Predicted Increases in Fish Methylmercury Muscle Tissue Concentrations In Goose Bay and Lake Melville

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1.0 INTRODUCTION

Nalcor Energy (Nalcor) is developing the remaining hydroelectric potential of the lower Churchill River through hydroelectric generating facilities at Muskrat Falls and Gull Island. The Muskrat Falls portion of the project, which is currently under construction, will result in the creation of a reservoir with a surface area of 101km^2. The existing river within the proposed footprint of the Muskrat Falls reservoir area has a surface area of ~60km^2 therefore the area of additional terrestrial flooding will be approximately 41km^2, representing a 65-70 percent increase in the existing waterbody surface area.

Many freshwater, estuarine, and marine fish species are within the project's zone of influence and could therefore be affected either directly or indirectly. Much of the baseline data required for the Environmental Assessment and Environmental Effects Monitoring (EEM) program described these species, their potential for interaction with the project, as well as the estimation of potential effects (e.g., Nalcor 2009; Amec 2016a). Increased human health risks to residents through potential increases in methylmercury concentrations and consumption of various fish species from Goose Bay and Lake Melville have been modeled and included in Nalcor's Human Health Risk Assessment (HHRA) (Dillon 2016). Simultaneous to this, additional assessments of methylmercury increase and potential human effects have been developed and published (see Schartup et al. 2016; Calder et al. 2016).

The life cycles and habitat used by fish species captured and consumed by local residents is key to understanding and predicting any potential future mercury increases and human health risk. Information on species distribution within and downstream of the Muskrat Fall reservoir, their abundance, trophic position within the foodweb, and baseline MeHg concentrations based on data collected since 1998 was presented and provided to the Independent Experts Committee (IEC) on two separate occasions; September 7, 2017 and February 15, 2018. The data collected directly from the river since 1998 clearly shows inconsistencies in how species exposure to potential increases in MeHg concentrations in the water, and hence the foodweb, have been applied to previous model predictions.

1.1 Purpose

The purpose of this document is to provide summary life history and habitat use by key species identified as being important in local diets that are targeted within Goose Bay and Lake Melville. This data is critical to determining the exposure of these species to any predicted increases in water MeHg concentrations caused by the reservoir. New reservoir mercury modelling and detailed hydrodynamic modelling that describes the predicted increase and distribution of water MeHg concentrations in Goose Bay and Lake Melville have been used to predict increases in fish tissue MeHg concentrations. It should be noted that to date, most concern by residents is related to fish species captured and consumed within the esturay environment downstream of the Muskrat Falls reservoir; Goose Bay and Lake Melville. As such, the Muskrat Falls reservoir area and the riverine section of the lower Churchill River are not the focus of this summary as these areas do not contribute to potential human exposure. It has also been conservatively assumed that total mercury concentrations in fish muscle tissue analyzed as part of the baseline program is methylmercury based on local comparisons of paired total and methylmercury samples (also see Anderson and Depledge 1997; Marrugo et al. 2007).

2.0 BIOACCUMULATION OF MEHG IN FISH

The primary exposure pathway to methylmercury by all aquatic organisms is almost exclusively via diet (e.g., Hall et al. 1997). The Lower Churchill River is predicted to transport MeHg in water to Goose Bay and Lake Melville. Areas of dynamic mixing between the freshwater surface layer and the underlying marine layer where light penetration is high will be where methylmercury in water will be accumulated by bacteria, phytoplankton and nanoplankton. This phenomenon will ultimately distribute methylmercury into the base of the aquatic food web across areas of exposure; however, recent hydrodynamic modelling shows that this occurs disproportionately. Relatively greater water concentrations of methylmercury will be available for accumulation in Goose Bay biota than Lake Melville because of a variety of factors including dilution, photo-demethylation (e.g., Sellers 1992), adsorption to particles, settling and progressive uptake by biota. Thus, where an organism spends its time feeding will dictate its magnitude of exposure. This has important implications in terms of predicted increases in fish MeHg.

For a fish to be exposed, it must occupy the same space as the contaminant for a period. Therefore, life history is an important factor, informing the magnitude of exposure on both a spatial and temporal scale to produce a change in tissue mercury concentrations. For this exercise, the predicted relative increase in MeHg concentration in water is assumed to be the predicted upper maximum relative increase in fish muscle tissue should the fish be fully exposed to that water concentration. The predicted relative increase in fish tissue MeHg in Goose Bay and Lake Melville also does not take into account the biomass of MeHG that can be produced by Muskrat Falls reservoir nor the biomass of biota within Goose Bay and Lake Melville for uptake; therefore, they are considered conservative overestimates. Biomass effects on accumulation of MeHg is addressed in a separate submission by Azimuth.

2.1 Predicted Methylmercury Increases in Water

Detailed modelling has been completed on the MeHg that will be generated by the Muskrat Falls reservoir (Harris and Associates 2018) using two models; RESMERC and Fludex. A portion of the methylmercury generated within the reservoir will be transported downstream to the lower reaches of the river, Goose Bay and Lake Melville. The quantities estimated were used as input to extensive hydrodynamic modelling of Goose Bay and Lake Melville which estimated MeHg increases based on reservoir MeHg outflows (Brunton 2018) and various natural processes that affect MeHg concentrations such as freshwater flows, salinity, currents, flushing, winds, ice, transport, photodegradation, and settling (Brunton 2018). Details of the hydrodynamic model are provided in Brunton (2018).

Hydrodynamic model results indicate that the generated MeHg from Muskrat Falls reservoir will be transported downriver via the upper freshwater layer that enters the estuary habitat. Therefore, it has been assumed that the general exposure concentration of prey occurs within the top 20m of the estuary, that is, within the combined surface freshwater layer and the upper saline water just below the freshwater layer. This zone would be productive and exposed to additional nutrients and MeHg. It is assumed that most prey will ultimately derive any increased accumulation of MeHg from within this zone. The hydrodynamic modelling also shows that as water from Muskrat Falls reservoir travels downriver and throughout Goose Bay and Lake Melville, predicted concentrations decrease. **Figure 2-1** provides the boundary between three distinct areas where concentrations differ; Goose Bay, West Lake Melville, and East Lake Melville. These three areas are identified as different “zones of exposure” for predicting increases in fish MeHg tissue concentrations. **Table 2-1** provides an estimate of the baseline water MeHg concentrations and the predicted relative increase concentrations (above baseline) for the three zones of exposure based on the hydrodynamic model results. The predicted relative increase in water is the mean of the consecutive three-year sequence with the highest predicted MeHg concentrations within the upper 20m of the water column, as described above. The rationale for using a three-year mean is to realistically estimate the level of exposure throughout the life span of those key fish species in Goose Bay and Lake Melville (see Section 2.2).

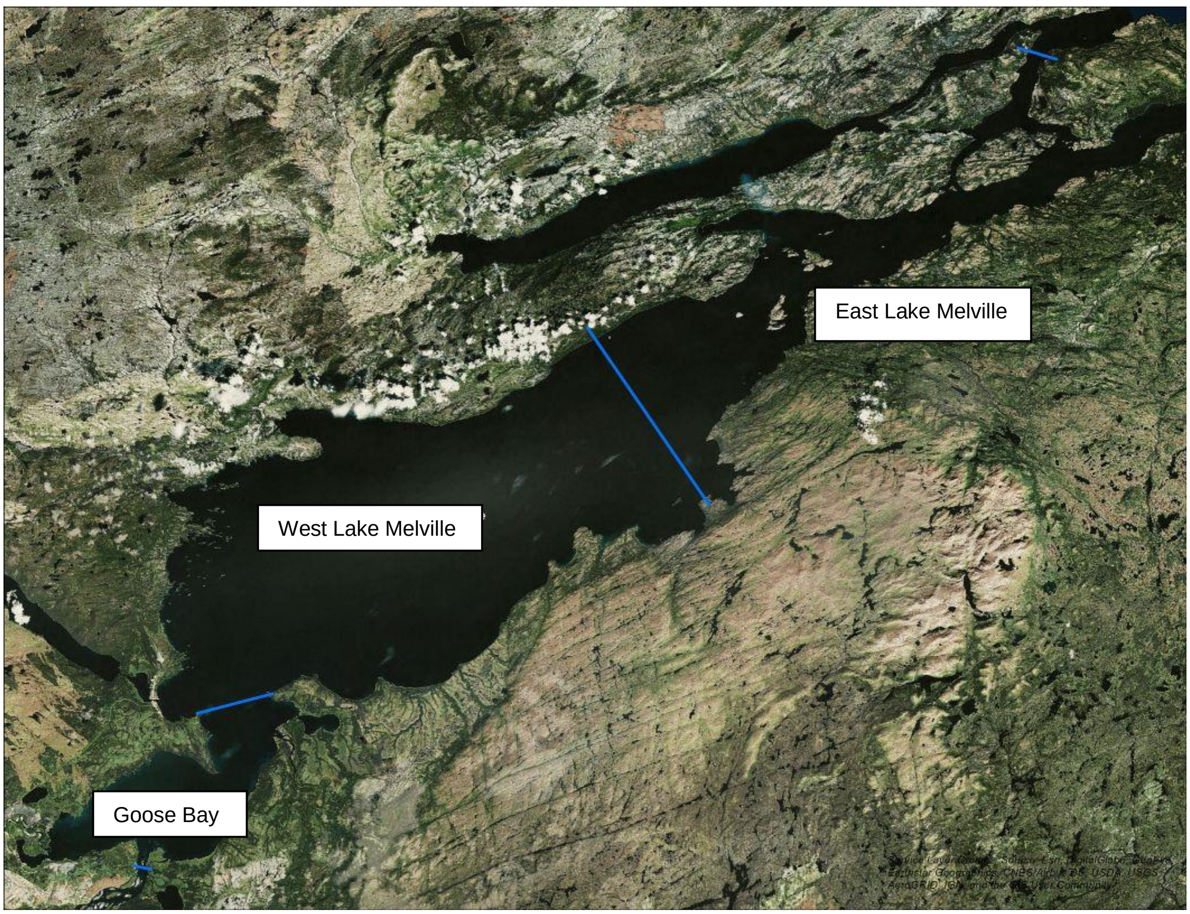

Figure 2-1: General overview of different zones of exposure based on hydrodynamic model (Brunton 2018)

Table 2-1: Hydrodynamic Model Estimates of water MeHg concentration (ng/L) increases (above baseline), Goose Bay, West Lake Melville, East Lake Melville

	Goose Bay	West Lake Melville	East Lake Melville
Baseline MeHg Water Concentration (ng/L)	0.017	0.017	0.017
Peak Concentration (max 3-yr; ng/L)	0.019	0.006	0.005
Relative MeHg Increase in Water	**2.12x**	**1.35x**	**1.29x**

2.2 Potential Fish Exposure to Methylmercury Increases in Water

Nalcor has collected baseline data since 1998 on the lower Churchill River, Goose Bay, and Lake Melville. Included in this baseline data are the ongoing results of species distribution and abundance, trophic feeding position, and total mercury concentrations in fish and seals. Detailed summaries of the results are provided in **Appendices A and B**.

In total, the baseline sampling program for the Lower Churchill Hydroelectric Development has sampled over 10,140 fish from over 20 different species between 1998-2017. While many species of fish have been identified as being consumed by residents in previous HHRAs (e.g., Calder et al. 2016 and Dillon 2016), many have either not been captured within or downstream of the Muskrat Falls reservoir (Amec 2017), have been captured within the marine environment beyond Lake Melville (e.g., Li et al. 2016; Calder et al. 2016), or do not feed in Lake Melville upon their return to tributaries to spawn. For these species, increases in MeHg exposure are not anticipated and have not been included in further estimates of bioaccumulation increases. These species include lake trout (*Salvelinus namaycush*), Atlantic salmon (*Salmo salar* – both anadromous and land-locked), Atlantic cod (*Gadus morhua*), Capelin (*Mallotus villosus*), and Arctic char (*Salvelinus alpinus*). Three species; brook trout (*Salvelinus fontinalis*), rainbow smelt (*Osmerus mordax*) and ringed seal (*Pusa hispida*) appear to be the most abundant and widespread species in Goose Bay and Lake Melville and perhaps not coincidentally, have been identified as preferred food species by local communities (Dillon 2016). These three species could therefore be exposed to greater methylmercury concentrations in prey due to the Muskrat Falls reservoir.

2.2.1 Brook Trout (*Salvelinus fontinalis*)

The brook trout is widely distributed throughout Newfoundland and Labrador (Scott and Crossman 1973), at least as far north as the Hebron Fiord (Black et al. 1986), where they have been reported to make extensive use of clear, cool (<20°C) lake habitats (Ryan and Knoechel 1994). Brook trout are known to have both landlocked and anadromous populations throughout Newfoundland and Labrador (Scott and Crossman 1964, 1998). Anadromous populations may spend one or two months feeding at sea in relatively shallow water, close to their natal stream, while others spend their entire life in freshwater (Scott and Crossman 1964; Morrow 1980; Power 1980; Ryan 1980; Scott and Scott 1988).

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 upriver of Gull Island (above the Muskrat Falls reservoir area) where river and shoreline substrates contain less fine sand and clay substrates (AGRA 1999; AMEC 2000). Brook trout have also been captured below Muskrat Falls within the main stem but at relatively low rates (AMEC 2000; AMEC 2007; AMEC 2009; Amec Foster Wheeler 2015a; Amec Foster Wheeler 2016a).

Based on habitat utilization data, brook trout use stream (i.e. tributary) habitat where spawning and young-of-year occur. Few samples have been collected within the main stem of the lower Churchill River below Muskrat Falls where only 33 have been captured in a combination of fyke nets and gillnets between 1998-2016; however, they are found in relatively higher numbers within the upper habitat of Caroline Brook. Larger numbers have also been sampled within both Goose Bay (191 total) and Lake Melville (535). In both estuarine environments, brook trout have had some of the highest CPUE and biomass of all species sampled (Amec Foster Wheeler 2015a; 2016a). This is most likely the result of the brackish environment of the estuary being a suitable habitat for anadromous brook trout to feed during the summer months. Typically, brook trout will not feed within an estuarine environment beyond several kilometers of its natal stream (Scott and Scott 1988); therefore, most of the brook trout captured in Goose Bay and Lake Melville are likely not far from their home freshwater tributary.

Specimens have been captured from every age-class between one and six (AGRA 1999; AMEC 2000; Amec Foster Wheeler 2015a; 2016a, 2016b). Mean length-at-age data shows they range between 82 mm in length at age one to almost 415 mm at age six. Growth is relatively linear throughout all years.

The diet of brook trout consists of a wide variety of food types including aquatic invertebrates, fish, and terrestrial invertebrates and vertebrates. Stomach content analysis and stable isotope data indicate that brook trout in the estuary feed primarily on marine prey such as sand lance (*Ammodytes americanus*), rainbow smelt, amphipods, and benthic invertebrates (see **Appendix B**). They are one of the top predators within the estuary food chain.

2.2.2 Rainbow Smelt (*Osmerus mordax*)

Rainbow smelt are typically a schooling, pelagic fish, inhabiting mid-water areas of inshore coastal waters (Leim and Scott 1966; Scott and Scott 1988; Scott and Crossman 1998). In Hamilton Inlet and Lake Melville, they are primarily an inshore anadromous species that occur within bays and estuaries, but are rare in the Churchill River freshwater system (Anderson 1985). They are an important species in that they feed on pelagic plankton and are an important food source for most estuarine piscivores such as gadids (e.g., cod species), flatfish (e.g., winter flounder) and salmonids (e.g. brook trout).

Smelt are typically anadromous, moving from estuaries such as Lake Melville and Goose Bay into nearby rivers and streams to spawn in the spring, likely before ice breakup (JWEL 2001). As the hatched larvae grow, they move into areas of higher salinity, such as deeper parts of the estuary or more coastal areas (JWEL 2001). Smelt begin to school at about 19 mm in length, moving into shallow water and returning to deeper channels during the day (Belyanina 1969). They will generally spend the summer feeding on copepods and planktonic larvae and in the fall, juveniles mix with adult schools and move into the upper parts of the estuary (Buckley 1989) where they remain for the winter.

Within Lake Melville, smelt seem to prefer deeper, cooler waters in the summer (JWEL 2001). The JWEL sampling program identified that smelt, which spend the summer in the cooler waters of Lake Melville, move into Goose Bay from August to October (JWEL 2001; AMEC/BAE 2001). There was a slight peak observed in abundance in October in the western portion of Lake Melville and was suggested to be the result of a migration toward the many rivers in the area (JWEL 2001).

Due to physical barriers, this species does not occur above Muskrat Falls in the Churchill River (Ryan 1980) and based on sampling, is very rare upstream of estuarine influences after spawning. Ryan (1980) recorded two specimens (which appeared to be anadromous) downstream of Muskrat Falls and Amec Foster Wheeler captured a lone adult by fyke net just downstream of Muskrat Island in 2016 (Amec Foster Wheeler 2016a). No other known reports occur in the literature for their presence within the freshwater portion of the lower Churchill River (Ryan 1980, Beak 1980, AGRA 1999, AMEC 2000) upstream of the Mud Lake confluence (AMEC 2000). In addition to sampling conducted related to the Project, the main stem between Happy Valley–Goose Bay and Muskrat Falls as well as several tributaries (eg. Birchy Creek and Caroline Brook), were sampled between 2006 and 2008 for the provincial Department of Transportation and Works. Sampling was conducted using fyke nets and tended gillnets through most open water months (i.e. July and October 2006, May and June 2007, April, May, and June 2008, and May 2009) but did not capture rainbow smelt (unpub. data).

Rainbow smelt have been routinely captured during ongoing baseline sampling since 1999 in both Goose Bay and Lake Melville. Sampling by Amec Foster Wheeler has captured approximately 136 and 155 from Goose Bay and Lake Melville, respectively. Baseline work completed by JWEL in 1998 captured a total of 991 rainbow smelt within Goose Bay / Lake Melville which comprised 31 percent of their total catch (JWEL 2001). Rainbow smelt sampled (AGRA 1998) were predominantly between 151-250mm in length with fairly linear growth through all age classes sampled (ages 1-8).

Stomach content analysis and stable isotope data indicate that like brook trout, rainbow smelt are one of the top predators within the estuary food chain and feed primarily on marine prey such as sand lance, other rainbow smelt, and amphipods/decapods (see **Appendix B**).

2.2.3 Ringed Seal (*Phoca hispida*)

The ringed seal is one of the most abundant and widely distributed resident Arctic pinnipeds (Muir et al. 1999). The following general species life history description is from Lowry (2016). As a species, ringed seals are widely distributed in ice-covered waters of the northern hemisphere, and they may presently number about three million animals (Lowry 2016). They prefer annual, landfast ice, but are also found in multi-year ice (Kingsley et al. 1985).

Throughout most of their range they use sea ice exclusively as their breeding, molting, and resting (haul-out) habitat, rarely if ever moving onto land (Frost and Lowry 1981, Reeves 1998). Reported mean age at sexual maturity for female Ringed Seals varies in the literature from 3.5 to 7.1 years (Holst and Stirling 2002, Krafft et al. 2006). Males likely do not participate in breeding before they are 8-10 years old. Ringed seals can be long lived, with ages close to 50 reported (Lydersen and Gjertz 1987). Regional productivity rates are variable; reproductive success depends on many factors including prey availability, the relative stability of the ice, and sufficient snow accumulation prior to the commencement of breeding (Lukin 1980, Smith 1987, Lydersen 1995).

Outside the breeding and molting seasons, Ringed Seal distribution is correlated with food availability (e.g., Simpkins et al. 2003, Freitas et al. 2008). Numerous studies of their diet have been conducted, and although there is considerable regional variation, several patterns emerge. Most Ringed Seal prey are small, and preferred prey tend to be schooling species that form dense aggregations. Fishes are usually in the 5-10 cm length range and crustacean prey in the 2-6 cm range. Typically, a variety of 10-15 prey species are found, with no more than 2-4 dominant prey species for any given area. Fishes are generally more commonly eaten than invertebrates, but diet is determined to some extent by availability of various types of prey during particular seasons as well as by preference, which in part is influenced by energy content of various available prey (Reeves 1998, Wathne et al. 2000). Commonly eaten prey includes cod species redfish, herring, and capelin in marine waters (Lowry et al. 1980, Holst et al. 2001, Labansen et al. 2007). Invertebrate prey species seem to become more important in the open-water season and often dominate the diet of young animals (Lowry et al. 1980, Holst et al. 2001). Large Amphipods, Krill, Mysids, Shrimps, and Cephalopods are all eaten by Ringed Seals and can be very important in some regions at least seasonally (Agafonova et al. 2007).

Ringed seal surveys in Goose Bay and Lake Melville have been completed in 2006 and each year between 2013-2016 (SEM 2007; Amec Foster Wheeler 2016a). During aerial surveys each whelping season, the lower reach of the Churchill River is flown for seal presence and in all years, no ringed seals have been recorded within the river itself (SEM 2007; Amec Foster Wheeler 2016a). Very few seals are observed within Goose Bay (Amec Foster Wheeler 2016a). However, it should be noted that harbour seals (*Phoca vitulina*) have been observed within the river during fisheries surveys during open water; the most observed at any location and time has been three (McCarthy, unpubl data). Using the seal density within the observed area (approximately 517km^2), a relative abundance estimate for the entire EEM zone was generated for each survey year. Relative abundances have ranged between 644 and 2,140 animals with the 2015 survey being the lowest to date (Amec Foster Wheeler 2016a). Seal ages in Goose Bay and Lake Melville, based on 2016 samples, typically range between pups and adults up to 32 years of age. Since seal samples from Goose Bay and Lake Melville are harvested by a local hunter for consumption by the local community, samples are generally biased toward younger animals.

Stomach content analysis has only identified rainbow smelt as prey; however, seals are sampled after whelping and foraging may be more restricted. In addition, pups would only be feeding on milk. Stable isotope data indicate ringed seals are the top predator in the estuary (above brook trout and rainbow smelt) and therefore feed on a variety of marine fish species.

2.2.4 Exposure Summary

Table 2-2 provides a summary of the annual percentage of time spent feeding in the identified estuary zones (Goose Bay, West Lake Melville, and East Lake Melville) for brook trout, rainbow smelt, and ringed seal.

Table 2-2. Summary of estimated percent annual exposure of key species within the identified estuary zones.

Species	Habitat Not Influenced by Muskrat Falls	Goose Bay	West Lake Melville	East Lake Melville
Brook Trout	30%	70%	70%	70%
Rainbow Trout	0%	20% - 100%	80%	80%
Ringed Seal	34%	0%	66%	

Brook trout would remain near their home stream but would feed within the estuary environment once reaching the age of three. Discussions with local fishers indicate that brook trout have been captured through the ice and therefore, it has been assumed that up to 70% of the year could be spent within the estuary environment with some (30%) overwintering in tributaries and upstream migration for spawning and feeding where no increases in MeHg exposure would occur. While they would not be anticipated to migrate between each of the estuary zones, the estimated annual exposure within each zone would be similar.

Rainbow smelt that live and are captured in Goose Bay / Lake Melville are assumed to spend their entire lives within this environment; that is, they do not migrate to Hamilton Inlet or further offshore. However, based on surveys of the area, it appears that many rainbow smelt congregate within Goose Bay for a couple of months in the fall. It was therefore assumed that rainbow smelt captured and consumed from the Lake Melville zones could have spent up to 20% of their time feeding within Goose Bay each year and this would increase their exposure to higher MeHg water concentrations. Those fish captured and consumed within Goose Bay are assumed to reside 100% within Goose Bay itself and therefore are predicted to have higher overall exposure than those captured within Lake Melville.

Ringed seals have not been observed within the Churchill River and Chaulk et al. (2013) stated that local residents reported that ringed seals are rarely observed in Lake Melville during the summer, compared to early spring. Chaulk et al. (2013) also noted that DFO (B. Sjare) was tracking seals in the area and the data suggested that ringed seals moved in and out of Lake Melville from other areas of coastal Labrador over the course of the ice-free period. While they are relatively abundant in Lake Melville in the winter, they are uncommon in Goose Bay based on surveys completed since 2006. Based on this available information, it is assumed that ringed seals captured and consumed from Lake Melville spend 66% of their time feeding there. An estimated 34% of their annual feeding would occur outside Lake Melville and therefore outside any exposure to increased water MeHg concentrations.

2.3 Predicted Increases in Fish Muscle MeHg Concentrations

Based on the predicted increases in MeHg concentrations in water within the three estuary zones (see **Table 2-1**) and the estimated time of exposure for key species (see **Table 2-2**), increases in fish MeHg muscle tissue were predicted (**Table 2-3**) using the product of the cumulative annual exposure to water predicted to have relative increases in MeHg concentration.

As stated previously, brook trout would remain near their home stream but would feed within the estuary environment once reaching the age of three. Since they would not migrate between each of the estuary zones, three separate predicted increases are provided; one for each zone where brook trout may be captured for consumption. As expected, brook trout are predicted to increase more in zones closer to Muskrat Falls. The predicted increases in brook trout tissue during the peak of MeHg in water (three-year max) are 78%, 25%, and 20% in Goose Bay, West Lake Melville, and East Lake Melville respectively.

Based on life history for rainbow smelt as described above and the relative increases in MeHg concentrations in water, the predicted increases during the peak of MeHg in water (three-year max) are 112%, 50%, and 46% in Goose Bay, West Lake Melville, and East Lake Melville respectively. These values are the weighted mean of the portion of time spent feeding in Goose Bay and each of the zones in Lake Melville (see Table 2-2).

Based on the available life history information, it was assumed that ringed seals captured and consumed from Lake Melville spend 66% of their time feeding there with 34% of their time outside Lake Melville. It was also assumed that seals would freely move between the whole area of Lake Melville that therefore their predicted increase in MeHg would be the weighted mean of the two Lake Melville zones (equal exposure of 33% feeding time in each zone). The predicted increases during the peak of MeHg in water (three-year max) is therefore 21% throughout Lake Melville.

As shown, predicted increases are between 20-112% based on species habitat use and MeHg increases in each of the identified zones. Biology and ecosystem play a critical role in fish exposure to increased MeHg concentrations from the Muskrat Falls reservoir and ultimately to human risk. These predicted increases will be incorporated into the HHRA.

Table 2-3: Summary of predicted increases in MeHg muscle tissue concentration in brook trout, rainbow smelt, and ringed seal

Species	Goose Bay			West Lake Melville			East Lake Melville		
	Predicted MeHg Increase	Baseline MeHg	**Predicted MeHg Conc (mg/kg)**	Predicted MeHg Increase	Baseline MeHg	**Predicted MeHg Conc (mg/kg)**	Predicted MeHg Increase	Baseline MeHg	**Predicted MeHg Conc (mg/kg)**
Brook Trout[a]	1.78x	0.07	**0.125**	1.25x	0.04	**0.050**	1.20x	0.03	**0.036**
Rainbow Smelt[b]	2.12x	0.02	**0.043**	1.50x	0.02	**0.030**	1.46x	0.04	**0.058**
Ringed Seal Tissue[a]	1.32x	-	**-**	1.21x	0.13	**0.157**	1.21x	0.13	**0.157**
Ringed Seal Liver[a]	1.32x	-	**-**	1.21x	13.42	**16.24**	1.21x	13.42	**16.24**

[a] mean MeHg tissue concentrations from 2017 samples.
[b] mean MeHg tissue concentrations from 2016 samples.

3.0 CLOSURE

The biological and habitat use data presented within this report has been compiled using baseline data collected by Amec Foster Wheeler and others since 1998. The methodologies used to collect and generate the data are generally accepted practices described in detail within the EEM and the Fish Habitat Compensation Plan baseline studies, and have been used for studies within the lower Churchill River, as well as other projects throughout Newfoundland and Labrador (AMEC 2013b).

Yours truly,

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Appendix A – Aquatic Species Habitat Overview, Churchill River, Goose Bay and Lake Melville, 1998-2016

Appendix B – Summary of Isotope and Stomach Data, Goose Bay / Lake Melville