Head Pond once formed. Provided below are the details of each Fish Habitat Compensation Tier.

5.1 TIER 1 - POST IMPOUNDMENT FISH UTILIZATION

There are important aspects of the proposed Project that need to be considered when addressing the potential effects of development; namely the post development fish habitat and ecology, stabilization of habitats and any possible constraints imposed by Project operation. It is also important to realize that the existing lower Churchill River is partially regulated by the Churchill Falls Generating facility and as such, the hydrology of the river, particularly in a temporal sense, is currently altered. The existing biota in the river has adapted over the past 40 years to deal with existing conditions caused by the operation of this facility such as altered flow patterns and relatively quick dewatering of nearshore habitat.

In total, 6,492ha of existing aquatic habitat will be inundated within the Muskrat Falls reservoir. Upon full reservoir inundation, it will comprise a total of 10,179ha of aquatic habitat, a net increase of **3,687ha**. Key changes related to features of the post-Project aquatic habitat that will affect the future fish assemblage include changes in water levels/velocities, water retention time within the reservoir, and operating regime. The Muskrat Falls facility will be operated as 'water in – water out' with most of the regulation, and associated water level changes, remaining in the Churchill Falls reservoirs, resulting in a minimal drawdown regime (i.e. Full Supply Level = 39m asl and Low Supply Level = 38.5m asl) for the Muskrat Falls reservoir. Owing to the nature of operations of the reservoir, there will be a gradient in future habitat conditions, from faster river habitat in the upper reaches, through to moderate-slow flows near the Muskrat Falls dam.

5.1.1 Predicted post-Project Habitat Availability

The overall available aquatic habitat within the lower Churchill River following the proposed establishment of the Muskrat Falls facility and reservoir are described below. These predictions are based on modeled characteristics related to the facility and baseline information on the river and its fish species. For example, the predicted future substrate compositions are based on reservoir shoreline mapping and existing survey data (AGRA 1999, AMEC 2000, AMEC 2001, AMEC 2007), surficial geology classifications of the new shoreline (see Appendix B of the Fish Habitat Compensation Strategy (AMEC 2010); IR#JRP.153 provided in AMEC 2012) and the expected relative quantity of shoreline within each classification.

Table 5.1 provides a summary of the general habitat characteristics for each habitat type predicted within the Muskrat Falls reservoir in terms of fish suitability. While some habitats may have similar water velocity ranges and substrate compositions to existing habitat types, the relatively deeper water depths of the Muskrat Falls reservoir will change its habitat suitability for various species. Therefore; future habitat types were further delineated within the reservoir using water depth to separate them into Nearshore (predicted habitat similar in water depth to existing similar habitat types) and Mid-Channel (predicted habitat deeper than existing habitat types). Modeled water depths within the reservoir were compared to the measured existing habitat depth ranges. Any predicted habitat type that was deeper than the existing water depth range was reclassified. As a result, each predicted post-Project habitat type has been defined as having both a Nearshore (water depths similar to existing habitat range) and Mid-channel (water depths greater than existing habitat range) component. **Figure** 5.1 presents the predicted post-Project habitat classification and distribution within the Muskrat Falls reservoir. Any habitat not within the footprint of the reservoir or facility will not be affected in terms of habitat characteristics and will remain similar to that described in the Habitat Quantification and Fish Habitat Compensation Strategy (AMEC 2010).

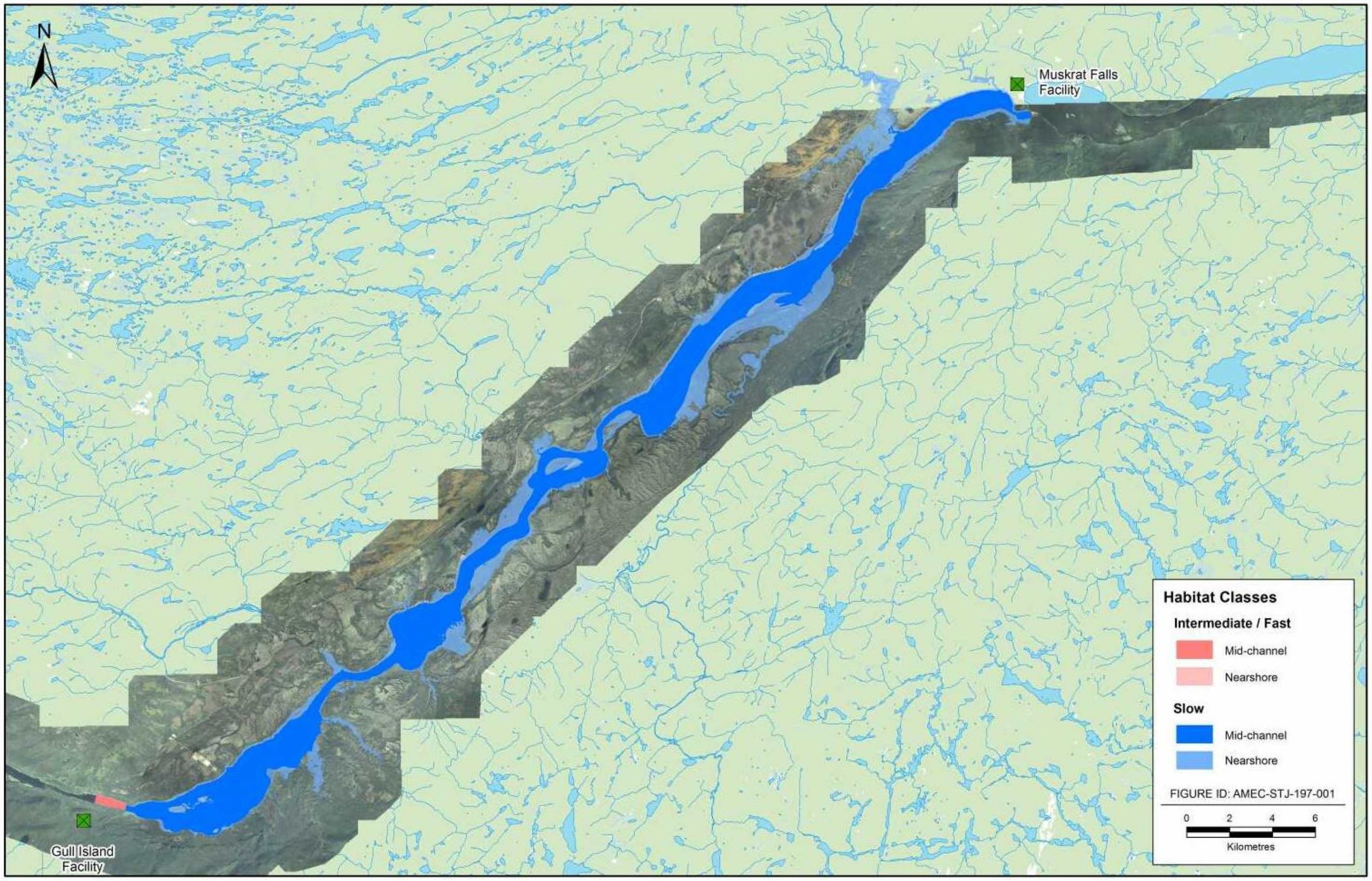
5.1.2 Predicted Effects and Changes to Fish Assemblage

The information above in **Section** 3.1.4 presents the fish species present in each river section. The predicted effects of the Muskrat Falls facility and reservoir in terms of changes in biological measures such as water quality are provided in the subsequent sections as they have been used in describing predicted effects on the fish assemblage and are important for monitoring and management. The overall predicted effect on the fish assemblage is also presented in this section.

Table 5.1. Summary of post-Project habitat, Muskrat Falls reservoir area.

Section	Habitat Classification	Habitat Area (ha)	Mean Water Velocity (m/s)	Mean Water Depth (m)	Mean Substrate Composition (%)						
					Bedrock	Boulder	Rubble	Cobble	Gravel	Sand	Mud/ Organic
Section Two (Muskrat Falls Reservoir: Muskrat Falls to Gull Island Rapids)	Slow[3]	9,262	0.12[1] (range: 0.03-0.37)	27.47[1] (range: 14.0-69.0)	0.0	0.0	9.3	10.0	0.0	80.7	0.0
	Intermediate	57	0.65[1] (range: 0.06-1.25)	9.49[1] (range: 4.8-15.32)	2.1	12.5	25.1	39.9	5.3	15.1	0.0
Tributary	Slow	832	0.60[2] (0.15 – 1.04)	0.84[2] (0.2 – 2.0)	0.0	12.7	28.3	50.9	4.8	3.3	0.0
	Intermediate	20	1.00[2] (0.12 – 1.81)	0.81[2] (0.3 – 2.5)	0.0	26.1	33.6	37.1	3.0	0.3	0.0
	Fast	8	1.46[2] (0.54 – 3.23)	1.01[2] (0.3 – 2.5)	0.3	20.0	21.3	31.6	20.4	6.7	0.0

[1] Values from established transects and HECRAS modeling at Mean Annual Flow (MAF).
[2] Values from measurements completed from established transects during surveys.
[3] Slow habitat includes both Nearshore and Mid-channel.



nalcor energy	LOWER CHURCHILL HYDROELECTRIC GENERATION PROJECT	amec
FIGURE NO: 3.5	**Predicted Future Habitat Classification, Muskrat Falls to Gull Island**	DRAFT DATE: 01/26/2010 REVISION DATE:

Figure 5.1. Predicted future habitat classification, lower Churchill River within the Muskrat Falls reservoir.

5.1.2.1 Predicted Habitat Quality

As previously described, Muskrat Falls reservoir will be contained within the segment of the lower Churchill River described as Section Two (**Figure** 3.2). The reservoir full supply water elevation (FSL) is 39m asl; low supply water elevation is 38.5m asl. This will increase the overall water level within the proposed Muskrat Falls reservoir by an average 15.4 m from 6.0 m to 21.4 m. There will be a maximum change in water depth at the downstream end of the reservoir (near Muskrat Falls) of 29.6 m. A thermocline will not form within the reservoir based on predicted water depths, velocities and turnover rate; therefore it remains characterized as riverine habitat JRP IR 54 – AMEC 2012). Within the Muskrat Falls reservoir, there will be a total of three habitat types; two Slow habitat types (Nearshore and Mid-Channel) throughout the majority of the reservoir and an area of Intermediate habitat near Gull Lake at the upriver extent of the reservoir which, based on predicted depths, has not been subdivided into Nearshore and Mid-channel (see **Figure** 5.1). The details have been provided in the Fish Habitat Compensation Strategy as well as Panel Hearing Undertaking #54 (AMEC 2010; JRP IR54 – AMEC 2012).

Both the Nearshore and Mid-Channel Slow habitat types will be similar in substrate composition to existing habitat in their respective areas (see **Table** 5.1) because the source of substrate material will remain similar. The mean velocity of these Slow habitat types have been modeled at 0.12m/s (range 0.03 - 0.37m/s) with a mean channel depth of 27.5m (range 14.0 - 43.0m) at a Mean Annual Flow (MAF) of 1,840 m^3/s.

The Intermediate habitat type is located on the upriver portion of the reservoir at the inflow of Gull Lake (**Figure** 5.1). The substrate in this section will also be maintained similar to what exists; primarily cobble and rubble (see **Table** 5.1). The mean velocity of this habitat has been modeled at 0.65 m/s (range 0.06 – 1.25m/s) with a mean depth of 9.5 m (range 4.8 – 15.3m). The lower portions of tributaries within the Muskrat Falls reservoir will be inundated and will become Tributary Slow habitat. Tributary habitat upstream of the reservoir boundary (i.e. above the 39 m elevation) will remain unaffected.

5.1.2.1.1 Shoreline Substrate Composition

Based on surficial geological mapping and sampling studies, the majority of the future reservoir shoreline will consist primarily of glacio-marine deposits and will be of a similar material that is currently present along the existing shoreline; that is, mainly sand and gravel, with fine and medium sand being the dominant sand sizes, while pebble, cobble and boulder-gravel occur in about equal proportions among the coarser deposits (AMEC 2011). Substrate compositions are based on geological investigations and substrate size classifications and therefore a comparison to those used in fish habitat classification methods is provided in **Table** 5.2.

Shorelines will slump as they stabilize and will provide sand, silt and larger substrates into the river. The majority of larger substrates will remain near the shoreline and assist in stabilization as wave energy and scour transport finer material off the shoreline into deeper portions of the reservoir. **Figure** 5.2 shows an example of natural armouring within the lower Churchill River valley where finer substrates are being removed and larger material is remaining along the exposed shoreline.

Table 5.2. Comparison of geotechnical and biological substrate size classifications.

Substrate Category	Biological Size Classes (m) (Grant and Lee 2004)	Geotechnical Size Classes (m) (AMEC 2011)
Bedrock	Continuous Solid Rock	Native Consolidated Rock
Boulder	0.25 – >1.0	>0.30
Rubble	0.14 – 0.25	
Cobble	0.03 – 0.13	0.075 – 0.30
Pebble	Range included in Gravel	0.00475 - 0.075
Gravel	0.002 – 0.03	
Sand	0.00006 – 0.002	Coarse: 0.002 – 0.00475
		Medium: 0.000425 – 0.002
		Fine: 0.000075 – 0.000425
Silt	<0.00006	<0.000075 (no plasticity)
Muck / Detritus	Organic Material	
Clay / Mud	Fine deposits between rocks	<0.000075 (plasticity)

Figure 5.2. Example of active armoring along the shoreline of the lower Churchill River valley.

The Intermediate habitat-type located on the upriver portion of the reservoir has substrate material of primarily fluvial and glaciofluvial origin. Fluvial deposits are dominantly sandy, ranging from silt to very coarse sand (fine, medium and coarse sand are most common). Pebble, cobble, boulder, and gravel are also present in higher quantities along the upper portions of Gull Lake (**Figure** 5.3). Substrate composition in this section will be maintained similar to the existing condition.

Figure 5.3. Example of shoreline substrate along the upper south portion of Gull Lake.

5.1.2.1.2 Total Suspended Sediment (TSS)

Banks, primarily within the Muskrat reservoir in the initial period after inundation, will contribute suspended sediment into the water column. Post-impoundment TSS concentrations modeled by Minaskuat (2008) indicate that initial shoreline erosion will result in an annual increase in the pulse of suspended sediment into the river within Muskrat Falls reservoir corresponding to the open water period when wave and current action would erode sediments from the shoreline. The greatest pulse of TSS is expected to occur, post-Project, during the initial year after impoundment and may be as high as 30 mg/L above baseline within the lower reach of the Muskrat Falls reservoir (**Figure** 5.4). For comparison, **Figures** 5.5 and 5.6 present examples of the Muskrat Falls area (southern shoreline near Edward's Brook) at 3mg/L and 28mg/L TSS concentrations. Similar to below Muskrat Falls, the proposed Muskrat Falls reservoir currently experiences considerable variation in TSS concentrations. In particular, suspended sediment concentrations have been recorded from <5 to 77mg/L within this area, with a mean of 18mg/L (Minaskuat 2007). This reach of the river is also primarily comprised of sandy substrate, resulting in naturally increased turbidity (Minaskuat 2007). In successive years after inundation, the additional pulse of TSS will diminish as the shoreline reaches equilibrium. Based on model predictions, TSS concentrations are expected to decline below 5mg/L above baseline within seven years. By the end of the 20 year modeling scenario, TSS concentrations in all reaches are predicted to be less than 2mg/L above existing baseline (Minaskuat 2008).

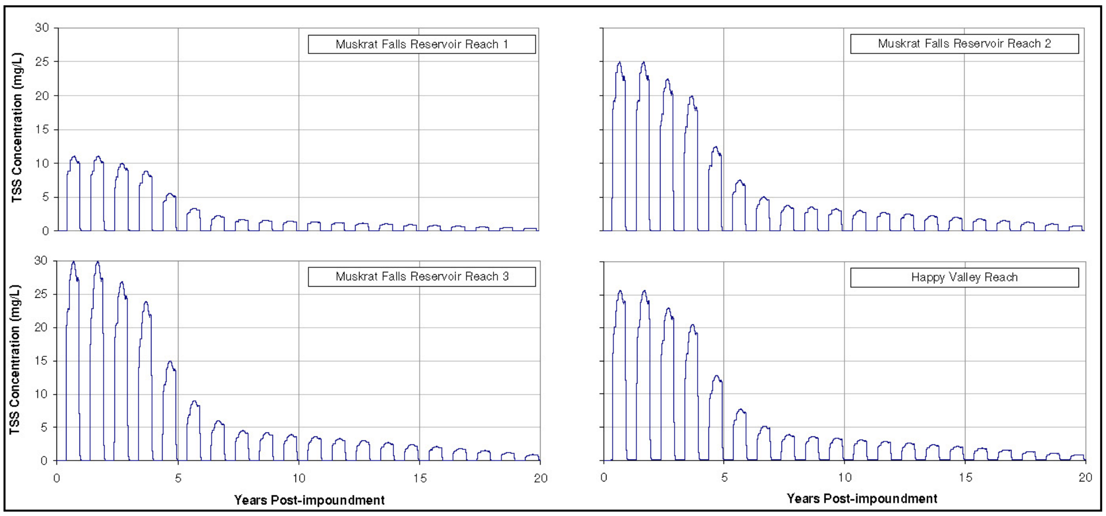


Figure 5.4. Modeled Total Suspended Solids Concentrations in the Churchill River (Figure 6-3 of Minaskuat 2008). Note baseline value is presented as "0" on the vertical axis (i.e. modeled values are "above baseline").

TSS and Total Phosphorous (TP) modeling was completed using bank stability results as a portion of its input data. It should be noted that the bank stability study used qualitative values derived from other locations within Canada with similar soil conditions, as they were not available from within the lower Churchill River area at the time. Subsequent geotechnical soil sampling in 2010 as part of the fish habitat compensation process (AMEC 2010) indicated that the values used in the bank stability study were comparable and therefore applicable. No subsequent changes were made to model results related to bank stability or water quality.

Figure 5.5. Water TSS sampled at 3mg/L just upriver of Edward's Brook natural large-scale erosion/slump, 2010.

Figure 5.6. Water TSS sampled at 28mg/L just in front of Edward's Brook natural large-scale erosion/slump, 2010.

Total Phosphorus (TP)

Total phosphorous concentrations are expected to increase in the proposed Muskrat Falls reservoir, with a peak predicted concentration of 0.99mg/L at the lower end of the reservoir (**Figures** 5.7) and to return to baseline as the reservoir stabilizes (Minaskuat 2008). Currently, in the location of the Muskrat Falls reservoir, TP concentrations have been measured between 0.008-0.102mg/L, with a mean of 0.023mg/L (Minaskuat 2008). By year fifteen of inundation, it is predicted that all model reaches will have TP concentrations similar to existing baseline (Minaskuat 2008).

It should be noted that the predicted best estimate of 0.99mg/L increases in TP were generated without the benefits of reservoir clearing considered (Minaskuat 2008). That is, it was assumed that there would be no removal of any above-ground biomass (eg. vegetation). Full removal of above-ground vegetation was predicted to result in a TP concentration estimate of 0.84 mg/L within the Muskrat Falls reservoir; a reduction of 0.15 mg/L from the 0.99 mg/L best-estimate (no clearing) scenario (Minaskuat 2008). As biomass removal will most likely fall somewhere between these extremes, actual concentrations are likely to be between 0.84 and 0.99mg/L in this reach (Minaskuat 2008).

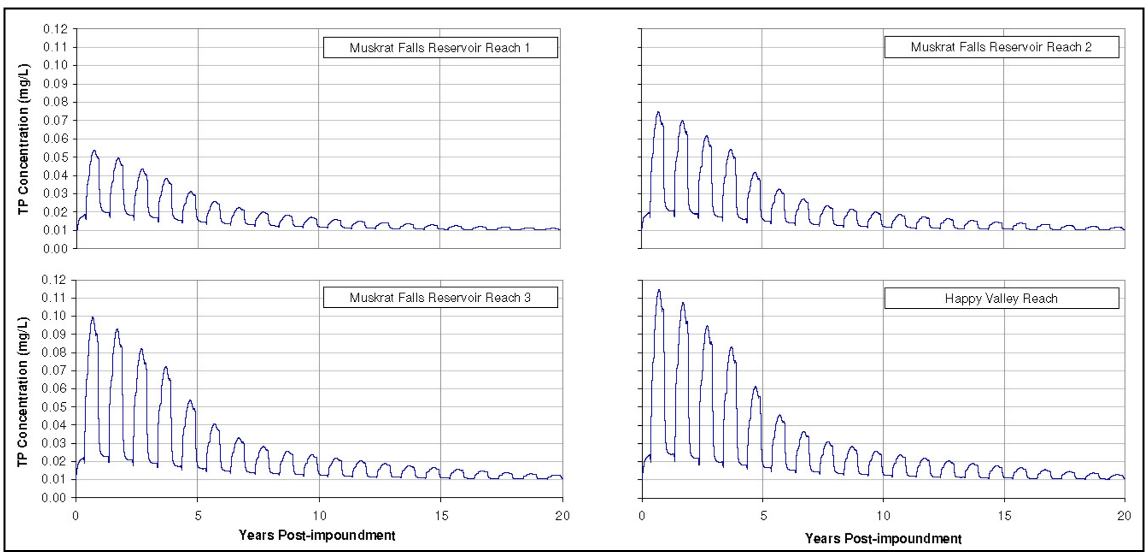


Figure 5.7. Modeled Total Phosphorous in the Churchill River (Figure 6-3 of Minaskuat 2008).

5.1.2.1.3 Temperature and Ice Dynamics

Reservoir formation on a river typically results in thermal energy gain (storage) during summer which is then released during winter. During winter, water released for hydropower production is warmer and therefore the river downstream takes longer to cool and for ice to generate. In spring, the water in the reservoir takes longer to warm and therefore takes longer for ice to melt. The relative influence of this phenomenon depends on the reservoir size relative to incoming flow rate, the surface area to volume ratio, the flushing/turnover rates, the depth of the water intake to the turbines and other factors (Hatch 2007). A small reservoir with high flow rates (i.e. with a high flushing rate) such as the Muskrat Falls reservoir will experience lesser effect.

Changes in temperature dynamics and ice formation related to reservoir creation was modeled for the Muskrat Falls reservoir (Hatch 2007). Creation of a reservoir on a river does not alter the overall range of water temperatures, as these are fixed at the extremes by the freezing point of water and prevailing summer air temperatures. The increased thermal capacitance of the reservoir can; however, alter both the timing of the thermal dynamics (lag effect) and the variability of the water temperature (Hatch 2007). Water temperatures were modeled for representative cold, average, and warm temperature years to obtain a comparison of the existing and predicted thermal regimes of the river. The two primary environmental effects of the Project on the thermal regime of the lower Churchill River will be the introduction of a time lag and a reduction in the variability of water temperatures.

For an average temperature year, the cool down and warm up periods in the Muskrat Falls reservoir are expected to occur about two weeks later than present (i.e. the length of winter conditions will be the same, but shifted two weeks later in time). **Figure** 5.8 presents the existing and predicted temperatures within the Muskrat Falls reservoir. In particular, reaches of the Churchill River within the proposed Muskrat Falls reservoir are predicted to be 1.0 to 3.5 degrees cooler throughout the summer months (May, June, July and August) and 1.2 to 2.6 degrees warmer during September and October. It is predicted that a stable ice cover will form over the Muskrat Falls reservoir (Hatch 2007). A leading edge will form in each tributary at the backwater limit of the reservoir. Given the general steepness of each of the tributaries, the reservoir environmental effects are not predicted to extend upstream into the tributaries beyond the reservoir leading edge.

Many life history attributes (e.g. timing of spawning) can be affected by water temperature and there may be a subtle shift in timing, but no more so than due to inter-annual variability in climate.

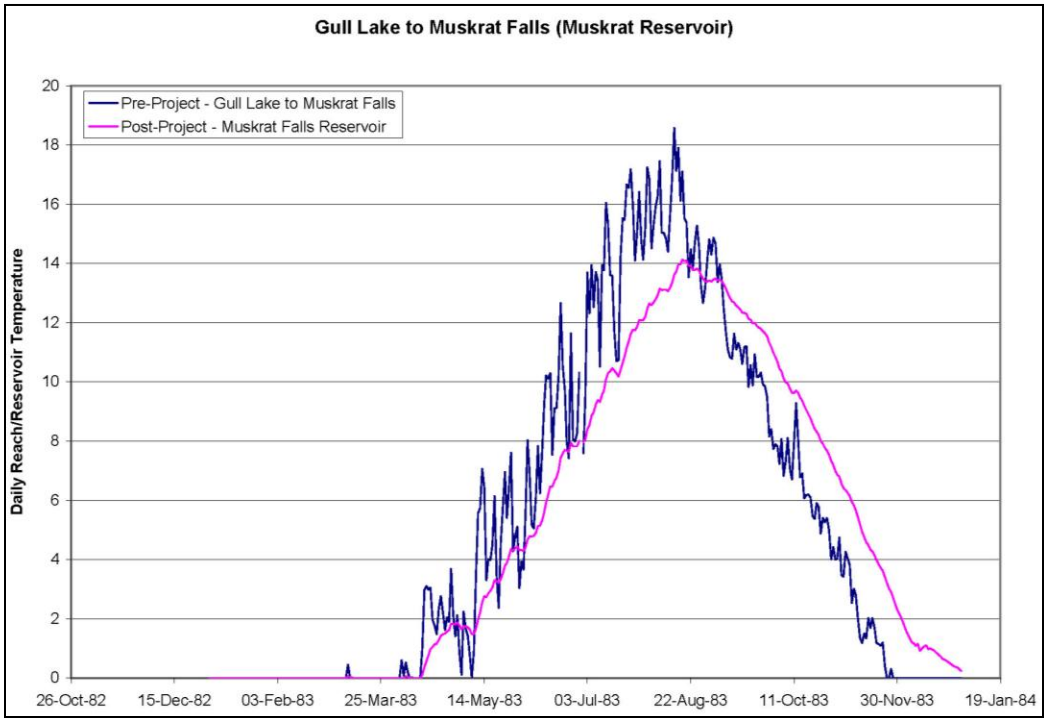


Figure 5.8. Predicted water temperature variability, Muskrat Falls reservoir.

5.1.2.1.4 Trophic Upsurge

Trophic upsurge is predicted during the time of habitat stabilization, when nutrients associated with shoreline stability are being released. Primary production can be altered due to changes in water transparency and nutrients, and both primary and secondary production can also be affected by water retention times.

The predicted changes in primary and secondary production within the Muskrat Falls reservoir has been described in **Section** 3.1.4 of the Fish Habitat Compensation Strategy (see IR response JRP 153-AMEC 2012). Considering light transmission effects only, primary production within the reservoirs could decrease by 50-75% in open water areas under the conservative, worst-case scenario during impoundment, recovering to 60-85% of initial conditions during the early years at Full Supply Level (FSL), and ultimately returning to at least baseline conditions in the long term as shown by TSS modeling (Minaskuat 2008). Any nearshore areas of heavy, local active erosion could see a reduction to 10-15% of pre-impoundment production levels during impoundment and early stabilization as well as during periods of strong, localized sediment re-suspension (AMEC 2010).

Impoundment of the Muskrat Falls reservoir will also result in water retention times slightly longer than the present continuous flow conditions in Gull Lake. The crustacean zooplankton community currently consists of cladocerans and copepods with generation times at summer water temperatures on the order of 1-2 weeks for cladocerans and approximately four weeks for copepods. Therefore, a move in the plankton composition character towards that observed in the upstream lakes in the Churchill watershed (lakes Michikamau through Lobstick) would not be anticipated due to the reservoir's still relatively rapid, 10-day flushing with respect to zooplankton population losses (AMEC 2010).

Full production of a zooplankton community within the Muskrat Falls reservoir is not likely due to the flushing rate of approximately 10 days. Any additional production would likely translate into limited long-term increases in fish production for those fish adapted for benthic and planktivorous feeding in Muskrat Falls reservoir; however, whether this increase would manifest in changes in the fish assemblage is unclear. **Table** 5.3 presents a summary of potential trophic feeding levels for each species captured in the proposed Muskrat Falls reservoir area. Opportunistic species such as brook trout and ouananiche may shift their feeding to more zooplankton in areas where these increases are identified (Brown and Rasmussen 2009). Also, species such as lake whitefish and lake chub would also be capable of taking advantage of increased plankton biomass.

Potential increases in fish productivity could be anticipated while secondary production is increased. The estimated increases in secondary production described above are not predicted to cause measurable changes in terms of overall fish productivity, nor to alter or cause large-scale trophic food web shifts in species within Muskrat Falls reservoir.

5.1.2.1.5 Benthic Macroinvertebrates

The macroinvertebrates/benthos of the lower Churchill River/reservoir system will change as a result of flooding and there is expected to be a longitudinal gradient in benthic communities related to the transition from fast river through slow river (reservoir) habitats. Currently, the lower Churchill River has a low species richness and biomass, and generally low rate of invertebrate production (JWEL 1999a). Baseline surveys indicate that tributaries and streams have a higher biomass and species richness and therefore may be important feeding areas for fish.

Shifting, sandy substrates, particularly in the reaches between Muskrat Falls and Gull Lake (i.e., the location of the Muskrat Falls reservoir), have lowest numbers of macroinvertebrate taxa and biomass and these habitats, both before and after flooding, are not conducive to high benthic production. After flooding, the most important areas for benthic production will be the nearshore and tributary confluence areas as these will support a modified but stable benthic community. The geomorphic characteristics of the river/reservoir nearshore and tributary confluence areas will determine species composition and overall production of the benthos. The temporal extent of the process of vegetation and soil removal will be important in establishing the future benthic community.

Table 5.3. Generalized feeding habits and food sources within the Muskrat Falls Reservoir area.

Species[1]	Potential Trophic Classification[2]	Food Sources Within Section Two[3]	General Food Types[4]
Longnose Sucker	Insectivore Herbivore	Detritus Aquatic Invertebrates	Primarily feed upon detritus and benthic invertebrates. They have been noted to feed upon fish eggs as well.
White Sucker	Insectivore Herbivore	Detritus Aquatic Invertebrates	Primarily feed upon detritus and benthic invertebrates. They have been noted to feed upon fish eggs as well.
Lake Whitefish/Dwarf Lake Whitefish	Herbivore Planktivore Insectivore Piscivore	Detritus Aquatic Invertebrates Fish	A wide range of aquatic and terrestrial invertebrates and planktonic creatures. Fish make up a small portion of the normal diet.
Lake Chub	Herbivore Planktivore Insectivore	Detritus Aquatic Invertebrates	Primarily feed upon aquatic insect larvae, with zooplankton and algal matter making up a small portion of diet.
Northern Pike	Piscivore Carnivore	Fish	Primarily feed upon fish, but have been noted to eat small mammals, frogs, and small water fowl.
Burbot	Insectivore Piscivore	Fish Aquatic Invertebrates	Juveniles primarily feed upon aquatic invertebrates. Once individuals have reached 500mm in length, they switch to a predominantly fish diet.
Round Whitefish	Planktivore Insectivore Piscivore	Detritus Aquatic Invertebrates	A wide range of aquatic and terrestrial invertebrates and planktonic creatures with fish making up a small portion of their diet.
Longnose Dace	Herbivore Insectivore	Aquatic Invertebrates Detritus	Primarily feed upon detritus and benthic invertebrates. They have been noted to feed upon fish eggs as well.
Ouananiche (Atlantic Salmon)	Planktivore Insectivore Piscivore Carnivore	Fish	A wide range of aquatic and terrestrial invertebrates, fish, and small terrestrial mammals.
Brook Trout	Herbivore Planktivore Insectivore Piscivore Carnivore	Aquatic Invertebrates Fish Detritus	A wide range of aquatic and terrestrial invertebrates, fish, and small terrestrial mammals. Plant matter makes up a small portion of their diet.

1 Only species which have been captured within Section two of the main stem lower Churchill River during the various Fish and Fish Habitat Studies have been included.

2 Trophic classification is based on literature as well as data from stomach content analysis conducted during various field programs

3 Stomach content analysis conducted by AGRA (1999); AMEC (2000); AMEC (2001)

4 General feeding habits derived from Scott and Crossman (1988) and Grant and Lee (2004)

5.1.2.2 Fish Assemblage and Fish Health

The formation of the Muskrat Falls reservoir and operation of the facility will affect the fish and fish habitat within it. The largest alteration by far will be the inundation of a portion of the lower Churchill River as a result of reservoir formation. For example, the reservoir will no longer contain the Fast Velocity habitat reaches that currently exist within the reservoir footprint and will behave, for the most part, more similar to the characterized Slow Velocity reaches within this river section.

Within the reservoir, fish biomass may initially decline on a per unit basis related to a dilution effect, followed by an increase after impoundment over the initial 3-5 years, and then decline to a more stable level thereafter (AMEC-Sikumiut 2007). Peak fisheries yields generally occur shortly after impoundment, in response to the trophic upsurge, and then diminish thereafter as the physical and chemical conditions, and the biological community stabilizes. The hydrological and habitat changes associated with creation and operation of the Project will result in certain habitat conditions being more suitable for some species. A detailed review of the generated species life stage habitat suitabilities is provided in the Fish Habitat Compensation Strategy (AMEC 2010; JRP IR 153 – AMEC 2012).

The existing habitat throughout the Muskrat Falls reservoir has been surveyed for habitat features and fish utilization. This data has been used to quantify the existing and predicted post-Project habitat equivalence (i.e., the product of habitat quantity and quality). The predicted habitat equivalence values have been used to identify those species life stages which may be seriously affected by habitat change. Details of the methodology are provided in AMEC (2001). An overview is provided below.

Table 5.4 presents the final Habitat Equivalent Units (HEUs) for each species (by life stage) for the Muskrat Falls reservoir. From a habitat preference and availability perspective, within the Muskrat Falls reservoir, species such as round whitefish, northern pike, ouananiche, and suckers have post-project HEU values that indicate the potential for reduced habitat function with respect to certain life stages. These affected species life stages have been incorporated in the design of physical compensation works outlined in **Section** 5.2 of this Plan. While the focus is on those species noted above, many species have been reviewed and incorporated in order that maximum benefit is achieved.

In addition, before habitats stabilize, there could be potential issues related to TSS and bank stabilization along portions of the Nearshore Slow habitat as it reaches equilibrium. As shown in **Figures** 3.5 and 3.6, current use of the Muskrat Falls area by brook trout and ouananiche is very low. They generally have spawning requirements for cleaner water/substrate than other species and are typically short lived. This would give them a disadvantage within habitat with a prolonged increase in TSS. Northern pike also require aquatic vegetation for spawning and for capturing prey (i.e. an ambush predator). While the low habitat equivalence values shown in **Table** 5.4 are partially a result of no aquatic vegetation initially being available within the reservoir, its function for northern pike is noted and has been considered in terms of physical compensation works.

Table 5.4. Comparison of existing and predicted post-Project Habitat Equivalent Units available for each species within the Muskrat Falls reservoir. These values do not include physical compensation works.

Species	Muskrat Reservoir (ha) Habitat Equivalent Units (ha)	
	Existing	**Post-Project**
Total Habitat Units (ha)	**6,479**	**9,320**
Northern Pike		
Spawning	4644	925
YOY	3096	185
Juvenile	6349	3
Adult	1234	10
Burbot		
Spawning	5457	629
YOY	6349	652
Juvenile	595	848
Adult	2294	1300
Brook Trout		
Spawning	869	2701
YOY	2073	1375
Juvenile	5761	3004
Adult	5854	2326
Ouananiche		
Spawning	2685	1914
YOY	996	2970
Juvenile	5885	617
Adult	3679	1673
Lake Whitefish[a]		
Spawning	1635	1799
YOY	774	1760
Juvenile	3077	4410
Adult	4017	5393
Round Whitefish		
Spawning	575	901
YOY	5660	2771
Juvenile	6218	2827
Adult	1333	529
White Sucker		
Spawning	3135	2397
YOY	1749	2214
Juvenile	614	2656
Adult	6365	36
Longnose Sucker		
Spawning	1106	1381
YOY	315	2031
Juvenile	5959	2827
Adult	2453	598
Lake Chub		
Spawning	1421	509
YOY	5228	2970
Juvenile	1836	2960
Adult	1277	2954

Species	Muskrat Reservoir (ha) Habitat Equivalent Units (ha)	
	Existing	Post-Project
Threespine Stickleback		
Spawning	3040	479
YOY	3040	96
Juvenile	3040	509
Adult	64	509
Longnose Dace		
Spawning	1604	596
YOY	4801	2202
Juvenile	2573	564
Adult	2619	2965
Sculpin		
Spawning	1689	2046
YOY	1565	2772
Juvenile	562	2957
Adult	5614	2961
Pearl Dace		
Spawning	1604	2423
YOY	4801	2202
Juvenile	2573	564
Adult	2619	2965

[a] Lake whitefish are described in Grant and Lee (2004) as being lacustrine and hence gives no suitabilities for young-of-year and juvenile life stages in riverine habitat.

Telemetry results conducted within the existing Muskrat Falls section of the river also indicate that several fish species may be using habitat within the main stem–tributary interface (termed delta habitat) for spawning and by inference, young-of-year rearing. These species include lake whitefish, white sucker, northern pike and brook trout. This information has also been incorporated into the physical compensation works to offset any reduced habitat function with respect to certain life stages within the Muskrat Falls reservoir area. **Figures** 3.5 and 3.6 present the species captured/sampled in the location of the Muskrat Falls reservoir to date. The figures show the relative abundance of each species in terms of their catch-per-unit effort (CPUE) for both gillnet and fyke net sampling. CPUE has been generated using the mean weight (grams) of fish captured for each net set and is an index of habitat productivity. Similar existing and stabile post-Project habitat types are expected to have similar productivity (e.g., Slow habitat following inundation will have simile CPUE as existing Slow habitat). In no instance is a species predicted to be lost from the fish assemblage that is currently residing within the Muskrat Falls reservoir and its tributaries.

5.2 TIER 2 - PHYSICAL COMPENSATION WORKS

While many species will be able to successfully utilize the habitat available within the Muskrat Falls reservoir, as described previously there are certain life stages identified that may require assistance. These will require modified and/or constructed habitat features to alleviate predicted challenges with respect to short-term habitat stability/water quality issues and/or long-term habitat deficiencies. Emphasis has been focused on the long term maintenance of fish populations within the reservoir, with priorities being placed on implementing compensation/enhancement efforts on susceptible and/or socially important species.

There are three general compensation construction works that will assist in achieving the goal of maintaining fish species diversity within the Muskrat Falls reservoir; shoreline and nearshore/shoal enhancement and stabilization, delta construction, and spawning vegetation. While each location and physical works has specific attributes and construction activities, they all follow a general construction sequence outlined below. **Figure** 5.9 provides an overview of the locations of physical compensation works throughout the Muskrat Falls reservoir.

Each compensation works location described below uses the existing surficial material at each site. The surficial geological mapping, as well as site-specific investigations, was used to determine whether locations were suitable for enhancement. Due to the large size of most of these sites, quarrying and movement of suitable material in the quantities necessary would not be practical or even possible in most instances as material requirements will be large and unavailable.

Changes in habitat, temporary shoreline instability, and/or water quality stabilization are most likely to affect northern pike, round whitefish, ouananiche, lake whitefish, suckers, and brook trout. These species were captured within the Muskrat Falls reservoir area, albeit some in low abundance, and will remain as part of the species assemblage once the reservoir is completed. Many of these species have life stages that prefer generally clearer water and hence would benefit from habitat with low TSS concentrations; the most sensitive life stages being spawning and young-of-year.

As with typical Fish Habitat Compensation Plans, monitoring of the stability and utilization of physical compensation works will be required. While many of the results will feed into the Adaptive Management (Tier 3) portion of the Plan, those monitoring activities related specifically to the physical construction works are described within this section of the document.

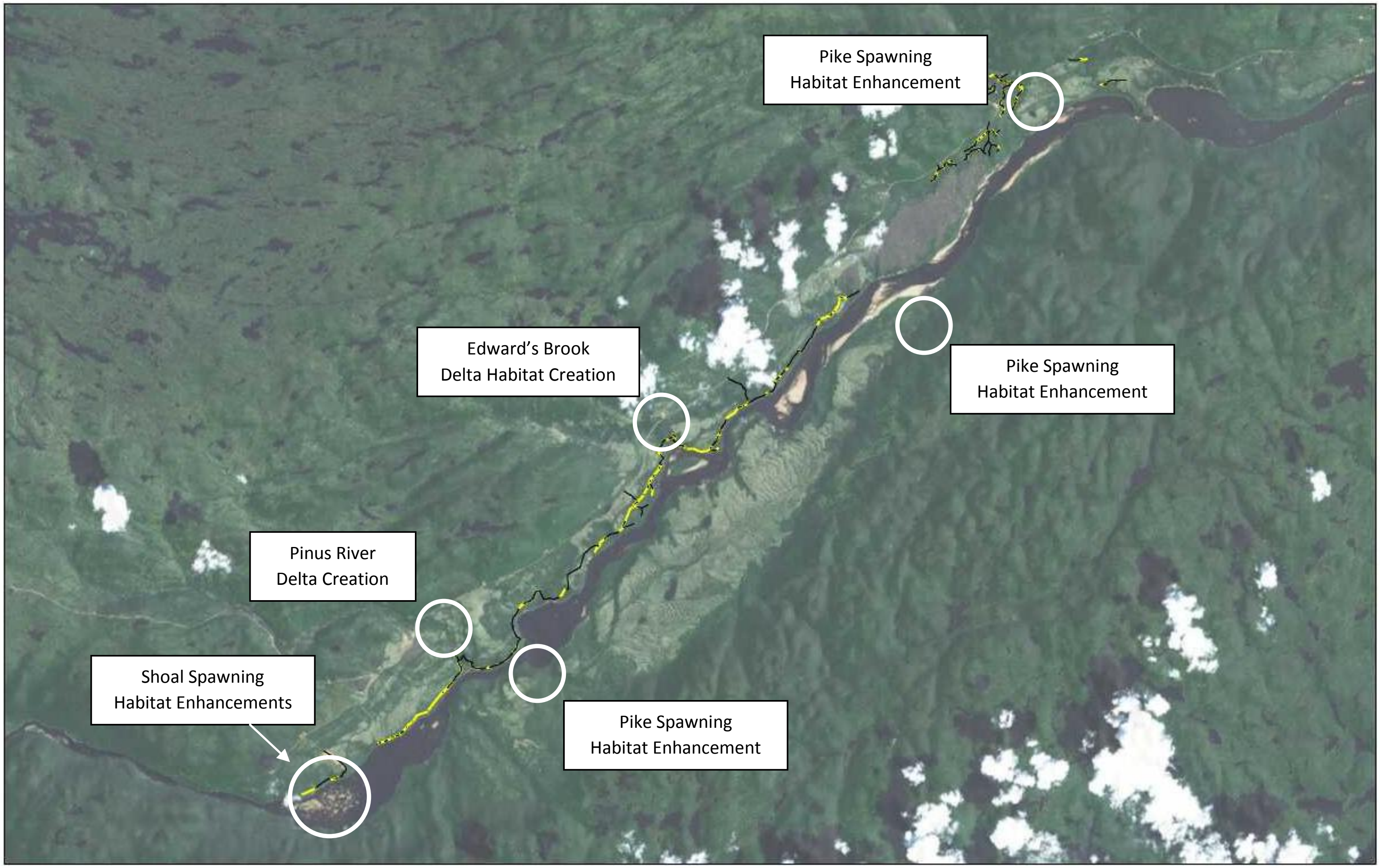


Figure 5.9. Overview of physical compensation works, Muskrat Falls reservoir (yellow lines indicate roads within the nearshore habitat).

5.2.1 Creation/enhancement (both constructed and passive) of Nearshore Habitat

Both operational and environmental considerations required the development of a Reservoir Preparation Plan to remove vegetation within the reservoir prior to inundation. The preferred option is to mechanically remove, where feasible, all trees that extend into an area 3m above maximum supply level to 3m below minimum supply level. It is anticipated that this will result in the near full harvest of the Muskrat reservoir. This extensive volume of terrestrial vegetation removal from the reservoir will greatly reduce the overall influx of nutrients and dissolved substances into the reservoir and hence will limit the overall trophic surge associated with reservoir formation as well as the potential for deep water anoxia. Vegetation removal will also provide an opportunity to manipulate sections of the nearshore habitat to benefit species within the reservoir. For example, in accessible areas the vegetative mat will be removed along the shoreline using available machinery during reservoir preparation (thereby reducing overall costs).

Design of the access roads for reservoir preparation has also been incorporated into the Compensation Plan. Due to the slope of the existing terrain, access roads will need to be terraced; material will be dozed or moved from higher elevations to lower elevations in order to construct a level travel surface of suitable material. Where practical and safe, these roads will be constructed within the 34-38m contours (as close to 38m being preferred). This elevation will allow the roads to be inundated upon reservoir filling and to remain inundated by at least one half meter through all operations. This will allow the Nearshore aquatic “terrace” to remain continuously watered for use by all life-cycle processes (eg. spawning and egg incubation). The terrace will also be within the zone of wave influence for cleaning as well as within water depths where light penetration will reach the substrate. Nearshore areas such as this are typically more productive than deeper, open waters. Road construction within these elevations will immediately expose substrate and initiate stabilization upon inundation. It should be noted; however, that increased vegetation removal can also increase the initial pulse of TSS into the reservoir (see Northcote and Atagi 1997) and therefore careful consideration of the total vegetation quantity initially removed is warranted.

Exposed substrate will provide suitable spawning and rearing habitat for round whitefish, ouananiche, brook trout, and other nearshore species upon inundation. The Nearshore habitat available for this enhancement has been determined in concert with detailed Reservoir Preparation planning. The locations and quantity of habitat to be enhanced are presented in **Figure** 5.10. GIS analysis estimates a total of 22.4 km of shoreline road would be included in the 34-38m contour around the Muskrat Falls reservoir. Most roads at this elevation within the reservoir will be Class B access roads (K. Sparkes, pers.comm.). Design criteria for this road class indicate a cleared right-of-way of 25m; however, the anticipated range would be 15-25m. Using these values, it is estimated that a total of **34-56 ha** of shoreline habitat within the Nearshore, shallow zone will be prepared and stabilized (i.e. actively prepared) prior to reservoir creation.

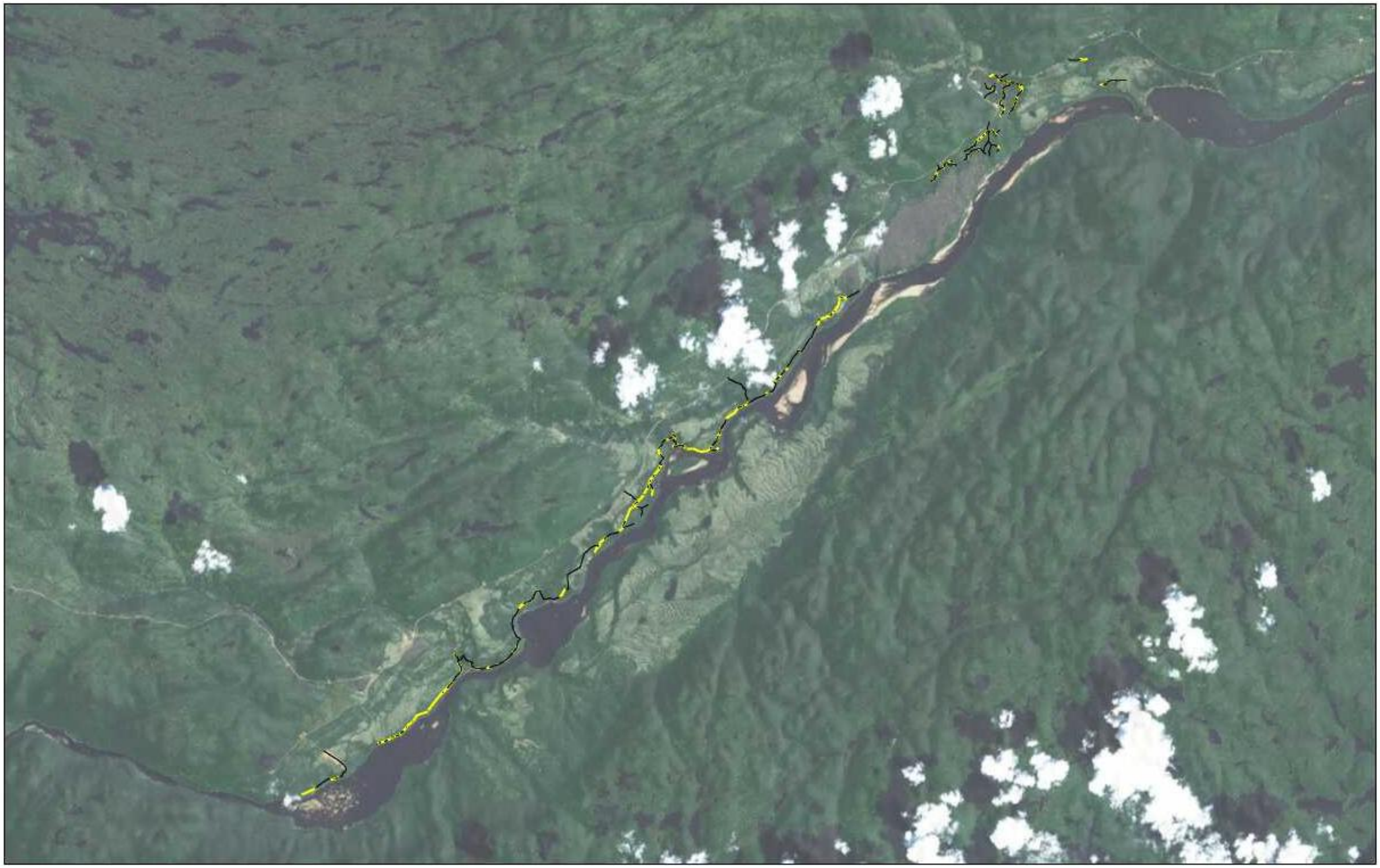


Figure 5.10. Nearshore habitat areas where access roads will be within the 34-38m contours (yellow portions of roads).

5.2.2 Creation/enhancement (both constructed and passive) of Shoal Habitat

The inflow of Gull Lake will be within and near the available Intermediate habitat in the proposed Muskrat Falls reservoir (**Figure** 5.1). The existing habitat is a series of large and small islands containing large quantities of gravel, boulder, cobble and rubble, where the river channels between them. These channels are currently being used for spawning by numerous species (JWEL 2000b). While the existing main velocity values are generally high throughout the area (see **Table** 5.5), lower, more suitable velocities are present within the channels and nearshore areas. **Figure** 5.11 presents the overall layout of the existing Gull Lake shoal area.

Table 5.5. Hydraulic model (HEC-RAS) velocity results for transects within the Gull Lake Shoal areas. Modeled Mean Annual Flow (MAF) of 1,761 m^3/s in Gull Lake area.

Transect chainage (km)	Pre-post Project	MAF (m^3/s)	Mean Velocity (m/s)	Max. Channel Depth (m)	Water Surface Elevation (m)
99.5	Pre	1761	1.49	4.96	34.26
	Post		0.37	9.72	39.02
98.8	Pre	1761	1.53	3.40	33.50
	Post		0.31	8.92	39.02
97.7	Pre	1761	1.48	2.53	31.83
	Post		0.15	9.72	39.02
96.7	Pre	1761	1.62	1.88	28.78
	Post		0.07	12.12	39.02
95.3	Pre	1761	0.78	4.01	27.71
	Post		0.06	15.32	39.02
94.5	Pre	1761	0.14	10.71	27.72
	Post		0.05	22.01	39.02

The modeled velocity and water depths (using the hydraulic model HEC-RAS) indicate that this area will be very suitable for salmonid spawning (ouananiche, brook trout, whitefish) within the Muskrat Falls reservoir. For example, this shoal area is predicted to have mean water velocities of 0.05-0.37 m/s and maximum channel depths between 9-22m with water depths over the shoals as shallow as 0.74m along some of the higher shoal elevations. The shoals in the upper section of Gull Lake will be prepared to increase the spawning/rearing suitability and function of the habitat.

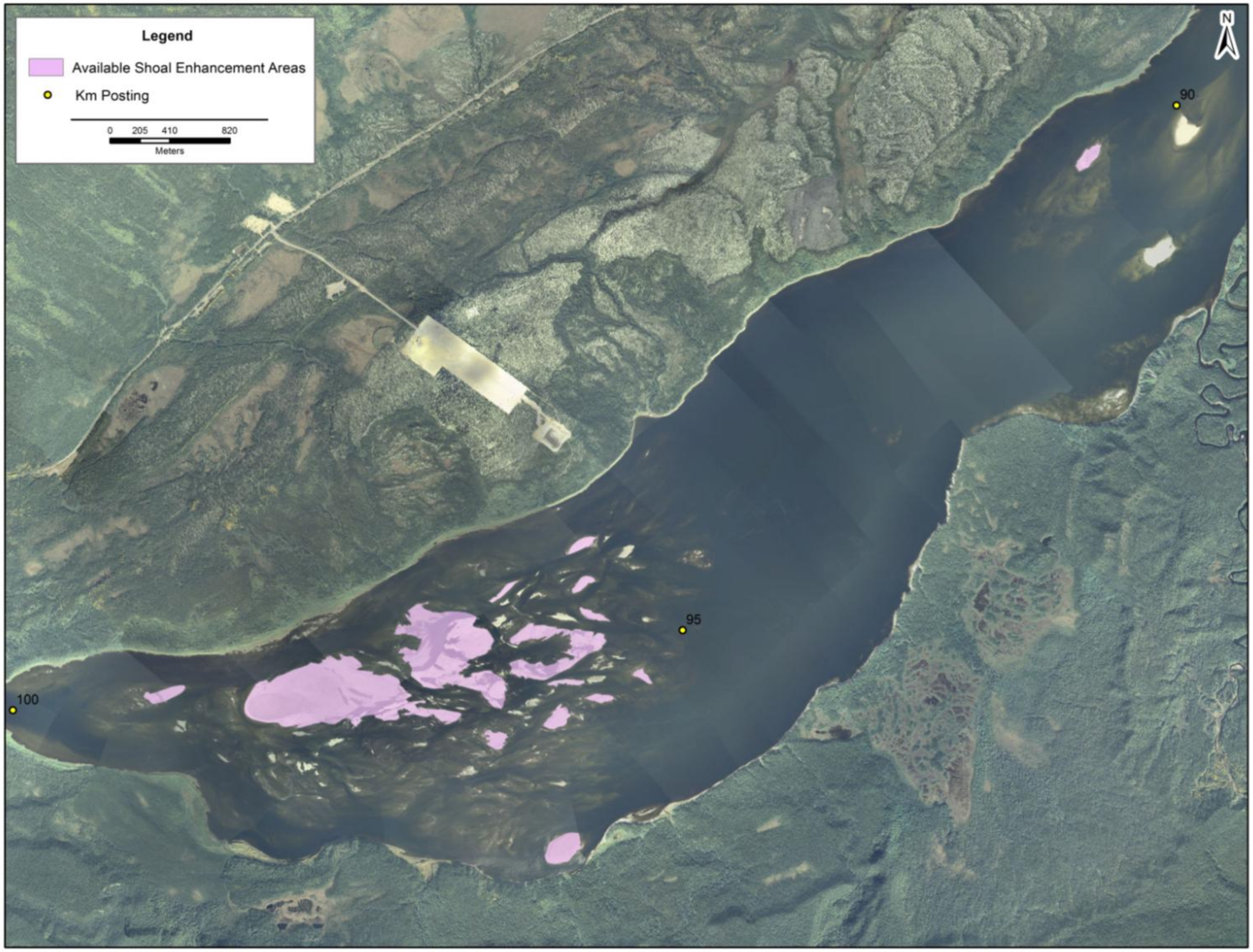


Figure 5.11. Gull Lake inflow and outflow shoals showing areas of available spawning habitat enhancement (shaded pink).

5.2.2.1 Species Utilization and Design Considerations

This area has been the focus of spawning habitat enhancement because of several factors, Including the following:

- it has suitable material present;
- it is within the upper portion of the Muskrat Falls reservoir and will therefore receive relatively unaltered, clean water flows;
- it has existing fish spawning and rearing in selected areas; and
- modeling of post-project habitat suggests suitable water velocities for spawning and rearing of young-of-year.

The primary emphasis of spawning habitat within the shoal area is directed at salmonid species (brook trout, ouananiche, whitefish) as they currently utilize the area and require relatively clean water and substrate for successful spawning and alevin emergence. However, other species can utilize these habitat conditions as well.

As previously stated, the modeled velocity and water depth results indicate that this area within the Muskrat Falls reservoir will be very suitable for salmonid spawning (ouananiche, brook trout, whitefish) (**Table** 5.5). The series of islands within Gull Lake will be sites of physical habitat creation/enhancement to maximize the spawning and rearing suitability and function of the habitat within the overall shoal complex (**Figure** 5.11).

The overall design philosophy of physical spawning enhancement at the shoals is to utilize the existing substrates and modeled water velocities and depths to provide the best possible environment for successful spawning and emergence of fish within the Muskrat Falls reservoir while maintaining effective cost, logistic, and safety control. A brief description of the habitat considerations related to spawning and young-of-year is provided below for the key species identified within the Fish Habitat Compensation FHC Plan that shoal habitat enhancements would be directed. It should be noted however, that many of the enhancements would also be suitable and beneficial to other species found within the Muskrat Falls reservoir. This information has been summarized from field sampling within the lower Churchill River as well as DFO's document "*Life History Characteristics of Freshwater Fishes Occurring in Newfoundland and Labrador, with Major Emphasis on Riverine Habitat Requirements*" (Grant and Lee 2004).

5.2.2.1.1 Brook trout (*Salvelinus fontinalis*)

Brook trout are found throughout the main stem and tributaries of the lower Churchill River between Muskrat Falls and Churchill Falls (Beak 1980; Ryan 1980; AGRA 1999; AMEC 2000, AMEC 2001), being most abundant in Section Three and Five (upriver of the Muskrat Falls reservoir to Lake Winokapau) (AGRA 1999; AMEC 2000). Brook trout were also captured below Muskrat Falls within the main stem, tributaries and estuary but at relatively lower rates (AMEC 2000; AMEC 2007; AMEC 2009b).

Design Considerations

Brook trout spawning typically occurs in September in Labrador, depending on water temperature. Groundwater upwelling (rather than water velocity) was identified as probably being the most critical factor in redd site selection (i.e., the location where the eggs will be laid and buried). Groundwater upwelling is beneficial in that it provides protection from freezing and carries dissolved oxygen, to and metabolic wastes away from, developing embryos. Spawning brook trout are also known to be able to locate new areas of upwelling groundwater, suggesting that gradients created by discharging groundwater may be used for homing to spawning areas. While the importance of groundwater upwelling with respect to trout spawning has not been documented in this province, the flow of water over and through potential redds sites is a key consideration in spawning habitat enhancements.

5.2.2.1.2 Atlantic salmon – ouananiche (*Salmo salar*)

Landlocked Atlantic salmon, commonly called ouananiche, are found throughout the main stem of the Churchill River between Muskrat Falls and Churchill Falls (Beak 1980; Ryan 1980; AGRA 1999), being most abundant in Section Three and Four (upriver of the Muskrat Falls reservoir to Lake Winokapau) (AGRA 1999; AMEC 2000). In Winokapau Lake, most ouananiche have been sampled in the littoral (near shore) and near-surface habitat of the profundal (open water) zone. Although typically a riverine species, ouananiche have not been captured in any tributary habitat within the Muskrat Falls reservoir area.

Design Considerations

Ouananiche spawning typically occurs in October to November, depending on water temperature; with females ascending tributaries to prepare redds (nests). Nesting sites are chosen by the female and are usually within a clean, well-aerated, gravel bottom riffle above a pool. Spawning has also been reported at the tail of pools on the upstream edge of riffles.

Ouananiche spawning substrates consist primarily of gravel and cobble, while bottoms of mud, silt or sand have been shown to be typically avoided. It should be noted however, that they have been observed spawning in substrates containing up to 18% fines (sand, silt and clay) with little apparent effect on subsequent egg survival.

5.2.2.1.3 Lake whitefish (*Coregonus clupeaformis*)

Although they are generally found in lakes, they are relatively abundant in the main stem of the Churchill River, as well as the adjoining lakes and ponds within its watershed (Anderson 1985). They are distributed throughout, from the upper reaches near the existing Churchill Falls Generating facility downstream to the estuary; however they are most abundant in the upriver segments; within and upriver of Winokapau Lake.

Design Considerations

Spawning typically occurs between October and December, although the spawning season can extend from mid-September to late January throughout its geographic range, with northern populations generally spawning earlier. In Labrador, spawning occurs from mid-September to November (Ryan 1980). Spawning duration is usually about one week, but can be spread out as long as a month. River spawning generally utilizes shallow riffles or rapids with a gravel/cobble substrate; however they have been observed spawning over sand and mud in some areas of their range. The flexibility of spawning locations (and the ability to switch from lakes to rivers, if necessary) indicates spawning is more closely linked to substrate type than water flow.

Spawning typically occurs at night where females randomly broadcast eggs over the bottom, which are then fertilized by males. The eggs are left unattended to incubate and hatch the following spring. In Labrador, incubation occurs from mid-September to mid-June and hatching from mid-May to mid-June.

5.2.2.2 Summary of Preferred Habitat Features

Based on the species habitat preferences outlined above for spawning and young-of-year, a heterogeneous bottom substrate and contouring is the overall preferred habitat feature to enhance the Gull Lake shoal areas. This feature would promote upwelling and changes in velocity and could be achieved by creating bottom undulations similar in form and function to a pool:riffle sequence in a river.

5.2.2.3 Shoal Habitat Construction

Construction was initially designed when Gull Island was to be developed first and as such, much of the shoal area would have been de-watered during Gull Island reservoir filling and therefore a greater area available to access and manipulate. Construction has since been modified to accommodate the available habitat and logistics based on Muskrat Falls being constructed first.

All vegetation will be removed from the existing exposed areas (these islands will be underwater once inundation is completed) in order to expose the underlying substrates (see **Figure** 5.3 for example of substrates in the Gull Lake shoal area). In order to enhance the spawning potential of these sites, the existing surface areas will be made more heterogeneous to induce greater water upwelling along and through the bottom substrates. This effect has been used in previous large-scale spawning and rearing habitat creations by Nalcor at Granite Canal. The created heterogeneous habitat within the tailrace was found to be very effective spawning areas for adult salmonids – landlocked Atlantic salmon (AMEC 2010b).

As part of the engineering design, an analysis was completed for a variety of construction options for the shoal area (AMEC 2012). Options included:

1. Construction of habitat ridges on the shoals (ridges) with access by
    a. barge,
    b. temporary bridge, and
    c. heavy lift (helicopter);
2. Construction of habitat "fingers" along the Gull Lake shoreline by temporary access road; and
3. Construction of habitat depressions using percussion and helicopter access.

The construction of ridges would include the mobilization and use of heavy equipment over multiple months or construction seasons to achieve a heterogeneous surface on the exposed islands to increase their potential for spawning and young-of-year rearing habitat suitability. Primary flow of the lower Churchill main stem is along the north shore (as can be seen in **Figure** 5.11), therefore access from the north shore via causeway would be restrictive. Barge transport of machinery would also be very difficult due to the fast flows within the same north channel (>1.5m/s), and outside the main channel it would be very shallow for effective barge navigation. These aspects increase both the cost and risk of this construction alternative on the Gull Island shoals such that they are unfeasible. The construction of habitat "fingers" along the Gull Lake shoreline does not provide any habitat enhancement on the shoals themselves and would be considerably smaller in habitat area (approximately 4.5ha). This alternative; therefore, does not provide the habitat enhancement anticipated per unit cost and is also therefore unfeasible. The preferred option to achieve the suitable habitat features is through the use of percussion to generate depressions in the surface of the islands which would generate the same habitat feature and function as ridges. Given the more mobile method, additional shoal areas are also available for enhancement (**Figure** 5.12).

This method has been developed and described using several assumptions:

- All equipment and material mobilization to the Gull Lake shoals will occur using helicopter from the existing Gull Island camp location, just north of the river;
- Additional islands are available/accessible using this method due to relatively lower machinery and personnel/material requirements;
- Fuel requirements can be met with supplied drums; and
- A suitable percussive material is available/acceptable by Nalcor and regulators.

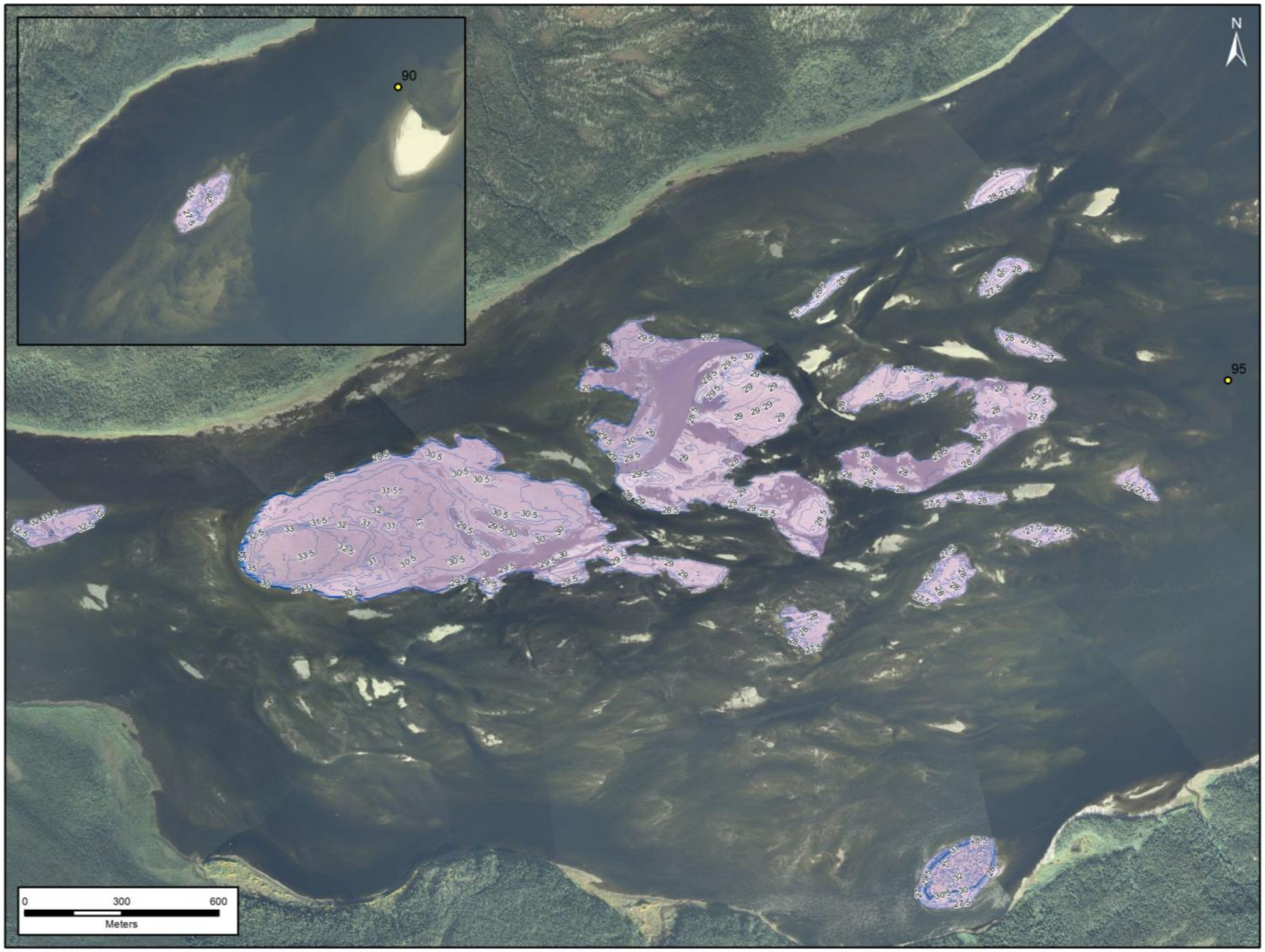


Figure 5.12. General location of Gull Lake shoal development using percussion method to generate depressions. Inset shows an island near the outflow of Gull Lake that would also be available using this method. Contours also shown with corresponding elevations based on Lidar.

Blasting experts indicate that the ideal material for use in generating depressions will have high gas generation, with low detonation velocities (C. Miles, pers. comm.) so that there is a balance between depth of depression and safe lift of material. It would also be beneficial to have low ammonia content to reduce runoff treatment requirements. This suggests that a cast booster-type material would be most suitable; however, a review of percussion material will be required prior to construction to ensure the optimal combination of measures. This will be completed with the selected contractor.

Construction will include excavating/drilling holes approximately 2m deep for the placement of charges with a small backhoe/front-end loader or mini-auger. Based on past experience, using the appropriate charge size and material can generate a depression approximately 2m in depth and 8m in diameter (**Figure** 5.13). The construction schedule will have several days of loading followed by sequential detonation to reduce the number of noise disturbances. It should be noted that the noise level of a blast does not increase as a result of multiple blasts therefore detonating several at once or in sequence, rather than individually, reduces overall noise disturbance (C. Miles, pers. comm.). Upon completion of a series of blasts, small front end loaders and/or skid-steer loaders will shape any areas requiring further enhancement/stabilization. It is estimated that up to 1,900 detonations will be required to complete depressions to achieve a similar density of habitat heterogeneity resulting from ridges; areas with existing heterogeneity will not have depressions created.

The time required to construct depressions is estimated based on the number of charges that can be prepared by each backhoe/drill per day. It is assumed that the time to prepare and plant the charge would be equivalent to the time required to excavate (i.e., total preparation time of each depression would be twice the excavation time). Given the total conservative estimated number of depressions required is 1,900, a rate of ten depressions prepared per day will require an overall time period of 39 days (assuming five backhoes/drills). With mobilization to the various islands and detonation/shaping time, this can be doubled to 78 days (approximately three months).

Using percussion rather than heavy machinery will allow all equipment related to this method to be transported to the islands using smaller locally available helicopters. These smaller sized machines have been used and transported by helicopter for past geotechnical investigations throughout the lower Churchill River. As a result, a larger number of islands can be included in the method; including at least one downstream with larger substrates of rubble, cobble and gravel (two of the three islands consist primarily of sand). This option will greatly reduce overall costs per ha of enhancement. In addition, the fuel requirements will be reduced along with associated movement (slinging by helicopter) of fuel to and from the site. It is assumed that fuel needs can be supplied in drums.

Access to the Gull Lake north shore by light machinery and charge material will be possible by helicopter. In total, 14 of the islands would be accessible using this method and therefore a total of **99ha** of fish habitat enhancement will be possible. Transport of personnel to and from the site will also be relatively straight forward; by helicopter or boat. This method is considered feasible.

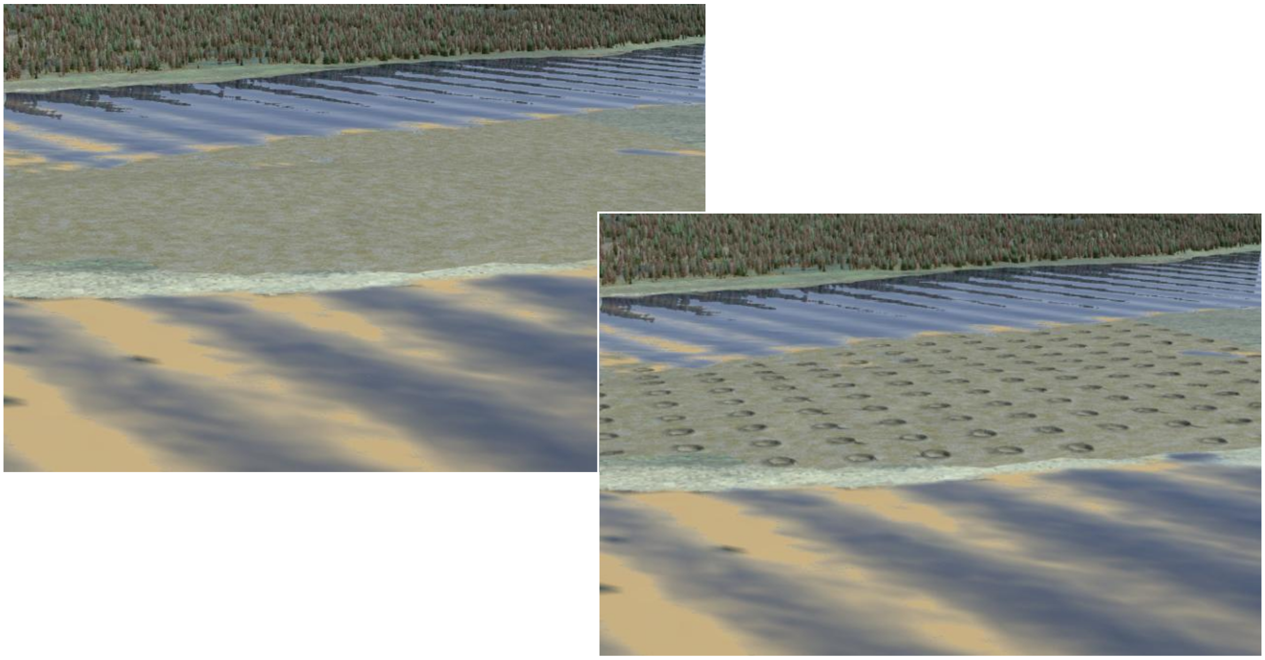


Figure 5.13. General schematic of Gull Lake shoal development. 3D rendering based on engineer design and GIS data (post-construction shown prior to inundation).

Since all equipment will be transported to the site without the use of additional roads or infrastructure, rehabilitation upon completion of the physical construction works will be limited to any fueling and maintenance infrastructure locations.

The movement of machinery to and from each island is considered moderate risk in terms of helicopter slinging. Each movement will require special trained personnel to assist in the movement; however, machinery can be moved without the need for disassembly. Lift coordinators (or lift masters) will be required to coordinate both the lift site at the existing Gull Island construction camp area as well as at the various shoal sites. Lifts will also require restricted access to the overall lift preparation area as well as the lift transport route (i.e., under the helicopter travel route). This may impede other activities during lifts such as reservoir preparation, travel along the proposed roadway for reservoir preparation, and movement within the Gull Island construction area. However, movement of machinery between the various islands would not likely impede other activities.

Physical construction will be completed under direction of a licensed and experienced blaster. Permits related to blasting will be completed and submitted for approval well in advance of any construction activity. The method will lift material using percussion; therefore, there will be a requirement for “no-go” zones during detonation. The timing of blasting will therefore require coordination between other activities in the area such as reservoir preparation.

All blasting will also require compliance with all regulations and guidelines for protection of fish and habitat such as Wright and Hopky (1998). All construction will be completed on the exposed islands therefore no in-water work is anticipated. All activities would be compliant with Nalcor's EPP for the project as well as the contractor's site-specific EPP. Any water to be released will be contained in a settling area to remove any TSS and excess ammonia. All small channels within the work area would be avoided and hence fish relocation is not anticipated.

5.2.3 Creation/enhancement of Delta Areas

Telemetry studies conducted on species within the existing river indicate that several species may be using habitat within the main stem/tributary interface (termed delta habitat) for spawning and by inference, young-of-year rearing. These species include lake whitefish, white sucker, northern pike, and brook trout (JWEL 2000b). Deltas are typically defined as low-lying deposits of sediment at the mouths of rivers (Trujillo and Thurman 2005). The term is used to describe the vast reaching sediment areas that are found in estuarine environments, however, by definition, deltas can also form at the confluence of tributaries and main stem rivers. Estuarine deltas are typically very rich in nutrients, and are noted as being highly productive. Tributary-main stem confluences have also been noted as being areas of higher productivity, and typically contain higher diversity and abundances than the surrounding areas (Rice et al. 2006). Rice et al. (2008) noted four driving factors that cause the increased production and diversity within confluence areas;

- Increased nutrient input from upriver tributary sources;
- Confluence presents a combination of three fluvial habitat types (upstream and downstream main-stem, and tributary);
- Unique biophysical characteristics (i.e. water chemistry, water temperature and feeding opportunities) present ecological opportunities which may not be present elsewhere in the main stem; and,
- Sediment input and water mixing zones can increase habitat heterogeneity.

Of the mechanisms that are presented above, increased nutrient input as well as increased habitat heterogeneity have been noted to be the most influential (Kiffney et al. 2006; Rice et al. 2006). Kiffney et al. (2006) note that large main stem rivers are typically nutrient limited, while small tributary streams, in many cases, lack ample quantity of sunlight, due to shading from riparian habitats, to maximize potential production. The addition of the nutrient rich stream waters into the well lit main stem environment can facilitate increased production rates. This is the primary factor leading to highly productive confluence zones. Likewise, organic debris and detritus are often times carried into the main stem river from the tributary. Increases in the organic matter within the confluence zone can create optimal habitats for aquatic invertebrates and small benthic feeding fish (i.e. sculpin, dace and juvenile suckers). These areas are often times chosen as nursery grounds, as juvenile fish can readily exploit the high abundance of aquatic invertebrates. These areas are also noted as being richer feeding grounds for adult fish.

The same forces acting to supply increased concentrations of nutrients, work to increase the habitat heterogeneity. Tributaries, where they form, generally flow through surficial geology of various substrate size-ranges. The smaller substrate sizes (eg. gravels and smaller) are slowly washed out of the tributary to its mouth where water velocities slow and the particles are deposited. These areas can provide habitat with substrates more suitable for spawning and young-of-year rearing for many species as well as locations for aquatic vegetation growth. The resulting 'delta' effectively breaks the continuum of the riverine habitat, and can create upwards of three distinct habitats within a short length of the main stem river. Upstream of the deposition is typically marked by a relatively deep, slow pool, while downstream reaches are often times characterized as faster, shallower habitat (Rice et al 2006). The third habitat type is the tributary stream itself. Many species of fish, in particular salmonids, utilize all these various habitat types throughout their life cycle. Kiffney et al. (2006) found that there were much higher abundances of juvenile salmonids within the vicinity of tributaries than in main stem reaches with no tributary input. As discussed, confluence zones are typically marked by high production rates, and high abundances of aquatic invertebrates.

In addition to substrates and nutrients provided by the tributary, delta habitat areas would also receive flows from the tributary and hence are less influenced by the higher TSS concentrations typically experienced in the lower Churchill River as well as that predicted during reservoir stabilization. Thermal regimes will also remain unchanged within tributary inflows to the reservoir. Delta habitat can be created at the new confluences of tributary streams to take advantage of the natural flows.

Limited delta habitat at the confluence of tributaries and the main stem currently exist in the lower Churchill River (see AMEC 2007). Subsequent review of tributaries within the Muskrat Falls reservoir area identified two potential areas to be suitable for delta creation; **Edward's Brook** and **Pinus River**. Delta creation at the mouth of these tributaries would provide an area of habitat with a clean water input source; i.e., from the delta inflows. While delta habitat at other tributaries will form over time, an estimated **26-29ha** of delta habitat will be created; **11-12ha** at Edward's Brook and **15-17ha** at Pinus River. The primary species shown to use existing Delta habitat, based on sampling and radio telemetry, are lake whitefish, white sucker, northern pike and brook trout. While not sampled to any high abundance, ouananiche will also benefit from the clearer water provided by the tributaries over the delta habitat and may be attracted to these areas. The higher species abundance in the Muskrat Falls area are white sucker which are spring spawners that free-cast demersal, adhesive eggs over sand and gravel. The species is found throughout the watershed but use nearshore/littoral habitat preferably. Lake whitefish are also found in the Muskrat Falls reservoir area. They primarily use Fast and Lacustrine habitat types with the lower Churchill River. Most of the specimens in the Muskrat Falls area have been captured in the Gull Lake area and Fast habitat near Pinus River. Both brook trout and ouananiche prefer clean, cool water particularly for spawning. Highest brook trout spawning habitat utilization is within smaller streams and tributary slow habitat while ouananiche show highest spawning utilization in faster habitat types (see AMEC 2010). Most specimens captured within the Muskrat Falls portion of the main stem were also within the Gull Lake and Pinus River areas. Northern pike also utilize delta habitat but require aquatic vegetation for egg deposition – this species will be addressed with other physical compensation works (see **Section** 5.2.4).

5.2.3.1 General Delta Construction

The construction practice for each location will be the large-scale removal of the remaining vegetation and overburden (i.e., what is left upon completion of reservoir preparation). This material will not be removed from the general location but will be "pushed" from the higher elevations to lower elevations. It will be placed at a lower elevation such that sufficient substrate material can be placed over it to inhibit decomposition and anoxic conditions. The suitable substrate material will be "cut and filled" in the habitat area such that all created habitat is at the general elevation of 0.5m below the low supply level of the reservoir (i.e. at 38.0m asl). **Figure** 5.14 provides a general schematic of the process. All physical fish habitat compensation works will be completed under the direction of an experienced biologist. Details specific to each site are provided in the following sections.

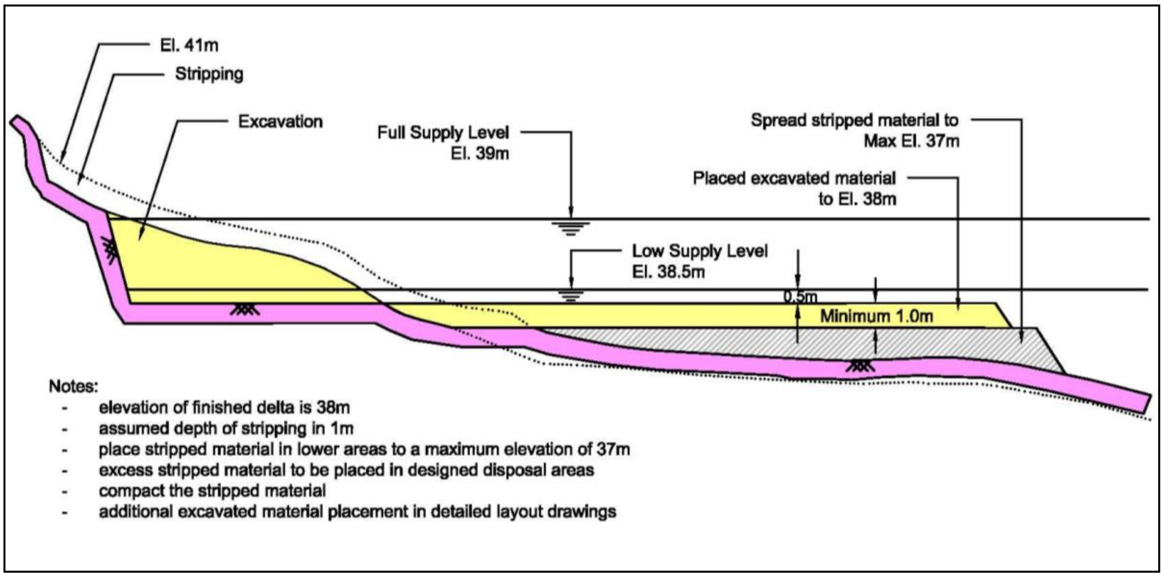


Figure 5.14. Schematic of general "cut and fill" associated with Delta Compensation Works.

At each location, the intention is to disturb the existing aquatic habitat as little as possible. This habitat continues to provide spawning and recruitment to the aquatic system and as such, will remain unaltered as long as possible, however, in order to get the delta habitat constructed as required, each tributary will be diverted around the construction site. Connectivity between upstream and downstream habitat will be maintained. Following construction/modification of any habitat area, the immediate site access areas will be re-contoured, landscaped and re-vegetated prior to inundation. This will be completed by machinery as it retreats from the area. If riparian vegetation is required around a created/enhanced habitat area, it will be rehabilitated immediately once the physical works are completed. Initial riparian re-vegetation will consist of hydroseeding (typical seed mix such as Canada No.1 Ground Cover Mixture). Larger vegetation will be transplanted from local sources as well as allowing natural revegetation (in particular alders) to become established. Local young trees such as aspen, birch, balsam fir, black spruce and alder will be transplanted near any disturbed areas to assist in stabilization and re-colonization of the disturbed area. All re-vegetation will be completed under the direction of an experienced botanist.

While the contractor will be responsible for final design, protection and implementation of the river diversions, the overall design has been developed based on existing information and anticipated environmental conditions. For example, the watershed of each river, the pro-rated flows, and the slope of the area have been used to determine the size of each diversion channel configuration and excavation. In advance of the bulk earthworks, the excavation of the river diversion channel will be constructed (in the dry) adjacent to the existing alignment of the river. Minor work may be required in the river to place berms and direct flow toward the diversion. The diversion channel will be lined to avoid excess erosion throughout and to limit the extent of the excavation. All material within the excavation will be stockpiled, or used in the development of the diversion, and later used to rehabilitate each excavation. Berms will be placed where necessary to direct water into/through the diversions, limit water velocity, and control erosion.

5.2.3.1.1 Design of Created/Enhanced Delta Habitat

Any enhanced habitat within Edward's Brook and Pinus River will have to consider the local flows which could be encountered. Inherent in this approach within a natural watercourse is the knowledge that the material exposed will be naturally shifted somewhat but most substrates will remain within the delta. The maximum flows at each delta have been considered with respect to habitat and substrate stability. Typical fall flows have also been incorporated into the design, as they will determine the appropriate slope and substrate depths in each reach to achieve the preferred range of water depth and velocity for spawning.

Since flows within the tributary watershed will not be modified as part of the compensation design (i.e. the natural hydraulic regime will remain unaltered), the underlying characteristics of any modified/created habitat will depend highly on local flow characteristics. That is, the general width, depth and slope of modified habitat will be such that the high flows naturally occurring in the system will be transported without excess erosion or damage. While habitat enhancements have been designed to maximize suitability for the species present, minimal disturbance of the existing riparian habitat is also desirable. Any riparian disturbance will attempt to take place at locations within areas of delta enhancement or in areas of lowest velocity. Bank stabilization will also be required in areas to avoid unstable conditions and slumping.

Hydraulic modeling was completed at each delta location to generate water depths and velocities across the habitat that are suitable for the fish as well as the substrates that will occupy the area. Models have focused on flows associated with spawning (September-October), high spring flows (May), and extreme flows during storms to ensure that substrates would not be flushed out of the deltas. Calculated water velocities have been compared against typical bedload movement velocities for substrates in streams (**Table** 5.6 extracted from DFO 1998).

Table 5.6 Transport velocities of different streambed materials (extracted from DFO 1998).

Material	Diameter (mm)	Transport Velocity (m/s)
Silt	0.005-0.05	0.15 - 0.20
Sand	0.25-2.5	0.30 – 0.65
Gravel	5.0-15	0.80 – 1.20
Fine to Coarse Stone	25-75	1.40 – 2.40
Cobble	100-200	2.70 – 3.90

Calculated water depths and slopes within each delta were also used to calculate tractive forces of the streambed material, which determines potential for streambed movements (Newbury and Gaboury 1993). Tractive force is used to describe the average sheer stress in a reach and can be determined by the average slope of the water surface and the depth of flow, under assumed uniform flow conditions.

Tractive force (kg/m^2) = 1000 x d x s

where d is the depth of flow (m) and s is the slope of water surface within the reach.

The tractive force of the streambed and the diameter of substrate which may be moved can be described as:

tractive force (kg/m^2) = incipient diameter (cm).

5.2.3.2 Pinus River Delta

Figure 5.15 provides the expected layout of the Pinus River delta based on the engineer design and GIS data (e.g., LiDAR, imagery, DEM). **Appendix** A provides the detailed engineer construction drawings. Based on the information and modeling presented below and in AMEC (2012), it is estimated that the Pinus River Delta will be **15-17ha** in size. Pinus River is a relatively large tributary of the lower Churchill River that enters from the north approximately 87km upriver (approximately 45km upriver from Muskrat Falls). Its drainage area is estimated at 1,105km^2 based on GIS watershed mapping. The existing hydrology station on both Pinus (farther upriver within the drainage basin) and Minipi Rivers were used to generate a pro-rated hydrograph (**Figure** 5.16) and flow duration curve (**Figure** 5.17) for the outflow of Pinus River (i.e., the area of delta creation). The hydrograph depicts the monthly flow variations for mean, maximum, and minimum flow rates. In general, the maximum daily flow is estimated at 276m^3/s with a mean annual flow of 16m^3/s. Ten percent of the time, flows are greater than 55m^3/s. Typically, seasonal variation is observed: where the lowest flows are observed in the winter months (February and March) and highest flows observed in the springtime (May and June). These high flows are presumably high from spring snowmelt runoff and large amounts of rainfall.

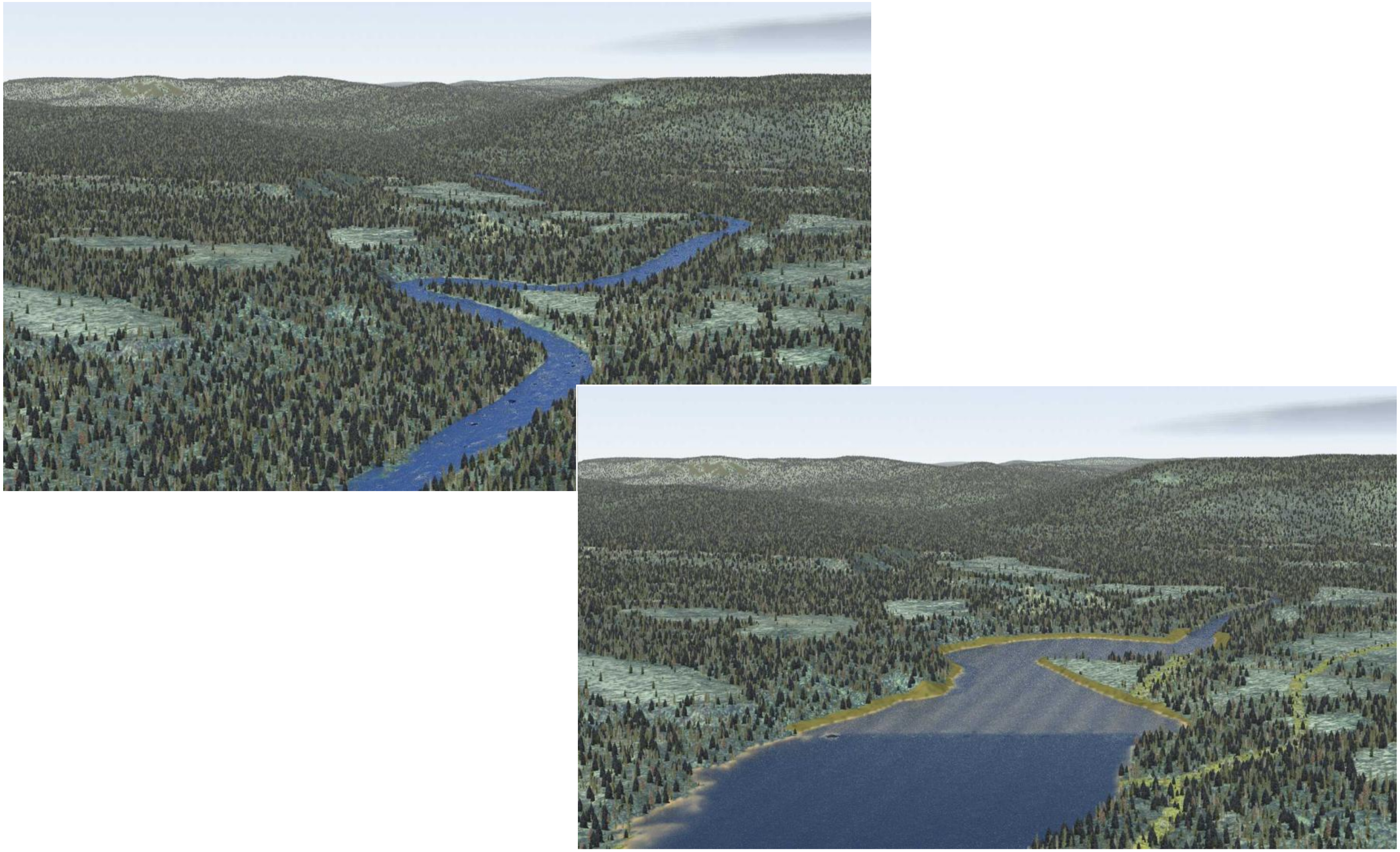


Figure 5.15. Pinus River Delta (pre- and post-construction), approximately 45km upriver of the proposed Muskrat Falls dam. 3D rendering based on engineer design and GIS data (lighter shading in water indicates extent of delta creation).

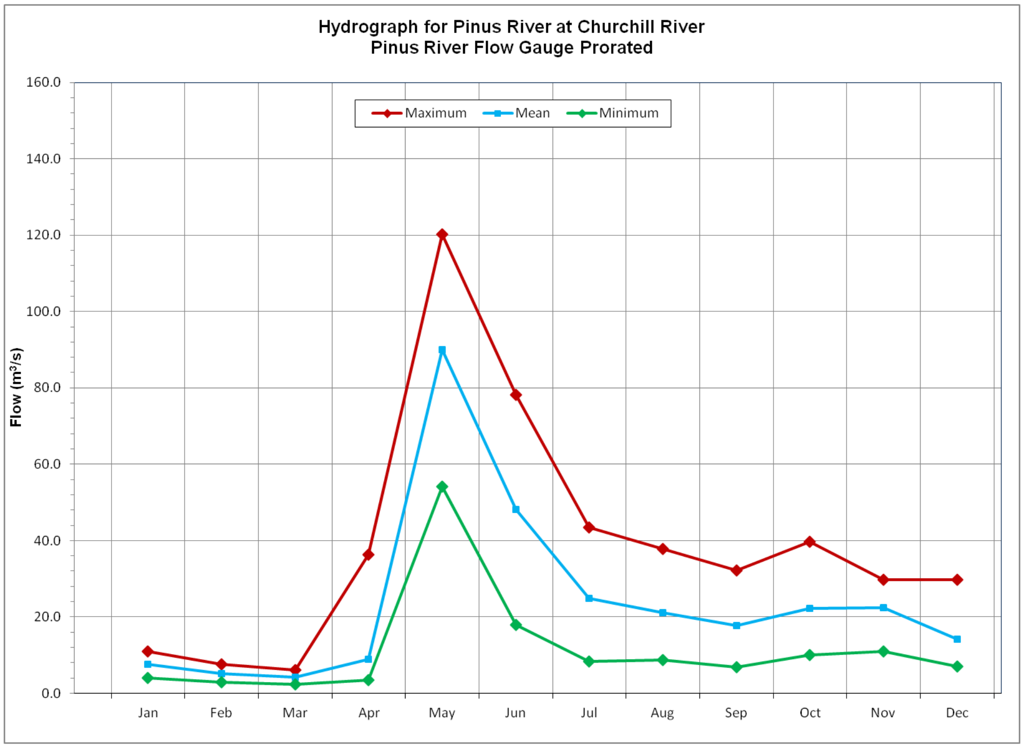


Figure 5.16. Typical monthly mean hydrograph, Pinus River.

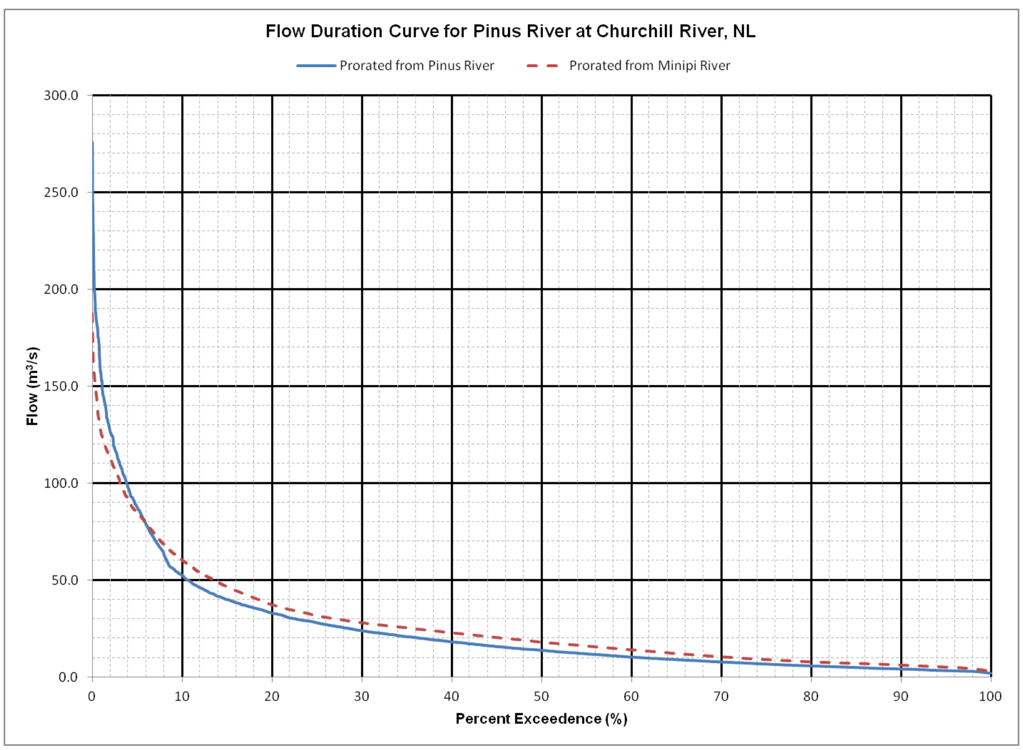


Figure 5.17. Prorated flow duration curves, Pinus River.

5.2.3.2.1 Surficial Geology

The surficial geology indicates that suitable spawning and rearing materials are present (e.g., proportions of gravel, sand and cobble/rubble). The area is also close to the existing Trans Labrador Highway and access would therefore be possible either from the highway or via reservoir preparation access roads within the reservoir. Material would be moved to expose a delta area at the new confluence between the tributary and the Muskrat Falls reservoir.

Based on surficial geological mapping (JWEL 2000), the Pinus River delta area is comprised of primarily fluvial material (**Figure** 5.18). Fluvial material is characterized as sediment deposited by modern rivers and small streams in channels. Fluvial deposits are dominantly sandy, ranging from silt to very coarse sand (fine, medium and coarse sand are most common).

Pebble, cobble and boulder gravel are also present. Deposits are generally horizontally bedded and moderately to well sorted. Clasts are subangular to rounded. **Figure** 5.19 presents a photo of Pinus River near the location of the delta creation.

Additional on-site sampling of the Pinus River delta area was completed in 2010 (AMEC 2011). Between elevations of 39m asl and 36m asl at the Pinus River flood plain, five test pits (PR-001 to PR-005) were manually excavated and advanced into unweathered, native soils at depths ranging from 0.5 mbgs to 1.5 mbgs. With the exception of test pit PR-004, a layer of rootmat / topsoil and weathered soils was encountered at the surface of all test pits. The thickness of this stratum ranged from 0.1 m to 0.2 m. The soil composition of unweathered, native soils beneath the surficial layers generally ranged from sandy silt (i.e., biologically classified as sand) to sand and gravel (i.e., biologically classified as coarse sand to small cobble) with trace silt. Trace sub-angular to sub-rounded cobbles (i.e. biologically classified as small cobble – rubble) were observed in test pit PR-003. Some sub-rounded cobbles were also noted in test pit PR-004.

5.2.3.2.2 Hydraulic Modeling

Two-dimensional hydraulic modeling of the Pinus River delta site was completed in 2011 using RiverFLO-2D software, a finite element model developed by Hydronia LCC. For the model, all material in the delta location up to the 42m asl elevation was presumed excavated and “cut and fill” operations completed to provide a delta with a submerged bottom elevation of 38m asl. The modeling was completed to determine the water depths and velocities at a range of natural flows from Pinus River. Results are provided in AMEC (2012). Modeling was also re-run in 2012 upon engineer design completion to confirm that preferred velocity and water depth conditions were maintained (AMEC 2012).

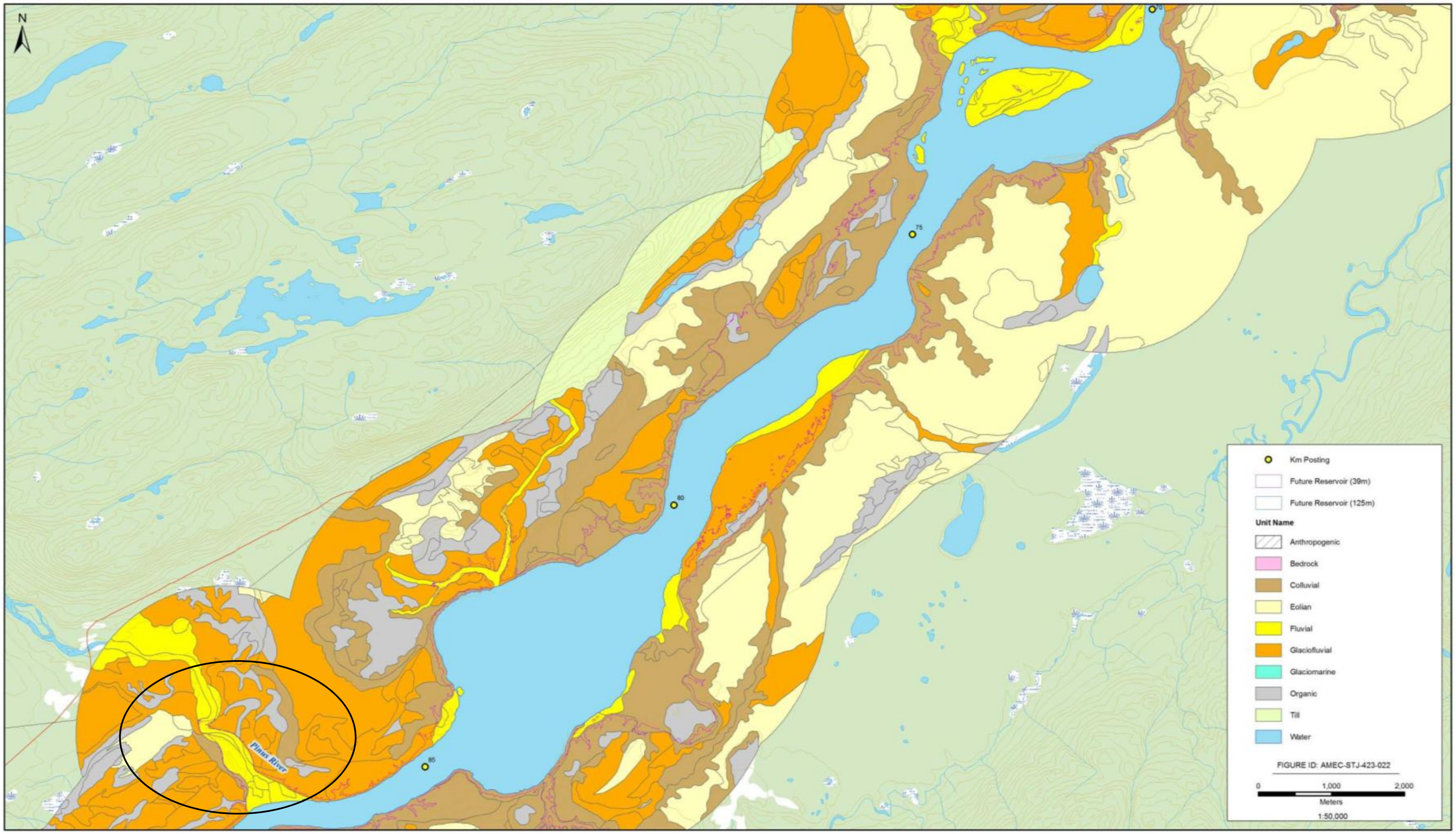


FIGURE 17

Surficial Geology and Geomorphology - Future Reservoir Shoreline

Figure 5.18. Surficial geology mapping of Pinus River area (JWEL 2000).

Figure 5.19. Pinus River, August 2010.

Model results were used in the preliminary design of the delta as well as to anticipate the level of bedload/substrate movement. For example, water velocity estimates indicate that:

- Berms or other instream structures, to manipulate flow direction and/or velocities will not be required;
- during construction there should be an engineered transition zone between the delta and the confluence with Pinus River to avoid excessive erosive velocities in this area; and
- during construction there should be consideration to the shape of the lower boundary of the delta where velocities are reduced (**Figure** 5.20).

Figures 5.21 and 5.22 provide the location and outlines of a series of transects across Pinus River that have been used to calculate the potential for substrate movements. Transect locations have been based on areas with higher estimated velocities and therefore higher overall potential for substrate scour/movement. Within Pinus River, extreme discharges of 276m^3/s as well as 10% exceedance flow (55m^3/s) have been used to estimate velocities in designed habitat (**Table** 5.7). At the extreme flow, velocities ranging from 0.92-2.12m/s can be expected, with the higher velocities near the narrower upstream entrance to the delta (**Figure** 5.20).

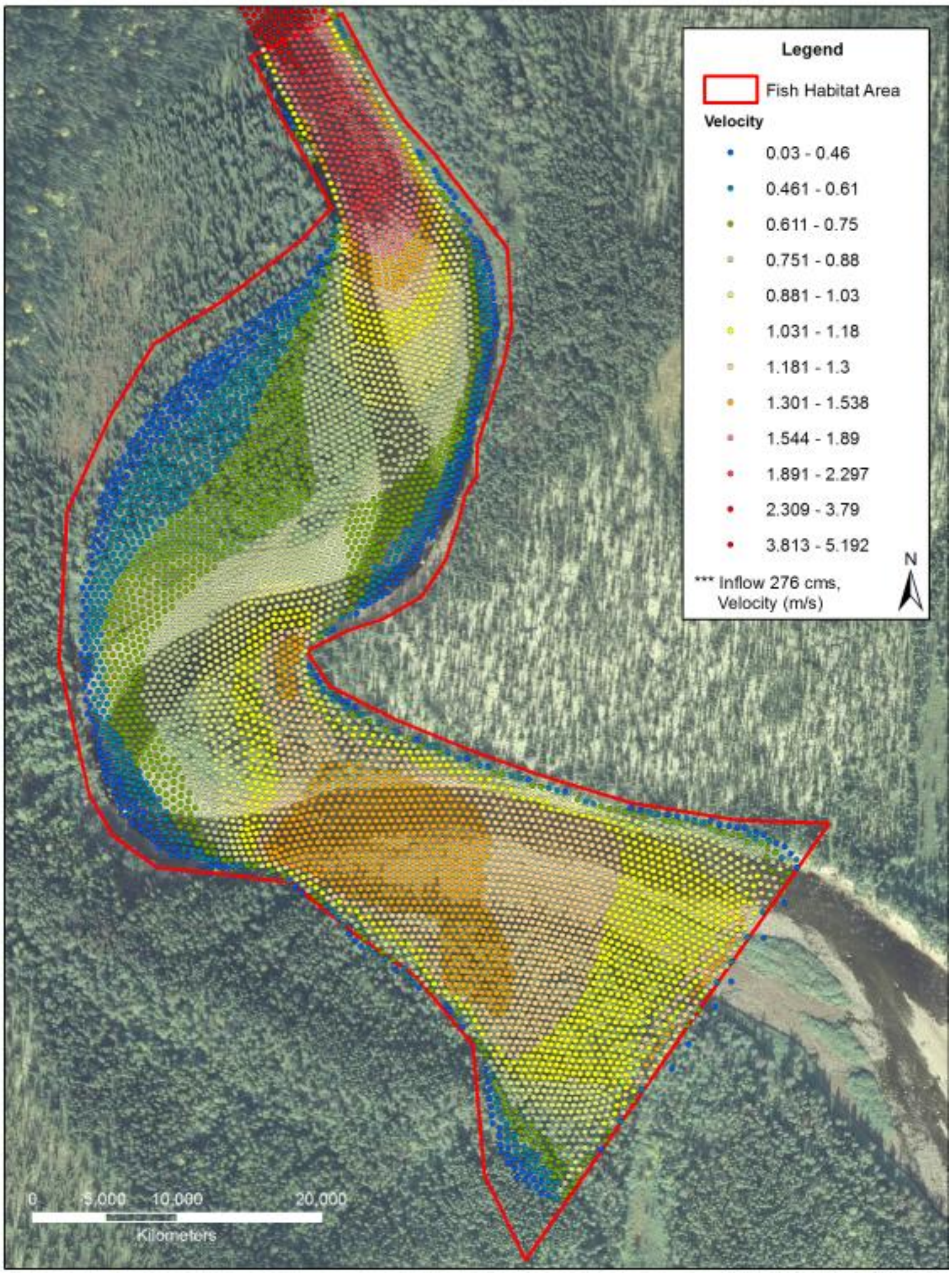


Figure 5.20. Pinus River 2012 hydraulic model results showing general distribution of water velocities (at 276m^3/s).

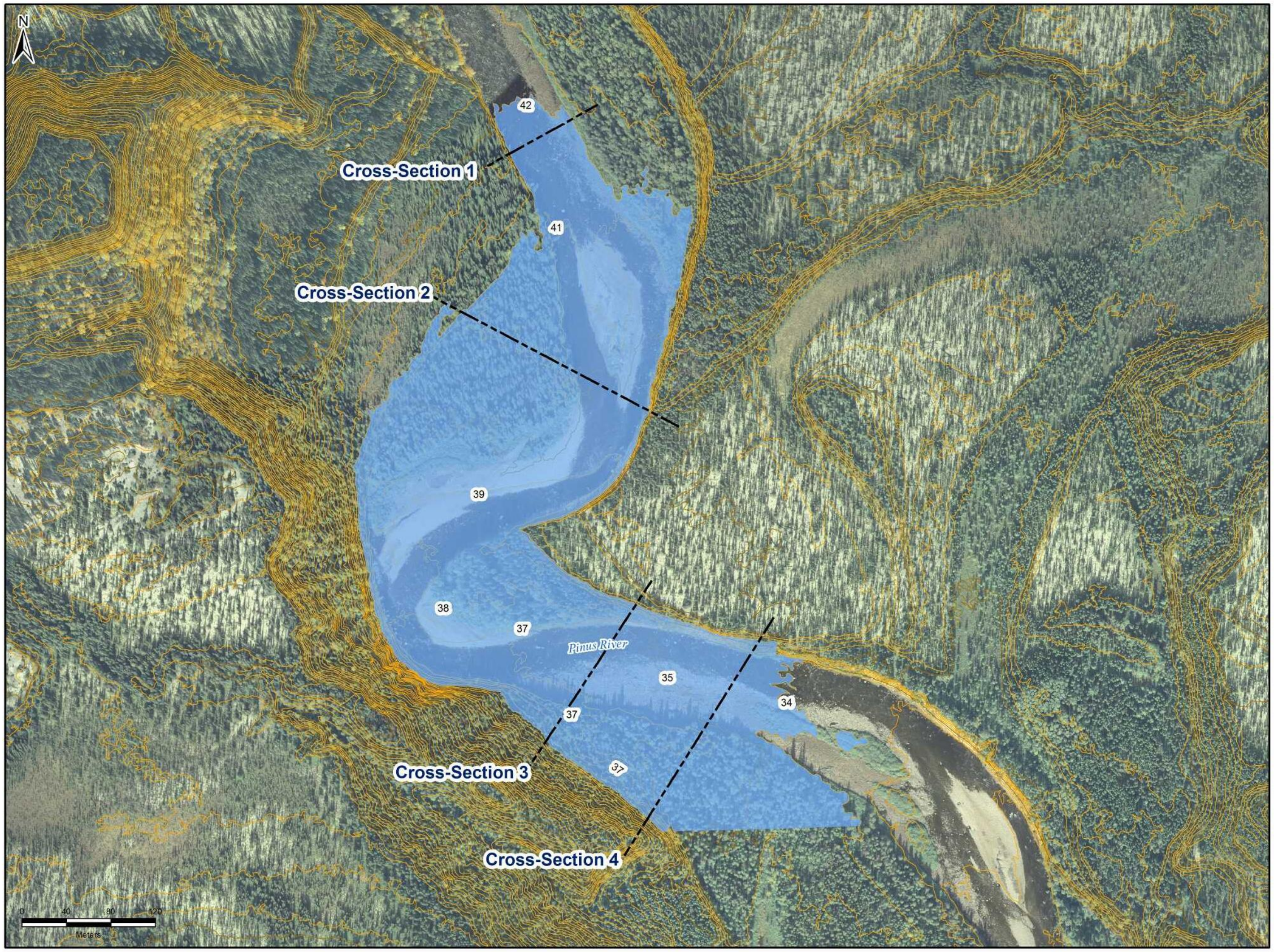


Figure 5.21. Transect locations across Pinus River for calculation of substrate movement potentials.

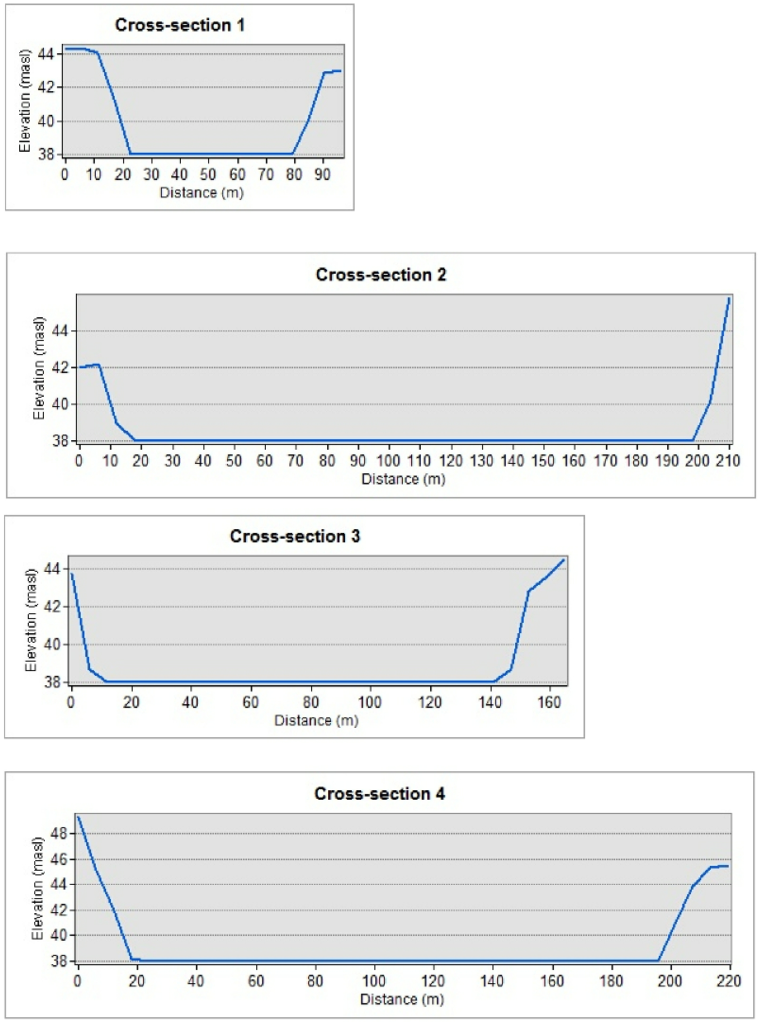


Figure 5.22. Transect profiles across Pinus River for calculation of substrate movement potentials.

Table 5.7 Summary habitat measures for proposed Pinus River delta based on hydraulic modeling.

Reach	Habitat Measures				
	Water Velocity (m/s)		Water Depth (m)		Slope (m/m)[1]
	Mean	Maximum	Mean	Maximum	
Typical Spawning Discharge (16m^3/s)					
Transect 1	0.13	0.41	0.72	1.10	0.001
Transect 2	0.07	0.12	0.91	1.04	0.001
Transect 3	0.11	0.16	0.89	1.01	0.001
Transect 4	0.08	0.12	0.85	1.00	0.001
10% Exceedance Flow (55m^3/s)[1]					
Transect 1	0.37	0.93	0.90	1.42	0.001
Transect 2	0.19	0.30	1.06	1.21	0.001
Transect 3	0.31	0.42	0.95	1.08	0.001
Transect 4	0.24	0.33	0.87	1.03	0.001
Extreme Flow (276m^3/s)					
Transect 1	0.87	2.12	1.78	2.90	0.001
Transect 2	0.50	0.92	2.04	2.34	0.001
Transect 3	1.00	1.35	1.51	1.73	0.001
Transect 4	0.95	1.28	1.14	1.36	0.001

[1] Delta is designed to have a bottom elevation of 38m (i.e, limited slope).

Based on transport velocities shown in **Table** 5.6, the velocity range during extreme flows would have the potential to move particles up to 50mm in size. As shown, Pinus has larger flows and larger potential to move and shift substrates than Edward's Brook. Additionally, the habitat measures outlined in **Table** 5.7 were used to calculate the estimated potential incipient particle diameters for both 10% exceedance (i.e. 55m^3/s) and extreme flows (i.e. 276m^3/s). In order to remain conservative, the maximum water depths at each transect was used in the calculations. In general, the habitat characteristics associated with the created delta habitat would remain suitable for spawning/rearing (**Table** 5.8). The largest particle size capable of movement using incipient particle calculations would be 2.9cm near the faster upper portion of the delta at 276m^3/s.

It is anticipated that smaller exposed material at Pinus River delta may be shifted/moved as a result of extreme flows from the Pinus River. The movement of material within a habitat improvement area with unregulated flows is typical and expected and will assist in flushing portions of the finer sands and silts. In areas with very high velocities (i.e., greater than 2m/s), larger material (greater than 75mm) will be screened and placed to enhance rearing and to protect excessive scouring. It is not expected that all substrate less than this diameter would be transported as it will lie within a matrix of larger material. While it can be expected that some movement of material will occur during extreme freshets, it is anticipated that the placed material would not be removed from the deltas. Movement/shifting of the smaller size materials at each delta (i.e., 20-50mm) during higher flow events, is anticipated and will expose the more suitable size class material for spawning and rearing and create a more heterogeneous delta habitat .

Table 5.8 Potential incipient particle diameters for each habitat design, Pinus River.

Habitat Design	Maximum Water Depth (m)	Slope[1]	Flow (m^3/s)	Incipient Particle Diameter (cm)
Transect 1	1.42	0.001	55	1.42
	2.90		276	2.90
Transect 2	1.21	0.001	55	1.21
	2.34		276	2.34
Transect 3	1.08	0.001	55	1.08
	1.73		276	1.73
Transect 4	1.03	0.001	55	1.03
	1.36		276	1.36

[1] Delta is designed to have a bottom elevation of 38m (i.e, limited slope).

It should be noted that the calculations above are used as a general indication of substrate stability and movement potential and are assumed under uniform flow conditions (Newbury and Gaboury 1993). The potential incipient particle diameters are based on a mean surface water slope for each reach which is a conservative oversimplification in most streams. The movement potential for substrate is therefore anticipated to be less than that indicated by these estimate calculations. As shown in **Table** 5.7 transport velocities for substrates greater than 75mm are not anticipated at extreme flows of 55 and 276m^3/s at Edward's Brook and Pinus River respectively.

Ice observations within the Gull Lake area were also reviewed for both delta areas to ensure that excessive ice thickness wouldn't severely damage any habitat created. In general, ice thickness measurements ranged between 0.5-0.8m. Therefore the minimum water depth of 0.5m at a low reservoir depth of 38.5m is considered a reasonable compromise between excessive water depth over the delta, which would reduce water velocities, and protection from potential ice. Ice formation in the initial years will also assist in substrate re-distribution and stabilization.

5.2.3.2.3 Construction method

The construction will be generally "cut and fill", using existing material at each site. While the exact construction methods will be determined by the successful contractor, **Appendix** A provides the draft engineer design drawings associated with Pinus River delta construction. The contractor will also have to submit a detailed, site-specific Environmental Protection Plan (EPP), Sediment and Erosion Control Plan, and final Diversion Channel design to Nalcor prior to commencement.

5.2.3.2.4 Timing

Construction timing will be as close to reservoir inundation as possible while ensuring risk of impact to timing of construction and reservoir creation is minimal. With final reservoir inundation scheduled to occur in July 2017, the delta habitat will be constructed in the summer/fall of 2016.

5.2.3.3 Edward's Brook Delta

Based on existing data, Pinus River delta was chosen as the primary delta habitat construction location as it will be the delta used by most species. Because of the adaptive and cautious nature of the plan, Edward's Brook is being constructed as an adaptive investment (i.e., a habitat bank) of additional habitat beyond what is considered required. It is included so that it is available to fish, and its results applied to the offset of the HADD determination, should the Pinus River delta habitat underperform. This is a conservative approach as once the reservoir is created, additional delta habitat construction will be impossible.

Figure 5.23 provides the general layout of the Edward's Brook delta area that is available for enhancement based on engineer design and GIS data (e.g., LiDAR, imagery, DEM). **Appendix** B provides the detailed engineer construction drawings. Based on the information and modeling presented below and in AMEC (2012), it is estimated that the Edward's Brook Delta will be **11-12ha** in size. Edward's Brook is a tributary of the lower Churchill River that enters from the north approximately 83km upriver (approximately 40km upriver from Muskrat Falls). Its drainage area is estimated at 233km^2 based on GIS watershed mapping. The existing hydrology station on both Pinus and Minipi Rivers were used to generate a pro-rated hydrograph (**Figure** 5.24) and flow duration curve (**Figure** 5.25) for the outflow of Edward's Brook (i.e., the area of delta creation). The hydrograph depicts the monthly flow variations for mean, maximum, and minimum flow rates. In general, the maximum daily flow is estimated at 58m^3/s with a mean annual flow of 3m^3/s. Ten percent of the time, flows are greater than 12 m^3/s. Typically, seasonal variation is observed, where the lowest flows are observed in the winter months (February and March) and highest flows observed in the springtime (May and June).

5.2.3.3.1 Surficial Geology

The surficial geology indicates that suitable spawning and rearing materials are present (eg. proportions of gravel, sand and cobble/rubble). The area is also close to the existing Trans Labrador Highway and access would therefore be possible either from the highway or via reservoir preparation access roads within the reservoir. Material would be moved to expose a delta area at the new confluence between the tributary and the Muskrat Falls reservoir.

Based on surficial geological mapping (JWEL 2000), the Edward's Brook delta area is comprised of fluvial and glaciofluvial material (**Figure** 5.26). Fluvial material is characterized as sediment deposited by modern rivers and small streams in channels.

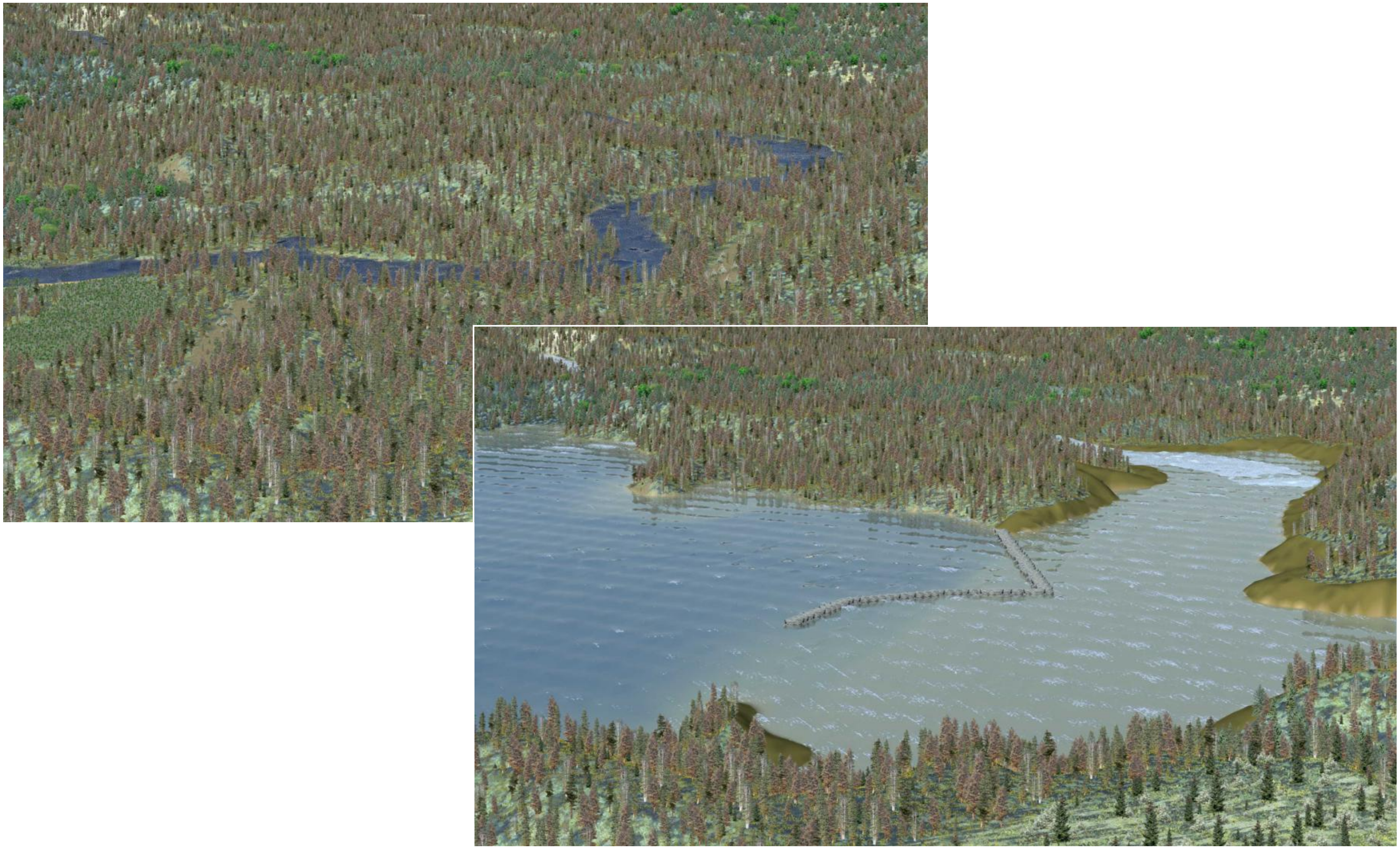


Figure 5.23. Edward's Brook Delta, approximately 40km upriver of the proposed Muskrat Falls dam. 3D rendering based on engineer design and GIS data (lighter shading in water indicates extent of delta creation).

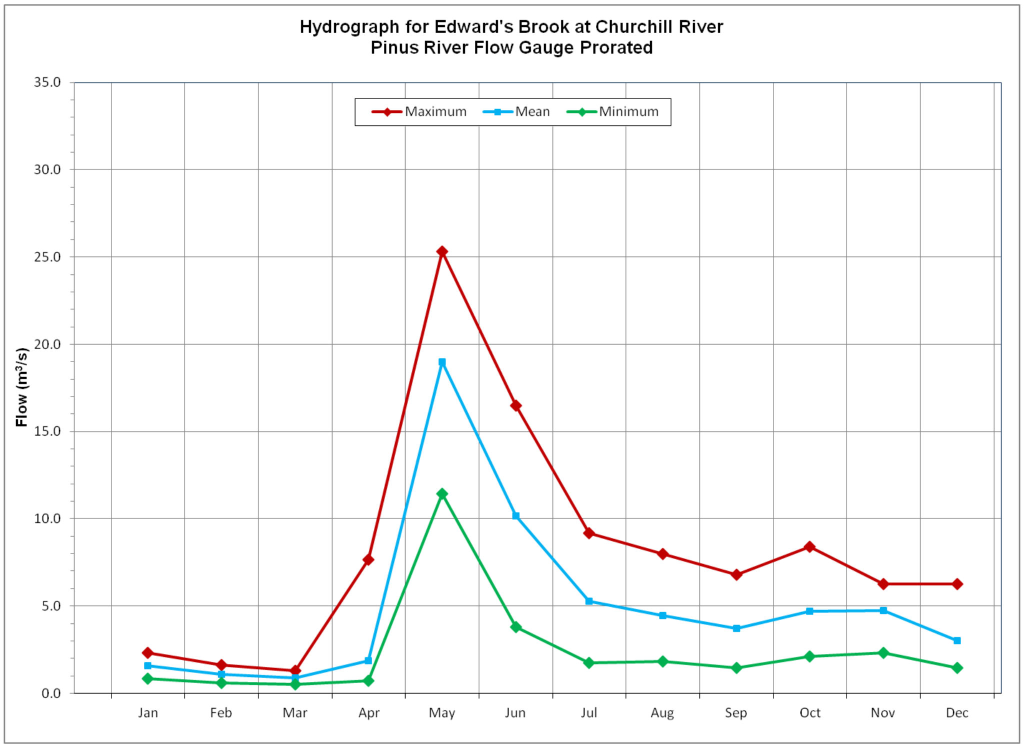


Figure 5.24. Typical monthly mean hydrograph, Edward's Brook.

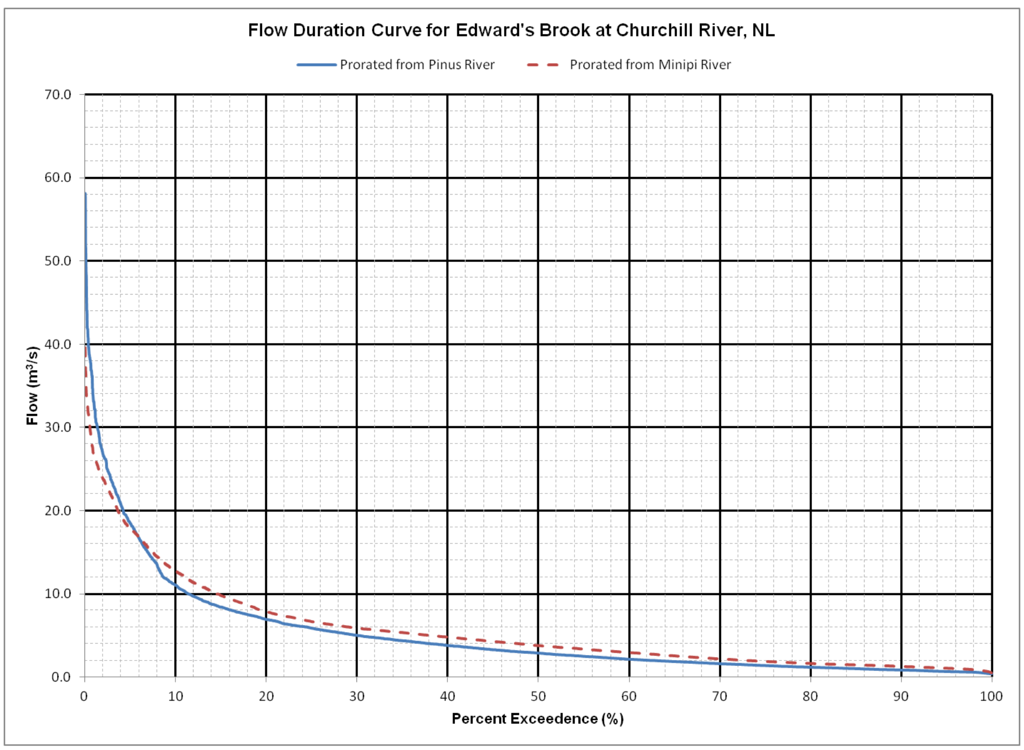


Figure 5.25. Prorated flow duration curves, Edward's Brook.

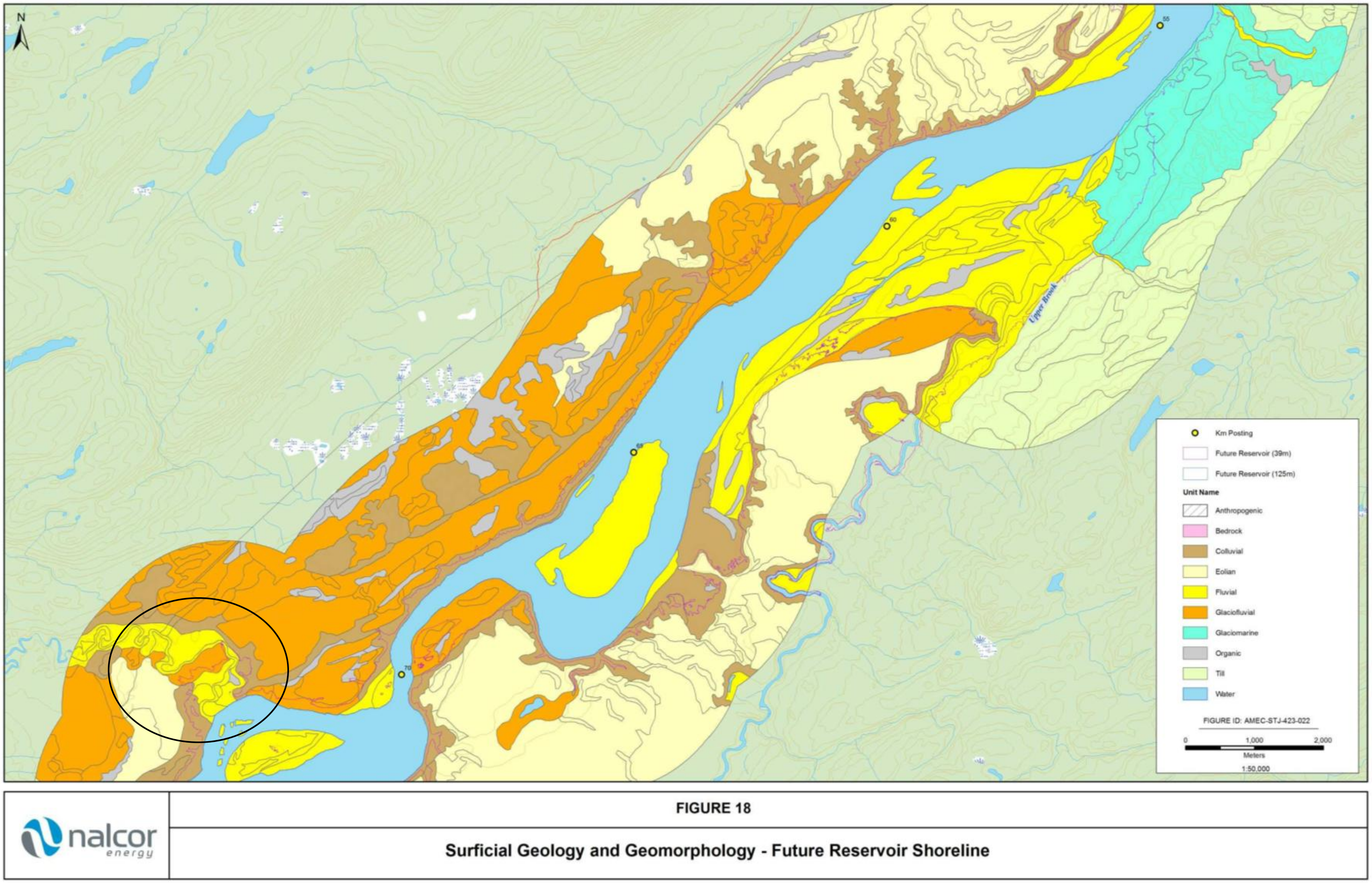


Figure 5.26. Surficial geology mapping of Edward's Brook area (JWEL 2000).

Fluvial deposits are dominantly sandy, ranging from silt to very coarse sand (fine, medium and coarse sand are most common). Pebble, cobble and boulder-gravel are also present. Deposits are generally horizontally bedded and moderately to well sorted. Clasts are subangular to rounded. Glaciofluvial material is sediment deposited by glacial meltwater rivers including subaerial river deposits (outwash), subglacial river deposits (eskers) and supraglacial deposits. It consists mainly of sand and gravel, with fine and medium sand the dominant sand sizes, while pebble, cobble and boulder gravel occur in about equal proportions among the coarser deposits. Clasts are generally subangular to rounded. Horizontal beds are the most common sedimentary structure. Sorting varies from poorly sorted sandy gravel to well sorted and very well sorted sand. Glaciofluvial deposits mainly form large terraces, but veneers and blankets are also abundant. **Figure** 5.27 presents a photo of Edward's Brook near the location of the delta creation.

Figure 5.27. Edward's Brook, August 2010.

Additional on-site sampling of the Edward's Brook delta area was completed in 2010 (AMEC 2011). Eight test pits (EB-001 to EB-006 and EB-008 to EB-009) were manually excavated between elevations of 39 masl and 36 masl at the Edwards Brook flood plain. A layer of rootmat / topsoil and weathered soils was encountered at the surface of all test pits. The thickness of this stratum ranged from 0.1 m to 0.5 m. Note that peat bog was observed at the surface of test pit EB-003. The soil composition of unweathered, native soils beneath the surficial layers generally ranged from sandy silt (i.e., biologically classified as sand) to gravelly sand (i.e., biologically classified as sand-small cobble) with some silt (i.e.

biologically classified as silt as well). Trace sub-angular to sub-rounded cobbles (i.e. biologically classified as small cobble – rubble) were observed in test pit EB-008. Trace quantities of clay were also noted in test pits EB-003 and EB-004.

5.2.3.3.2 Hydraulic Modeling

Similar to Pinus River, two-dimensional hydraulic modeling of the Edward's Brook delta site was completed in 2011 using RiverFLO-2D software. For the model, all material in the delta location up to the 42m elevation was presumed excavated and "cut and fill" operations completed to provide a delta with a submerged bottom elevation of 38m asl. The modeling was completed to determine the water depths and velocities at a range of natural flows from Edward's Brook. Results are provided in AMEC (2012). Modeling was also re-run upon engineer design completion to confirm that preferred velocity and water depth conditions were maintained. Model results were used in the preliminary and detailed design of the delta as well as to anticipate the level of bedload/substrate movement. For example, water velocity estimates indicate that:

- a berm will be required in order to deflect flow into a portion of the delta habitat;
- consideration be given to the removal of a portion of the identified delta habitat, as flows will not be capable of maintaining delta habitat conditions (see areas of low velocity in **Figure** 5.28); and
- during construction there should be an engineered transition zone between the delta and the confluence with Edward's Brook to avoid excessive erosive velocities in this area (**Figure** 5.28).

Figures 5.29 and 5.30 and provide the location and outline of a series of transects across Edward's Brook that have been used to calculate the potential for substrate movements. The transect locations have been based on areas with higher estimated velocities and therefore higher overall potential for substrate scour/movement. Within Edward's Brook, extreme discharges of 58m^3/s as well as the flow of 12m^3/s which is exceeded 10% of the time (i.e. 10% exceedance flow) have been used to estimate velocities in designed habitat (**Table** 5.9). At the extreme flows, maximum velocities ranging from 0.44-0.77m/s can be expected. This velocity range at extreme flows would have the potential to move particles up to 5mm in size based on information provided in **Table** 5.6.

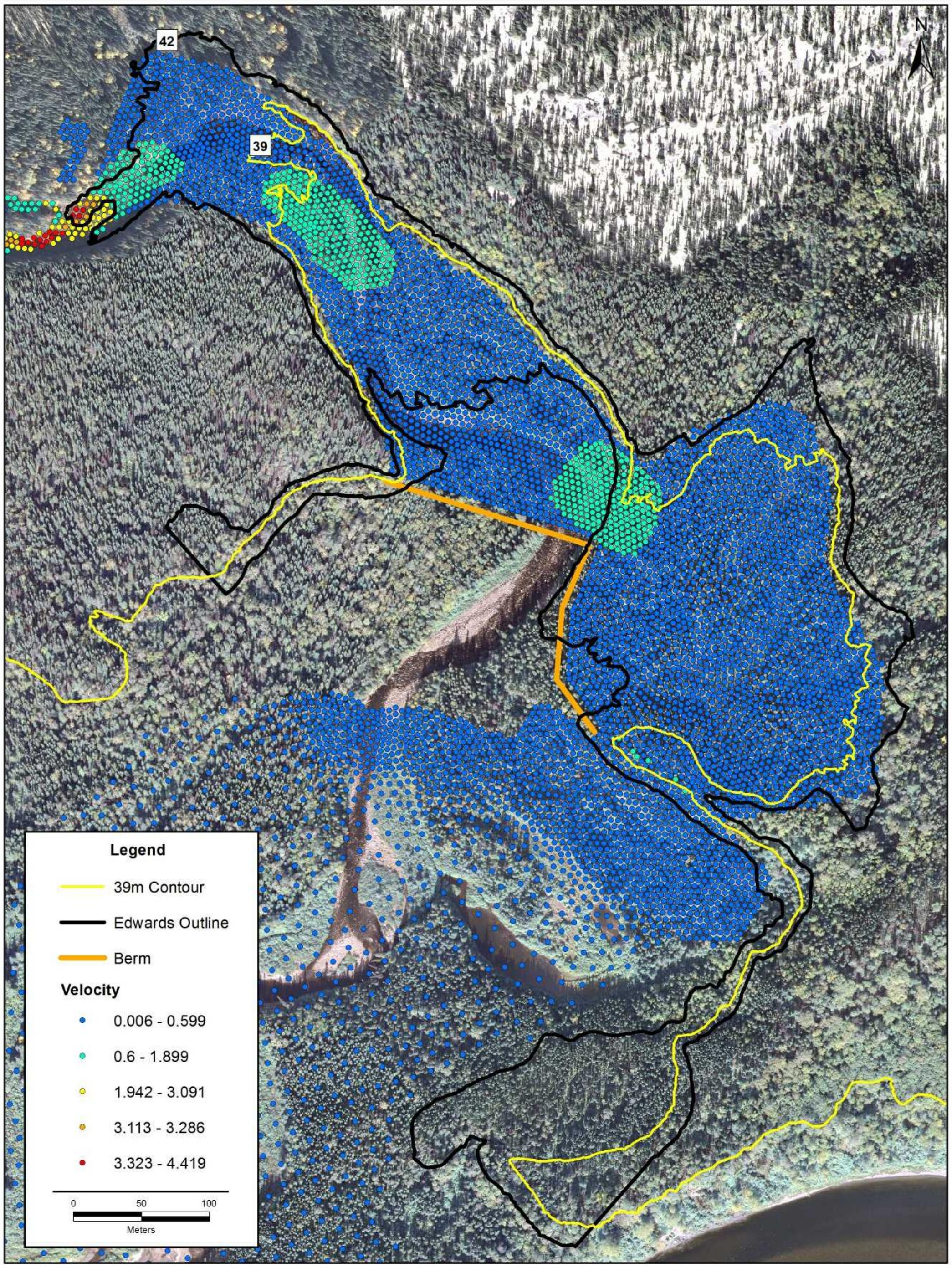


Figure 5.28. Edward's Brook 2012 hydraulic model results showing delta areas and general berm placement.

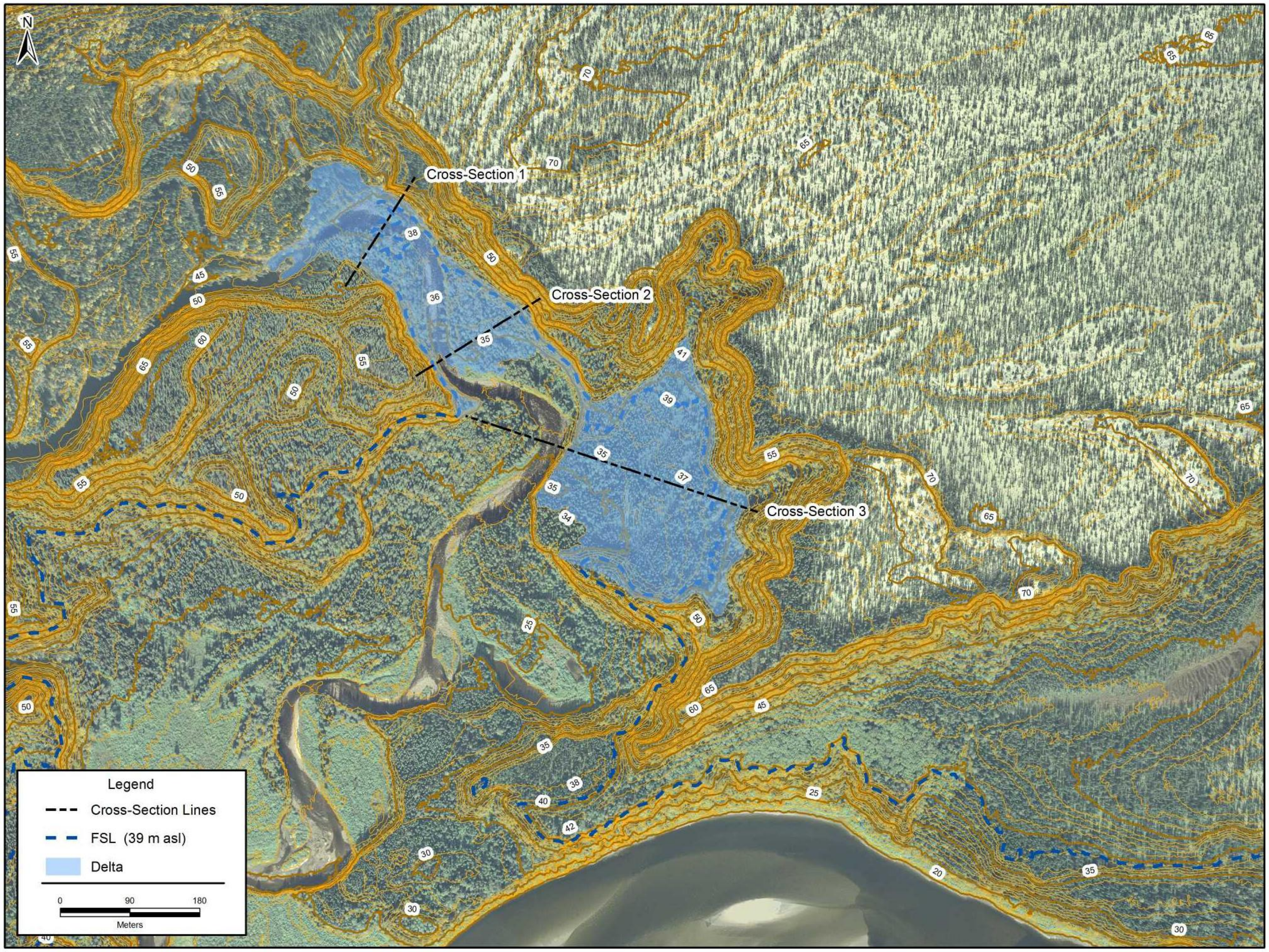


Figure 5.29. Transect locations across Edward's Brook for calculation of substrate movement potentials (numbers indicate elevations).

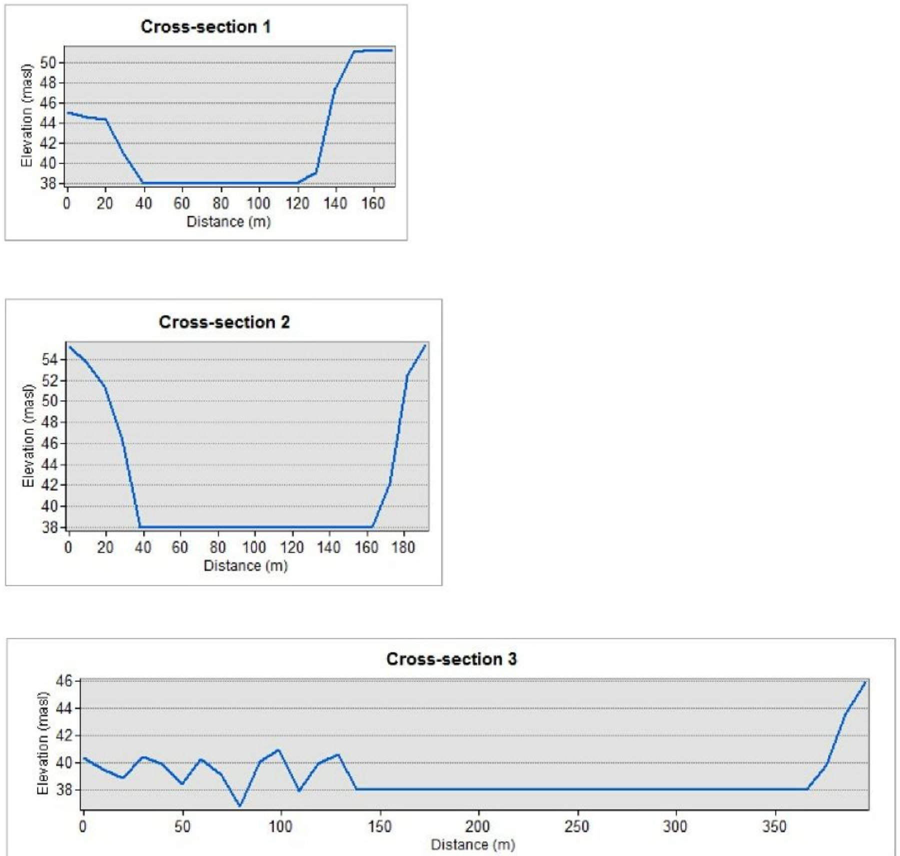


Figure 5.30. Transect profiles across Edward's Brook for calculation of substrate movement potentials. Note rock berm along a portion of Cross-section 3.

Table 5.9 Summary habitat measures for proposed Edward's Brook delta based on hydraulic modeling.

Reach	Habitat Measures				
	Water Velocity (m/s)		Water Depth (m)		Slope (m/m)[1]
	Mean	Maximum	Mean	Maximum	
10% Exceedance Flow (12m³/s)					
Transect 1	0.09	0.22	0.63	1.09	0.001
Transect 2	0.08	0.16	0.77	1.89	0.001
Transect 3	0.04	0.21	0.45	1.01	0.001
Extreme Flow (58m³/s)					
Transect 1	0.27	0.59	0.87	1.51	0.001
Transect 2	0.24	0.44	0.98	2.20	0.001
Transect 3	0.16	0.77	0.47	1.11	0.001

[1] Delta is designed to have a bottom elevation of 38m (i.e, limited slope).

Based on the habitat measures outlined in **Table** 5.9, the estimated potential incipient particle diameters for both 10% exceedance flow (i.e. 12m^3/s) and extreme flows (i.e. 58m^3/s) have been calculated (**Table** 5.10). To remain conservative, the maximum water depth at each transect was used in the calculations. In general, the habitat characteristics associated with the created delta habitat would remain suitable for spawning/rearing. The largest particle size capable of movement would be 2.2cm at the extreme flow of 58m^3/s.

Table 5.10 Potential incipient particle diameters, Edward's Brook.

Habitat Design	Mean Water Depth (m)	Slope[1]	Flow (m³/s)	Incipient Particle Diameter (cm)
Transect 1	1.09	0.001	12	1.09
	1.51		58	1.51
Transect 2	1.89	0.001	12	1.89
	2.20		58	2.20
Transect 3	1.01	0.001	12	1.01
	1.11		58	1.11

[1] Delta is designed to have a bottom elevation of 38m (i.e, limited slope).

As a result of the above calculations, it is anticipated that smaller exposed material at Edward's Brook delta may be shifted/moved as a result of extreme flows. The movement of material within a habitat improvement area with unregulated flows is typical and expected. While it can be expected that some stabilization of material will occur during extreme freshets, it is anticipated that the placed material would not be removed from the delta. It should also be noted that movement/shifting of the smaller size materials (i.e., less than 3cm) during higher flow events, is anticipated and will expose the more suitable size class material for spawning and rearing and create a more heterogeneous delta habitat.

It should be noted that the calculations above are used as a general indication of substrate stability and movement potential and are assumed under uniform flow conditions (Newbury and Gaboury 1993). The potential incipient particle diameters are based on a mean surface water slope for each reach which is a conservative oversimplification in most streams. Due to the generally lower flows, finer material may be flushed from the delta or settle in backwater areas and form area of aquatic vegetation.

Ice observations within the Gull Lake area were also reviewed for both delta areas to ensure that excessive ice thickness wouldn't severely damage any habitat created. In general, ice thickness measurements ranged between 0.5-0.8m. Therefore the minimum water depth of 0.5m at a low reservoir depth of 38.5m is considered a reasonable compromise between excessive water depth over the delta, which would reduce water velocities, and protection from potential ice. Ice formation in the initial years will also assist in re-distribution and stabilization.

5.2.3.3.3 Construction method

The construction will be generally "cut and fill", using existing material at each site. While the exact construction methods will be determined by the successful contractor, Appendix B provides the draft engineer design drawings associated with Edward's River delta construction.

5.2.3.3.4 Timing

Construction timing will be as close to reservoir inundation as possible while ensuring risk of impact to timing of construction and reservoir creation is minimal. With final reservoir inundation scheduled to occur in mid-July 2017, the delta habitat will be constructed in the summer/fall of 2016.

5.2.4 Aquatic Vegetation (Spawning)

The cleaned shorelines associated with access road construction, shoal enhancements in Gull Lake, and Delta construction will all have limited aquatic vegetation associated with them. Northern pike are spring spawners which typically utilize shallow bays, inlets or river edges with submergent or emergent vegetation with little to no current flow (Cott 2004; Casselman and Lewis 1996; Scott and Crossman 1998; Mingelbier and Brodeur 2008; Inskip 1982). They are broadcast spawners which mean they release adhesive eggs which stick to submerged vegetation (Inskip 1982; Grant and Lee 2004; Bradbury et al. 1999). Reported depths of spawning are variable but typically range between 5-250 cm with spawning in deeper littoral areas and shoals occurring as the spawning season progresses (Bradbury et al. 1999; Inskip 1982; Grant and Lee 2004; Farrell et al. 2006). In addition to northern pike, pearl dace and threespine stickleback also use aquatic vegetation for spawning.

Typical spawning vegetation is a mat of moderately dense flooded vegetation (Bradbury et al. 1999). Preferred vegetation includes areas of flooded rushes, grasses and sedges (Bradbury et al. 1999; Casselman and Lewis 1996; Inskip 1982); however they have been shown to utilize a variety of submergent and emergent vegetation as well as flooded terrestrial vegetation (Carbine 1942; Franklin and Smith 1963; McCarraher and Thomas 1972; Grant and Lee 2004; Inskip 1982; Casselman and Lewis 1996). For example, Inskip (1982) indicate that northern pike spawned over a variety of natural substrates including grasses (*Spartina* spp.), sedges (*Cyperaceae*), spikerushes (*Eleocharis* spp.), canary grass (*Phalaris* spp.) and water plantain (*Alisma* sp.) but also utilized scattered vegetative debris and deciduous leaves.

The use of artificial material by pike for spawning has been investigated by several researchers and material such as mowed hay, flooded hay bales, and flooded winter wheat plots have been noted (McCarraher and Thomas 1972 and Inskip 1982). Successful spawning over manmade structures has also been documented by Gillet and Dubois (1995) who researched the use of several terrestrial plant species and plastic trellis as artificial spawning substrates. Specifically, branches of spruce (*Picea abies*), juniper (*Juniperus communis*) and cypress (*Cupressus glabra*) were used to create artificial spawning habitat. Not only do these structures provide spawning habitat for adults but also later serve as suitable habitat for young pike. Specifically, Sandström and Karås (2002) indicate that previous work conducted by Gillet and Dubois (1995) and Nash et al. (1999) found that artificial habitat constructed of small spruce trees was suitable for young pike since the material was not too dense for small fish but was too dense for larger predatory fish to penetrate. Areas of unharvested wood due to excess slope will be left in place during inundation. **Figure** 5.31 presents the locations of shoreline where harvesting will not be completed due to safety or access challenges. In locations where they do not impede navigation, the trees will remain and provide submerged conifer trees and branches for spawning and cover.

Natural re-establishment of submergent, emergent and riparian vegetation will occur along the reservoir margins and nearshore areas but in the interim, the use of artificial spawning material would be beneficial to the maintenance of northern pike populations within the Muskrat Falls reservoir. Therefore, in addition to natural material, select locations will be prepared with artificial spawning habitat. The circled areas in **Figure** 5.31 are three locations where remaining timber and vegetation are not anticipated to impede navigation as they are up river in small confluence tributaries. Trees will be prepared in advance of reservoir inundation by "girdling" or removing a complete "ring" of bark around each tree. This kills the tree but leaves it standing (similar to the result of porcupine feeding on the bark of a tree). In general, the dead, standing trees will act as an adhesive substrate for eggs. In addition, by killing them in advance, the canopy will be opened for the regeneration of smaller grasses, shrubs and trees to begin. This will allow smaller trees and plants to start thick regeneration and hence provide floodable, vegetative spawning material. Once the reservoir is formed, the large dead trees, and smaller shrubs and regeneration, will stand within the nearshore area of the reservoir and provide spawning locations for northern pike. The trees will originate between the 34-38m elevations so that a variety of water depths will be available within each location. Upon inundation, mats of plastic spawning fabric will also be permanently deployed to provide pike spawning material in these areas. The total surface area of spawning fabric will depend on logistics and access, however, at least two units (200m^2) will be deployed throughout each in a series of 1mx10m wide strips. The prepared spawning areas at the three identified locations will be at least **0.5ha each** (for a total of **1.5ha**) and follow the contours of the new reservoir.

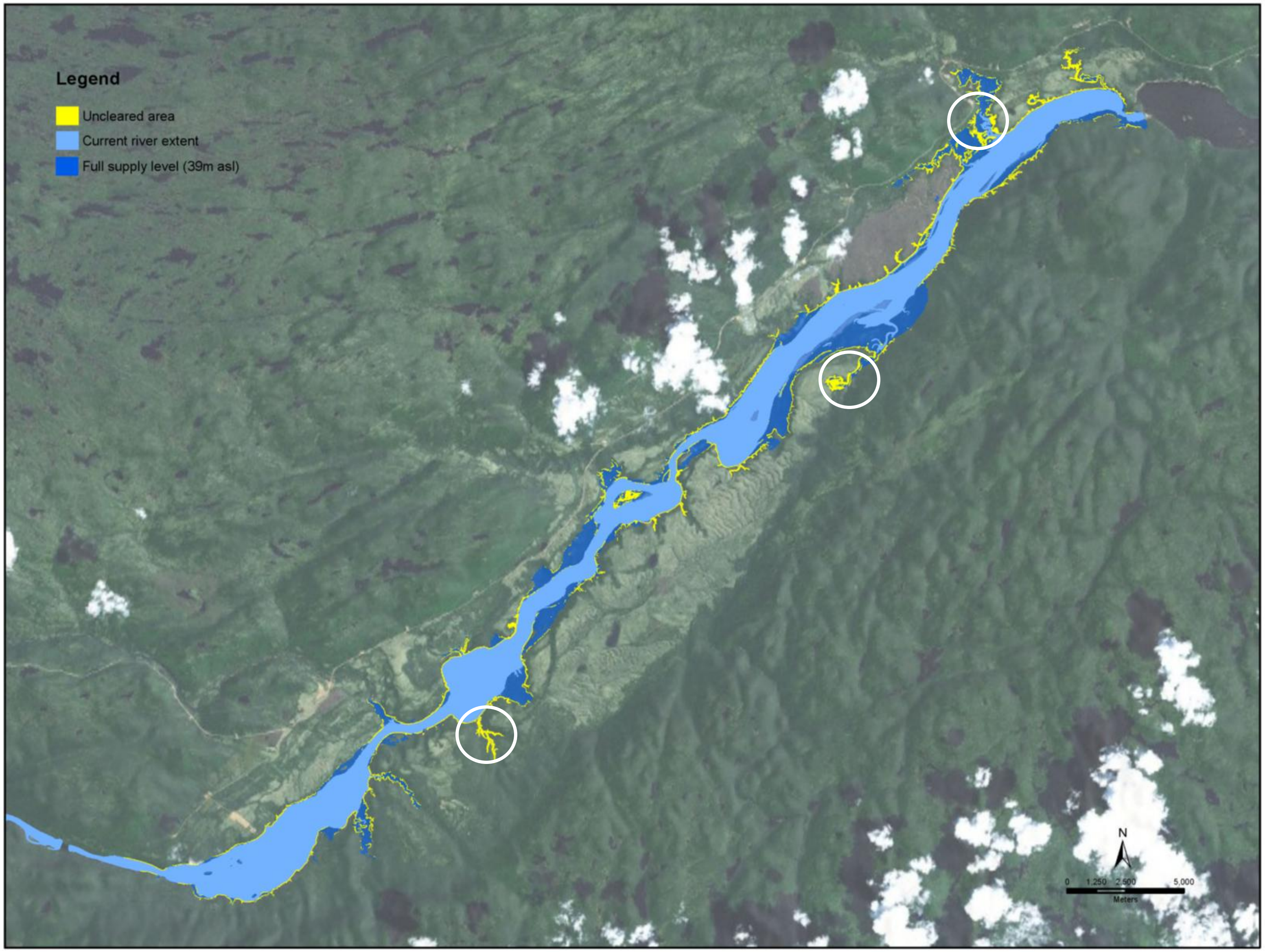


Figure 5.31. Areas of incomplete harvesting and proposed areas of pike spawning habitat enhancement (circles), Muskrat Falls reservoir.

5.2.5 Physical Compensation Works Monitoring

Nalcor is committed to monitoring the physical compensation work components for biological utilization and structural integrity. Where possible, all annual monitoring will be conducted within the same spatial and temporal boundaries to limit seasonal variability of results. The monitoring program will serve two objectives:

- Evaluate the completeness and effectiveness of compensation measures undertaken; and
- Provide information on fish species/ life stage utilization of the created/modified habitat.

Provided below are the details of the monitoring for the physical compensation works including the monitoring variable, the method, duration, frequency, analysis and reporting. The physical compensation works monitoring will also provide valuable input to the Adaptive Management (Tier 3) portion of the Plan, which is detailed in **Section** 5.3 below.

5.2.5.1 Duration

For biological measures, post-construction monitoring will generally be conducted annually for a period of three years immediately following inundation (e.g., 2018, 2019, 2020) and then bi-annually up to and including 2028. Similar to that described for the Adaptive Management monitoring, a review of results will be completed in early 2023 and 2028. Structural monitoring will also be conducted on the same schedule. The results of monitoring will be submitted annually to DFO (by March 31 of the following monitoring year). Monitoring programs are adaptive by nature and as such any necessary modifications to the physical works monitoring program would occur following each annual monitoring report, as well as at each five-year Major Program Review, by both Nalcor and DFO. **Table** 5.11 provides an overview of the monitoring and schedule.

5.2.5.2 Created/enhanced Nearshore Habitat

In general, performance criteria to determine successful implementation of the created/enhanced nearshore habitat portions of the physical compensation works will be:

- Retention of exposed shoreline and substrate features including revegetation; and
- Presence and initial increase in numbers of species and life stages utilizing nearshore habitat, and a catch-per-unit effort that approaches baseline.

Provided below are the measures and method summaries of the monitoring program associated with nearshore habitat creation outlined within the Plan.

Table 5.11. Summary of sampling schedule associated with physical compensation works monitoring.

Activity/Task	Monitoring Year										
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Created/Enhanced Nearshore Habitat											
Shoreline Stability	■	■	■		■		■		■		■
Substrate Stability	■	■	■		■		■		■		■
Fish Utilization	■	■	■		■		■		■		■
Created/Enhanced Shoal Habitat											
Habitat Stability	■	■	■		■		■		■		■
Hydrology	■	■	■		■		■		■		■
Grain Size Distribution	■	■	■		■		■		■		■
Fish Utilization	■	■	■		■		■		■		■
Redd Surveys	■	■	■		■		■		■		■
Created/Enhanced Delta Habitat											
Habitat Stability	■	■	■		■		■		■		■
Hydrology	■	■	■		■		■		■		■
Grain Size Distribution	■	■	■		■		■		■		■
Fish Utilization / Population Estimates	■	■	■		■		■		■		■
Redd Surveys	■	■	■		■		■		■		■
Aquatic Vegetation (Spawning)											
Spawning Vegetation Stability	■	■	■		■		■		■		■
Fish Utilization	■	■	■		■		■		■		■
Spawning Surveys	■	■	■		■		■		■		■
Monitoring Results and Major Program Review						★					★

5.2.5.2.1 Shoreline Stability

The stability of the shoreline will be visually inspected on the prescribed schedule at predetermined locations (**Figure** 5.32). Inspections will include an assessment of bank stability using available as-built surveys and photo records as a template along the identified areas where decommissioned roads will be at the appropriate elevation for terracing. Any sign of shoreline erosion due to ice or slumping will be recorded and input to the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3 below). A photographic record will be completed of all features and included in annual reports.

5.2.5.2.2 Substrate Stability

The composition of the bottom substrates will be inspected on the prescribed schedule. Inspections will include a visual inspection of nearshore habitat as well as physical sampling using an appropriate ponar grab (will have protective screens to ensure finer material is maintained with sample). Each sample will be collected (the top 0.2m), labeled, georeferenced, and analyzed for grain size at an accredited lab. Grain size distribution throughout the enhanced nearshore area will be assessed based on comparisons to baseline (as-built composition). Grain size distribution of material will determine whether changes in composition are occurring.

Grain size analysis using standard sieves will be conducted on the existing baseline nearshore material along the terraced roadway. These will serve as the baseline from which other monitoring years will be compared. The overall baseline sieve samples will be plotted on a single graph and used to derive an "envelope" (i.e. the upper and lower limits passing each sieve size will be used as the baseline of grain size distribution) for comparison to data collected during monitoring years. This information will also be input to the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3 below). A photographic record, and grain size distributions, will be included in annual reports.

5.2.5.2.3 Fish Utilization

Monitoring of fish utilization in created/enhanced nearshore habitat will be conducted on the prescribed schedule at each of the selected locations using the following standard methods to achieve the above compliance criteria. Non-lethal sampling of fish within nearshore habitat will be conducted between June 15 and September 15 of each sampling year. Sampling techniques are typically fyke netting and baited minnow traps. Nets will be set to sample at least the dawn and dusk periods for a minimum of twenty net-nights of effort within the areas identified in **Figure** 5.32. Sampling intensity and locations will reflect that required to accurately determine habitat utilization. Each captured fish will be identified to species. Catches will be separated by species and life stage to generate catch-per-unit effort values (biomass). These values will be used as an annual comparison of utilization as well as direct comparison to historic biomass catch-per-unit effort as applicable.

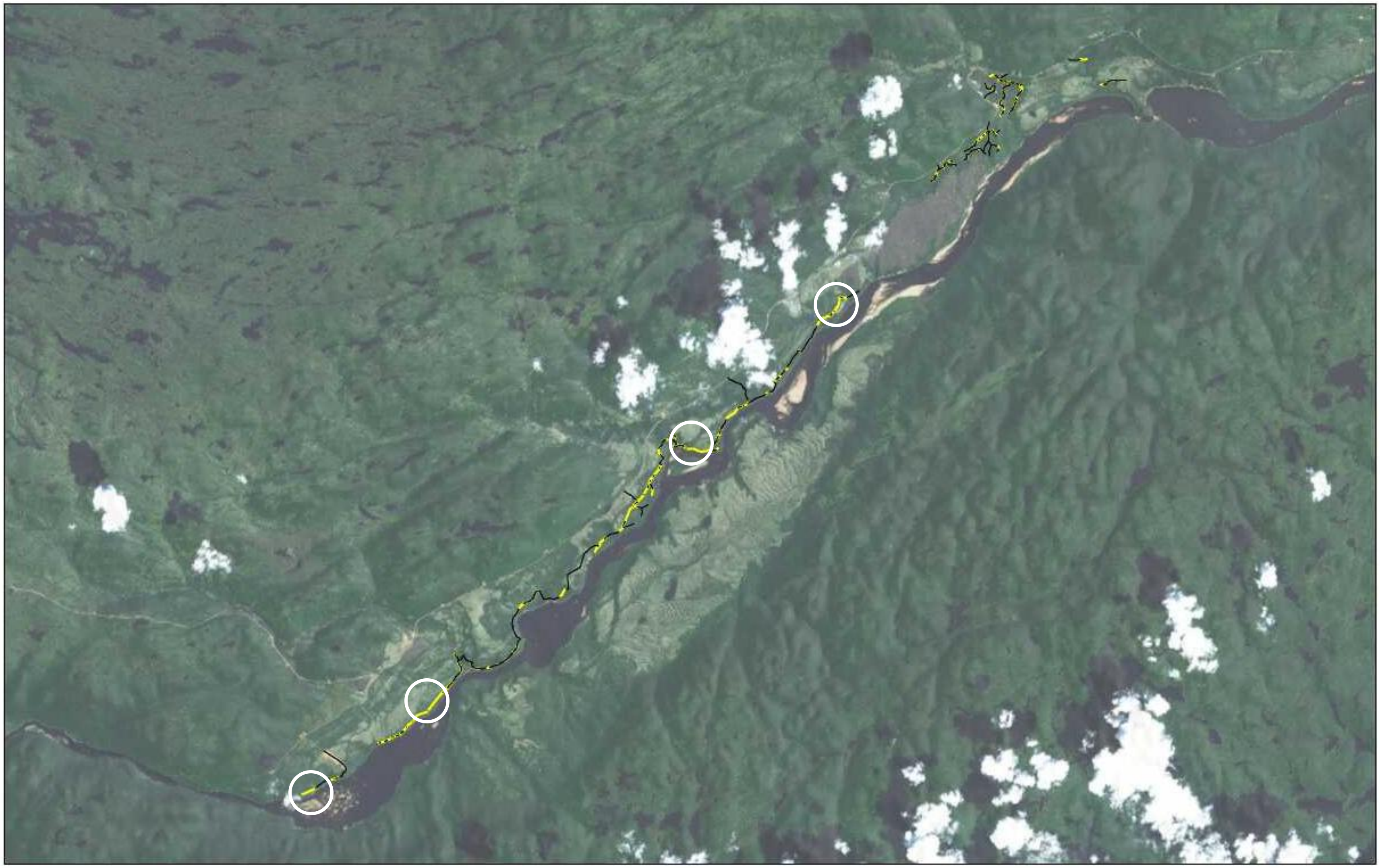


Figure 5.32. Locations of nearshore habitat monitoring, Muskrat Falls reservoir.

Each captured fish will be measured, weighed and a scale sample collected (as required). These data will provide information regarding each life stage, biomass, as well as ongoing growth comparisons (e.g., length-at-age). Any observations of the presence of fish and their associated behaviours will also be recorded during the sampling program. Fish utilization and growth data will also be incorporated to the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

5.2.5.3 Created/Enhanced Shoal Habitat

In general, performance criteria to determine successful implementation of the created/enhanced shoal portions of the physical compensation works will be based upon:

- Retention of designed habitat features as determined by surveying and mapping;
- Maintenance of acceptable grain size distribution;
- Evidence of suitable water velocities for spawning and rearing at created features; and
- Evidence of utilization by fish within the created/enhanced riverine habitat.

Provided below are the measures and method summaries of the monitoring program associated with the created shoal habitat outlined within the Plan. **Figure** 5.33 provides the sampling locations within the shoal habitat for each monitoring measure.

5.2.5.3.1 Habitat Stability

Habitat stability will be assessed against as-built drawings and specifications at the prescribed schedule. All as-built habitat boundaries will be georeferenced and incorporated into a Geographic Information System (GIS) so that any instability can be detected and mitigated, as necessary within the Adaptive Management framework.

Bathymetric surveys of the entire enhanced habitat will be conducted according to the prescribed schedule using a digital sounder with synchronized GPS. Features to be recorded will include overall footprint of the shoals (to be compared against the as-built GIS boundary), presence of habitat features, and elevation of bottom structures relative to sea-level. The data will be post-processed to produce bathymetric maps capable of being directly compared to as-built data and previous maps generated from bi-annual mapping. The data generated from the habitat stability monitoring will be input to the Adaptive Management framework to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

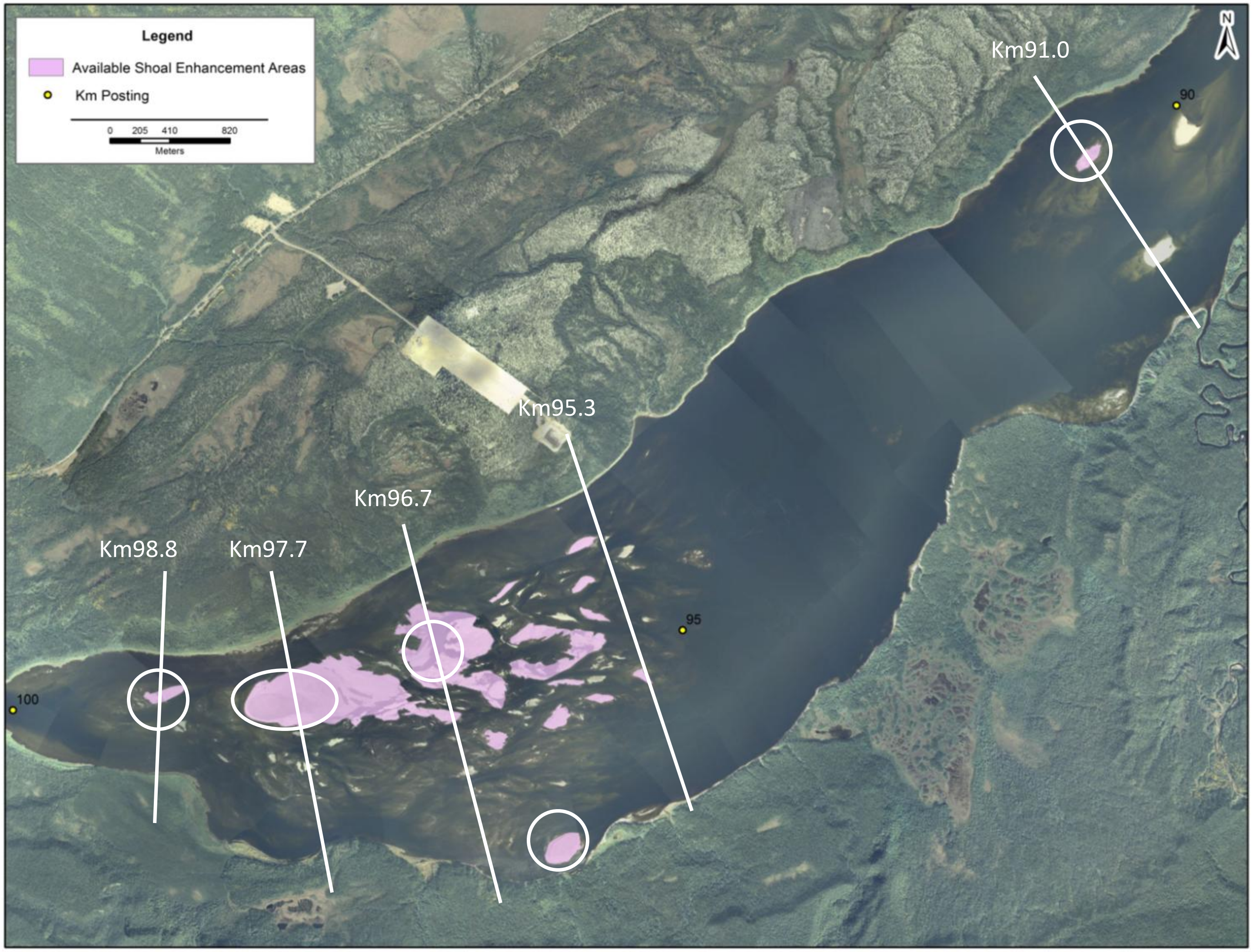


Figure 5.33. Location of shoal habitat monitoring (circles and transect lines), Muskrat Falls reservoir. Bathymetry will occur in pink shaded areas.

5.2.5.3.2 Hydrology

The anticipated hydrology of the created shoal habitat will be assessed against the model/design criteria. Water discharge and velocity measurements will be conducted during river high, medium, and low flow conditions (as determined by the Churchill River Below Grizzle Rapids gauging station - NF03OE0051) at established monitoring transects within the habitat as shown in **Figure** 5.33. This will include measurements of wetted width at each established transect as well as water depth, velocity, and discharge. Velocity profiles and discharge measurements will be conducted using a suitable Acoustic Doppler Current Profiler (ADCP) capable of measuring water velocity to 0.01 m/s accuracy and within the water depths anticipated. Discharge will also be calculated using the ADCP. The unit will be capable of real-time georeferencing to allow mapping of all survey paths to confirm transect applicability and incorporation into GIS. Velocity profiles will be measured with bins of at most 0.2m water depth so that a complete velocity profile section can be generated at each transect. A comparison to the established design criteria will be conducted.

5.2.5.3.3 Grain Size Distribution

Due to the anticipated water depths in some areas of the shoals, substrate composition will be determined using drop video as well as direct sampling using ponar grab according to the prescribed schedule.

The substrate composition of the shoals will be completed using drop video along established transects that will traverse the entire width of the area such that representative samples are recorded (**Figure** 5.33). The results will be directly comparable to as-built (visual record) substrate compositions collected prior to inundation. The system will be capable of recording all information in a geo-referenced format for post-processing and archiving. The camera system will have a graded frame (and laser assisted sizing) such that substrate sizes and composition can be determined. As-built visual records will be collected at select sites and sieve analysis samples collected prior to inundation. These records will provide a visual composition record relative to sieve results which will be used for direct comparison to video survey results.

Grain size distribution and movement can be assessed by many methods; however given the overall depth range anticipated throughout the shoals, direct sampling will be safely completed by ponar grab. The ponar grab will be equipped with fine mesh screens to assist in retaining any finer material during collection and retrieval. Each sample will be collected, labeled, georeferenced, and analyzed for grain size at an accredited lab. Grain size distribution throughout the shoal area will be assessed based on comparisons to baseline grain size distribution of shoal material.

Grain size analysis using standard sieves will be conducted on the existing shoal material. This will serve as the baseline from which other monitoring years will be compared. The baseline sieve samples will be plotted on a single graph and used to derive an acceptable "envelope" (i.e. the upper and lower limits of percent passing each sieve size will be used as the baseline of grain size distribution) for comparison to data collected during future monitoring years. Grain size data will also be incorporated into the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

5.2.5.3.4 Fish Utilization

Monitoring fish utilization in created/enhanced shoal habitat will be conducted according to the prescribed schedule using the following standard methods to achieve the above compliance criteria. Non-lethal sampling of fish within shoal habitat will be conducted between June 15 and September 15 of each sampling year. Sampling techniques are typically fyke netting and baited minnow traps. Nets will be set to sample at least the dawn and dusk periods for a minimum of twenty net-nights of effort. Sampling intensity and locations will reflect that required to accurately determine habitat utilization (see **Figure** 5.33). Each captured fish will be identified to species. Catches will be separated by species and life stage to generate catch-per-unit effort values (biomass). These values will be used as comparisons of utilization across years.

Each captured fish will be measured, weighed and a scale sample collected (as required). These data will provide information regarding each life stage, biomass as well as ongoing growth comparisons (e.g., length-at-age). In particular, young-of-year (YOY) will be identified and used as an indication of recruitment. Any observations of the presence of fish and their associated behaviours will also be recorded during the sampling program.

In addition to live-capture sampling, drop video along transects will be completed between June 15 and September 15 to determine fish species utilization of the shoal habitat. The video system will be deployed along established transects to record and identify fish species life stages utilizing the habitat. The system will be capable of recording all information in a geo-referenced format for post-processing and archiving. The camera system will have a graded frame such that an estimate of length for each fish can be determined. Additional behavioural notes such as substrate use and location within the water column will be collected. Fish utilization and growth data will also be incorporated into the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3 below).

5.2.5.3.5 Redd Surveys

Redd surveys will be used to determine the spawning success of the shoal habitat. Surveys will focus on fall spawning species (i.e. salmonids) as they would be the primary fisheries concern and would also be the primary users of gravel-cobble substrate for spawning (many spring spawners utilize submerged vegetation or broadcast spawn over a variety of substrate types). Surveys will be conducted each monitoring year from October 15 – October 31 and consist of non-intrusive counts of fish, spawning behaviour and redd presence. This survey method was successfully utilized within the tailrace habitat at Granite Canal. Experienced biologists will use video transects of the shoals (similar to those for fish utilization and grain size monitoring) to record redds, fish presence and spawning behavior. The system will be capable of recording all information in a geo-referenced format for post-processing and archiving. All data will be input to a GIS so that annual comparisons of quantity and distribution can be made. Spawning data will also be incorporated into the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

5.2.5.4 Created/Enhanced Delta Habitat

In general, performance criteria to determine successful implementation of the created/enhanced delta portions of the physical compensation works will be based upon:

- Retention of designed habitat features as determined by surveying and mapping of created;
- Maintenance of acceptable grain size distribution;
- Suitable water velocities for spawning and rearing at created features; and
- Utilization by fish within the created/enhanced riverine habitat.

Provided below are the monitoring measures and method summaries associated with created shoal habitat. **Figures** 5.34 and 5.35 provide the sample locations within the Pinus River and Edward's Brook delta habitats for each monitoring measure.

5.2.5.4.1 Habitat Stability

Habitat stability will be conducted against as-built drawings and specifications according to the prescribed schedule. All as-built habitat boundaries will be georeferenced and incorporated into a Geographic Information System (GIS) so that any instability can be detected and mitigated, as necessary within the Adaptive Management framework.

Bathymetric surveys of the entire enhanced habitat will be conducted at the prescribed schedule using a digital sounder with synchronized GPS that can produce bathymetric mapping of the bottom structure. Features to be recorded will include overall boundary of the deltas, in particular the downstream extent (to be compared against the as-built GIS boundary), presence of habitat features, and elevation of bottom structures relative to sea-level. The data will be post-processed to produce bathymetric mapping capable of being directly compared to as-built data and previously conducted bi-annual mapping. The data generated from habitat stability monitoring will be incorporated into the Adaptive Management framework to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

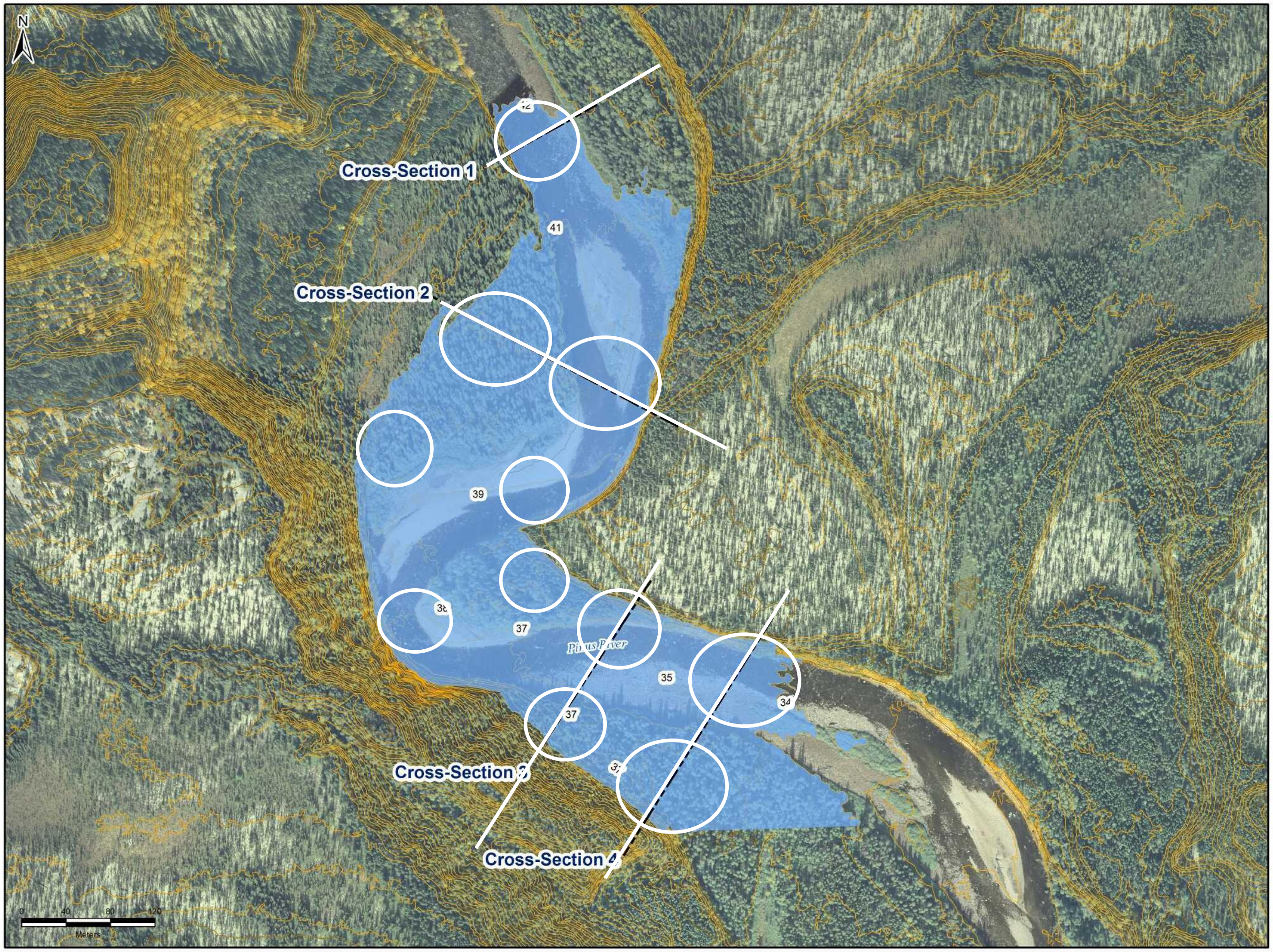


Figure 5.34. Location of Pinus River delta habitat monitoring, Muskrat Falls reservoir. Transects will be measured for velocity, circles indicate areas of fish utilization monitoring while substrate sampling occurs throughout the area.

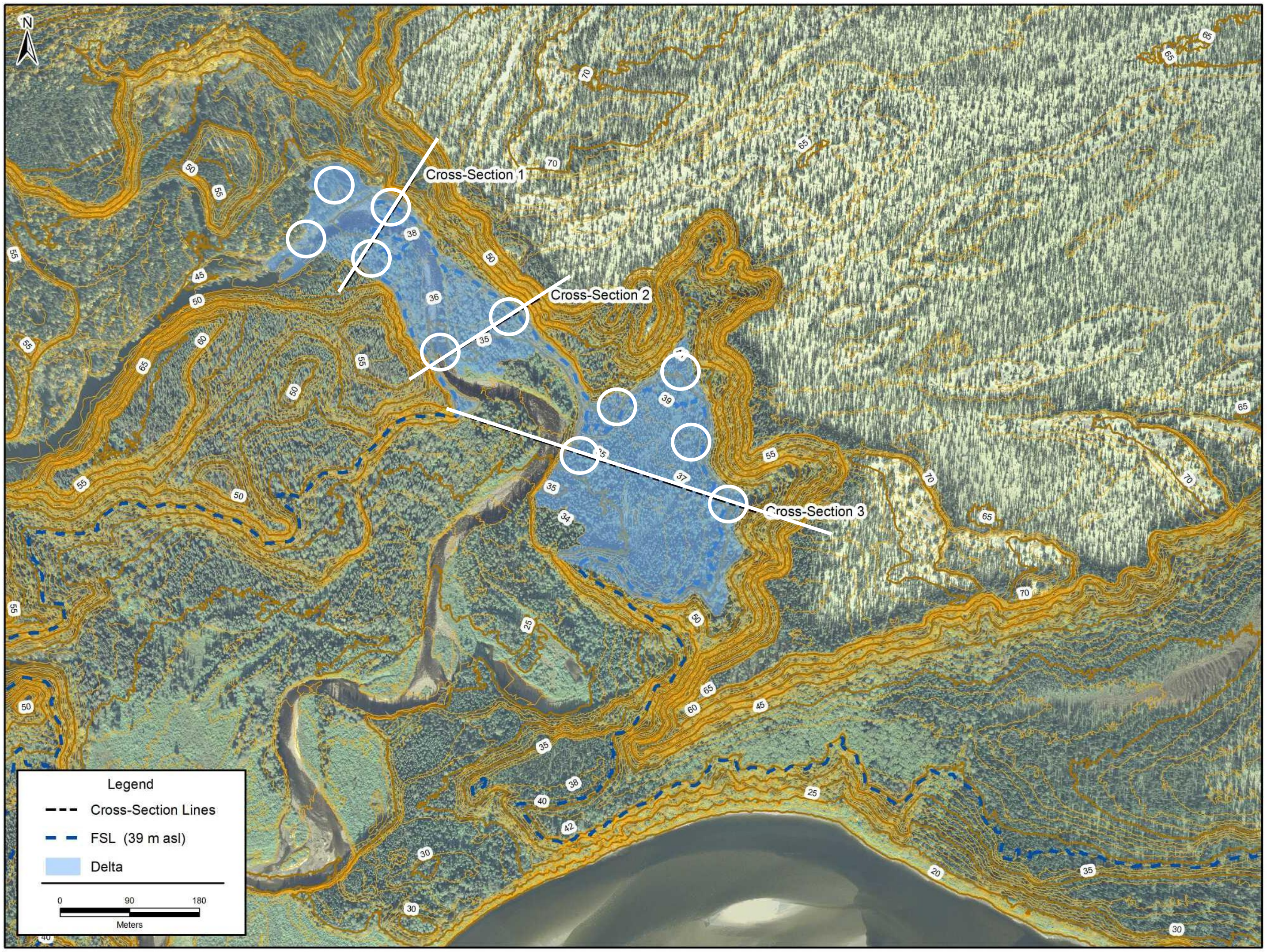


Figure 5.35. Location of Edward's Brook delta habitat monitoring, Muskrat Falls reservoir. Transects will be measured for velocity, circles indicate areas of fish utilization monitoring while substrate sampling occurs throughout the area.

5.2.5.4.2 Hydrology

The anticipated hydrology of the created delta habitat will be assessed against the model/design criteria. Water discharge and velocity measurements will be conducted during river high, medium, and low flow conditions (as determined by the Pinus River gauging station – (http://www.env.gov.nl.ca/wrmd/ADRS/v6/Template_Station.asp?station=03OE011) at established monitoring transects within the habitat (**Figures** 5.34 and 5.35). This will include measurements of wetted width at established transect stations (applicable locations will be determined once inundation is completed) as well as water depth and velocity. Velocity profiles and discharge measurements will be conducted using a suitable Acoustic Doppler Current Profiler (ADCP) capable of measuring water velocity to 0.01 m/s accuracy and within the water depths anticipated. Discharge will also be calculated using the ADCP. The unit will be capable of real-time georeferencing to allow mapping of all survey paths to confirm transect applicability and incorporation into GIS. Velocity profiles will be measured with bins of at most 0.2m water depth so that a complete velocity profile section can be generated at each transect. A comparison to the established design criteria will be conducted.

5.2.5.4.3 Grain Size Distribution

Grain size distribution and substrate movement can be assessed by many methods; of which several have been incorporated in Newfoundland and Labrador. Gravel retention will be monitored using modified pit-samplers, based on those implemented in Granite Canal and Copper Lake (*see* Scruton *et al.* 1995 and AMEC 2010b), as well as freeze coring. Modified pit-samplers will be installed at fixed locations throughout each watershed to ensure representative samples are collected. In total, fifteen samplers will be installed at each rehabilitated/enhanced area. Freeze cores will be collected from locations near the modified pit-sample locations. Any material collected by the samplers will be assessed for grain size using standard sieves.

Grain size distribution throughout the deltas will be assessed against baseline grain size distribution of pre-inundation material. Grain size analysis using standard sieves will be conducted on the material used in delta construction and these will serve as the baseline from which monitoring in future years will be compared. The baseline sieve samples will be plotted on a single graph and used to derive an acceptable "envelope" (i.e. the upper and lower limits of percent passing each sieve size will be used as the baseline of grain size distribution) for comparison to data collected during future monitoring years. Grain size data will also be incorporated into the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

5.2.5.4.4 Fish Utilization/Population Estimates

Monitoring of fish utilization in created/enhanced delta habitat will be conducted according to the prescribed schedule (June 15 and September 15) using the following standard methods to assess utilization of created delta habitat using live-capture estimates, fish numbers, biomass, age structure and length-at-age. In particular, young-of-year (YOY) will be identified and used as an indication of recruitment. Four quantitative electrofishing survey locations will be established within each delta habitat area. Baseline population estimates conducted prior to inundation will be used to compare monitoring results.

Captured fish will also be measured, weighed, and an aging structure collected (as required). Catches will be separated by species and life stage to generate age structures of fish utilization as well as length-at-age values. This data will provide information regarding each life stage biomass as well as ongoing growth comparisons (eg. length-at-age). Fish utilization data will also be incorporated into the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

5.2.5.4.5 Redd Surveys

Redd surveys will be used to determine the use of delta habitats for spawning. Surveys will focus on fall spawning species (i.e. salmonids) as they would be the primary fisheries concern and would also be the primary users of gravel-cobble substrate for spawning (many spring spawners utilize submerged vegetation or broadcast spawn over a variety of substrate types). Surveys will be conducted each monitoring year from October 15 – October 31 and consist of non-intrusive counts of fish, spawning behaviour and redd presence. Experienced biologists will traverse each habitat area shoreline recording redds, fish presence and spawning behavior. All redds and fish will be recorded along with a georeferenced position. All data will be input to a GIS so that annual comparisons of quantity and distribution can be made. Spawning data will also be incorporated into the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

5.2.5.5 Aquatic Vegetation (Spawning)

Performance criteria of the spawning habitat (aquatic vegetation) portion of the physical compensation words associated with northern pike will be:

- Retention of designed vegetation and artificial spawning features; and
- Presence and initial increase in numbers of spawning northern pike, and an increase in catch-per-unit effort in young-of-year that approaches baseline.

Provided below are the measures and method summaries of the monitoring program associated with created northern pike spawning habitat. **Figure** 5.36 provides the sample locations for each monitoring measure.

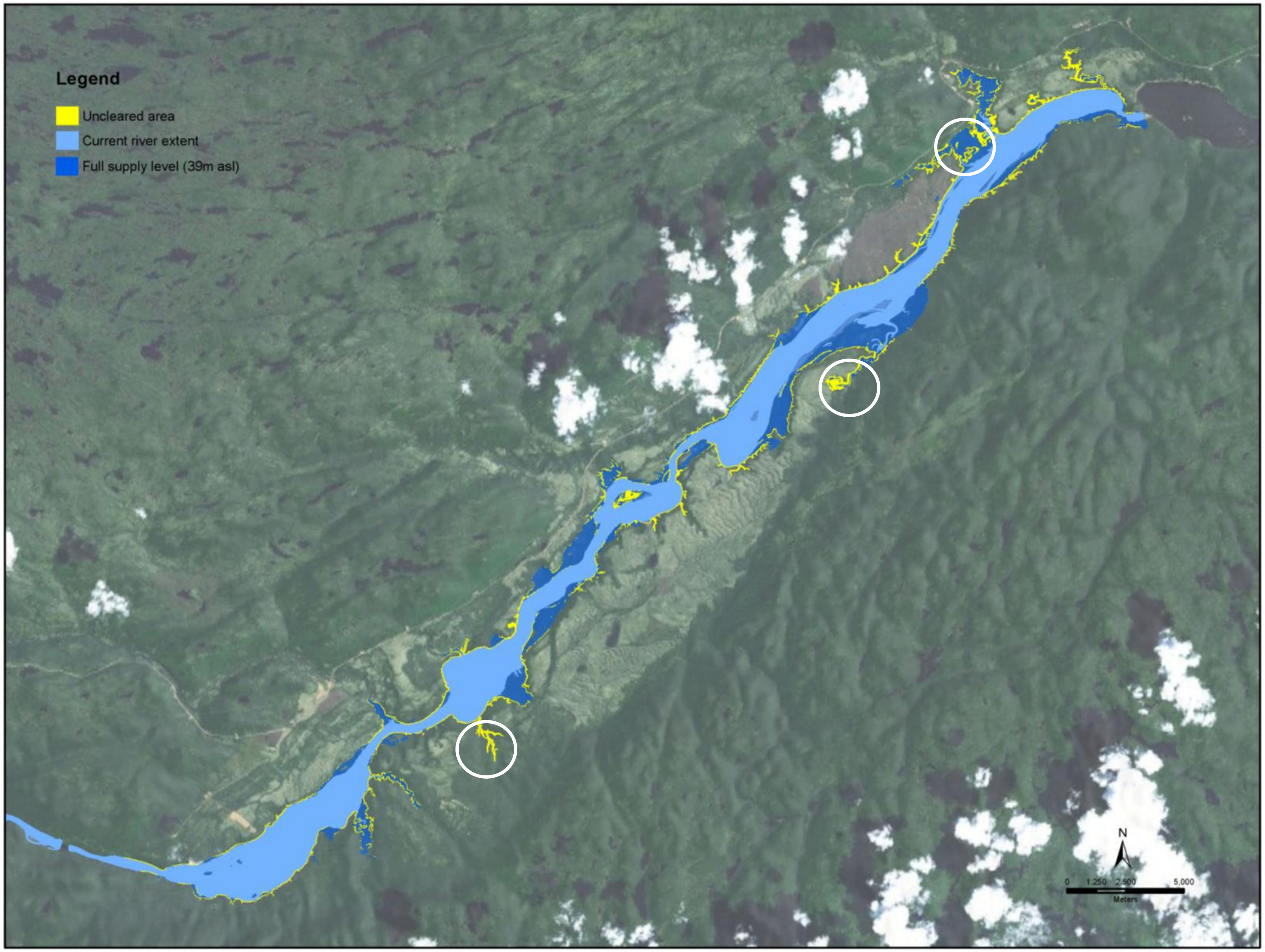


Figure 5.36. Location of aquatic vegetation habitat monitoring, Muskrat Falls reservoir.

5.2.5.5.1 Spawning Vegetation Stability

The stability of the prepared vegetation will be visually inspected according to the prescribed schedule. Inspections will include an assessment of tree stability (whether trees left standing are becoming unstable and falling) and artificial spawning bed stability (whether the bed material is remaining in place and at the appropriate water depth). Any sign of nearby erosion due to ice or slumping will be recorded. A photographic record will be completed of all features and included in annual reports. Spawning habitat stability data will be incorporated into the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

5.2.5.5.2 Fish Utilization

Monitoring of fish utilization (northern pike juveniles and young-of-year) of created spawning areas will be conducted according to the prescribed schedule using the following standard methods.

Non-lethal sampling of fish within the spawning areas will be conducted between June 15 and July 15 to determine juvenile and young-of-the year use of the area early in the season before the water retreats and warms. Sampling techniques will include fyke netting and baited minnow traps. Nets will be set to sample at least the dawn and dusk periods for a minimum of twenty net-nights of effort. Sampling intensity and locations will reflect that required to accurately determine habitat utilization. Each captured fish will be identified to species. While the focus will be on northern pike, each captured fish will be identified by species. Catches will be separated by species and life stage to generate catch-per-unit effort values (biomass). These values will be used as comparisons of utilization across years. Each captured fish will also be measured, weighed and an aging structure collected (as required). This data will provide information regarding each life stage biomass as well as ongoing growth comparisons (eg. length-at-age). Visual observations for the presence of fish and behaviours of fish will also be recorded during the sampling program timeframe.

Fish utilization data will also be incorporated into the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

5.2.5.5.3 Spawning Surveys

Monitoring of northern pike spawning activity and egg deposition in created spawning areas will be conducted according to the prescribed schedule using the following standard methods.

Spawning surveys will be used to determine the success of artificial spawning material and vegetation within the treed areas. Surveys will focus on northern pike; therefore, they are to be conducted between April 15 and May 30 of each monitoring year. Surveys will consist of non-intrusive, visual surveys of fish, fish behaviour and egg density. Experienced biologists will traverse each habitat area by boat observing fish presence and spawning behavior. All fish will be recorded along with a georeferenced position. Egg density will also be measured on artificial spawning material (both prepared trees/vegetation and artificial spawning mats). Egg density will be recorded as the total number of eggs laid per 0.01m^2 grid (10cm x 10cm). A total of at least 25 grids will be analyzed at each spawning area to ensure adequate sample size. All data will be input to a GIS so that annual comparisons can be made.

Egg density data will be incorporated into the Adaptive Management Program to determine whether results trigger further investigations and/or mitigations (see **Section** 5.3).

5.2.6 Physical Compensation Works Monitoring Results Reporting

Construction/mitigation reporting is required throughout the duration of physical compensation works construction. Monitoring reports are required throughout the duration of monitoring activities.

5.2.6.1 Construction/Mitigation Reporting

Upon completion of each year's construction, a report outlining the habitat-related activities will be provided to DFO. This report(s) will provide "as built" drawings and descriptions of all compensation work to which subsequent years of monitoring data can be compared. The construction report will describe all construction activities along with all utilized mitigations, whether standard or site-specific. This report is required upon completion of each year of construction (by March 15 of the following year).

5.2.6.2 Monitoring Reporting

An annual report for each prescribed monitoring year will be produced, and will be evaluated with respect to performance criteria (where applicable), and related to results of previous monitoring. Reports will be submitted to DFO for information and review. The schedule for submission of annual reports will be March 31 of the following year to allow for data to be analyzed and presented. This will also allow time for any required change/remediation to be decided upon and discussed prior to the following monitoring season. It is anticipated that reporting associated with the physical construction works monitoring will be included in a single report which will also include results and actions related to the Adaptive Management Program.

5.3 TIER 3 – MONITORING AND ADAPTIVE MANAGEMENT

Adaptive Management is a key element of this Fish Habitat Compensation Plan. It provides a process for monitoring the aquatic ecosystem, and should intervention warrant, applying appropriate mitigation. While many fish species have shown they will respond quickly and adaptively to change, it is likely a fish community will require time to stabilize owing to issues related to reservoir stabilization, trophic surge and species responses as described in **Section** 5.1.2.1. These are just some of the reasons why it has been very difficult to directly link fish response to habitat changes over short time scales (Minns et al. 1996). The Adaptive Management Program is therefore based on long-term and comprehensive monitoring of ecosystem changes and stabilization so that maximum ecosystem function and benefit is achieved and maintained.

Nalcor continues to collect extensive baseline data on fish and fish habitat and have incorporated this into their monitoring program and compensation design. They have also incorporated a technical strategy for fish habitat compensation that involves environmental planning, engineering design, construction management and monitoring. As part of ensuring that the Compensation Plan is as successful as possible, Nalcor is committed to implementing Continuous Improvement and Adaptive Management measures with a rationale of risk reduction and elimination. The inclusion of Adaptive Management into the Monitoring Program has also provided a framework for development of a scientific, defensible, logical approach.

In developing this approach to Continuous Improvement and Adaptive Management, Nalcor used its internal policy, as presented in Section 1.1.2 of Volume 1A of the Environmental Impact Statement (EIS), and referred to the Operational Policy Statement issued by the Canadian Environmental Assessment Agency (CEAA) entitled "Adaptive Management Measures Under the *Canadian Environmental Assessment Act*". This latter document defines adaptive management as a "*planned and systematic process for continuously improving environmental management practices by learning about their outcomes. Adaptive Management provides flexibility to identify and implement new mitigation measures or to modify existing ones during the life of a project*" (CEAA 2012).

Adaptive management includes quantifying management and scientific uncertainties and sensitivities, predicting ranges of potential changes, and developing scientifically defensible management options and scenarios. It includes planning for and managing those changes to reduce risks or to take advantage of potential new opportunities to improve performance that may present themselves.

As a result, Nalcor's Adaptive Management Approach includes:

1. Design of a conceptual model based on local conditions;
2. A management plan (goals, objectives and activities);
3. Establishment of adequate baseline data and variability;
4. Development of monitoring and/or follow-up programs;
5. Implementation of management and monitoring/follow-up programs;
6. Analysis of data and communication of results;
7. Use results to evaluate the attainment of goals and objectives;
8. If necessary, adaptation; and
9. Pursuit of process until goals and objectives are met.

Inherent in this approach is the recognition that ecosystem response is complex and challenging to predict. Employing extensive baseline data and well designed, scientifically-based compensation plans improve chances of success, but there always will be some level of uncertainty regarding the effectiveness of compensation mitigation measures. The adaptive management approach involves a systematic feedback mechanism that builds upon the initial understanding of the system (e.g. habitat characterization and species utilization), based on effectiveness monitoring (e.g., indicators). The results of the ongoing monitoring will be compared against baseline measure variability and pre-established targets or thresholds. Deviations from targets will trigger a decision/adjustment in practice or mitigation to address the issue in question. **Figure** 5.37 presents a general schematic of the Adaptive Management Program (AMP) process. Environment Canada (EC) has a similar outline for AMP monitoring which is presented in **Table** 5.12. It should be noted in the EC table, that the terms of significant statistical change, critical effect size, critical threshold, probable effects level and management strategy require definition relative to specific monitoring objectives.

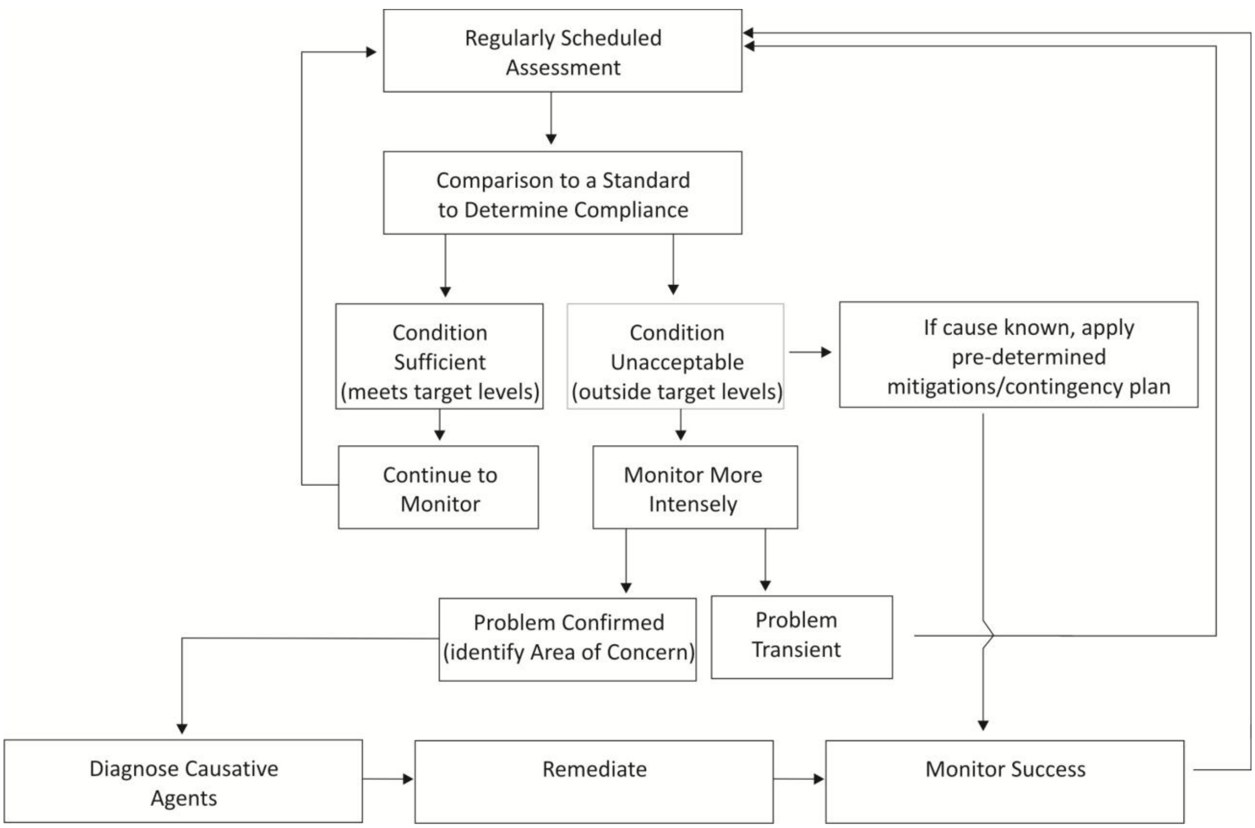


Figure 5.37. Typical monitoring schematic (based on Cairns et al. 1993).

In addition to having the capacity to detect an undesirable effect, an AMP should outline potential mitigations where possible. This removes ambiguity related to the final steps in an AMP, that is, what happens if criteria and/or triggers are exceeded? For each specific environmental measure and/or indicator identified within this AMP, potential mitigation options have been outlined to the extent possible in the appropriate sections below. Not only are the monitoring plans and triggers adaptive, all mitigations that are considered in the creation of this Plan, may be adapted as mitigations occur or as techniques develop.

Table 5.12. Summary of Actions under an Adaptive Management program (reproduced from Environment Canada 2011).

Level	Trigger	Consequence
Effect	Significant statistical change	Seek confirmation
Warning Sign	Exceeds critical effect size, and is confirmed	Increase monitoring frequency to define extent and magnitude of change
Response Sign	Exceeds critical threshold effect size and is getting worse	Investigate cause
Action Level	Passes probable effects level or water quality criterion	Change in management strategy warranted

Periodic observation of ecosystem health provides the opportunity to validate predictions of impact in the real world and provides mechanisms for implementing corrective actions into a management plan. This iterative process is described by the term biological monitoring; *the ongoing assessment of environmental conditions to ensure that previously formulated objectives are being maintained* (Hellawell 1978). Several steps are required in the development of an effective AMP. The initial step is to establish the objectives and goals, so that the monitoring results can be used to measure, confirm, detect and/or mitigate against established criteria. Implementation of an effective monitoring program is contingent upon the development of explicit, generally accepted ecosystem conditions to be achieved and maintained (i.e. ecosystem objectives). The objectives of this AMP are derived from the core objectives of the Fish Habitat Compensation Plan, specifically detecting and mitigating changes in the aquatic environment and fish utilization. The monitoring program should establish explicit measures that are useful in judging the extent to which specific objectives have been achieved. Thus, measures (e.g., indicators) cannot be identified until goals and objectives are specified (e.g., see Bertram and Reynoldson 1991). The objectives of this Fish Habitat Compensation Plan have been identified in **Section** 5.0 and are repeated below:

1. *To maintain the predicted post-Project habitat within the Muskrat Falls reservoir area;*

    - This objective will be achieved by meeting the goals of habitat stability as described in the various models and predictions related to bank stability and water quality.

2. *To maintain the existing species diversity within the Muskrat Falls reservoir area;*

    - This objective will be achieved by meeting the goals of species-life cycle habitat utilization within the Muskrat Falls reservoir area. This will also be achieved by meeting the species utilization targets of the enhanced/created habitats described in **Section** 5.2 of the Plan.

3. *To maintain the existing health of those fish species within the Muskrat Falls reservoir area*.

   - This objective will be achieved by meeting the targets of species health.

The objectives of the Plan are related to the quality of habitat and the utilization and health of fish in the Muskrat Falls reservoir area. With management objectives and goals specified, a framework can be developed for **indicator selection,** analysis of indicator data and incorporation of subsequent results in the AMP.

5.3.1 Indicator Selection

An environmental indicator can be defined as "*a characteristic of the environment that, when measured, quantifies the magnitude of stress, habitat characteristics, degree of exposure to the stressor, or degree of ecological response to the exposure*" (Hunsaker and Carpenter 1990). Environmental indicators need to be selected that are useful in judging the degree to which specified environmental objectives have been achieved or maintained. Selection is important since any long-term monitoring program will only be as effective as the indicators chosen. Indicator measures serve several purposes in the context of environmental monitoring. Above all, the selected indicator must be defensible (Cairns et al. 1993).

A review of monitoring approaches has been conducted to assist in establishing a defensible, valid, and rigorous monitoring/management framework approach. The general approach applied here has been developed since the early 1990s and has been incorporated and reviewed against various large monitoring programs (e.g., Hunsaker and Carpenter 1990; Cairns et al. 1993; Dowdeswell et al. 2010).

The goal of an Adaptive Management and Monitoring Program should be to answer the following questions as outlined in Cairns *et al*. (1993):

1. Are stated objectives being met?
2. If stated objectives are not being met, what is the cause?
3. How can potential causes (or challenges) be predicted before they compromise the objectives?

In addition, a fourth question can be added:

4. How can potential impacts (or challenges) be mitigated?

The first question is addressed by providing an ongoing evaluation of environmental conditions using meaningful and cost-effective indicators. The second relates to diagnosing the cause. Identifying causes of missed objectives is often a much more difficult task as 'causality' can require measurements of additional information (e.g. stressors or other processes) and carefully executed monitoring/experiments. Preferably, identification and diagnosis of problems should occur as early as possible so that remedial actions can be taken before substantial ecosystem change or damage has occurred (Cairns et al. 1993). The third question requires careful choice of indicator(s) and the fourth requires that the AMP consider the possible ecosystem changes or damages that could occur and to provide known, standard mitigations that can be initiated as soon as possible.

5.3.2 Indicator Selection Criteria

The principal goal of this Adaptive Management/Monitoring Program is to monitor and manage the chemical, physical, and biological characteristics of the altered habitat so that ecological stabilization and predicted conditions can be monitored. Early detection of potentially damaging conditions is also an important part of the design so that any required remediation can be initiated as early as possible. In order for an AMP to be as comprehensive as possible and to address the questions above, it needs three indicator types; **Verification, *Diagnostic***, and ***Early Warning***.

Verification indicators are those chosen to measure fish and fish habitat conditions to determine whether ecosystem objectives are being met. They are the most obvious part of any monitoring plan, and therefore, their results should be readily communicable to regulators, the public and stakeholders. They basically answer question 1; are stated objectives being met? The most effective verification indicators are those that integrate many characteristics related to the ecosystem and the stated objective. For example, individual or population attributes of ecologically and/or socially important species (e.g., biomass of brook trout), can be a useful verification indicator as its ecological attributes depend on many functioning elements of the ecosystem (e.g., prey, spawning habitat, appropriate thermal conditions).

The integrative nature of verification indicators often makes them less effective at determining why objectives are not being met. Other information that strategically target key stressors or processes can be used for such determinations. These are ***Diagnostic Indicators*** and should be inherently linked to the previously mentioned verification indicators. It should be noted that sometimes diagnostic information may incorporate controlled laboratory testing to study cause and effect relationships (Cairns et al. 1993).

The use of verification and diagnostic indicators together allow for detection of a potential problem and identification of the source. Challenges occur when problems are detected and identified when it's already too late to make cost-effective adjustments to the system (i.e. tipping point of the ecological system has been surpassed). As such, it is prudent to include ***Early Warning indicators*** in monitoring programs as well. Early warning indicators identify impending problems before they exert substantial impact on the ecosystem. While they may not represent AMP objectives, they typically are linked and/or show increased sensitivity to common stressors.

The following indicator characteristics, based on Cairns (et al. 1993), were sought out for the Muskrat Falls AMP that identify indicators that will be cost-effective, scientifically sound and relevant. The specifics of each indicator are presented in AMEC (2012):

1. **Biologically relevant**, i.e., important in maintaining a balanced community;
2. **Sensitive** to stressors without an extreme response or extreme natural variability;

3. **Broadly applicable** to many stressors and sites;
4. **Diagnostic** of the particular stressor causing the problem;
5. **Measureable**, i.e., capable of being operationally defined and measured using a standard procedure with documented performance and low measurement error;
6. **Interpretable**, i.e., capable of distinguishing acceptable from unacceptable conditions in a scientifically and legally defensible way;
7. **Cost-effective**, i.e., inexpensive to measure, providing the maximum amount of information per unit effort;
8. **Integrative**, i.e., summarizing information from many unmeasured indicators;
9. **Historical data** are available to define nominative variability, trends, and possibly acceptable and unacceptable conditions;
10. **Anticipatory**, i.e., capable of providing an indication of degradation before serious harm has occurred; early warning;
11. **Nondestructive** of the ecosystem;
12. Potential for **continuity** in measurement over time;
13. Of an **appropriate scale** to the management problem being addressed;
14. **Not redundant** with other measured indicators, i.e., providing unique information;
15. **Timely**, i.e., providing information quickly enough to initiate effective management action before unacceptable damage has occurred; and
16. **Socially relevant**, i.e., of obvious value to and observable by shareholders.

Tradeoffs between desirable characteristics, costs, and quality of information are inevitable when choosing indicators; however, each indicator selected for the Muskrat Falls AMP meets the criteria of Cairns et al. (1993) unless otherwise specified. Moreover, the selected indicators are considered standard, accepted methods for detecting natural or predicted levels of change, providing diagnostic information or early warning of ecosystem change. **Tables** 5.13-5.15 present the indicators incorporated in the Adaptive Management Plan that address habitat stability, habitat suitability, and habitat utilization (production indices) objectives.

5.3.2.1 General Indicator Development and Analysis

While the specific aspects of each selected indicator are described in the following sections, a general description of the framework used for indicator development is provided below in the following steps:

- Hypothesis formulation and establish management thresholds;
- Hypothesis testing through;
    - Sample collection,
    - Statistical analysis; and
- Review and reporting

Table 5.13. Key Indicator Attributes of the Habitat Stability Adaptive Management Program. Indicator types are as follows (V: Verification; D: Diagnostic; E: Early Warning).

Monitoring component	Indicator	Indicator type	Data collection	Area of inference	Available baseline
Shoreline Stability	Unvegetated shoreline	V	Satellite	Entire reservoir (focus on low stability terrain)	Comparisons to upstream control sites
	Total reservoir perimeter	V	Satellite	Entire reservoir	2012 Imagery
	Unvegetated shoreline	D	On-site transects	Areas of concern	NA
	Wind (speed, direction, duration)	D	On-site weather station	Areas of concern	Historic data for Goose Bay and Churchill Falls airports
	Rainfall	D	On-site weather station	Areas of concern	Historic data for Goose Bay and Churchill Falls airports
	Wave measurements	D	Modeled from on-site weather data	Areas of concern	Historic data for Goose Bay and Churchill Falls airports
Sediment Transport	Bathymetry	V	On-site mapping	Entire reservoir	Pre-reservoir bathymetry (LIDAR)
	Velocity/depth profiles	D	ADCP transects	Areas of Concern	NA
	Substrate composition	D	Visual/ Ponar samples	Areas of Concern	NA

Table 5.14. Key Indicator Attributes of the Physical Habitat Suitability Adaptive Management Program. Indicator types are as follows (V: Verification; D: Diagnostic; E: Early Warning).

Monitoring component	Indicator	Indicator type	Data collection	Area of inference	Available baseline
Physico-chemical Characteristics	Velocity/depth profiles	V	ADCP transects	Entire reservoir	NA
	Shoreline substrate composition	V	Transects co-located with ADCP	Entire reservoir	NA
	Mid channel substrate composition	V	Transects co-located with ADCP	Entire reservoir	NA
	Total Suspended Solids	V	Grab samples	Index of Entire reservoir	1999, 2006, 2010-inundation
	Total Phosphorus	V	Grab samples	Index of Entire reservoir	1999, 2006, 2010-inundation
	Temperature	D	Data-logger	Index of Entire reservoir	2010-inundation
	Ice Formation	D	Data-logger	Index of Entire reservoir	2010-inundation
	Turbidity	D	Data-logger	Index of Entire reservoir	2010-inundation
	Dissolved Oxygen	D	Data-logger	Index of Entire reservoir	2010-inundation
	Dissolved Oxygen	D	Grab samples	Index of Entire reservoir	1999, 2006, 2010-inundation
	pH	D	Data-logger	Index of Entire reservoir	2010-inundation

Table 5.15. Key Indicator Attributes of the Habitat Suitability (Biological Production) Adaptive Management Program. Indicator types are as follows (V: Verification; D: Diagnostic; E: Early Warning).

Monitoring component	Indicator	Indicator type	Data collection	Area of inference	Available baseline
Biological	Primary Productivity	V	Grab samples	Index of Entire reservoir	1999, 2006, 2010-inundation
	Phytoplankton Population Dynamics	E	Grab samples	Index of Entire reservoir	1999, 2006, 2010-inundation
	Zooplankton Population Dynamics	E	Grab samples	Index of Entire reservoir	1999, 2006, 2010-inundation
	Benthic macroinvertebrates community structure	E	Rock bag colonization	Delta / reservoir edge habitat	2011-inundation
	Fish CPUE	V	Electrofishing	Delta habitats	1998, 2000, 2010 to inundation
	Fish CPUE	V	Fyke netting	Slow reservoir habitats	2006, 2010 to inundation
	Fish Abundance/Presence	V	Snorkeling	Delta/reservoir edge habitat	2012-inundation
	Fish CPUE	D	Minnow traps	Deep reservoir habitats/Areas of concern	2012 to inundation
	Fish CPUE/Presence	D	Angling	Areas of Concern	NA
	Redd Surveys	D	On-site sampling	Delta habitats	2012 to inundation
	Habitat use/movement	D	Telemetry	Areas of Concern	NA
	Fish Growth / Condition	V	Scale analysis	Entire reservoir	1998, 1999, 2010-inundation
		V	Fulton's Condition Factor	Entire reservoir	1998-2000, 2006, 2010-inundation
	Fish Age-structure	D	Scale/otolith analysis	Areas of concern	1998, 1999, 2010-inundation
	Fish trophic status	D	Stable Isotope Analysis	Entire reservoir	2010-inundation
	Fish diet (live stomach evacuation)	D	Stomach lavage	Areas of concern	2012-inundation
	Fish Disease	D	AVC/Hepatic Index	Areas of concern	2013 - inundation
	Fish Fecundity	D	Gonadosomatic Index	Entire reservoir	2012-inundation
	Fish stress	E	Cortisol/glucose analysis	Entire reservoir	2012-inundation
	Vegetation Growth	E	Satellite	Entire reservoir	2007, 2013-inudation

5.3.2.1.1 Hypothesis Formulation

Hypothesis formulation serves to establish explicit goals and identifies the necessary spatial and temporal scales to test hypotheses. Hypotheses must be stated in a manner (Null hypothesis; Alternate hypothesis) that can be tested statistically wherever possible (Thomas 1992). Each verification indicator will have a clear hypothesis statement on which sampling and statistical evaluations will be focused.

5.3.2.1.2 Hypotheses Testing

Each hypothesis will be tested using appropriate sample collection, analysis and testing. The specific design and implementation of each test is provided in the appropriate sections.

5.3.2.1.2.1 Approach to statistical analysis

Monitoring the effectiveness of habitat compensation will be based on comparisons to baseline conditions and where possible, model-derived predictions. Throughout the monitoring period, ecological status and trend will be reported. Ecological status will be assessed against target conditions (in most cases baseline conditions). In some cases, where change is expected for an indicator, status will be based on model predictions of change. Trends in ecological condition will also be reported so that mitigations can be enacted or prepared prior to an associated change in status. Furthermore, trends will also provide a feedback mechanism for adaptive management activities. Conceptually, it is expected that for some elements of the ecosystem (e.g. total phosphorus, suspended solids), conditions will move away from baseline as inundation occurs, peak soon after and stabilize to a new equilibrium within 15-20 years (**Figure** 5.38). For other important ecosystem elements (e.g. oxygen levels in the water), change is not expected to result from the reservoir.

Ecological Status

Ecological status of each indicator will be assessed based on concordance with established ecological targets. In most cases, a target zone will be derived from baseline conditions. Typically a quantile approach will be used, i.e. the target zone would reflect the range of 80% of the baseline values (see green zones **Figure** 5.39). In other cases, models predict that baseline conditions will shift following reservoir formation. Target zones, will reflect these expected shifts from baseline.

For all indicators, ecological status will be assessed following every data collection period using a GAM (generalized additive model; Zuur et al. 2009) time-series model (**Figure** 5.39).

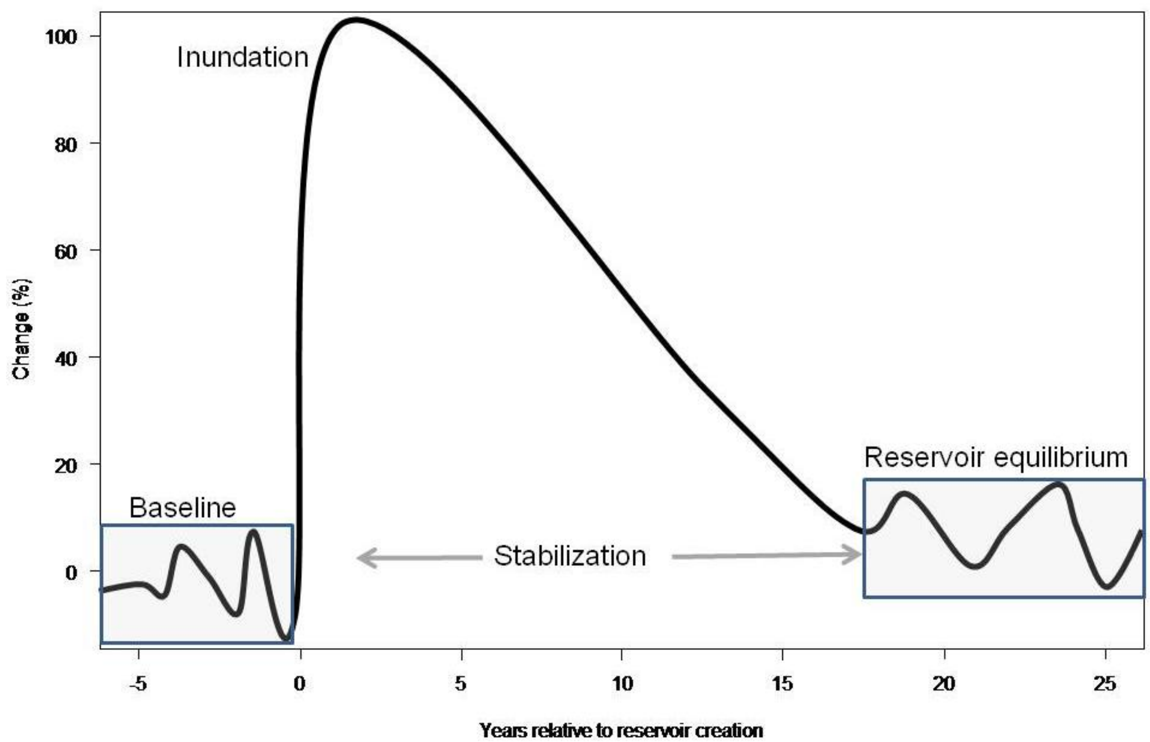


Figure 5.38. The conceptual model of environmental change associated with the creation of the Muskrat Falls reservoir. Reservoir inundation occurs at Year 0 and is followed by a peak in environmental change. In subsequent years, the environmental conditions stabilize and reach a new equilibrium.

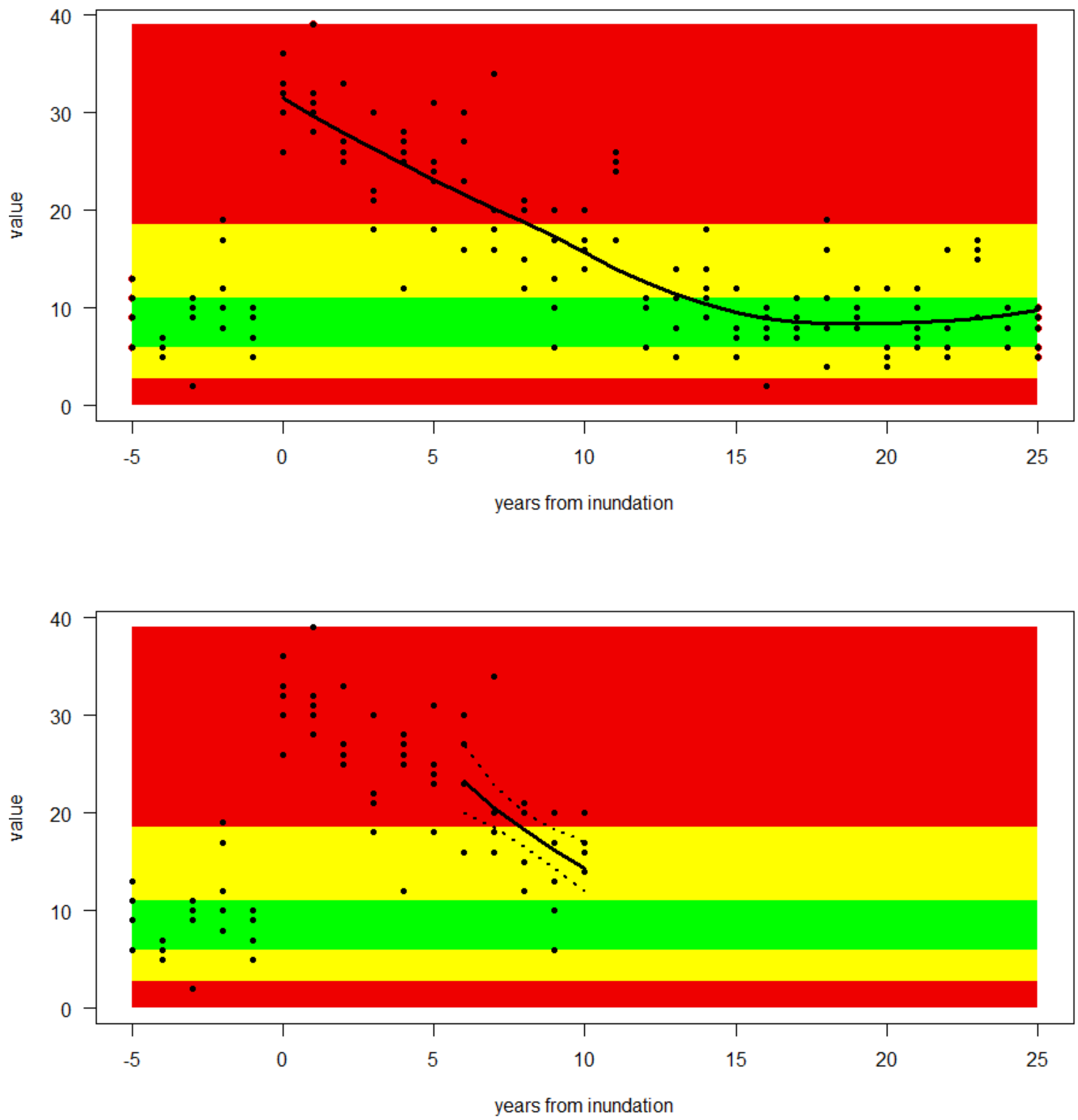


Figure 5.39. A hypothetical time series analysis using a GAM (top panel) for status and a generalized linear model for trend (bottom panel). This GAM assessment example was applied 20 years after inundation while the trend analysis was applied in years 6 through 10 after inundation. Note that the model estimate for the last year of data will be used to assess status.

Model values of the latest sampled year will be used to compare against ecological targets (based on baseline or predictive models). This approach has several benefits:

1) GAMs are appropriate to use in linear and non-linear applications. While many parameters have been modeled, the exact response to achieve equilibrium in certain parameters are uncertain, and the ability to accommodate linear and non-linear relationships is desirable;
2) the approach is versatile, allowing a variety of types of ecological data to be assessed in a uniform manner. Specifically, data that is not normal (i.e. Gaussian) are not appropriate for many conventional statistical tests. Also, data from long term monitoring programs typically require a means to avoid pseudoreplication associated with repeated measurements from fixed sites over time. GAMs permit alternate error structures and mixed effects models and therefore are ideal for this statistical application;
3) GAMs have an additional benefit of 'smoothing' time series data, as model values in a given year are influenced to some degree by previous years. Such an approach is more robust to spurious results and provides improved information on long-term trends.

Some monitoring indicators (e.g. benthic invertebrate and plankton communities) consist of multiple components, and consequently their data is referred to as multivariate. Often such rich datasets are reduced to examinations of taxonomic richness or abundance at the cost of losing considerable information. However, using multivariate analysis techniques, it is possible to acquire a more holistic understanding of community impact that incorporates change in community structure (relative proportions of each species) and abundance. These approaches also provide information on which components have changed the most and what environmental variables are most correlated with the changes. The multivariate approach proposed for the Muskrat Falls AMP will evaluate post-inundation conditions relative to baseline using a Bray-Curtis Index (Bray and Curtis 1957) of community similarity. These index values will be examined on an annual basis using an ANOSIM test (Clarke and Green 1988), which is a multivariate permutation-based analog of ANOVA. A representation of a multivariate analysis, that compares potentially impacted sites and reference sites, is presented in **Figure** 5.40.

Trend

Determining trends in ecological conditions will require a slightly different approach. Forecasting whether ecological equilibrium will occur on the predicted timescales is important for adaptive management purposes. Therefore a method that allows for predictions of ecological change is necessary (GAMs cannot do this). An appropriate alternative to GAMs are generalized linear models (**Figure** 5.39). These linear models allow for predictions of future conditions and address concerns of pseudoreplication and non-normal error structures. As linear models are sensitive to the length of the time series, trend analysis will be restricted to a 5 year window. This a-priori timeframe will allow trends to reflect recent adaptive management activities, yet provide a reasonable timeframe to evaluate ecological change. Ecological trends that are occurring very slowly may not be detected with this approach. However, such trends should provide more time for corrective action to be taken and will ultimately be noted by status target exceedances.

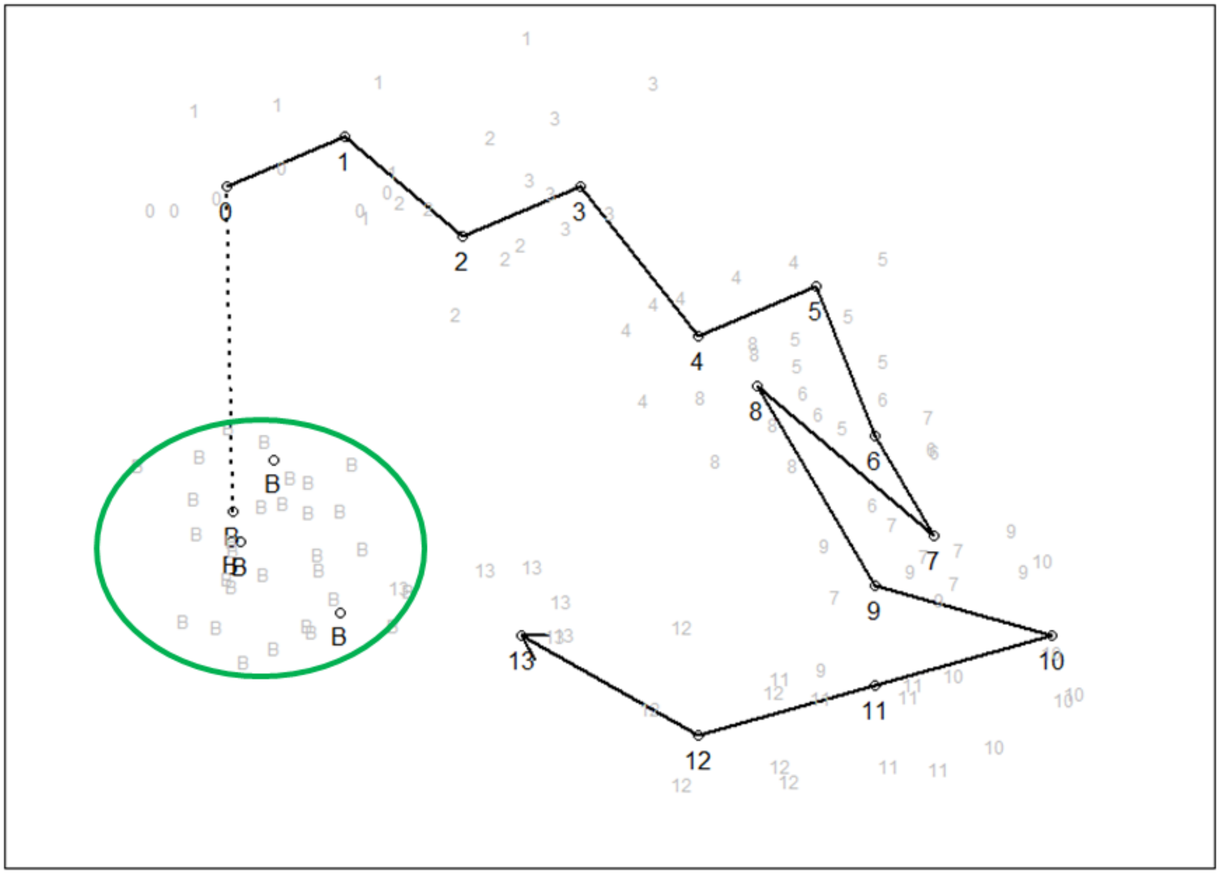


Figure 5.40. A hypothetical multivariate ordination of a community data set from the Muskrat Falls Reservoir. Baseline samples are denoted with "B"s, while the remaining samples are labelled with the year of collection relative to inundation. Grey labels represent sample replicates while bolded labels represent the centroid for each year. The dark line indicates the chronology of community change. This dataset shows the baseline condition ("B"s contained in the green circle) based on 5 years of data collection. In this scenario, the community changes from baseline following inundation (dashed line) and eventually begins a return to baseline conditions following year 10.

Variability

Variability in environmental conditions is an important characteristic of an ecosystem. Changes to environmental variability can have notable consequences on the biota. For example, habitat disturbance often causes variance in environmental conditions, favouring certain types of organisms that are adapted to deal with change. Variability of univariate measures will be evaluated with a permutation based method. Specifically, the range of values measured prior to reservoir formation will be compared to those measured after reservoir formation. To determine statistical significance, indicator values will be randomly re-assigned to two groups and the associated difference between the two groups recalculated (10,000 permutations). If the distribution of differences from randomly assigned (simulated) values do not encompass those observed in the field ($\alpha = 0.05$), significant change to variability, associated with reservoir formation will be concluded.

Peak Exceedance

Finally, in cases where indicators are expected to peak shortly after inundation (**Figure** 5.38), monitoring data will be evaluated for single year exceedances of predictions. For this evaluation, a one-sample t-test is appropriate for assessing whether mean ecological conditions differ from the predicted peak value. As it is only a concern if ecological values exceed predictions, statistical power can be gained by using a one-tailed test.

Statistical Power

There are two types of errors that are a part of probability-based statistical analysis: Type I (detecting an effect when none exists) and Type II (failing to detect an effect when one exists). In a well-designed, properly replicated monitoring program, Type I and Type II errors are kept low. In most applications, Type 1 error rates (α) are set to 0.05. However, since reducing Type I error has the effect of increasing Type II error (sample sizes being equal), many monitoring programs utilize more liberal Type I error rates (e.g. 0.2). Such an adjustment is justified when the societal risk of not detecting environmental change (Type II error) is greater than that associated with 'false alarms' caused by higher Type I error. Recent EEM design literature (EC 2010) recommends that the probability of both Type I and II errors be set equivalently (i.e. α=β). In order to remain conservative, this monitoring program will aim for Type I and Type II error rates of 0.1.

5.3.2.1.3 Review and Reporting

As with any monitoring program, the results need to be clear and communicable to all stakeholders. Reports will be generated at designated intervals for each indicator in a way that allows for effective communication to a wide variety of stakeholder groups. In some cases, the basic information on the status (on target or not) and trend (indicator improving or declining) may be sufficient. Where necessary or desired, this 'tip of the iceberg' summary information can be supported by more in-depth documentation of data, analysis and conclusions. **Appendix** C presents examples of monitoring status summaries that will provide an overview of ongoing results in a plain, non-technical format. Note that the results, data and text presented related to these examples are fictitious.

5.3.3 Environmental Indicator Descriptions

The description of each indicator type (i.e., early warning, verification, diagnostic) is provided in the following sections. These descriptions include, where applicable, available baseline data, monitoring procedures, statistical analysis and timing and triggers of the various levels of adaptive response. Additional information is provided in AMEC (2012). The indicators have been organized in each of the main monitoring function groups; **habitat stability**, **habitat suitability** and **habitat utilization**. Additional baseline data collection is ongoing for many selected indicators and therefore final variability descriptions and corresponding triggers for decisions cannot be finalized until baseline data collection is complete (i.e., once the reservoir has been formed). Nonetheless, indicator details relating to measurements of natural variability, trigger development and the trigger process and associated potential management action are provided. **Table** 5.16 provides an overview of the monitoring schedule for each parameter.

5.3.3.1 Habitat Stability

Included in habitat stability monitoring are two general habitat measures; shoreline stability and sediment transport. Each is presented within this section with its environmental indicators used for monitoring and management.

5.3.3.1.1 Shoreline Stability

Shoreline stability is one of two general habitat measures for monitoring habitat stability. It is important as the shoreline of the Muskrat Falls reservoir has been predicted to require 10-20 years to stabilize based on existing bank slopes and substrates as well as estimated wave energy generated across the reservoir water surface (AMEC 2008). It is also important as the shoreline will be the primary source of Total Suspended Solids (TSS) as it erodes, slumps and stabilizes.

The creation of the Muskrat Falls reservoir will lead to the inundation of certain shoreline glaciomarine deposits and cause instability and greater potential occurrence of earth-slide-earth flows during stabilization. Slope failures within glacial marine soils are not uncommon; due predominantly to the fineness (typically silt and clay size particles) of this soil and low consolidation. Published research has indicated that the filling of reservoirs and fluctuations in water levels within them may promote instability and restart historical slope failures (Zaruba, 1979) and that reservoir filling is a major cause leading to bank instability (Riemer, 1992). The International Commission on Large Dams indicated that 75% of landslides which developed within reservoirs were the reactivation of historical landslides (ICOLD 2002). Therefore, localized failures in these areas would be common upon initially raising the reservoir, until the formation of a new shoreline and beach/inshore (see Section 6.1 of AMEC 2008 report). The potential presence of layers of differing gradations of soil may also add to its instability. Riemer (1992) reviewed 60 known case histories on reservoirs created during large dam construction and indicated that approximately 85% of slope failure events occurred either during construction and/or during reservoir filling, or within two years of project completion. The occurrence and magnitude of the slides was also found to increase during periods of prolonged wet conditions, such as intense rainfall and spring conditions. Once a stable shoreline has been developed, failures due to undermining of the river bank are anticipated to become minimal and similar to existing conditions.

Table 5.16. Summary of sampling schedule associated with Adaptive Management monitoring indicators.

Activity/Task	Monitoring Year																						
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Shoreline Stability																							
Unvegetated Edge using Satellite Imaging																							
Total Reservoir Perimeter using Satellite Imaging																							
Weather Monitoring (wind, rainfall, temperature)																							
Wave Measurements [1]																							
Sediment Transport																							
Bathymetry																							
Substate Composition [1]																							
Velocity / Depth Profiles [1]																							
Physico-Chemical Characteristics																							
Total Suspended Solids																							
Total Phosphorus																							
Velocity / Depth Profiles																							
Shoreline Substrate Composition																							
Mid-Channel Substrate Composition																							
Ice Formation																							
Water Quality (temperature, turbidity, pH, dissolved oxygen)																							
Biological																							
Primary Production (carbon uptake)																							
Phyto and Zooplankton [2]																							
Aquatic Vegetative Growth [2]																							
Fish Habitat Utilization (electrofishing, snorkeling, netting)																							
Fish Trophic Feeding Level																							
Fish Growth and Condition																							
Fish Movement [1]																							
Fish Fecundity [1]																							
Redd Surveys [1]																							
Fish Diet [1]																							
Fish Age Structure [1]																							
Fish Disease Profile [1]																							
Fish Stress [2]																							
Benthic Invertebrate Community [2]																							
Monitoring Results and Major Program Review																							

[1] Diagnostic Investigation triggered by Verification Indicator Results - no standardized sampling schedule

[2] Early Warning Indicators

Once a stable shoreline is established within the reservoir, the relatively small water level fluctuations associated with Muskrat Falls reservoir operation are predicted to have a minimal effect on the stability of glaciomarine deposits. This is because changes in the confining pressure, as well as the pore water pressure, within such a narrow reservoir operating range (± 0.5 m from full supply level) is unlikely to influence the glaciomarine deposits in other parts of the slope.

5.3.3.1.1.1 Remote Sensing

Remote sensing of shoreline stability is the measurement of visible shoreline features from remote imagery (i.e., satellite and/or air photo). Imagery is georeferenced within a GIS so that each feature can be located (geo-marked) and compared between multiple observations to detect changes. The direct indicator measurement is the boundary location of the leading riparian edge around the Muskrat Falls reservoir.

Hypothesis Formulation

The following hypotheses are presented relative to Bank Stability and remote sensing data:

1. **H_0:** The rate of reservoir bank erosion will have a declining trend post inundation, within the first 15 years of full reservoir creation and stabilization.
   H_a: The rate of reservoir bank erosion will not have a declining trend post inundation, within the first 15 years of full reservoir creation and stabilization.

2. **H_0:** The rate of reservoir bank erosion will stabilize to pre-impoundment rates beyond 15 years of full reservoir creation and stabilization.
   H_a: The rate of reservoir bank erosion will not stabilize to pre-impoundment rates beyond 15 years of full reservoir creation and stabilization.

Hypotheses Testing

Hypothesis testing will be completed using the baseline reservoir erosion rates estimated for the lower Churchill River within the Muskrat Falls reservoir area between 2007 and 2015. The established baseline aerial extent as well as the linear rates at selected transects will be compared directly with subsequent satellite imagery measurements. Since the initial hypotheses are based on a 15 year timeframe to stabilization upon full reservoir inundation, satellite imagery (Geo-Eye1 black & White) will be collected each year for the first 15 years for comparison to baseline and again in 204 and 2037. Monitoring beyond 2032 will depend on results of the initial 15 years and will be determined at the 15 year Major Program Review.

The temporary creation of the Head Pond in September 2015 will likely initiate some erosion and stabilization along its shoreline at 25m elevation; however, it will not be at the final reservoir shoreline elevation of 39m and therefore will not be directly applicable to hypothesis testing based on full reservoir inundation (e.g., the 15 year predicted time to shoreline stabilization will not begin until full inundation in July 2017). Due to the limited timeframe of Head Pond formation (September 2015 to July 2017), any slumping would not be considered a trigger to further investigation or triggers for mitigations along the temporary shoreline as these would be temporary in nature as well. It should be noted that changes in water quality such as TSS and TP as well as any major slumps (at least 2 million m^3 of material as determined using GIS) will be monitored/investigated within Head Pond and potential mitigations related to significant increases would be implemented if the effects would persist into the full reservoir. While shoreline erosion within the Head Pond will be temporary and mitigations not likely initiated, it would be useful to monitor the shoreline to inform the adaptive management program and to provide insight to how the reservoir may react at initial full inundation. Therefore, imagery and analysis will be completed during 2016; after Head Pond formation and prior to full reservoir creation. **Table** 5.17 provides an overview of the anticipated construction schedule relative to Head Pond formation as well as an overview of initial baseline/monitoring during this timeframe.

Table 5.17. Summary of Head Pond formation timing and monitoring activities.

Activity/Task	Year of Activity					
	2013	2014	2015	2016	2017	2018
Muskrat Falls Facility Construction Activity						
Rock Coffer dams for spillway and tailrace						
River Diversion through Spillway						
Head Pond Formation						
Reservoir Full Impoundment						
Shoreline Stability						
Unvegetated Edge using Satellite Imaging						
Total Reservoir Perimeter using Satellite Imaging						
Weather Monitoring (wind, rainfall, temperature)						
Physico-Chemical Characteristics						
Total Suspended Solids						
Total Phosphorus						
Bathymetry						
Ice Formation						
Monitoring Results and Major Program Review						

[1] Diagnostic Investigations triggered by Verification Indicator Results during monitoring after full impoundment

[2] Early Warning Indicators not monitored during Head Pond formation

[3] 2018 begins full impoundment monitoring

Imagery will be collected each fall (i.e., September-October) so that vegetation is highly visible and that all annual events (e.g., spring melt/thaw, summer flows, and heavy rains) are captured as much as possible within each year. **Table** 5.18 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.18. Summary of Habitat Stability - Remote Sensing attributes.

Attribute	Attribute Rating
Indicator Type	Verification
Biologically relevant	Shoreline stability is a direct indicator of habitat stabilization, habitat quality and suitability as it influences, substrate distributions, water quality and productivity (TP).
Sensitive	Remote sensing is a direct measure of shoreline stability, therefore the measurement is sensitive to change. The temporal scale is appropriate given the expected scale of change. Accuracy of imagery is also appropriate to detect changes.
Measureable	Easily measureable within GIS. Image resolution must be sufficient to detect anticipated erosion and movement of shoreline boundary (i.e. 1-2 m resolution). An area of severe shoreline erosion would be detectable.
Interpretable	Qualitatively, shoreline erosion is expected to show a decreasing trend that will stabilize after 15 years.
Historical data	Yes, historical air photos are available for georeferencing, although limited. Additional satellite imagery is being acquired prior to inundation (2013-2015).
Baseline Requirements	Requires baseline imagery and GIS determination of shoreline extent for comparison to post-Project.
Sampling Schedule	Remote sensing to be completed every year during the first 15 years following full inundation, 2034 and 2037. Sampling frequency after 2032 will be dependent on results of 15 year Major Program monitoring review.
AMP Triggers	Areas of large-scale slumping will be identified (labeled as Area of Concern). Areas of large-scale slumping will trigger direct measurement (**Section** 5.3.3.1.1.2), wave calculations/measurements (**Section** 5.2.3.1.1.3). A large-scale slump is defined to be of similar size to that which occurred near Edward's Brook in 2010 – at least 2 million m^3 of material (determined using GIS).
Mitigation(s)	• No mitigations based solely on remote sensing; however, the trigger-related activities noted above may initiate mitigations at select sites. Direct measurements/investigation (wave influence) results could promote various mitigation measures. Depending on effect of large-scale slumping and the cause, mitigations available include: • Turbidity barriers • Bank erosion protection (seeding), alder/tree live-staking, Curlux sheeting • Wave protection (rocks or aquatic vegetation) • Shoreline stabilization (water cannon or other physical decrease in bank slope)

5.3.3.1.1.2 Direct Measure of Large-Scale Slump Area

Direct measures of conditions in Areas of Concern will be conducted to assist in determining the mechanism(s) involved in a failure as well as possible need for further triggers such as mitigation(s) related to protection of aquatic habitat. A large-scale slump is defined to be of similar size to that which occurred near Edward's Brook in 2010 – at least 2 million m^3 of material (determined using GIS).

The typical formulation of hypotheses, testing, statistical analysis, and measurement of variability are not applicable to this triggered investigation. Measurements at large-scale slumps within the reservoir will be continued until determined unnecessary by DFO. **Table** 5.19 presents a summary of the primary attributes of this diagnostic indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012). As noted above, an investigation of this type would be initiated within the Head Pond area as it would assist in informing the adaptive management process.

5.3.3.1.1.3 Real Time Weather Measurements

As indicated in AMEC (2012), freeze/thaw cycles can be a contributing factor to bank erosion. The investigation of the recent earth slide-earth slump on the south shore across from Edward's Brook included gathering existing records of rainfall quantity (can affect pore pressures) prior to the slump as well as overall air temperatures (for freeze/thaw cycles). Information like this will be useful in identified Areas of Concern due to large-scale slumping. Since the exact timing of a slump cannot be predicted, this information will be collected on a continual basis if it is to be used as an effective diagnostic tool. **Table** 5.20 presents a summary of the primary attributes of this diagnostic indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

5.3.3.1.1.4 Wave Measurements

As indicated in AMEC (2012), shoreline erosion and stability in reservoirs can be heavily influenced by wave heights and energy affecting the shoreline and dislodging soil particles. If an Area of Concern due to large-scale slumping is identified, additional calculations and/or measurements on wave height/energy will be triggered to determine the extent wave energy is affecting the shoreline erosion duration and/or frequency. Wave energy can be determined in two ways; calculations based on wind / reservoir data and direct measure (AMEC 2012). The sampling method will be finalized based on the site-specific location as well as the degree of erosion. **Table** 5.21 presents a summary of the primary attributes of this diagnostic indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.19. Summary of Habitat Stability - Large-Scale Slumping Investigation attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic
Biologically relevant	Direct measures at locations of large-scale erosion/slumping will allow characterization and diagnosis of the event as well as provide relevant information related to possible long-term stability of the area and mitigations.
Sensitive	Measurements would be completed at specific sites of slump events, therefore the rate and sensitivity in terms of diagnosing specific conditions is high.
Measureable	Easily measureable at site-specific locations. Measurements and methods may be adapted based on site conditions.
Interpretable	Measurements will be interpretable as each will be focused on specific aspects of a location. Therefore, measurements of slump characteristics will be directly compared to historic/literature data collected on additional areas/slumps.
Historical data	Yes, historical slump measurements and literature are available for comparison and analysis, although limited site-specific data.
Baseline Requirements	Large-scale slumps occurring prior to inundation will continue to be investigated but baseline for post-Project analysis is not applicable.
Sampling Schedule	Investigations will be triggered and completed at each large-scale slump within the Muskrat Falls reservoir.
AMP Triggers	This investigation would be triggered along with weather/wave measures based on remote sensing; future triggers based on these investigations would be mitigation (see below).
Mitigation(s)	Depending on effect of large-scale slumping and the cause, mitigations available include: • Turbidity barriers • Bank erosion protection (seeding), alder/tree live-staking, Curlex™ sheeting • Wave protection (rocks or aquatic vegetation) • Shoreline stabilization (water cannon or other physical decrease in bank slope)

Table 5.20. Summary of Habitat Stability - Real-Time Weather attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic (air temperature, rainfall, wind speed/direction)
Biologically relevant	Direct measures of environmental conditions affecting habitat stability of the Muskrat Falls reservoir and surrounding area. Will allow greater diagnostic capabilities in areas of identified Areas of Concern due to large-scale slumping.
Sensitive	Measurements would be collected continuously at the Muskrat Falls facility therefore the rate of collection is high. These data are collected for weather forecasts and therefore sensitivity is high.
Measureable	Easily measureable using standard equipment installed at the Muskrat Falls facility or at nearby weather stations (i.e. airports, provincial stations).
Interpretable	Measurements are standard as are interpretation of results. Therefore, measurements of weather will be directly compared to historic/literature data collected.
Historical data	Historical weather data available from various long-term, continuous stations from both Goose Bay and Churchill Falls airports.
Baseline Requirements	Ongoing data collection at Goose Bay and Churchill Falls airports and at various climate stations in Upper Lake Melville and Labrador.
Sampling Schedule	During Muskrat Falls operations, additional weather data will be collected at Muskrat Falls powerhouse.
AMP Triggers	None
Mitigations	• None specific to real-time weather results.

Table 5.21. Summary of Habitat Stability - Wave Measurement attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic (calculated and measured)
Biologically relevant	Wave action and energy upon the Muskrat Falls shoreline can have a direct biological effect on the reservoir ecosystem in terms of shoreline stability (and time to shoreline stability), shoreline substrate composition, and water quality (TSS and TP). Will allow greater diagnostic capabilities in areas of active slumping.
Sensitive	Meteorological measurements needed for calculations of wave heights and energy would be collected continuously at the Muskrat Falls facility therefore the rate of collection is high. If required, direct measure could be completed in Areas of Concern based on indications of high erosion (remote sensing indicating earth slump-earth flow).
Measureable	Easily calculated using data collected from standard equipment installed at the Muskrat Falls facility. Direct measure would also be collected by standard equipment; however deployment and data retrieval/analysis is more challenging/costly.
Interpretable	Measurements are standard as are interpretation of results.
Historical data	No. Waves within Muskrat Falls reservoir have only been estimated using equations because until the reservoir is created, actual weather measures across the reservoir can only be assumed based on existing data.
Baseline Requirements	Not applicable.
Sampling Schedule	To be triggered based on large-scale slumping or ongoing bank erosion greater than predicted.
AMP Triggers	If wave energy is determined to be a contributing factor to shorelines remaining unstable longer than predicted, mitigations would be triggered to reduce influence.
Mitigations	• Shoreline stabilization (water cannon or other physical decrease in bank slope) • Wave protection (rocks or aquatic vegetation)

5.3.3.1.2 Sediment Transport

Bank stabilization, as described above, will include the formation of a new shoreline along the Muskrat Falls reservoir. This will involve the movement of shoreline substrate both by suspension and bedload transport. Suspended sediment (TSS) can be transported within the water column relatively long distances as shown by the various TSS models (e.g., Minaskuat 2008; Oceans 2010). Bedload movement is the transport of larger substrate material that doesn't readily go into suspension but moves while generally still in contact with the bottom. As such, the material does not travel as far as that in suspension. The potential issues related to sediment transport are increased TSS, shifting substrate composition and/or smothering ecologically important areas (i.e. areas with larger substrates) with finer material. Increases in TSS have been identified as a verification indicator related to habitat suitability (water quality) and its monitoring as such is addressed in **Section** 5.3.3.2.2. The movement and shifting of material within the reservoir, and its potential to affect habitat stability, will be assessed using the following methods: bathymetry, Acoustic Doppler Current Profiler (ADCP) and direct measure of substrate composition. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

5.3.3.1.2.1 Bathymetry

The predicted bathymetric contours of the Muskrat Falls reservoir have been generated using LiDAR imaging of the lower Churchill River and bathymetric mapping conducted in 2006 (**Figure** 5.43). The vertical accuracy of LiDAR imaging is estimated at ±0.45m and therefore this bathymetric map represents a reasonable approximation; however, reservoir preparation activities such as road creation and vegetation removal will most likely alter the nearshore reservoir contours somewhat prior to inundation. Upon full reservoir creation, an initial bathymetric survey will be completed in late 2017 or early 2018 and used as a baseline for comparison to ongoing conditions. Monitoring every three years thereafter will be sufficient. While Head Pond will be created in late 2015, bathymetric mapping of this temporary waterbody is not scheduled as any final changes in bottom contouring will be mapped during the baseline survey in 2017 and used for ongoing monitoring.

Hypothesis Formulation

The habitat types within the Muskrat Falls reservoir have been predicted. These have been partly based on changes in water depth and substrates. The following hypothesis is presented relative to sediment transport as it relates to habitat stability:

1. **H_o:** the bathymetry of Muskrat Falls reservoir will not change as a result of bank stability causing sediment transport

   H_a: the bathymetry of Muskrat Falls reservoir will change as a result of bank stability causing sediment transport.

Hypothesis Testing

While not subject to standard direct statistical analyses, changes in reservoir bathymetry will be determined based on comparison of bottom contour differences generated prior to, and immediately after, inundation to those measured within the post-inundation reservoir.

Table 5.22 presents a summary of the primary attributes of this verification indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.22. Summary of Bathymetry Indicator attributes.

Attribute	Attribute Rating
Indicator Type	Verification
Biologically relevant	Water depth is an important factor for the distribution of many aquatic animals and plants. Any large-scale changes in the quantity and/or distribution of habitat can change the habitat suitability of the reservoir.
Sensitive	The method should be able to detect the scale of change that is predicted.
Measureable	Methods of bathymetric mapping are well established.
Interpretable	Generated bathymetry will be georeferenced and standardized to elevations above sea level (asl) therefore all profiles can be imported to GIS and directly compared/interpreted.
Historical data	Bathymetry within the Muskrat Falls reservoir has been completed using LiDAR data (historical bathymetry can only be generated using existing terrestrial contours until the reservoir is inundated).
Baseline Requirements	Baseline bathymetry based on LiDAR imagery and initial reservoir inundation surveys.
Sampling Schedule	Sampled in 2018, after full inundation and again every three years post-inundation for twenty years (2037). Sampling frequency after the first 10 years may be altered dependent upon results and project monitoring review.
AMP Triggers	Areas of large-scale bathymetry alterations (changes of bathymetric contours greater than 5m) will trigger further investigations into habitat suitability (see substrate composition (**Section** 5.3.3.1.2.3), water depth/velocity (**Section** 5.3.3.2.1).
Mitigations	• Mitigations would depend on results of additional triggered investigations. • Mitigations associated with substrate compositions would depend on results of additional triggered diagnostic investigations; however, direct mitigations related to water velocities in an identified Area of Concern could include dredging/moving material to re-establish velocities. • Mitigations would depend on results of additional triggered investigative monitoring (i.e., whether changes in substrate composition are having a negative effect on fish/ecosystem); however, direct mitigations related to substrate composition in an identified Area of Concern could include flushing finer sediments (silts) using jet pumps to re-establish substrates.

5.3.3.1.2.2 Water Velocity Profiles

Water velocity profiles will be triggered as a Diagnostic Indicator within identified Area(s) of Concern based on results of bathymetric mapping. Transects will be completed using an Acoustic Doppler Current Profiler (ADCP). Transects will be established within identified Area(s) of Concern based on a bathymetric trigger as large-scale habitat alteration may affect habitat suitability and/or fish utilization. Transects will be established at each Area of Concern where they will encompass the entire width of the reservoir so that a complete depth/velocity/discharge profile can be recorded. Results will be compared to the existing habitat type characteristics for the Area of Concern to determine if the habitat type is to be re-characterized/re-classified and whether further investigations related to potential changes in fish utilization are to be triggered. **Table** 5.23 presents a summary of the primary attributes of this diagnostic indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012). It should be noted that water velocity profiles are also a Verification Indicator relative to habitat suitability; this is described in **Section** 5.3.3.2.

5.3.3.1.2.3 Direct Measure of Substrate Composition

The biological implications associated with changed substrate composition are the primary reason for monitoring this indicator. A change in substrate from gravels/cobbles (typical spawning habitat) to finer material such as sands/silts has the potential to limit habitat for fish spawning, rearing, and benthic macroinvertebrate production.

Substrate composition investigations in areas identified as having large-scale habitat alteration (i.e. changes of bathymetric contours greater then 5m and/or changes of areas from one habitat type to another) will involve one of two methods; visual inspection and ponar sampling. **Table** 5.24 presents a summary of the primary attributes of this diagnostic indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012). It should be noted that substrate composition is also a Verification Indicator related to habitat suitability; this is described in **Section** 5.3.3.2.

Table 5.23. Summary of Habitat Stability - water velocity attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic for bank stability and habitat availability.
Biologically relevant	Water velocity will provide information on why aquatic habitats are changing and if it is related to sediment transport. Any large-scale changes in the quantity and/or distribution can have a subsequent change in the use of the reservoir by resident fish species and/or benthic macroinvertebrates.
Sensitive	Water velocity profiles will detect large scale, ecologically meaningful deviations from predictions.
Measureable	Water velocity profiling is an established and proven method. Using GPS, these transects will also be repeatable.
Historical data	No historical data exists as the reservoir is yet to be created. Nonetheless, model predictions are available.
Baseline Requirements	Additional water velocity profiles prior to inundation not required as this measure is relative to an identified Area of Concern based on changes in bathymetric contours.
Sampling Schedule	Water velocity profiles triggered within an identified Area of Concern would continue until determined by regulators to no longer be necessary.
AMP Triggers	If the mean velocity at a transect is outside the bounds of the predicted range for the habitat type (e.g., **Table** 5.1), sampling of habitat utilization would be triggered (**Section** 5.3.3.3.4 - fish sampling) to determine if the detected deviation in habitat measures is affecting fish use of the habitat. Potential mitigations would depend on these results.
Mitigations	• Mitigations would depend on results of additional triggered diagnostic investigations; however, direct mitigations related to water velocities in an identified Area of Concern could include dredging/moving material to re-establish velocities. • If results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Nutrient inputs or extractions ▪ Substrate modifications (addition or flushing) ▪ use of aerators (pumped surface water spray) to provide additional dissolved oxygen in select areas ▪ additional physical habitat enhancement.

Table 5.24. Summary of Habitat Stability - Direct Measures of Substrate Composition (Visual and/or Ponar) attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic for back stability and habitat availability
Biologically relevant	Any significant changes in the habitat composition and/or distribution can affect the use of the reservoir by resident fish species and/or benthic macroinvertebrates.
Sensitive	The techniques employed will capture the changes anticipated from large scale destabilization events.
Measureable	Substrate composition will be measured using standard and proven methods.
Interpretable	Deviations from predicted substrate composition are readily interpretable by comparison using Chi-square analysis.
Historical data	Predicted compositions of post-inundation are based on existing measurements.
Baseline Requirements	Baseline substrate composition of each habitat area has been gathered and predicted.
Sampling Schedule	Collected at identified Area(s) of Concern until determined no longer necessary by regulators.
AMP Triggers	If a significant change in substrate composition is detected, further investigation assess biological change in habitat function will follow. These activities will include: ○ Review existing biological data for each Area of Concern (e.g., would the change expect a negative reaction by fish/ecosystem?) ○ Focused sampling on fish species utilization of the Area of Concern as outlined in **Section** 5.3.3.3.4 - fish sampling.
Mitigations	• Mitigations would depend on results of additional triggered investigative monitoring (i.e., whether changes in substrate composition are having a negative effect on fish/ecosystem); however, direct mitigations related to substrate composition in an identified Area of Concern could include flushing finer sediments (silts) using jet pumps to re-establish substrates. • If results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Nutrient inputs or extractions ▪ Substrate modifications (addition or flushing) ▪ use of aerators (pumped surface water spray) to provide additional dissolved oxygen in select areas ▪ additional physical habitat enhancement.

5.3.3.2 Habitat Suitability (Physico-chemical Characteristics)

Within the suite of habitat suitability indicators, there are two general measures; physico-chemical and biological. The physico-chemical indicators are used to monitor the suitability of the habitat itself for the various fish life stages within the Muskrat Falls reservoir. This includes Verification Indicators of habitat depth and velocity, substrate composition, and water quality. It also includes Diagnostic and Early Warning Indicators of plankton dynamics, aquatic vegetation growth, benthic macroinvertebrates, and fish physiology. Each physico-chemical indicator is presented within this section along with how they fit within the Adaptive Management framework.

5.3.3.2.1 Direct Measure of Habitat Characteristics (Water Velocity and Depth)

ADCP transects will be used as a Verification Indicator to accurately measure the water depth and velocity profile of habitat types throughout the Muskrat Falls reservoir to confirm they remain within the habitat ranges described in **Table** 5.1. Transects will be completed across the entire reservoir width at selected pre-established locations so that a complete depth/velocity/discharge profile can be recorded. The data will be used to verify concordance with the predicted habitat type attributes, particularly mean water velocity. While Head Pond will be created in late 2015, water velocity and depth measurements of this temporary waterbody are not scheduled as any final changes in these parameters will be compared to predicted values upon final reservoir inundation.

Hypothesis Formulation

The biological implications of changed water velocities are important in determining the suitability of the various habitat types within the reservoir. A statistical test can be completed on the measured data to determine whether a significant change in water velocity characteristics has occurred. The following hypotheses will be used to evaluate change in water velocity resulting from reservoir formation and stabilization:

1. **H_0:** The mean and range of water velocities within each habitat type predicted within the reservoir will not change from that predicted (**Table** 5.1).
   H_a: The mean and range of water velocities within each habitat type predicted within the reservoir will change from that predicted (**Table** 5.1).

Table 5.25 presents a summary of the primary attributes of this verification indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.25. Summary of Habitat Suitability - water velocity attributes.

Attribute	Attribute Rating
Indicator Type	Verification for habitat suitability
Biologically relevant	ADCP measures will determine if predicted values of water velocity persist within the reservoir. Changes to mean water velocity can have a subsequent change in the use of the reservoir by resident fish species.

Attribute	Attribute Rating
Sensitive	ADCP is the state-of-the-art system for measuring water velocity and is highly accurate. The sensitivity of the indicator to water velocity should exceed those of the fish species of interest.
Measureable	ADCP is a well established and proven method for measuring water velocity.
Interpretable	ADCP measurements of depth profile and velocity are easily compared to predicted habitat type attributes.
Historical data	Reservoir creation will render existing data irrelevant, therefore direct comparison with historical data not necessary.
Baseline Requirements	Additional ADCP transects prior to inundation are not required. Model results at established transects are available for post-project comparisons.
Sampling Schedule	Sampled in 2018, after full inundation and again every three years post-inundation for twenty years (2037). Sampling frequency after the first 10 years may be altered dependent upon results and Major Program Reviews.
AMP Triggers	If the mean velocity at a transect is outside the bounds of the predicted range for the habitat type (e.g., **Table** 5.1), additional ADCP transects will be established and sampled to determine the potential extent of change (i.e., to identify an Area of Concern). Within an identified Area of Concern, an investigation as to what the change could mean for fish utilizing the habitat will be triggered. This will include: ○ review of fish utilization and health data from the area, if already included in a sampling regime, or ○ collection of this data (fish utilization see **Section** 5.3.3.3.4, fish health see **Section** 5.3.3.3.6) if not within the ongoing collection regime.
Mitigations	• Mitigations would depend on results of triggered investigations on fish utilization and health (i.e., whether changes in water velocities or depth are having a negative effect on fish/ecosystem); however, direct mitigations related to water velocities or depths in an identified Area of Concern could include dredging/moving material to re-establish velocities or depths. • If results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Nutrient inputs or extractions ▪ Substrate modifications (addition or flushing) ▪ use of aerators (pumped surface water spray) to provide additional dissolved oxygen in select areas ▪ additional physical habitat enhancement .

5.3.3.2.2 Direct Measure of Habitat Characteristics (Substrate Composition)

Substrate composition of each habitat type will be used as a Verification Indicator to accurately measure the composition of substrate throughout the Muskrat Falls reservoir to confirm they remain within the habitat ranges described in **Table** 5.1. Transects will be completed across the entire reservoir width at selected pre-established locations so that a complete substrate composition, including nearshore and mid-channel, profile can be recorded. The data will be used to verify the predicted substrate composition within each habitat type. While Head Pond will be created in late 2015, substrate composition of this temporary waterbody is not scheduled as any final changes will be compared to predicted values upon final reservoir inundation.

Hypothesis Formulation

As described above, the biological implications of changed substrate composition are the principal concern. However, a statistical test can be completed on the measured data to determine whether a significant change in the substrate composition has occurred. The following hypotheses will be used to evaluate change in substrate composition resulting from reservoir stabilization:

1. **H_0:** The proportion of each substrate type identified within each predicted habitat type will not change from that predicted (**Table** 5.1).
   H_a: The proportion of each substrate type identified within each predicted habitat type will change from that predicted (**Table** 5.1).

Table 5.26 presents a summary of the primary attributes of this Verification Indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.26. Summary of Habitat Suitability - Substrate Composition attributes.

Attribute	Attribute Rating
Indicator Type	Verification
Biologically relevant	Any changes in the composition and/or distribution can cause a subsequent change in the use of the reservoir by resident fish and other aquatic species.
Diagnostic	This indicator can be used for diagnostics related to fish habitat use.
Measureable	Ponar grabs and visual surveys are proven methods for substrate composition.
Interpretable	Shifts in substrate composition can be compared to predicted values as well as habitat preferences for various fish species.
Historical data	Existing substrates within the river and reservoir shoreline area have been investigated and incorporated into predicted compositions.
Baseline Requirements	Additional baseline substrate composition within the existing main stem will be completed during reservoir preparation activities as road construction will expose many areas of nearshore substrate. Estimated substrate composition at each transect above the existing river (i.e. within the reservoir) will be collected prior to inundation.

Attribute	Attribute Rating
Sampling Schedule	Sampled in 2018, after full inundation and again every three years post-inundation for twenty years (2037). Sampling frequency after the first 10 years may be altered dependent upon results and Major Project Reviews.
AMP Triggers	If a significant change in substrate composition is detected, further investigation will be triggered. Effected habitat will be quantified and assessments will be made regarding the impact on biological function: ○ a review of the substrate composition distribution within Muskrat Falls reservoir. This may include further transect measurements to delineate with finer detail the distribution of habitat change, ○ a review of the habitat change and biological use of each by the fish species present. If potential changes in habitat utilization are possible as a result of altered substrate composition, additional focused sampling on fish species utilization of the habitat type will be conducted as outlined in **Section** 5.3.3.3.4 - fish utilization.
Mitigations	• Mitigations would depend on results of additional triggered diagnostic monitoring (i.e., whether changes in substrate composition are having a negative effect on fish/ecosystem); however, direct mitigations related to substrate composition in an identified Area of Concern could include flushing finer sediments (silts) using jet pumps to re-establish substrates. . • If results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Nutrient inputs or extractions ▪ Substrate modifications (addition or flushing) ▪ use of aerators (pumped surface water spray) to provide additional dissolved oxygen in select areas ▪ additional physical habitat enhancement .

5.3.3.2.3 Direct Measure of Habitat Characteristics (Water Quality)

Water quality includes many measures including temperature (and ice formation), Total Suspended Solids (TSS), Total Phosphorous (TP), turbidity, a variety of metals, and dissolved oxygen. Post-project changes are predicted for many water quality measures based on existing values and modeling, therefore these are considered Verification Indicators. Each is presented below, with those considered Verification Indicators described first. Indicators include real-time as well as *in-situ* sampling.

The Canadian Council of the Ministers of the Environment (CCME) has developed Canadian Water Quality Guidelines for the Protection of Aquatic Life (PAL) (CCME 1999). The document acknowledges that an ecosystem has usually developed over a long period of time and the organisms have become adapted to their environment. This is very evident within the lower Churchill River, particularly within the area of the Muskrat Falls reservoir as many measures are naturally above CCME guideline levels. The guidelines also state that PAL guidelines are not restricted to a particular (biotic) species, but species-specific information is provided in the respective fact sheets and in more detail in the supporting documents, so that the water quality managers and users may determine the appropriateness of the guideline for the protection and enhancement of local species. This has been taken into consideration with respect to each measure below in determining the monitoring requirements and triggers, given the natural variability and background levels of measures within the lower Churchill River.

5.3.3.2.3.1 Total Suspended Solids (TSS)

TSS has been previously modeled (Minaskuat 2007) for the Lower Churchill River (see **Section** 5.1.2.1.2 above). The greatest pulse of TSS is expected to occur, post-Project, during the initial year after impoundment and may be as high as 30 mg/L above baseline within the lower reach of the Muskrat Falls reservoir (see **Figure** 5.4). The proposed Muskrat Falls reservoir area currently experiences considerable variation in TSS concentrations, with concentrations recorded in 2006-2007 from 1.3 to 77mg/L, with an annual mean of 18mg/L (Minaskuat 2007). This reach of the river is primarily comprised of sandy substrate, resulting in naturally high levels of turbidity (Minaskuat 2007). In successive years of reservoir maturation, the pulse of TSS is predicted to diminish as the shoreline reaches equilibrium. Based on model predictions, TSS concentrations are expected to be less than 5mg/L above the existing baseline within seven years. By the end of the 20 year modeling scenario, TSS concentrations in all reaches are predicted to be less than 2mg/L above existing baseline (Minaskuat 2008).

Hypothesis Formulation

The following hypotheses are presented relative to predicted TSS concentrations:

1. **H_0:** An increase in TSS concentration, above predicted concentrations, will not occur.
   H_a: An increase in TSS concentrations, above predicted concentrations, will occur.

2. **H_0:** After an initial peak in TSS concentrations, there will be a downward trend toward baseline within the first 20 years of reservoir stabilization.
   H_a: After an initial peak in TSS concentrations, there will not be a downward trend toward baseline within the first 20 years of reservoir stabilization.

3. **H_0:** TSS concentrations will be within 2mg/L of pre-Project baseline within the first 20 years of reservoir stabilization.
   H_a: TSS concentrations will not be within 2mg/L of pre-Project baseline within the first 20 years of reservoir stabilization.

Hypotheses Testing

Hypothesis testing will be completed using the measured baseline TSS values for the proposed Muskrat Falls reservoir prior to full inundation. The mean annual baseline concentration will be compared directly with measured values collected from samples within the Muskrat Falls reservoir. Since the initial hypotheses are based on a 20 year timeframe to stabilization, TSS samples will be collected each year during the ice-free season for the first 20 years for comparison to baseline, unless results indicate a return to baseline much earlier than predicted. In this case, the sampling frequency may be reduced.

The temporary creation of the Head Pond in September 2015 will likely initiate some erosion and stabilization along its shoreline at 25m elevation and hence increase TSS values; however, it will not be at the final reservoir shoreline elevation of 39m and therefore will not be directly applicable to hypothesis testing based on full reservoir inundation (e.g., the 20 year predicted time to TSS return to baseline will not begin until full inundation in July 2017). Even though Head Pond has a limited timeframe (September 2015 to July 2017), any significant increases in TSS above what would be initially predicted during full reservoir stabilization will be considered a trigger to further investigation/mitigation along the temporary shoreline. **Table** 5.17 provides an overview of the anticipated construction schedule relative to Head Pond formation as well as an overview of initial baseline/monitoring during this timeframe.

Table 5.27 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

5.3.3.2.3.2 Total Phosphorous (TP)

New reservoirs undergo an initial peak of increased productivity based on the release of soluble nutrients from soils and flooded vegetation (Baxter and Glaude 1980; Hayeur 2001). Upon flooding, nutrients (phosphorus and nitrogen) are released and through microbial action can become biologically available. For example, in the La Grande system of Québec, reservoir creation resulted in a substantial increase in total phosphorus and silica, which were both considered limiting nutrients for productivity in that northern environment (Hayeur 2001). The spike in nutrients is transient, with the initial spike in oxygen demand and nutrients generally decreasing over time in reservoirs, as available organic matter decreases. Ultimately, the nutrient supply stabilizes and reaches an equilibrium based on nutrient inputs from the surrounding watershed and through autotrophic (phytoplankton) production. In the Robert-Bourassa reservoir, the changes in physical and chemical characteristics of the water peaked in the first two to three years after flooding and generally returned to baseline values nine to ten years later. The Caniapiscau reservoir, a large flooded lake subject to considerable drawdown, had peak values six to ten years after flooding with a return to background after 14 years. Hydro-Québec has concluded it takes 10 to 15 years for the water quality in reservoirs to regain physical and chemical characteristics similar to pre-impoundment conditions and other natural water bodies nearby (Hayeur 2001).

Table 5.27. Summary of Habitat Suitability - TSS attributes.

Attribute	Attribute Rating
Indicator Type	Verification
Biologically relevant	High TSS concentrations can cause a change in the suitability and/or use of the reservoir by resident fish species.
Sensitive	TSS is a sensitive indicator of erosion and a moderately sensitive indicator of fish habitat suitability.
Measureable	Measures of TSS are standard and well tested.
Interpretable	Results are interpreted by comparing to CCME guidelines, predicted values and baseline values.
Historical data	Existing TSS seasonal profiles are available and will continue to be collected until reservoir formation. These data generated predicted TSS concentrations that will be used for assessment.
Baseline Requirements	Ongoing baseline data collection at RTWQ stations May-November.
Sampling Schedule	A similar sample schedule to baseline will be maintained for 20 years following full inundation (i.e., samples collected at each RTWQ station during the open water season between 2018-2037). Sampling frequency after the first 10 years may be altered dependent upon results and project monitoring review. Monitoring will also be conducted within Head Pond.
AMP Triggers	If a significant change in TSS is detected, further investigations will be triggered as to the spatial distribution of the exceedance and potential biological change in habitat function: ○ A review of TSS results and determination of potential to affect habitat function, primary productivity or fish health; ○ Further TSS sampling to delineate Area(s) of Concern; and ○ If potential changes in habitat function are possible as a result of changes in TSS, additional focused sampling of fish species health will be triggered (**Section** 5.3.3.3.6).
Mitigations	• Turbidity barriers • Bank erosion protection (seeding, Curlex™ sheeting, alder/tree live-staking) • Wave protection (rocks or aquatic vegetation) • Shoreline stabilization (water cannon or other physical decrease in bank slope)

Hypothesis Formulation

The following hypotheses are presented relative to predicted TP concentrations:

1. **H_0:** An increase in TP concentration, above predicted concentrations, will not occur.
   H_a: An increase in TP concentrations, above predicted concentrations, will occur.

2. **H_0:** After an initial peak in TP concentrations, there will be a downward trend toward baseline within the first 15 years of reservoir stabilization.
   H_a: After an initial peak in TP concentrations, there will not be a downward trend toward baseline within the first 15 years of reservoir stabilization.

3. **H_0:** TP concentrations will be within 2mg/L of pre-Project baseline within the first 15 years of reservoir stabilization.
   H_a: TP concentrations will not be within 2mg/L of pre-Project baseline within the first 15 years of reservoir stabilization.

Hypotheses Testing

Hypothesis testing will be completed similar to that described for TSS above; using the measured baseline TP values for the lower Churchill River within the Muskrat Falls reservoir prior to inundation. The established mean annual baseline concentration will be compared directly with measured values collected from samples within the Muskrat Falls reservoir. Since the initial hypotheses are based on a 15 year timeframe to stabilization, TP samples will be collected each year during the ice-free season for the first 15 years for comparison to baseline, unless results indicate a return to baseline much earlier than predicted. In this case, the sampling frequency may be reduced.

The temporary creation of the Head Pond in September 2015 will likely initiate some erosion and stabilization along its shoreline at 25m elevation and hence increase TP values; however, it will not be at the final reservoir shoreline elevation of 39m and therefore will not be directly applicable to hypothesis testing based on full reservoir inundation (e.g., the 20 year predicted time to TP return to baseline will not begin until full inundation in July 2017). Even though Head Pond has a limited timeframe (September 2015 to July 2017), any significant increases in TP above what would be initially predicted during full reservoir stabilization will be considered a trigger to further investigation/mitigation along the temporary shoreline. **Table** 5.17 provides an overview of the anticipated construction schedule relative to Head Pond formation as well as an overview of initial baseline/monitoring during this timeframe.

Table 5.28 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.28. Summary of Habitat Suitability - TP attributes.

Attribute	Attribute Rating
Indicator Type	Verification
Biologically relevant	The TP concentrations within Muskrat Falls reservoir area are naturally low with increases predicted during the first 15 years of reservoir stabilization. While the predicted increases are not anticipated to have a substantial negative effect, unexpectedly high TP concentrations and/or distribution can have a subsequent change in the suitability and/or use of the reservoir by resident fish species as well as fish growth.
Sensitive	TP is often a limiting factor for primary production. As such it is very sensitive for diagnosing ecosystem change.
Measureable	Methods are standard and well-tested.
Interpretable	High levels of TP will indicate impacts related to reservoir creation.
Historical data	Existing TP data are available and will continue to be collected until reservoir formation.
Baseline Requirements	Additional TP sampling at RTWQ stations (grab samples) throughout 2012, 2013 and 2014.
Sampling Schedule	A similar sample schedule to baseline will be maintained for 20 years following full inundation (i.e., samples collected at each RTWQ station during the open water season between 2018-2037). Sampling frequency after the first 10 years may be altered dependent upon results and project monitoring review. Monitoring will also be conducted within Head Pond.
AMP Triggers	If a significant change in TP is detected, further investigations will be triggered regarding: ○ Overall distribution and biological change in habitat function, primary productivity or fish health; ○ Further TP sampling to delineate Area(s) of Concern. ○ Additional focused sampling of fish species health (**Section** 5.3.3.3.6) as well as dissolved oxygen (**Section** 5.3.3.2.3.6) will be triggered
Mitigations	• Turbidity barriers • Bank erosion protection (seeding, Curlex™ sheeting, alder/tree live-staking) • Wave protection (rocks or aquatic vegetation) • Shoreline stabilization (water cannon or physical decrease in bank slope)

5.3.3.2.3.3 Water Temperature

Water temperature has been predicted as part of ice dynamics modeling (Hatch 2007) and results described in **Section** 5.1.2.1.4 above. For an average temperature year, the cool down and warm up periods in the Muskrat Falls reservoir is expected to occur about two weeks later than present (i.e. the length of winter conditions will be the same, but shifted two weeks later in time). **Figure** 5.8 presents the existing and predicted temperatures within the Muskrat Falls reservoir. In particular, reaches of the Churchill River within the proposed Muskrat Falls reservoir are predicted to be 1.0 to 3.5 degrees cooler throughout the summer months (May - August) and to be 1.2 to 2.6 degrees warmer during September and October.

Many life history attributes (e.g. timing of spawning) are triggered by temperature and there may be a subtle shift in timing, but it is not predicted to be any more so than due to inter-annual variability in climate. Any continuous or re-occurring large deviations in thermal regime; however, have the potential to affect both habitat function and fish health. Therefore water temperature is characterized as a Diagnostic Indicator. **Table** 5.29 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012). During Head Pond creation, RTWQ stations may be relocated to their final locations along the full reservoir shoreline. Therefore, it is not anticipated that full monitoring of water temperature will be available during this time.

5.3.3.2.3.4 Ice Formation

Ice formation will be of particular social interest related to transportation below Muskrat Falls and into Lake Melville and this will be monitored as part of the EEM program (under separate cover). In this Plan, ice formation within the Muskrat Falls reservoir as well as at the physical compensation works at the Pinus River and Edward’s Brook deltas will be monitored. The issues related to ice formation and changes in thermal regime are potential changes to life stage processes and/or productivity shifts within the reservoir and any physical disturbance of habitat due to scour or crushing. For the most part, ice formation will be a Diagnostic Indicator associated with habitat suitability (biological) as it relates to potential effects of fish life stage processes such as spawning, egg incubation/protection, and growth.

Ice dynamics modeling was conducted for the entire river potentially affected by both the Muskrat Falls and Gull Island reservoirs (Hatch 2007). It is predicted that a stable ice cover will form over the Muskrat Falls reservoir (Hatch 2007). A leading ice edge will also form in each tributary at the backwater limit of the reservoir. Given the general steepness of each of the tributaries, the reservoir environmental effects are not predicted to extend upstream into the tributaries beyond the reservoir leading edge.

The formation of ice and its potential to affect habitat stability will be assessed using the following methods; air/water temperature measurement and direct measures of ice formation/break up timing.

Table 5.29. Summary of Habitat Suitability - Water Temperature attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic
Biologically relevant	Direct measures of environmental conditions affecting habitat suitability and/or fish health. Will allow greater diagnostic capabilities.
Sensitive	The sensitivity of the instrument is sufficient to detect biologically meaningful change.
Measureable	Easily measureable using standard equipment installed at real-time stations.
Interpretable	Measurements are standard. Measurements of water temperature will be directly compared to historic/literature data collected.
Historical data	Historical water quality data available from various long-term, continuous monitoring stations.
Baseline Requirements	Ongoing water temperature measurements at RTWQ stations.
Sampling Schedule	A similar sample schedule to baseline will be maintained for 20 years following full inundation (i.e., samples collected at each RTWQ station during the open water season between 2018-2037). Sampling frequency after the first 10 years may be altered dependent upon results and project monitoring review.
AMP Triggers	No specific triggers based on water temperature results.
Mitigations	• None specific to water temperature results.

Air/Water Temperature Measurements

While mitigations related to air and water temperatures are not likely possible, monitoring will provide an indication of the timing of ice formation and breakup within the Muskrat Falls reservoir. Air temperatures will be monitored at a real-time weather station to be constructed at the Muskrat Falls generation facility, while water temperatures will be measured at the real-time stations. Water temperature data from the reservoir will also be measured throughout the year with thermal instrumentation installed within the internal surge chamber of the penstock/powerhouse where it will be protected from ice damage. This will reduce the potential for icing of the probe and allow for safe maintenance and retrieval of information. Both air and water temperature data will be collected at least on an hourly basis. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Direct Measure

The direct measure of the timing of freeze up and break up is very difficult without a dedicated observer or instrument. As a result, direct measure of the timing of ice formation and breakup can be best monitored and recorded using remote video systems similar to those currently installed at the outflow of Mud Lake (http://www.env.gov.nl.ca/wrmd/ADRS/v6/Template_Station.asp?station=NLENCL0004) and Grizzle Rapids just upriver from Gull Lake (http://www.env.gov.nl.ca/wrmd/ADRS/v6/Template_Station.asp?station=03OE013). A remote system will be installed at the Muskrat Falls facility that will overlook the reservoir.

5.3.3.2.3.5 Turbidity

Turbidity is currently one of the measures recorded at each real-time water quality monitoring station. While not previously modeled, it is closely associated with TSS and can be a measurable surrogate for TSS if a site-specific relationship between them is established. As a result, turbidity is characterized as a Diagnostic Indicator as long-term increases could affect fish habitat utilization and health due to the potential for movement away from higher turbidity or changes in feeding/predation. **Table** 5.30 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012). During Head Pond creation, RTWQ stations may be relocated to their final locations along the full reservoir shoreline. Therefore, it is not anticipated that full monitoring of turbidity will be available during this time.

5.3.3.2.3.6 Dissolved Oxygen (DO)

While TSS and TP can be naturally variable and can occur at higher levels than CCME guidelines, fish can tolerate these conditions over short to moderate time periods. In contrast, fish may be less able to tolerate stressful levels of other variables like dissolved oxygen (DO). As such, DO is an important biological measure and Diagnostic Indicator within the reservoir as low concentrations in water can cause habitat to be unsuitable. Deeper habitat would be particularly vulnerable should circulation within and through the reservoir be insufficient to cause adequate mixing. Fish can compensate for hypoxia (low oxygen levels) by several behavioural responses: increased use of air breathing or aquatic surface respiration, changes in activity level or habitat, and avoidance behaviour (CCME 1999). CCME freshwater quality guidelines for cold water systems are a minimum of 9.5 mg/L for early life stages and 6.5 mg/L for other life stages (CCME 1999). A series of real-time water quality stations have been established throughout the lower Churchill River which will continue to operate when the Muskrat Falls facility is operating. Each unit continuously records a series of measures between May and November (Ice free season) including DO. **Table** 5.31 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012). During Head Pond creation, RTWQ stations may be relocated to their final locations along the full reservoir shoreline. Therefore, it is not anticipated that full monitoring of dissolved oxygen will be available during this time.

Table 5.30. Summary of Habitat Suitability - Turbidity attributes.

Indicator Attribute	Attribute Rating
Indicator Type	Diagnostic
Biologically relevant	Turbidity is a direct measure of environmental conditions affecting fish health.
Sensitive	The measurements will be at a level that is more than adequate for characterization of the measure (typical turbidity sensor accuracy).
Measureable	Easily measureable using standard equipment installed at real-time stations.
Interpretable	Interpretation of data is clear.
Historical data	Historic water quality data available from various long-term, continuous stations.
Baseline Requirements	Ongoing turbidity monitoring at the RTWQ stations during ice free (May-November) period.
Sampling Schedule	A similar sample schedule to baseline will be maintained for 20 years following full inundation (i.e., samples collected at each RTWQ station during the open water season between 2018-2037). Sampling frequency after the first 10 years may be altered dependent upon results and project monitoring review.
AMP Triggers	None. Turbidity will be measured as a diagnostic indicator and as a potential surrogate for TSS, therefore triggers for TSS would apply: • If a significant change in TSS is detected, further investigations will be triggered as to the spatial distribution of the exceedance and potential biological change in habitat function: ○ A review of TSS results and determination of potential to affect habitat function, primary productivity or fish health; ○ Further TSS sampling to delineate Area(s) of Concern; and • If potential changes in habitat function are possible as a result of changes in TSS, additional focused sampling of fish species health will be triggered (**Section** 5.3.3.3.6).
Mitigations	Turbidity can be a surrogate for TSS therefore mitigations would be based on TSS: • Turbidity barriers • Bank erosion protection (seeding, Curlex™ sheeting, alder/tree live-staking) • Wave protection (rocks or aquatic vegetation) • Shoreline stabilization (water cannon or other physical decrease in bank slope)

Table 5.31. Summary of Habitat Suitability - DO attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic
Biologically relevant	DO is a direct measure of environmental conditions affecting habitat suitability for fish and invertebrates.
Sensitive	The measurements will be more than adequate characterization of the measure (typical DO sensor accuracy).
Measureable	Easily measureable using standard equipment installed at real-time stations.
Interpretable	Interpretation of DO is routine using CCME guidelines.
Historical data	Historic water quality data available from various long-term, continuous stations.
Baseline Requirements	Ongoing DO monitoring at the RTWQ stations during the ice free (May-November) period.
Sampling Schedule	A similar sample schedule to baseline will be maintained for 20 years following full inundation (i.e., samples collected at each RTWQ station during the open water season between 2018-2037). Sampling frequency after the first 10 years may be altered dependent upon results and project monitoring review.
AMP Triggers	If DO is recorded below CCME guidelines, additional sampling will be completed using portable instruments to determine Area(s) of Concern. Additional sampling related to Fish Utilization (**Section** 5.3.3.3.4) and Fish Growth (**Section** 5.3.3.3.6) will be triggered within Area(s) of Concern.

Mitigations	• Mitigations would depend on results of triggered investigations however, direct mitigations related to DO in an identified Area of Concern could include flushing of area to remove excess debris and surface pumping to re-oxygenate.
	• If results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked:
	  ○ modification/alteration of the habitat within the Area of Concern or another appropriate location:
	    ▪ Nutrient inputs or extractions
	    ▪ Substrate modifications (addition or flushing)
	    ▪ use of aerators (pumped surface water spray) to provide additional dissolved oxygen in select areas
	    ▪ additional physical habitat enhancement.

5.3.3.3 Habitat Suitability (Biological)

Two of the objectives within the Fish Habitat Compensation Plan relate directly to the fish living within the reservoir; *maintain the existing species diversity within the Muskrat Falls reservoir area* and *maintain the existing health of those fish species within the Muskrat Falls reservoir area*. As a result, it is only appropriate that a large focus of the monitoring program is on the use of the predicted habitat by fish and their health. A large number of predictions have been made regarding how species will use the habitat and these require monitoring to verify the predictions. A description of the monitoring indicators, their methods, and how they fit within the Adaptive Management framework are provided below.

5.3.3.3.1 Primary Production

Generally, modest nutrient additions associated with flooding are considered beneficial for biota in oligotrophic systems. It is noteworthy that baseline phytoplankton biomass in the Churchill watershed lakes is considered oligotrophic and low in comparison to other locations in Newfoundland and Labrador and in most temperate areas of the world (JWEL 1999b). Low phyto- and zooplankton productivity has been partially attributable to high flushing rates in the mostly riverine sampling sites (Gull Lake, Flour and to a lesser extent Winokapau Lake) (JWEL 1999b). Any response in production to the trophic upsurge must be considered in relation to this baseline.

Within the Muskrat Falls reservoir, water transparency is predicted to initially decrease as a result of increased TSS during initial impoundment and stabilization. Nutrients such as Total Phosphorus (TP) are also predicted to initially increase above baseline; however both of these conditions have opposing effects on production. The Areal Production/ P_{max} values expected under these varying conditions can be predicted. Pre-impoundment primary production in the lower Churchill River is currently estimated at 3 to 3.5 times P_{max}. Considering light transmission effects only, primary production could decrease by 50-75% in open water areas under the described conservative, worst-case scenario during impoundment, recovering to 60-85% of initial baseline conditions during the early years at full supply level, and ultimately increasing to slightly above pre-impoundment conditions in the long term. Any nearshore areas of heavy, local active erosion could see a conservative, worst-case reduction to 10-15% of pre-impoundment production levels during impoundment and early stabilization as well as during periods of strong, localized sediment re-suspension.

Existing data from the lower Churchill River and experience from other reservoir systems have been used to predict the effects of Muskrat Falls reservoir formation on primary production. Primary production is therefore a Verification Indicator. While Head Pond will be created in late 2015, primary production within of this temporary waterbody is not scheduled as any final changes will be compared to predicted values upon final reservoir inundation.

Hypothesis Formulation

The following hypotheses are presented relative to predicted Primary Production estimates:

1. **H_0:** An increase in Primary Production, above predicted concentrations, will not occur.
   H_a: An increase in Primary Production, above predicted concentrations, will occur.

2. **H_0:** After an initial peak in Primary Production, there will be a downward trend toward baseline within the first 15 years of reservoir stabilization.
   H_a: After an initial peak in Primary Production, there will not be a downward trend toward baseline within the first 15 years of reservoir stabilization.

3. **H_0:** Primary Production will be within 85% of pre-Project baseline within the first 15 years of reservoir stabilization.
   H_a: TP concentrations will not be within 85% of pre-Project baseline within the first 15 years of reservoir stabilization.

Hypotheses Testing
Hypothesis testing will be completed similar to that described for TSS and TP above; using the measured baseline primary production values for the lower Churchill River within the Muskrat Falls reservoir prior to inundation. The established mean annual baseline concentration will be compared directly with measured values collected from samples within the Muskrat Falls reservoir. Since the initial hypotheses are based on a 15 year timeframe to stabilization, primary productivity samples will be collected each year during the ice-free season for the first 15 years for comparison to baseline, unless results indicate a return to baseline much earlier than predicted. In this case, the sampling frequency may be reduced.

Table 5.32 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.32. Summary of Habitat Suitability - Primary Production attributes.

Attribute	Attribute Rating
Indicator Type	Verification
Biologically relevant	The rate of change in primary production can change the trophic dynamics and alter fish health and population dynamics within the reservoir.
Sensitive	The proposed methods will be adequately sensitive to meaningful biological change.
Measureable	Methods are published in the scientific literature.
Interpretable	Post-reservoir primary production can be measured and compared to that predicted. Baseline will provide further information to potentially refine predictions prior to impoundment.
Historical data	Baseline data exists for this indicator.
Baseline Requirements	Additional baseline data collection is required in August 2013 - 2015.
Sampling Schedule	Sampling will be conducted annually (August) for the first 10 years (2018-

Attribute	Attribute Rating
	2027) after inundation. Sampling beyond 2027 will be at three-year intervals until 2037; however the frequency of sampling beyond 2027 may be altered dependent upon results and project monitoring review.
AMP Triggers	If a significant change in mean annual Primary Production is detected beyond that predicted, it will trigger further investigation: ○ a review of other annual data including TSS, TP and fish health within Muskrat Falls reservoir ○ further sampling of Primary Production throughout the reservoir to delineate Area(s) of Concern. If potential negative changes in water quality (i.e.TSS and/or TP – **Sections** 5.3.3.2.3.1 and 5.3.3.2.3.2) or fish health (i.e. condition index) are noted during data review, additional focused sampling on fish species health in the Area of Concern will be conducted as outlined in **Section** 5.3.3.3.6 - fish health.
Mitigations	• Mitigations would depend on results of triggered investigations; however, if Primary Production is determined to be causing a significant negative effect on fish health, mitigations to adjust it would be triggered. These include addition of flocculants to reduce TSS and nutrient inputs. • If results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Nutrient inputs or extractions ▪ Substrate modifications (addition or flushing) ▪ use of aerators (pumped surface water spray) to provide additional dissolved oxygen in select areas ▪ additional physical habitat enhancement.

5.3.3.3.2 Phytoplankton / Zooplankton Population Dynamics

Initially, post-impoundment changes in water quality may show a decline in density of primary and secondary producers, primarily as a dilution effect (Baxter and Glaude 1980). Soon after flooding, subsequent decomposition of soils and vegetation will rapidly release minerals and nutrients, fuelling a trophic upsurge. In western Labrador and within the Churchill River system, Ostrofsky and Duthie (1980) investigated productivity of a natural lake, a new reservoir (Smallwood) and an established reservoir (Ossakmanuan). Productivity of the new reservoir was about twice those of the other two sites, with the older Ossakmanuan Reservoir (eight years post-flooding) similar to a natural lake.

Impoundment of the Muskrat Falls reservoir will result in longer retention times than the present continuous flow conditions. This will allow the potential opportunity for the phytoplankton and crustacean zooplankton community to develop indigenous populations rather than those transported into the area by currents from lakes upriver. The crustacean zooplankton community consists generally of cladocerans and copepods with generation times at summer water temperatures on the order of 1-2 weeks for cladocerans and approximately 4 weeks for copepods. Muskrat Falls Reservoir is estimated to have a retention time of approximately 10 days and this time can be used to calculate the instantaneous losses imposed by advection (loss to the outflow) on the zooplankton populations (Campbell et al. 1998). Zooplankton population birth rates must exceed these loss rates, plus other rates of natural mortality, in order for the population to grow.

It is expected that the Muskrat Falls reservoir will experience a minimal trophic upsurge after flooding, it will be moderated by the small amount of flooded area (approximately 41 km^2), the fact that there will be areas in the system that will remain largely riverine in character and the operation of the system as a 'water in – water out' facility (which will result in flushing of nutrients and plankton). These factors are expected to reduce the magnitude of the fish trophic upsurge and associated response of phytoplankton and zooplankton to the nutrient increase.

This Indicator will act as an **Early Warning Indicator** as it will indicate a shift in the phyto/zooplankton species composition and/or biomass available for fish species within the reservoir. A shift in this food source may cause shifts in prey availability or trophic feeding levels and hence change their health and/or community structure.

Statistical tests will be completed on measured community similarity to determine whether a significant change in the species composition and biomass has occurred. Baseline phytoplankton and zooplankton samples are currently being collected during August, September and October in the same locations as those for primary production (carbon uptake). Replicate quantitative samples for phytoplankton and zooplankton will be collected and analyzed in the lab.

Since potential changes in fish health and/or community structure can be anticipated until reservoir stabilization, phyto/zooplankton samples will be collected each year for the first 10 years, and then at three-year intervals, unless results indicate stabilization of the composition much earlier (**Table** 5.16). In this case, the sampling frequency may be reduced.

Table 5.33 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.33. Summary of Habitat Suitability - Phyto/Zooplankton attributes.

Attribute	Attribute Rating
Indicator Type	Early Warning, Diagnostic and Verification
Biologically relevant	Changes in phyto/zooplankton composition and/or biomass can change the trophic dynamics within the reservoir and this can alter fish health and population dynamics.
Sensitive	Meaningful levels of change will be detected with this approach.
Measureable	Standard published methods are being used for this indicator.
Interpretable	Post-reservoir plankton community structure can be measured and compared to baseline using Bray-Curtis Indices.
Historical data	Data will be compared with collected baseline (1998, 2011, 2013, 2014).
Baseline Requirements	Ongoing baseline sampling required in 2013 and 2014 (August, September and October).
Sampling Schedule	Sampling will be conducted annually (August) for the first 10 years (2018-2027) after inundation. Sampling beyond 2027 will be at three-year intervals until 2037; however the frequency of sampling beyond 2027 may be altered dependent upon results and project monitoring review.
AMP Triggers	Significant changes in either phyto/zooplankton community structure or biomass may indicate a change in potential food availability within Muskrat Falls Reservoir. Triggers will include investigation of trophic feeding (isotope –**Section** 5.3.3.3.6.3) and fish growth (**Section** 5.3.3.3.6).
Mitigations	• None specific to plankton community structures or biomass; however mitigations would depend on results of triggered investigations. • If results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked: o modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Nutrient inputs or extractions ▪ Substrate modifications (addition or flushing) ▪ use of aerators (pumped surface water spray) to provide additional dissolved oxygen in select areas ▪ additional physical habitat enhancement .

5.3.3.3.3 Benthic Macroinvertebrates

Currently, the lower Churchill River has a low species richness and biomass, and generally low rate of invertebrate production (JWEL 1999a). Baseline surveys indicate that tributaries and streams have a higher biomass and species richness and therefore may be important feeding areas for fish.

Shifting, sandy substrates, particularly in the reaches of the Muskrat Falls reservoir area, have lowest numbers of macroinvertebrate taxa and biomass and these habitats will not become conducive to high benthic production after inundation. In many reservoirs, particularly those created from flooding of rivers, there may be a longitudinal variation in the benthic community structure reflecting the change from more riverine to more lacustrine habitats (Northcote and Atagi 1997). After flooding, the most important areas for benthic production will be the nearshore areas as these will support a modified but stable benthic community. The geomorphic characteristics of the river/reservoir nearshore areas will determine species community structure and overall production of the benthos. The temporal extent of the process of overburden removal (i.e., shoreline stability) will be important in establishing the future benthic community.

The biological implications of changes in benthic macroinvertebrate species community structure and/or biomass are considered particularly relevant to fish. For example, a reservoir may have a similar overall benthic macroinvertebrate biomass to pre-project but the community structure could be comprised of species that are not preferable for the resident fish species. Statistical tests will be completed to determine whether a significant change in the species community structure and biomass has occurred.

In order to accurately measure any variations in the benthic macroinvertebrate species composition and biomass, a standardized monitoring method that remains consistent is necessary (Bowman and Bailey 1997). In order to have all variables remain constant, an *artificial substrate* will be employed. Baseline benthic macroinvertebrate samples are currently being collected in the area of the Muskrat Falls reservoir using standardized rock-bags (Clarke et al. 1997). The analysis of the samples will include identification to family for determination of Bray-Curtis Indices (Bowman and Bailey 1997; Feio et al. 2006; Bailey et al. 2001) as well as the calculation of total biomass.

Table 5.34 presents a summary of the primary attributes of this **Early Warning Indicator**. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.34. Summary of Habitat Suitability - Benthic Macroinvertebrate attributes.

Attribute	Attribute Rating
Indicator Type	Early Warning and Diagnostic
Biologically relevant	Changes in benthic macroinvertebrate composition and/or biomass can change the trophic dynamics within the reservoir and this can alter fish health, production and population dynamics within the reservoir.
Sensitive	Biologically meaningful differences in composition and biomass will be detected.
Measureable	Methods for collection and analysis are well documented.
Interpretable	Post-reservoir benthic macroinvertebrates can be measured and compared to baseline.
Historical data	Only recently collected baseline data exists from the reservoir area. Communities from other areas of Labrador exist in the CABIN database maintained by Environment Canada.
Baseline Requirements	Baseline sampling is required in remaining years prior to inundation.
Sampling Schedule	Sampling will be conducted annually (August) for the first 10 years (2018-2027) after inundation. Sampling beyond 2027 will be at three-year intervals until 2037; however the frequency of sampling beyond 2027 may be altered dependent upon results and project monitoring review.
AMP Triggers	Significant changes in either benthic macroinvertebrate community structure or biomass may indicate a change in potential food availability within Muskrat Falls reservoir. Triggers will include investigation of fish trophic feeding (isotope –**Section** 5.3.3.3.6.3) and fish growth (**Section** 5.3.3.3.6).

Mitigations	• None specific to benthic macroinvertebrate community structure or biomass; however mitigations would depend on results of triggered investigations.
	• If results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked:
	    ○ modification/alteration of the habitat within the Area of Concern or another appropriate location:
	        ▪ Nutrient inputs or extractions
	        ▪ Substrate modifications (addition or flushing)
	        ▪ use of aerators (pumped surface water spray) to provide additional dissolved oxygen in select areas
	        ▪ additional physical habitat enhancement .

5.3.3.3.4 Direct Measure of Fish Species Utilization

The calculation of an index of the productive capacity of habitat-types within the Muskrat Falls reservoir has been based upon the extensive fish species utilization database collected from the study area. This data is the foundation for catch-based habitat utilization indices that have been used to quantify habitat. As a result, it is an important metric in determining the success of compensation works as well as measuring the effect of reservoir formation and stabilization. The index development has been described in detail within the HADD quantification reports (e.g., AMEC 2001) and the Fish Habitat Compensation Strategy (AMEC 2010).

While many capture methods were employed in the determination of existing habitat use, growth and health (e.g., age, maturity, stomach contents, mercury concentration), the monitoring associated with post-reservoir will focus on live-capture methods whenever possible. It will be important to limit the number of fish sacrificed as it may have a direct effect on fish populations and ongoing sampling success within the reservoir. This is particularly important given the relatively long monitoring timelines. As a result, the following methods will be the focus:

- Electrofishing
- Fyke Netting
- Calibrated Snorkel Surveys
- Minnow/Charr Traps
- Angling
- Redd Surveys
- Hydro-acoustics

Each method is briefly described separately below as well as in AMEC (2012). There are multiple methods outlined because each has advantages and limitations in terms of the species they will capture and the habitats where they can be successfully deployed. It should be noted that the variations in the gear types used to assess differing habitats cannot easily be compared; therefore the gear chosen for each habitat type will remain unchanged for the duration of the monitoring program.

The catch data will not be used to generate Habitat Equivalent Units (HEUs) as was the method for quantifying habitat, but will be used to generate indices of habitat utilization/production. As a result, the reduction in gillnet use will not affect the monitoring effectiveness of habitats within the Muskrat Falls reservoir. The overall metric (utilization) is based on several measures, depending on the method of sampling. The measures include:

- **Biomass** (weight) of fish/life-stage per unit effort or area (generated through electrofishing, fyke netting, minnow/charr trapping, and angling);
- **Population Estimate** is the number of fish/life-stage per unit area (generated through electrofishing);

- **Catch-per-Unit-Effort (CPUE)** is the number of fish/life-stage captured through a fixed period of sampling effort. This differs from population estimates because it is based on sampling time more so than sample area. This is generated from fyke netting, minnow/charr trapping and angling;
- **Recruitment** is the number of species young-of-year captured within each habitat type by the various sampling methods. This dataset will be a subset of the population estimates (electrofishing) but will be used as a metric for recruitment in areas of habitat creation; and
- **Species / Life Stage Presence/Absence** (generated through snorkel surveys).

The overall outline of hypothesis formulation, statistical testing and trigger(s) for Fish Habitat Utilization are similar regardless of the sample method. Therefore these outlines will follow general descriptions of each method below. All generated values will be separated by species and life stage for direct comparison to predicted utilization values. **Figure** 5.41 provides the sample locations/zones for fish species utilization and other associated sampling. These are based on successful past sampling locations.

5.3.3.3.4.1 Electrofishing

Electrofishing is a standard sampling method that provides excellent data on fish community composition within important tributary habitat types. It will be used to assess the habitat utilization, species presence/absence and standing stocks of tributary and stream habitats. Stations will be completed during late summer (August-September) as per existing sampling so that values are comparable between sample years. In order to maintain consistency within datasets from year to year, population and biomass estimates will also be normalized to one habitat unit ($100m^2$). Ongoing collection of population data from electrofishing prior to impoundment will increase baseline data.

5.3.3.3.4.2 Fyke Netting

Fyke nets are a form of passive sampling, which is generally non-destructive; meaning the majority of fish captured will be live released following processing. Processing includes the collection of lengths, weights and species identification. Fyke nets are generally set for at least a 16-hour duration, which will encompass the dusk to dawn period, when fish movement is generally more prevalent. Ongoing collection of CPUE and biomass data from habitats prior to impoundment by fyke net will increase baseline data.

5.3.3.3.4.3 Calibrated Snorkel Surveys

Electrofishing and other passive sampling methods (e.g., fyke nets) generate very useful data in terms of the overall utilization of fish life stages within various habitat types but they do not provide data on whether each species / life stage is utilizing specific habitat features related to substrate size, velocity or water depth.

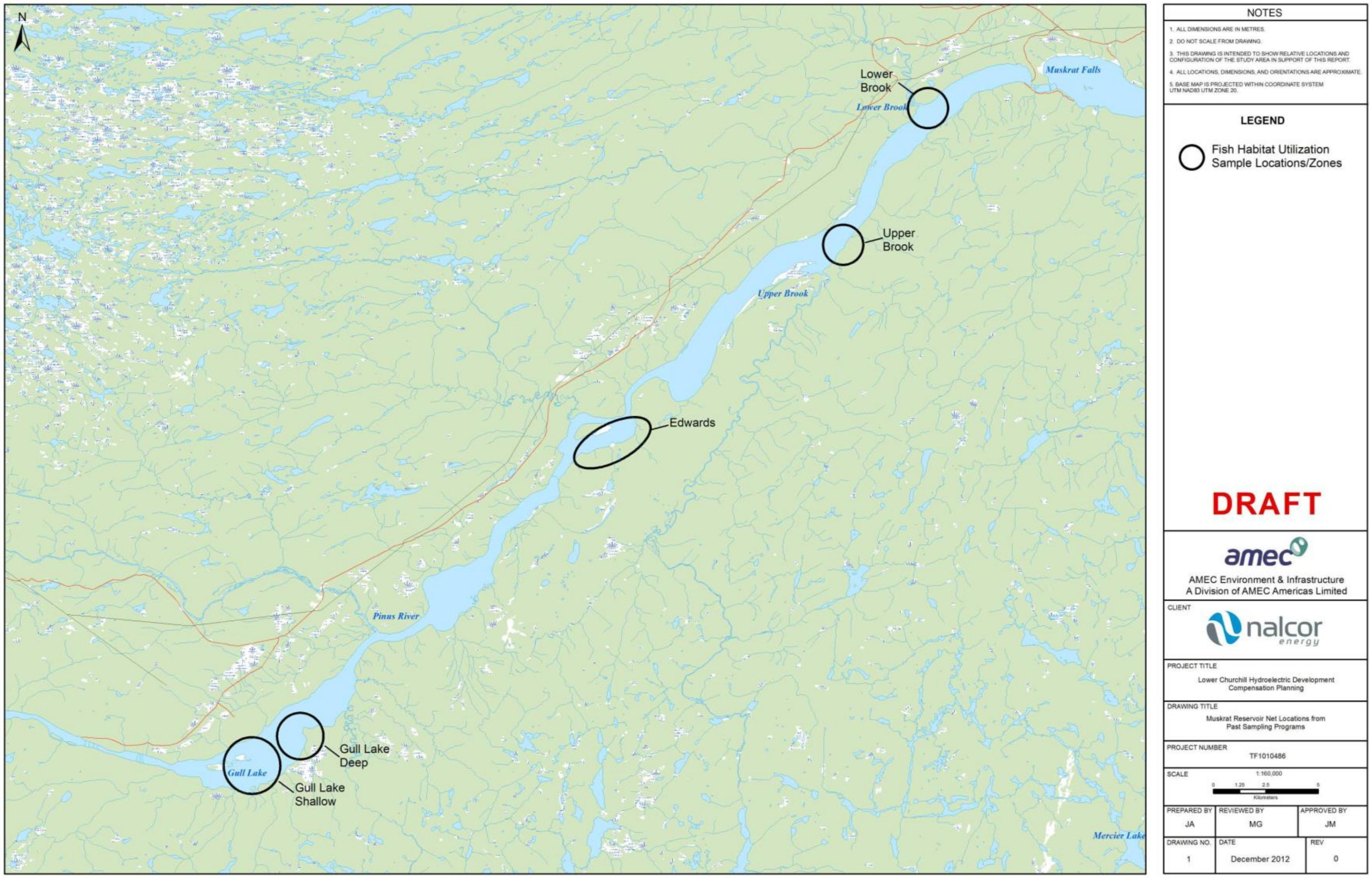


Figure 5.41. Fish habitat utilization sampling locations/zones, Muskrat Falls reservoir.

This may be particularly useful in determining habitat requirements as an estimate of abundance for a given habitat. The method employed has been used in other monitoring programs in the province such as Granite Canal (AMEC 2005; 2007; 2008b; 2010b) and Northeast River (AMEC 2011).

To augment the fish numbers and habitat use, a series of random habitat measures of substrate, velocity and depth will also be recorded. This is useful to determine if fish are using habitat based solely on availability (i.e. the percentage of habitat type being used is similar to that available) or whether they are selecting habitat based on preference.

Hypothesis Formulation

Hypothesis testing will be completed for fish utilization measures (electrofishing, fyke netting and calibrated snorkel surveys) using the corresponding measured baseline (i.e., population/CPUE/biomass/abundance) values for the lower Churchill River within the Muskrat Falls reservoir prior to inundation. The established mean annual baseline values will be compared directly with measured values collected from samples within the Muskrat Falls reservoir. Since the initial hypotheses are based on a 20 year timeframe to stabilization, utilization samples will be collected each year during the ice-free season for the first 20 years for comparison to baseline, unless results indicate a return to baseline much earlier than predicted. In this case, the sampling frequency may be reduced.

The following hypothesis is presented relative to predicted fish utilization measures (electrofishing, fyke netting, and calibrated snorkel surveys):

1. **H_0:** Fish utilization values will be similar to values predicted for the relevant habitat types within the Muskrat Falls reservoir.
   H_a: Fish utilization values will not be similar to values predicted for the relevant habitat types within the Muskrat Falls reservoir.

Hypothesis Testing

With the repeated use of the same established locations and sampling timeframe, the standard statistical comparison between mean annual estimate results and the overall mean annual baseline value will be completed using ANOVA analysis. Both the overall mean annual baseline and the annual values will have measures of variability. Significant negative differences between the mean annual monitoring values and baseline values will trigger additional investigation. **Table** 5.35 presents a summary of these indicators. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.35. Summary of Habitat Suitability – Electrofishing, Fyke Netting, and Snorkel Survey attributes.

Attribute	Attribute Rating
Indicator Type	Verification Indicator
Biologically relevant	Changes in habitat-specific biomass may reflect changes to system wide production.
Sensitive	Fish surveys are often associated with considerable variation. Nonetheless it is anticipated that meaningful biological changes will be detected.
Measureable	Standard quantitative and index sampling, measurement, and analysis.
Interpretable	Post-reservoir species population estimates using electrofishing, CPUE and abundance from other methods, can be measured and compared to baseline.
Historical data	Baseline data exists from previous studies as well as ongoing data collection.
Baseline Requirements	Baseline sampling is ongoing prior to inundation.
Sampling Schedule	Sampling for fish habitat utilization will occur throughout the first three years after full impoundment (2018-2020) and then every second year until 2028. Following the 2028 results and project monitoring review sampling will be completed every third year; however the frequency of sampling beyond 2028 may be altered dependent upon results and project monitoring review.
AMP Triggers	If a significant negative change in mean annual values (i.e., a reduction) is detected, an Area of Concern is identified and further investigations will be triggered including: ○ a review of other annual fish utilization data including catch rates and biomass of similar species and life stages from other habitat types within the Muskrat Falls reservoir; ○ a review of age-structure data from similar species from other habitat types within the Muskrat Falls reservoir; ○ a review of water depth and velocity, flow, air/water temperature, and dissolved oxygen within the identified Area of Concern; If potential reductions in fish species catch rates (i.e., reductions in population/CPUE/biomass/abundance) from other methods within the same habitat also appear to be low, additional focused sampling on fish species presence/utilization and habitat conditions will be conducted: ○ index electrofishing stations, minnow/charr traps, and angling (**Sections** 5.3.3.3.4.4 - 5.3.3.3.4.5). ○ an increase in the sample size of the appropriate sample method (quantitative electrofishing and/or fyke netting and/or snorkel surveys will be completed).

<table>
<tr><th>Attribute</th><th>Attribute Rating</th></tr>
<tr><td></td><td>If potential habitat measures are determined to be contributing to reduced suitability for fish production, additional focused sampling on habitat conditions will be conducted:
further transect measurements of water depth and velocity (Section 5.3.3.2.1 - ADCP). Water quality measurements of dissolved oxygen and temperature will also be initiated (Section 5.3.3.2.3 – water quality).
If fish utilization reductions include young-of-the year or juvenile life stages within the Edward's Brook and Pinus River deltas, ice depth sampling (Section 5.3.3.2.3.4 - Ice measurements) and redd surveys (Section 5.3.3.3.4.6 - Redd surveys) will be triggered to determine whether thicknesses may be affecting habitat (e.g., egg incubation success).</td></tr>
<tr><td>Mitigations</td><td>If results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked:
modification/alteration of the habitat within the Area of Concern or another appropriate location:
Nutrient inputs or extractions
Substrate modifications (addition or flushing)
use of aerators (pumped surface water spray) to provide additional dissolved oxygen in select areas
additional physical habitat enhancement</td></tr>
</table>

5.3.3.3.4.4 Minnow/Charr Traps

Minnow/charr traps are another form of passive, non-destructive sampling, similar to fyke nets. A key difference between minnow traps and charr traps are size, with charr traps being considerably larger. Each type is generally a cylindrical trap with entrance doors on each end. They are set in various water depths but are typically set on the bottom. Similar to fyke nets, they are generally set for at least a 16-hour duration, which will encompass the dusk to dawn period, when fish movement is generally more prevalent.

Minnow/charr traps have been successful in other programs but have been deployed within the lower Churchill River with limited success. In part, this may be due to the high water velocities within most habitat types. This method will likely be more useful as a Diagnostic tool in lower velocity and vegetated habitat where it will catch YOY pike and juveniles (spawning habitat creation) (see **Section** 5.2.4). **Table** 5.36 presents a summary of the primary attributes of this indicator.

5.3.3.3.4.5 Angling

Angling is a sampling method that has few limits to habitats that can be sampled. It has been used in every habitat type within the lower Churchill River to augment catch data from more quantitative sampling methods, particularly faster flowing habitat where other sampling is difficult, ineffective or unsafe. Angling will be conducted in habitat areas where a reduction in fish utilization has been detected and hence will be a useful Diagnostic Indicator within the Muskrat Falls reservoir. **Table** 5.36 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.36. Summary of Habitat Suitability - Minnow/Charr Trap and Angling attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic Indicator
Biologically relevant	Changes in fish species habitat utilization can change the overall population and dynamics within the reservoir.
Sensitive	Changes to composition and biomass would be measurable at a meaningful level.
Measureable	Standard quantitative sampling, measurement, and analysis.
Interpretable	Post-reservoir species habitat utilization (CPUE) using minnow/charr traps can be measured and used to monitor success of habitat utilization.
Historical data	Only ongoing baseline data collection.
Baseline Requirements	Limited baseline sampling using minnow/charr traps and angling is continuing prior to inundation because it is not considered a method for determining quantitative fish utilization.
Sampling Schedule	To be deployed in identified Area(s) of Concern related to low fish utilization.
AMP Triggers	None specific to results of minnow/charr traps or angling.
Mitigations	• If results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked: o modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Nutrient inputs ▪ Substrate modifications (addition or flushing) Other site-specific mitigation based on investigations may also be developed.

5.3.3.3.4.6 Redd Surveys

Spawning in an area can be confirmed by capturing young-of-year using previously described methods (e.g., electrofishing and snorkeling). In this way, habitat for spawning is being confirmed as well as early survival. In the event that young-of-year numbers are lower than expected for a species, redd surveys will be triggered to determine whether adults are locating/using the habitat (particularly constructed habitat) to spawn. These data will provide a means to determine what is causing the shortfall; lack of spawning activity in the area or poor early survival. **Table** 5.37 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

5.3.3.3.5 Direct Measure of Fish Species Movement (Telemetry / Tagging)

Radio telemetry is a very specific monitoring tool that can track the movements and habitat use of tagged fish within the Muskrat Falls reservoir. As described above, it is a Diagnostic tool that would be triggered as a result of significant reductions in young-of-year fish and a significant reduction in redd numbers within an identified Area of Concern. While baseline fish movements were studied using telemetry 1998-1999, the data would not be directly comparable to specific telemetry monitoring, particularly at identified Areas of Concern. Therefore, this method does not lend itself to monitoring but will provide very specific habitat utilization and movement data of tagged fish and identify other spawning areas that are being used. **Table** 5.38 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

5.3.3.3.6 Direct Measure of Fish Species Health (Growth, fecundity, feeding, age-structure)

Measurements of fish condition and population structure have been collected from species within the Churchill River since the original hydroelectric proposals of the 1970s (e.g., Bruce 1974 and Ryan 1980). This considerable collection of data will be augmented and used to monitor fish species health within the Muskrat Falls reservoir area. The data will form the basis of assumptions used in predictions of fish utilization health (growth, fecundity, feeding, age-structure).

Fish species health has metrics that encompass all three indicator classifications; Verification, Diagnostic and Early Warning. The majority of the fish will be live-captured and hence the methods of obtaining health measurements are, for the most part, applicable for animals that will be live-released. Typically, fish will not need to be sacrificed except for some methods used for triggered investigations. **Table** 5.39 shows a summary of the measures that are generally associated with each sampling technique. A summary of the fish health metrics are provided in the following sections.

Table 5.37. Summary of Habitat Suitability - Redd Survey attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic Indicator
Biologically relevant	Changes in fish species spawning habitat utilization can change the overall health of a population and its eventual persistence within the reservoir.
Sensitive	The rate of measurement is annual (sampled in May/June or October) therefore the sensitivity of the measurement in terms of rapid detection is low but results would be measurable at a meaningful level.
Measureable	Yes. Standard sampling and analysis.
Interpretable	Redd density and spawning activity can be measured and compared as the reservoir matures.
Historical data	Yes. Created spawning habitat will be surveyed as a result of triggered investigation; however, redd surveys at existing tributary confluences (Pinus, Edwards, McKenzie) to determine baseline densities.
Baseline Requirements	Ongoing baseline redd surveys are continuing prior to inundation, however this method is considered a diagnostic indicator.
Reservoir Schedule	Redd surveys are diagnostic and triggered as a result of reduced young-of-year fish utilization values associated with spawning habitat.
AMP Triggers	Redd survey results can trigger further investigations, particularly if redd numbers/spawning activity is considered extremely low. A low number of young-of-year combined with a subsequent determination of low spawning activity/redd formation could be an indication that adult fish are not able to find, or use, spawning habitat for its intended purpose. An Area of Concern would be identified. If a significant reduction in mean annual redd number is determined, addition investigation as to the overall fish utilization of adults for all habitat types within the Muskrat Falls reservoir (data review) as well as potential challenges in locating spawning habitat will be triggered (see **Section** 5.3.3.3.5 - radio telemetry).
Mitigations	• If results indicate a significant reduction in fish utilization/spawning, additional triggers to investigate potential mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Substrate modifications (addition or flushing) ▪ Predator management (removal) Other site-specific mitigation based on investigations may also be developed.

Table 5.38. Summary of Habitat Suitability - Telemetry Survey attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic Indicator
Biologically relevant	Changes in fish species spawning habitat utilization can change the overall health of a population and its eventual persistence within the reservoir. Changes in spawning activity may be a result of inability to find habitat.
Sensitive	The rate of measurement is annual (sampled in September-October) therefore the sensitivity of the measurement in terms of rapid detection is low but results would be directly measurable at a meaningful level.
Measureable	Yes. Standard sampling method and analysis.
Interpretable	Movements of tagged fish are relatively easy to interpret; however, the behaviour behind the movement is more challenging. Movements can be compared to habitat type and life-cycle.
Historical data	No. Telemetry would be initiated by specific triggers caused by reduced habitat utilization. Results would be relevant for fish within the reservoir at the time of monitoring.
Baseline Requirements	None
Reservoir Schedule	Triggered based on redd/spawning/young-of-year monitoring results.
AMP Triggers	If spawning locations and spawning success cannot be identified as part of the combined telemetry/redd/young-of-year monitoring, a Species of Concern will be identified: • additional sampling locations will be triggered (i.e. further surveys for spawning in other tributaries); • Investigation of Gonadosomatic Index (GSI) on Species of Concern (**Section** 5.3.3.3.6.6 – fecundity).
Mitigations	• If results indicate a significant reduction in fish spawning success, additional triggers to investigate potential mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Substrate modifications (addition or flushing) ▪ Water quality modification (nutrients, oxygen) ▪ Predator management (removal) Other site-specific mitigation based on investigations may also be developed.

Table 5.39. General Measurements/Samples colelcted with each sampling technique.

Biological Measure	Fyke Net	Electrofishing	Snorkeling	Angling	Gillnets
Species Identification	X	X	X	X	X
Length	X	X	X[3]	X	X
Weight	X	X		X	X
Sex	X[3]	X[3]	X[3]	X[3]	X
Primary Aging Structure[1]	X[6]	X[6]		X[6]	X
Secondary Aging Structure[2]	X	X		X	X
Isotope Fin Clip	X	X		X	X
Stomach Contents	X[4,5]	X[4,5]		X[4,5]	X
Fecundity	X[6]	X[6]		X[6]	X
Applicable Habitat Types	Main stem, Tributaries	Tributaries	Main stem, Tributaries	Main Stem, Tributaries	Main Stem, Tributaries

1 Primary aging structures are: Otoliths from salmonids and burbot, Operculum from Suckers and Cleithra from Northern Pike
2 Secondary aging structure for most are scales collected from below and behind the dorsal fin
3 Estimated values
4 Collection is dependent upon stress of individual fish captured
5 Can complete live stomach evacuation
6 Would require sacrifice of animal – not preferred

5.3.3.3.6.1 Growth Rate

The growth rate of each fish species will be monitored using calculations of length-at-age and length-weight relationships (Ricker 1975). Length-weight calculations will provide an indication of fish health, as it is affected by recent behaviour (e.g., feeding, migrating, territory defense, maturation), whereas length-at-age calculations typically represent annual growth rates and therefore indicate longer term trends. Since fish health metrics are not predicted to change as a result of reservoir formation, this will be a useful **Verification Indicator** within the Muskrat Falls reservoir.

Hypothesis Formulation

The overall premise for the use of fish biomass to represent habitat suitability/productivity is that more suitable habitat can produce more biomass. It is assumed that if fish cannot meet their energy requirements within a particular habitat type they will utilize more of that habitat (i.e., increase their territory or habitat area needed to maintain adequate growth) or move to another habitat type or area that can support its needs. In this way, more suitable habitat is predicted to have greater numbers of fish and greater biomass per unit area.

The following hypothesis is presented relative to predicted fish health measures (growth):

1. **H_0:** Fish health values will remain similar to existing baseline values.
   H_a: Fish health values will not remain similar to existing baseline values.

It should be noted that in order to remain precautionary, very little habitat use is predicted for the deeper water of the Muskrat Falls reservoir since the habitat measures are considered beyond the ranges listed in the literature (Bradbury et al. 2001). As a result, the focus of hypothesis testing and trigger development is on habitats predicted to have fish utilization; Nearshore main stem (reservoir), Intermediate main stem (reservoir), and tributary habitat types. **Table** 5.40 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.40. Summary of Habitat Suitability - Growth Rate attributes.

Attribute	Attribute Rating
Indicator Type	Verification Indicator
Biologically relevant	Decreases in fish species growth rates would indicate that fish are unable to adapt to changing habitats and stresses. This can change the overall health of a population and its eventual persistence within the reservoir.
Sensitive	The rate of measurement is annual (fish generally sampled throughout June and August-September). Two rates of measurement are presented; condition factor will provide information relevant to shorter scale impacts while length-at-age will provide information on ongoing, long-term impacts. Measurement methods are sufficient to detect meaningful biological change.
Measureable	Standard sampling method and analysis.
Interpretable	Measurements are standard and analysis is straight forward. Calculated values can be compared to existing baseline values.
Historical data	Baseline growth data are available for comparison.
Anticipatory	No.
Baseline Requirements	Ongoing baseline data collection will continue prior to inundation.
Sampling Schedule	Sampling for fish growth will be similar to that for habitat utilization. It will occur throughout the first three years after full impoundment (2018-2020) and then every second year until 2028. Following the 2028 results and project monitoring review sampling will be completed every third year; however the frequency of sampling beyond 2028 may be altered dependent upon results and project monitoring review.
AMP Triggers	If a significant negative change in mean monitoring values (i.e., a reduction) is detected, an appropriate Area/Species of Concern will be identified; further investigation will be triggered: • a review of other growth data of similar species in other habitat types within the reservoir area • a review of habitat suitability results within the identified Area/Species Life stage of Concern including TSS, TP, water depth and velocity, flow, and dissolved oxygen

Attribute	Attribute Rating
	• Comparison of growth values between habitat types. If the significant negative change in monitoring values indicates that effect could be wide spread (multiple significant negative changes detected for the same species life stage in more than one habitat type) or long-term (more than one year of significant negative change detected in the Area/Life stage of Concern), additional focused sampling on fish species health/presence and habitat conditions will be conducted: ○ Additional fish species health/presence sampling (e.g., gillnetting). ○ Additional fish sampling including disease profiling (see **Section** 5.3.3.3.6.5 - disease profile) and feeding (see **Section** 5.3.3.3.6.4 - feeding). ○ Additional habitat sampling including transect measurements of water depth and velocity (**Section** 5.3.3.2.1 - ADCP);. Water quality measurements of dissolved oxygen and temperature will also be initiated (**Section** 5.3.3.2.3 – water quality).
Mitigations	• If results of additional triggered investigations indicate a significant reduction in fish growth and/or health caused by habitat suitability changes, additional triggers to investigate mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Substrate modifications (addition or flushing) ▪ Water quality modification (nutrients, oxygen) ▪ Predator management (removal) Other site-specific mitigation based on investigations may also be developed.

5.3.3.3.6.2 Age-Structure / Composition

While ongoing monitoring of the number of fish and/or biomass for each species provide information on habitat productivity and how the overall population is using the available habitat types, changes within the population structure could occur that would not be detected using these metrics. For example, the overall number of individuals and total biomass may remain relatively stable within Muskrat Falls reservoir for years while older individuals in the population are being lost and not replaced (i.e. recruitment failure). This could continue to occur undetected until significant reductions in biomass are finally realized. This could be a serious threat to population viability, particularly for longer living species. As a result, young-of-year (YOY) will be monitored as a **Diagnostic Indicator**, triggered as a result of several Early Warning Indicators (i.e., benthic macroinvertebrate, plankton) and sampling (electrofishing, fyke netting, and snorkel survey). YOY will include a total number of specimens (CPUE) as well as biomass; a key indicator of recruitment. **Table** 5.41 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

5.3.3.3.6.3 Isotope Trophic Feeding Level

Analysis of fish stable isotopes (ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$)) has been conducted in the lower Churchill River, Goose Bay and Lake Melville since 2010. Analyzing stable isotope ratios provides data on the general trophic position of the species, the habitat that is predominantly utilized, and primary food sources (Jardine et al 2003).

For species residing within what will be the Muskrat Falls reservoir, changes in food web dynamics in terms of predator/prey availability, behaviour and abundance could change as a result of habitat changes (e.g., TSS and/or turbidity). While habitat changes are predicted to occur and time for reservoir stabilization and maturation is anticipated, the highly variable existing environment and the adaptability of the resident species would not suggest any large-scale changes in trophic feeding levels. Isotope analysis will therefore be monitored as a **Diagnostic Indicator** of fish health. **Table** 5.42 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

5.3.3.3.6.4 Feeding (Stomach Contents)

Most studies of fish diets rely on examination of stomach contents to quantify prey abundance and/or feeding patterns and behaviour. Stomach contents can give an indication of the recent prey consumption including species, trophic level, quantity being consumed as well as the habitat type being used during feeding (based on habitat requirements of prey items). Since most sampling of fish will be based on live-capture techniques, stomach contents will be collected using the levage technique (Seaburg 1957; Guy and Brown 2007). Food items within a fish's stomach are flushed by use of pressurized water. Remote sampling requires small tubes with flexible bulbs that flush food out of the stomach. Samples will be identified and associated with the associated fish metrics (e.g., length, weight). Stomach samples will be analyzed using methods similar to those for benthic macroinvertebrates (see **Section** 5.3.3.3.3). **Table** 5.43 presents a summary of the primary attributes of this **Diagnostic Indicator**. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.41. Summary of Habitat Suitability - Age Structure / Composition attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic Indicator
Biologically relevant	Changes to YOY CPUE/biomass within the Muskrat Falls Reservoir could reflect a decrease in population viability, whether through reduced recruitment or changes in mortality.
Sensitive	YOY monitoring will be able to detect biologically meaningful changes in the ecosystem.
Measureable	Methods and analysis are standard.
Interpretable	Calculated values can be compared to existing baseline values.
Historical data	Age structure is available for all existing fish sampling activities. Therefore existing baseline data is available for comparison. Baseline data collection is ongoing until inundation.
Baseline Requirements	Sampling until inundation will augment the available baseline database.
Sampling Schedule	Sampling will be conducted during fish collections associated with other Indicators (e.g., electrofishing, snorkeling, netting).
AMP Triggers	If a significant negative change in YOY CPUE/biomass is detected within a habitat type, An appropriate Species/Area of Concern will be identified and additional analysis of YOY data for the same fish species will be triggered for other habitat types. Further investigations, to determine the spatial extent and long term potential of impacts will be initiated. If a wide spread or long-term effect is determined, further investigation would be triggered for focused sampling on spawning success (see **Section** 5.3.3.3.4 – electrofishing, redd surveys, telemetry).
Mitigations	• Specific mitigations related to a significant reduction in recruitment of younger fish will be dependent upon the results of all biological, habitat and physico-chemical investigations used to identify the issue(s). Potential mitigation measures would include: ○ selective removal of specific predators/competitors of the fish species of concern to provide additional opportunity for habitat use and survival, ○ flushing of finer material (i.e. silt) from larger substrates using water pumps to increase habitat use and potential prey (food) production, and ○ additional habitat enhancement to encourage recruitment and survival of identified species life stages. Other site-specific mitigation based on investigations may also be developed.

Table 5.42. Summary of Habitat Suitability - Isotope attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic
Biologically relevant	Changes in feeding behaviour could represent fundamental changes in the ecology of the system and have repercussions to population dynamics as well as the ecosystem's trophic structure.
Sensitive	It is well established that these methods are sensitive to changes in trophic status.
Measureable	Standard methods are used but require specialized laboratory techniques.
Interpretable	Monitoring values can be compared to existing baseline values to determine change.
Historical data	Isotopes have been collected since 2010 and will continue to be part of ongoing baseline sampling.
Baseline Requirements	Baseline data collection will continue until inundation.
Sampling Schedule	Sampling will be conducted during fish collections associated with other Indicators (e.g., electrofishing, snorkeling, netting).
AMP Triggers	If trophic feeding levels change, the Species of Concern will be identified and additional investigations will be triggered: • additional information or data review related to the Species of Concern's length-at-age values (see **Section** 5.3.3.3.4) and disease profile (**Section** 5.3.3.3.6.5).
Mitigations	• Since a change in trophic feeding does not specifically determine a negative effect on species health (e.g., growth, fecundity), no specific mitigations would be initiated based on isotope results alone. • If results of additional triggered investigations indicate a significant reduction in fish growth and/or health, additional triggers to investigate mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Substrate modifications (addition or flushing) ▪ Water quality modification (nutrients, oxygen) ▪ Predator management (removal) Other site-specific mitigation based on investigations may also be developed.

Table 5.43. Summary of Habitat Suitability - Feeding (stomach contents) attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic
Biologically relevant	Changes in diet diversity would indicate change in prey abundance, habitat use and/or growth of socially relevant fish species.
Sensitive	It is expected that this method will be useful in detecting biologically meaningful changes.
Measureable	Methods are well used and documented.
Interpretable	Results can be compared to existing baseline values using multivariate analysis.
Historical data	Baseline data will be available for comparison.
Baseline Requirements	Feeding monitoring will be completed each year prior to inundation (2013-2015).
Sampling Schedule	Feeding (stomach content) investigation would be triggered by changes in food availability or fish growth for an identified Species of Concern; therefore no established reservoir sampling schedule.
AMP Triggers	A significant reduction in fish health (**Section** 5.3.3.3.6) will trigger additional investigations into potential mitigations.
Mitigations	• Since a change in feeding results does not specifically determine a negative effect on species health (e.g., growth, fecundity), no specific mitigations would be initiated based on stomach content results alone. • If results of additional triggered investigations indicate a significant reduction in fish growth and/or health, additional triggers to investigate mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Substrate modifications (addition or flushing) ▪ Water quality modification (nutrients, oxygen) ▪ Predator management (removal) to allow identified species to recover. Targeted species for removal would be live-captured and relocated (most likely downstream of Muskrat Falls). Other site-specific mitigation based on investigations may also be developed.

5.3.3.3.6.5 Disease Profile

Reduced growth and change in isotope trophic level within the Muskrat Falls reservoir (see **Section** 5.3.3.3.6 – growth and isotopes) will trigger disease profiling, which will assist in determining whether parasite/disease loading is a factor in reduced fish health.

Disease profiles of resident fish will be used as a **Diagnostic Indicator** in the event that verification indicators of fish health show significant reductions. **Table** 5.44 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

5.3.3.3.6.6 Fecundity

Fecundity represents reproductive potential. There are various measures of fecundity but those that quantitatively describe gonad production are relatively simple. Gonadosomatic indices (GSI) are the relative weight of gonad to body weight. Fish that are sampled for fecundity using the GSI method will also have stage of maturity assessed, using the stages determined by Nikolsky (1963).

This metric is considered a **Diagnostic indicator** and since it requires lethal sampling, would be triggered as one of the last investigations associated with reduced spawning success (see **Section** 5.3.3.3.5 - radio telemetry). **Table** 5.45 presents a summary of the primary attributes of this **Diagnostic Indicator**. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC(2012).

5.3.3.3.6.7 Fish Physiology

Stress in a fisheries context can be defined as *a non-specific response of the body to any demand made upon it beyond its normal resting state, to the point that the chances of survival may be reduced* (Selye 1973; Brett 1958). Long-term exposure to environmental stress is a concern because of the possible detrimental effects on important fish performance elements, such as metabolism, growth, disease resistance, reproductive capacity, condition and ultimately the survival of fish populations (Barton et al. 2002). Baseline sampling for blood glucose has not been conducted in past sampling but will be included in the ongoing baseline data collection to assess the method and determine its potential applicability as an **Early Warning Indicator**. **Table** 5.46 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.44. Summary of Habitat Suitability - Disease Profile attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic
Biologically relevant	Changes in parasite loading or disease can alter fish health and population dynamics within the reservoir.
Sensitive	The rate of measurement is annual (fish generally sampled throughout June and August-September), therefore the sensitivity of the measurement in terms of rapid detection is low.
Measureable	Lethal sampling for disease profiles is relatively straight forward; however, analysis is specialized.
Interpretable	Disease profile sample collection is relatively straight forward with analysis being more specialized (UPEI veterinary lab). Results can be compared to existing baseline values.
Historical data	Yes. Disease profiles of most species will be included in ongoing data collection and incorporated into the ongoing database. Therefore existing baseline data is available for comparison.
Baseline Requirements	Ongoing baseline data collection is continuing prior to reservoir formation in order to establish baseline disease profiles for comparison to post-Project results. This will determine whether disease profile is contributing to reduced growth.
Sampling Schedule	Disease profile diagnostics would be triggered as a result of significantly reduced health within the Muskrat Falls reservoir (**Section** 5.3.3.3.6 – fish growth); therefore no established reservoir sampling schedule.
AMP Triggers	If a significant change in parasite composition is determined and it is shown to be a major contributor to reduced fish growth (**Section** 5.3.3.3.6) an appropriate Species/Area of Concern will be identified and additional investigations triggered into the extent within the reservoir and possible causes: • a review of other annual fish growth data of similar species life stage from other habitat types within the reservoir area • a review of habitat suitability results within the identified Area/Species Life stage of Concern including TSS, TP, water depth and velocity, flow, and dissolved oxygen • Comparison of growth values between habitat types.
Mitigations	• No mitigations directly related to parasite composition and/or loading; however results of additional triggered investigations will be used to determine appropriate habitat-based mitigations related to growth/health decreases. • If results of additional triggered investigations indicate a significant reduction in fish growth and/or health caused by habitat suitability

Attribute	Attribute Rating
	changes, additional triggers to investigate mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Substrate modifications (addition or flushing) ▪ Water quality modification (nutrients, oxygen) ▪ Predator management (removal) Other site-specific mitigation based on investigations may also be developed.

Table 5.45. Summary of Habitat Suitability - Fecundity attributes.

Attribute	Attribute Rating
Indicator Type	Diagnostic
Biologically relevant	Changes in fecundity could cause reduced reproductive success and hence reduced recruitment. This could alter population dynamics and species persistence within the reservoir.
Sensitive	The rate of measurement is annual (fish generally sampled throughout spawning seasons of June and August-September). The sensitivity of the measurement in terms of rapid detection is high.
Measureable	Lethal sampling for fecundity is relatively straight forward.
Interpretable	Fecundity sample collection and analysis is relatively straight forward. Results can be compared to existing baseline values.
Historical data	Fecundity values will be collected during ongoing data collection and incorporated into the existing database. Therefore existing baseline data will be available for comparison.
Baseline Requirements	Ongoing baseline data collection is continuing prior to reservoir formation in order to establish baseline fecundity for comparison to post-Project results. This will determine whether fecundity is contributing to reduced spawning success.
Sampling Schedule and AMP Triggers	Sampling of fecundity would be triggered as one of the last investigations due to reduced spawning success as (**Section** 5.3.3.3.5) it is a lethal sampling method; therefore no established reservoir sampling schedule.
Mitigations	• Mitigations related to fish utilization (**Section** 5.3.3.3.4) redd surveys (**Section** 5.3.3.3.4.6), and telemetry (**Section** 5.3.3.3.5) are described in their relevant sections indicated. • If utilization/health results indicate a significant reduction in fish utilization and/or fish health, additional triggers to investigate potential mitigation measures would be invoked:

Attribute	Attribute Rating
	○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Nutrient inputs or extractions; ▪ Substrate modifications (addition or flushing); ▪ use of aerators (pumped surface water spray) to provide additional dissolved oxygen in select areas. • If redd survey/telemetry results indicate a significant reduction in fish utilization/spawning, additional triggers to investigate potential mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Substrate modifications (addition or flushing); ▪ Water quality modification (nutrients, oxygen); ▪ Predator management (removal). Other site-specific mitigation based on investigations may also be developed.

Table 5.46. Summary of Habitat Suitability - Fish Physiology (blood glucose) attributes.

Attribute	Attribute Rating
Indicator Type	Early Warning
Biologically relevant	Significant increases in blood glucose levels will provide an indication that stress levels in fish are elevated and that more severe health issues may arise in the future.
Sensitive	The method may reflect recent and long-term stress. The method has been published and with control of sampling time and techniques, should provide meaningful conclusions on fish stress.
Measureable	Stress is measureable in the field on live-captured fish using proven techniques.
Interpretable	Results will be compared to baseline values and will be interpretable when seasonality and species is taken into account.
Historical data	Baseline data will be available for comparison.
Baseline Requirements	Baseline data collection will continue prior to reservoir formation.
Sampling Schedule	This method is an Early Warning Indicator, therefore blood glucose will be sampled in each monitoring year on fish collected for other measures.
AMP Triggers	If a significant negative change in mean blood glucose values (i.e., an increase) is detected an appropriate Species life stage/Area of Concern will be identified and further investigations triggered including: ○ a review of other annual fish growth data of similar species / life

Attribute	Attribute Rating
	stage from other habitat types within the Muskrat Falls reservoir area ○ a review of habitat suitability results within the identified Area/Species /Life stage of Concern including TSS, TP, water depth and velocity, flow, and dissolved oxygen. ○ Comparison of blood glucose values between habitat types would provide an indication that the significant negative change has the potential to become more wide spread or whether it appears to be isolated to a particular habitat type or species. If the significant increase in mean blood glucose values indicates that the effect could be wide spread (multiple significant negative changes detected for the same species life stage in more than one habitat type) or long-term (more than one year of significant change detected in the Area/Life stage of Concern), additional focused sampling on fish species health will be conducted, including: ○ disease profiles (see **Section** 5.3.3.3.6.5 - disease profiles) ○ feeding (see **Section** 5.3.3.3.6.4 - feeding) ○ fish sampling for blood glucose (i.e., additional sampling by electrofishing, fyke netting, angling) ○ Water quality measurements of dissolved oxygen and temperature will also be initiated (**Section** 5.3.3.2.3 – water quality).
Mitigations	• Mitigations would depend on results of triggered investigations. Potential mitigations are provided in the relevant sections indicated above. • If results of additional triggered investigations indicate a significant reduction in fish growth and/or health caused by habitat suitability changes, additional triggers to investigate mitigation measures would be invoked: ○ modification/alteration of the habitat within the Area of Concern or another appropriate location: ▪ Substrate modifications (addition or flushing) ▪ Water quality modification (nutrients, oxygen) ▪ Predator management (removal) to allow identified species to recover. Targeted species for removal would be live-captured and relocated (most likely downstream of Muskrat Falls). • If results of additional triggered investigations indicate a significant reduction in fish growth and/or health caused by water quality changes, additional triggers to investigate mitigation measures would be invoked. Mitigations would depend on results of triggered

Attribute	Attribute Rating
	investigations however, direct mitigations related to most water quality are: ○ flushing of area to remove excess debris and surface pumping to re-oxygenate; ○ Turbidity barriers; ○ Bank erosion protection (seeding, Curlex, alder/tree live-staking) ○ Wave Protection (rocks or aquatic vegetation); ○ Shoreline stabilization (water cannon or other physical decrease in bank slope). Other site-specific mitigation based on investigations may also be developed.

5.3.3.3.7 Vegetation Growth

Aquatic vegetation within Muskrat Falls reservoir is important habitat for spawning and rearing of northern pike; a large predator. Large changes (either an increase or decrease) in key predator species, such as northern pike may disrupt species composition, distribution or stability. Therefore any large-scale change in the abundance and distribution of aquatic vegetation will need to be managed before it translates into severe alteration in species abundance or fish community structure within the reservoir. The quantity of aquatic vegetation throughout the Muskrat Falls reservoir will be an **Early Warning Indicator**.

5.3.3.3.7.1 Remote Measure of Vegetation Growth

Remote measures of vegetation growth will be conducted using similar methods as those used for determining changes in overall reservoir aerial extent (see **Section** 5.3.3.1.1.1 – remote sensing). Specifically, each imagery series will be accurately georeferenced and input into GIS such that the visible areas of aquatic vegetative growth can be digitized. The boundary of aquatic vegetation will be easily distinguishable from open water within the imagery and will allow detection of change as vegetation advances, retreats or maintains its distribution. The spatial extent from each year can be analyzed using this **overall aquatic vegetation area**. The aerial measurements will take the entire Muskrat Falls area into consideration and therefore any change in aquatic vegetation quantity and distribution can be documented. Air photo interpretation of the aquatic vegetation distribution within the lower Churchill River in the Muskrat Falls reservoir area has been completed using the 2007 georeferenced digital air photo imagery. In total, five areas contain a total of 171.39ha (± 0.57ha) of aquatic vegetation, accounting for approximately 2.5 percent of the total water surface area. **Table** 5.47 presents a summary of the primary attributes of this indicator. Additional detail regarding the rationale for indicator selection, development and utilization is provided in AMEC (2012).

Table 5.47. Summary of Habitat Suitability - Aquatic Vegetation attributes.

Attribute	Attribute Rating
Indicator Type	Early Warning
Biologically relevant	The extent of aquatic vegetation can change the habitat suitability for large predator populations (northern pike). Changes to such populations can severely affect the population dynamics within the reservoir.
Sensitive	The method is a census approach and therefore changes to spatial extent of vegetation will be easily detected.
Measureable	Easily measureable within GIS. Image resolution must be sufficient to detect change in aerial extent (i.e. 1-2 m resolution).
Interpretable	Standard interpretation based on baseline habitat availability.
Historical data	Data will be compared with baseline conditions..
Baseline Requirements	Baseline data has been collected based on 2007 digital air photography. Additional baseline delineation of aquatic vegetation will be completed with each satellite imagery set collected prior to reservoir formation (see **Section** 5.3.3.1.1.1 – remote sensing).
Sampling Schedule	Sampling will be conducted annually (August) for the first 10 years (2018-2027) after inundation. Sampling beyond 2027 will be at three-year intervals until 2037; however the frequency of sampling beyond 2027 may be altered dependent upon results and project monitoring review.
AMP Triggers	Because this indicator is being used to warn of potential challenges in fish species / life-stage changes due to an increase in northern pike predation, triggered investigations will focus on this mechanism. If a significant increase in aquatic vegetation extent or rate of change is detected, the following will be triggered: ○ surveys of northern pike utilization (particularly spawning) of expanding areas of aquatic vegetation and surveys of fish distribution and growth (see **Sections** 5.3.3.3.4 - catch per unit effort and **Section** 5.3.3.3.6 - growth/age structure). The results of these specific investigations could trigger mitigations.
Mitigations	• Mitigations would depend on results of triggered investigations; however, significant increases in spawning and utilization for northern pike, could trigger mitigations related to vegetation and/or population control: • Aquatic Vegetation Management: ○ Removal of excess vegetation ○ Disturbance of excess vegetation • Northern Pike Population Control: ○ Juvenile / Adult animal removal ○ Spawning / egg incubation disturbance

	• A significant decrease in spawning and utilization for northern pike, could trigger mitigations related to spawning habitat enhancement: • Installation of additional artificial spawning materials • Establishment/transplanting of nearshore aquatic vegetation

5.4 FISH HABITAT COMPENSATION MONITORING SCHEDULE

Nalcor is committed to monitoring all aspects of its Fish Habitat Compensation components. Components will be monitored for biological utilization, effectiveness, and structural integrity. The frequency of post-construction monitoring associated with this Plan has been developed based on predictions related to effect size, timelines for physical reservoir stabilization, and discussions with regulators. Monitoring programs are adaptive by nature and may require modification. Any necessary modifications to the program would occur following review of each monitoring report by DFO and Nalcor. As a result, the timelines for various aspects will be modified as required to provide a monitoring program that is relevant, cost-effective, and defensible. As indicated previously, the overall monitoring schedule is provided in **Table** 5.16. Within each monitoring year, habitat measures will have specific timelines. **Table** 5.48 presents the timeline within a monitoring year.

Table 5.48. Summary of annual monitoring schedule for each indicator.

Measure	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RTWQ[1]												
Water Quality[2]												
Ice												
Vegetation												
Prim. Prod.												
Plankton												
Benthic Inverts												
Fish Habitat/Health[3]												
Redd Surveys												

[1] Real-time Water Quality (RTWQ) included water temperature, turbidity, pH and dissolved oxygen, chlorophyll a.

[2] Water samples will be collected on a monthly basis and will coincide with the calibration schedule for RTWQ stations; measures will include TSS, total Phosphorus and Dissolved Oxygen

[3] Fish Habitat Utilization includes CPUE surveys, snorkel surveys and population estimates, Fish Health includes; fecundity, growth rate, isotope feeding level, disease profiling, physiology and population age structures. Isotope and secondary aging structures (scales) will be collected annually as they do not require lethal collection. Other measures of fish health will be collected following a "trigger."

6 STAKEHOLDER CONSULTATION

Typical public consultation associated with the Compensation Planning process occurs prior to final acceptance of a Plan by the proponent and DFO. This Project and compensation is larger and much more inclusive than typical plans and therefore additional consultation has been conducted throughout the process to include as much input from regulators, stakeholders and the public as possible.

The draft Compensation Plan began more than ten years ago with baseline data collection in 1998. A Compensation Strategy Framework was created in 2009, which outlined the general aspects of the Strategy including the post-Project Habitat predictions, Adaptive Management Program and potential sites for physical compensation works. The Framework was then the subject of a series of Technical Workshops in both St. John's and Goose Bay where aboriginal groups, stakeholders and users of the river were invited to participate and provide discussion and comment on any aspect of the Framework. The results of these workshops, in terms of issues related to physical compensation works locations and the approach, were incorporated into a Compensation Strategy in May 2010. This strategy was again subject to a similar series of Technical Workshops in both St. John's and Goose Bay. The Workshops were generally several hours in duration and consisted of a detailed presentation of the Compensation Strategy and discussions of technical and general details as requested by participants. All discussion, concern and comments were recorded and considered in strategy development and ongoing Plan design.

In addition to public consultation, DFO has cooperated in Framework, Strategy and Plan development through review of drafts and through workshops on Adaptive Management and Effects Monitoring. During these interactions, concepts for monitoring and compensation were presented and discussed. The initial monitoring workshop was conducted in June 8-9, 2010 and another Adaptive Management and Environmental Effects Monitoring workshop on February 29-March 2, 2012.

Nalcor presented the draft Plan to the public and identified stakeholders for input and comment during public information sessions in Goose Bay on January 16, 2013. Documentation and reporting on comments received on the Plan, and the measures proposed/taken to address past suggestions and concerns, have been completed and submitted with the final Plan. In general, no major comments or concerns regarding the Plan or EEM were identified, however, northern pike were again indicated as an undesirable species. The monitoring described within this plan will address any significant increases in pike numbers, not only from a public point of view, but also in terms of affecting the species diversity within the Muskrat Falls reservoir.

7 REPORTING

At the completion of each construction season, a compensation works report will be submitted to DFO. The report will detail the compensation works completed within that year and will provide "as built" information that will be used as baseline conditions for monitoring habitat stability and function. Annual reports shall incorporate summary data from all previous years.

An annual report will also be produced from the results of the adaptive monitoring program. The report will be submitted to DFO for information and review. In order to permit a thorough review and provision of timely comments and suggestions for upcoming sampling, DFO will require the report submission by March 31 of the year following monitoring. Ice information, if not finalized and ready, will follow by April 30.

In addition to reporting requirements to DFO under the Authorization, updates will be considered for other stakeholders should the interest warrant.

8 CLOSURE

The biological information and habitat design presented in this report have been prepared in accordance with generally accepted practices and are based on the information obtained from previous field investigations by others as well as those completed by AMEC since 1998 on the lower Churchill River.

Sincerely,
AMEC Environment & Infrastructure,
A Division of AMEC Americas Limited

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APPENDIX A

Design Drawings; Pinus River

APPENDIX B

Design Drawings; Edward's Brook

APPENDIX C

Example Status Summary Reports
*Data, graphs, and text are fictitious