Final

Whale Tail Pit Project: Predicted Changes in Fish Mercury Concentrations in the flooded area of Whale Tail Lake (South Basin)

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Gary Mann and Randy Baker (Azimuth) were responsible for examining baseline mercury data from environmental media, fish mercury modelling (empirical), weight-of-evidence assessment and authored the report. Reed Harris (R. Harris Environmental) was reviewed the report and he together with Dave Hutchinson conducted mechanistic mercury model simulations (RESMERC).

Field data were collected by Eric Franz (Azimuth), with assistance by Kevin Muckpaloo of AEM and Baker Lake.

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ACRONYMS

AEM	Agnico Eagle Mines Ltd.
CCME	Canadian Council of Ministers of the Environment
CRM	Certified Reference Material
DQO	Data Quality Objective
dw	dry weight
GPS	Global Positioning System
MAM	Mammoth Lake
NEM	Nemo Lake
NF	Near-field
QA/QC	Quality Assurance / Quality Control
REF	Reference
SQG	Sediment quality guidelines
UTM	Universal Transverse Mercator
WQG	Water quality guidelines
WTN	Whale Tail Lake North Basin
WTN-Ex	Whale Tail Lake North Basin (shallow)
WTS	Whale Tail Lake South Basin
ww	wet weight

1. INTRODUCTION

1.1. Background

The Amaruq Exploration Property is a 408-square kilometer area located on Inuit Owned Land, approximately 150 kilometers north of Baker Lake and approximately 50 kilometers northwest of the Meadowbank mine (**Figure 1-1**). Agnico Eagle Mines Limited (AEM) leased exploration rights to the Amaruq Exploration Property from Nunavut Tunngavik Incorporated (NTI) in April 2013. AEM's exploration activities have been conducted under a land use permit issued by the Kivalliq Inuit Association (KIA) and a water licence issued by the Nunavut Water Board (NWB).

AEM intends to pursue development of the Whale Tail satellite open pit located on the Amaruq site as an extension to the operational Meadowbank Mine. This report presents results of a comprehensive study conducted to predict the magnitude of change in fish mercury concentrations associated with the planned temporary flooding of the South Basin of Whale Tail Lake (hereafter referred to as the "Whale Tail Lake (South Basin)").

1.2. Environmental Setting

The Whale Tail Pit and Meadowbank projects are situated in the barren-ground central Arctic region of Nunavut within an area of continuous permafrost known as the Wager Bay Plateau (Campbell et al. 2012). The landscape around the Amaruq property consists of rolling hills and relief with low-growing vegetative cover and poor soil development. Numerous lakes are interspersed among boulder fields, eskers and bedrock outcrops, with indistinct and complex drainages (**Figure 1-2**). The near-field (NF) lakes within the Amaruq Exploration Property are Whale Tail Lake (WTL), Nemo Lake (NEM), and Mammoth Lake (MAM). These are headwater ultra-oligotrophic/oligotrophic (nutrient poor with low biological productivity) lakes, situated on the watershed boundary that separates the Arctic and Hudson Bay drainages.

As is common of headwater lakes, all of the project lakes have small drainage areas relative to the surface area of the lakes themselves. A drainage divide separates Nemo Lake to the north from Mammoth and Whale Tail Lake to the south (Golder 2015a). Local inflow from surrounding terrain is the predominant influence on water movement within the system. Small stream channels connect the project area lakes, although there is little flow between lakes except during freshet and possibly none during winter months. Movement by fish between lakes is also rare, as populations remain quite isolated from one another (Portt and Associates 2015b). The ice-free season on these lakes is short, with ice break-up in late-June to mid-July and ice-up beginning in late September or early October. Thus, water only typically flows between lakes for a period of 4-5 months, between June and October as connecting channels between lakes are completely frozen for the rest of the year.

1.3. Description of Proposed Flooded Area of Whale Tail Lake (South Basin)

The construction of the Whale Tail Dike will result in blocking the normal flow of water in the watershed; in the literature, this type of diversion and "back-flooding" of water is commonly referred to as impoundment or a reservoir. This water will be diverted around the project and discharged directly into Mammoth Lake via a constructed diversion channel. To facilitate this, the water level of the South Basin must be increased to reach a diversion elevation, which will also result in the flooding of a number of small chain lakes (A18, A19, A20, A21, A22, A55, A62, A63, A65), ponds (A-P1, A-P53) (**Figure 1-2**). Information regarding the diversion was obtained from Appendix 6-F of the FEIS (Golder, 2016) and from updated information provided directly by Golder Associates (**Appendix B**). Key facts relevant to predicting changes in fish mercury concentrations include:

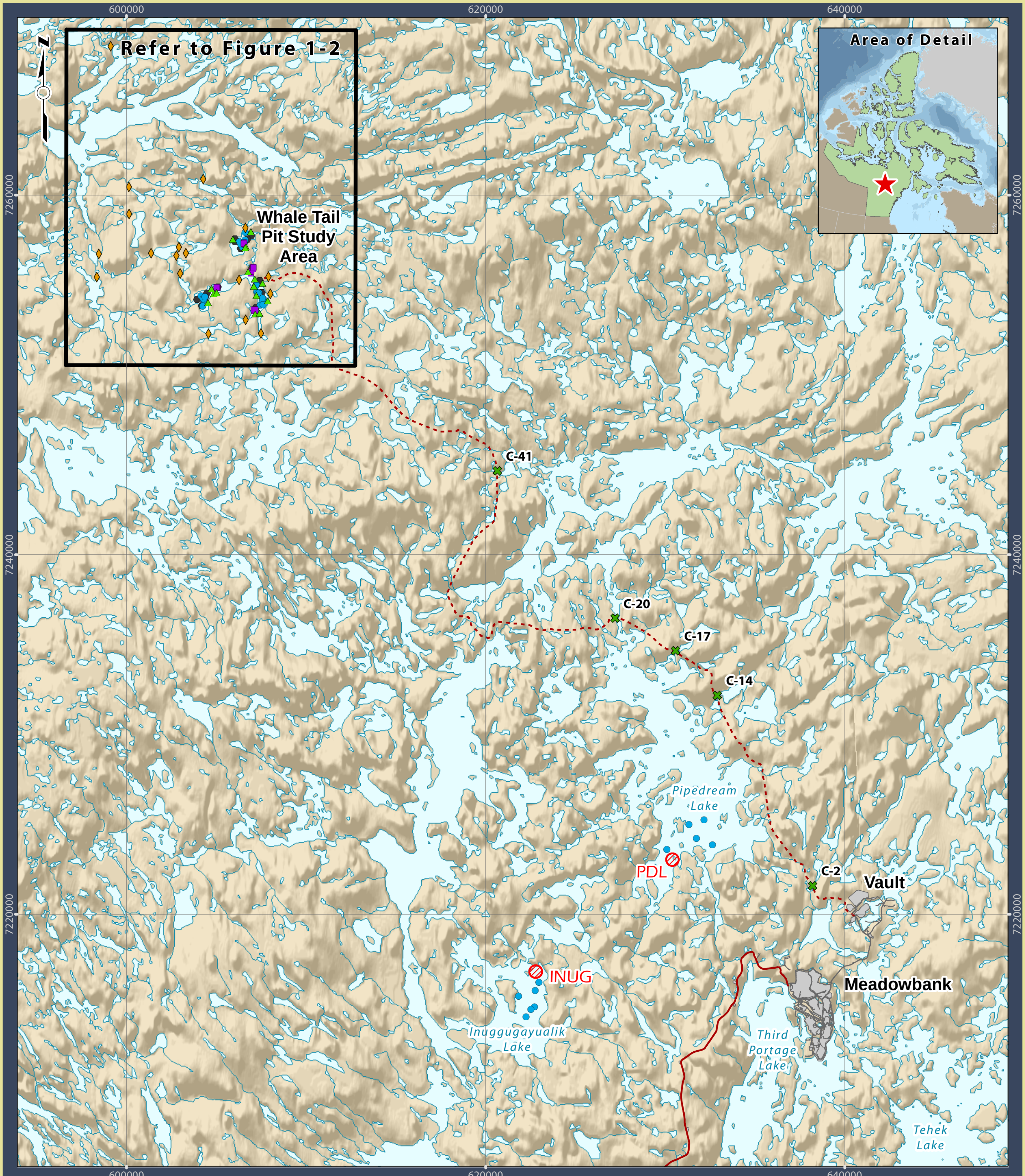
- Baseline water elevation of Whale Tail Lake is 152.5 m asl
- Construction of the Whale Tail Dike is planned from June 2018 to February 2019
- Flooding of the Whale Tail Lake (South Basin)from February 2019 – June 2020 (5 months) via dewatering of the basin north of the dike and from capture of freshet water; maximum elevation is 156 m asl, a difference of 3.5 m
- Total area of the maximum extent of the Whale Tail Lake (South Basin) 3,851,450 m^2. Of this, 1,575,487 m^2 will be flooded terrestrial habitat and 1,382,516 m^2 is original aquatic habitat.
- Total annual flow through the diversion is expected to be approximately 2M m^3
- Maximum elevation maintained from June 2020 to April 2022, approximately 2 years
- Return to baseline elevation of 152.5 m by November 2022, six months later

1.4. Approach

Understanding potential mercury dynamics in the proposed Whale Tail Lake (South Basin) is critical to developing predictions for fish tissue concentrations. Key factors include: bathymetry (surface area to volume), hydrology (catchment size and planned operations), limnology (e.g., stratification, dissolved oxygen), chemical parameters (e.g., pH, sulphate, dissolved organic carbon, baseline mercury), the available carbon pool (terrestrial habitats being flooded) and ecological factors. The most important of these are food chain length, fish species composition, life history (age, growth, diet) and baseline fish mercury concentrations.

Considering the above, the following approach was pursued to achieve the aforementioned overall objective:

- *Relevant background information* (**Section 2**). This section starts with an overview of mercury dynamics in aquatic environments, with emphasis on reservoir creation. It then focuses on presenting and discussing key baseline data for terrestrial and aquatic media.
- *Predicted changes in fish mercury concentrations* (**Section 3**). This section presents two complementary approaches to predicting post-impoundment changes in fish mercury concentrations. The first approach compares the expected conditions in the proposed Whale Tail Lake (South Basin) "reservoir" with those associated with two types of Canadian reservoirs: (a) those where maximum fish mercury concentrations generally increased by less than three times baseline concentrations and (b) those where maximum fish mercury concentrations increase by more than three times baseline. The second approach uses empirical models founded on relationships derived from existing Canadian reservoirs to predict changes in fish mercury concentrations. Methods used follow recent best management practices developed in Ontario for small-scale hydropower projects (Hutchinson Environmental Services Ltd [HESL] 2016), including the application of modifying factors to account for the relatively short life span of the flooded Whale Tail Lake (South Basin). Modifying factors were developed two ways: (1) based on actual monitoring data from existing reservoirs and (2) based on scenarios run using a mechanistic (process-based) mercury model (RESMERC). To understand the implications of the results, predicted changes are presented within the context of allowable servings per month following Health Canada guidance. A weight-of-evidence approach is used to integrate the two sets of results. Key uncertainties are also discussed, along with their likely influence on the predictions.



Legend

2015 Sampling Locations
- Tributary Station
- Periphyton Station
- Sentinel Station
- Sediment and Benthos Station
- Water Quality Station

2014 Sampling Locations
- Water, Sediment, and Benthos Station

* Note: water, phytoplankton, sediment, and benthos were submitted for analysis at these locations in 2014.

- Sediment/Coring/Benthic Invertebrate Quality Sampling Station
- All Weather Access Road
- Proposed Access Road
- Meadowbank Mine Plan 2015
- Lake
- River

0 2 4 6 8

Kilometres

Projection: UTM Zone 14 NAD83

Data Sources:
Natural Resources Canada, GeoBase®
National Topographic Database
Agnico-Eagle Mines Limited.
Azimuth Consulting Group Inc.

Figure 1-1
Meadowbank - Whale Tail Pit Study Area Overview

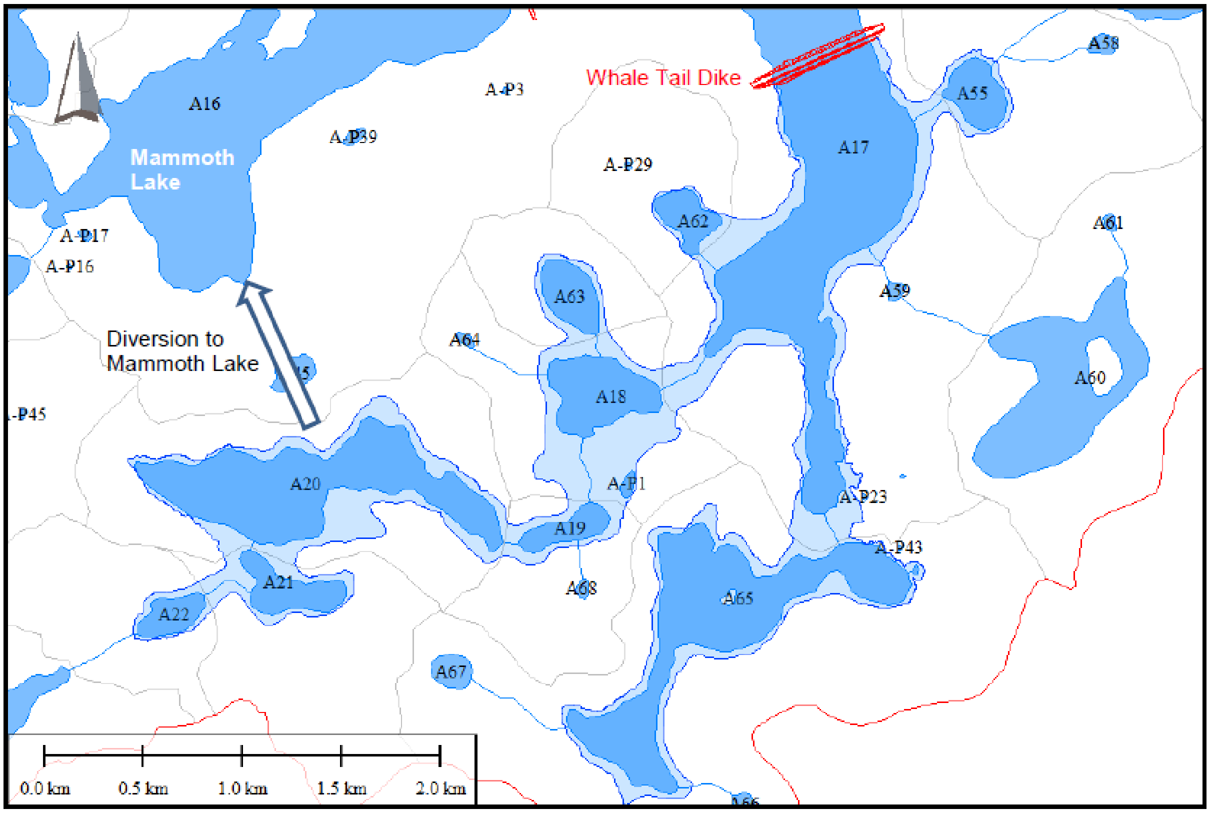
Whale Tail Pit Project

Prepared for: AGNICO EAGLE

By: CASLYS CONSULTING

December 21, 2015

Figure 1-2. Whale Tail Lake (South Basin) - Area Overview.



2. RELEVANT BACKGROUND INFORMATION

The section reviews essential background information on mercury in the environment and those factors that are most important drivers of mercury methylation dynamics in aquatic environments. While this section is not intended to be an exhaustive review of literature, it is sufficiently detailed enough to support our assessment. Knowledge of more than 40 years of investigations in several Canadian reservoirs are used here to inform how raising the water level in Whale Tail Lake and inundating the surrounding soils will affect mercury methylation and ultimately, bioaccumulation by fish in the lake.

2.1. Mercury in the Environment

Mercury is a naturally occurring element that is commonly found in low concentrations in all environmental media including water, sediment, soil, vegetation and in all animal species (Eisler 2000). Mercury is a recognized contaminant with no known biological function. Mercury occurs primarily in inorganic forms, but can be transformed by biotic and abiotic processes into organo-metal compounds (e.g., methylmercury [MeHg]; inorganic Hg + organic Hg = total Hg [THg]), which are the most readily accumulated and more toxic form of mercury (Eisler 2000).

The predominant means by which methylmercury is generated is via the natural, microbial transformation of inorganic mercury (Hecky et al. 1987) in sediments. The methylation process is mostly performed by sulphate reducing bacteria in anaerobic sediments (Gilmour and Henry 1991, Ramlal et al. 1993). All fish contain mercury which occurs primarily (i.e., >90% of the total) as methylmercury (Bloom 1992). In benthic invertebrates and zooplankton, the proportion of the total mercury concentration that is in the methyl form is typically between 30% and 50%, depending on the group (Tremblay et al. 1996, Hall et al. 1997). Methylmercury is unlike most other compounds in that its concentration (and relative proportion) tends to increase through progressively higher trophic levels in the food chain (i.e., biomagnification).

Diet has been shown to be the dominant pathway for methylmercury uptake by biota (Hall et al. 1997), whether within the invertebrate food web (Tremblay et al. 1996) or within fish. Generally, top-level predatory fish, such as lake trout (*Salvelinus namaycush*), have higher tissue mercury concentrations than fish that consume plankton, such as lake whitefish (*Coregonus clupeaformis*), or fish consuming zooplankton, such as Arctic char (*S. alpinus*). In addition, there is a well-known relationship between fish size or age and mercury content (Bodaly et al. 1984, Somers and Jackson 1993). Larger, older fish tend to have higher mercury concentrations than smaller, younger fish. These within-species differences are due to size-related dietary shifts and to duration of exposure. This phenomenon is true in all lakes and rivers, but these differences can become exacerbated following reservoir creation, which will be explored below.

In Arctic lakes, fish consume less food per unit body mass than in temperate lakes because of lower energetic requirements (because of cold water temperatures) and lower availability of food. This influences growth rates of Arctic fish which tend to be quite slow, leading to smaller fish of a similar age than in temperate lakes. As we will discuss later, this may have a significant effect on the rate of accumulation of mercury in muscle tissue over time.

2.2. Reservoir Creation and Mercury

When new reservoirs are created, terrestrial organic soils containing 'fresh' carbon are inundated, leading to a rapid decomposition of this new nutrient source. The decomposition process consumes oxygen and creates much more favorable conditions for mercury methylation by sulphate reducing bacteria, than under natural conditions. A by-product of the accelerated decomposition of carbon, which contains small amounts of inorganic mercury, is enhanced production of methylmercury. Once methylmercury generated by bacteria is incorporated into their tissue, it adds to the existing pool in the aquatic system and becomes concentrated by biota at increasingly higher steps up the food web (Hall et al. 2007).

The phenomenon of increased methylmercury generation was first studied in depth within Southern Indian Lake and along the Churchill River diversion MB in the mid-1980's (Bodaly et al. 1987). Since then, a tremendous amount of research has been conducted, particularly in northern Manitoba and Quebec, to explore the relationships between reservoir creation and those factors that affect the rate and duration of methylmercury generation in newly flooded soil / sediment.

While early research focused on large hydroelectric developments, recent efforts have been undertaken in experimentally created lakes located within the Experimental Lakes Area (ELA) of northwestern Ontario (Bodaly et al., 2004). These systems can be well characterized prior to flooding and can be monitored closely using a mass balance approach. For example, Hall et al. (2005) showed that methylmercury production increased exponentially in sediment, contributing to elevated concentrations in water and zooplankton (Paterson et al. 1998, Tremblay et al. 1998a). Mercury in finescale dace, a forage species, increased between two and three fold within 3 years after inundation (Bodaly and Fudge 1999).

In large reservoirs, fish mercury concentrations of longer lived species (e.g., whitefish, northern pike, lake trout) typically peaked within 6 – 8 years after inundation. Concentrations remain elevated above background for between 15 and 25 years, depending on environmental conditions (Schetagne et al. 2003, Bodaly et al. 2007). This trend has been observed in many reservoirs in both northern Manitoba and Quebec.

Despite advancing the science regarding reservoir creation and methylmercury generation and bioaccumulation over the past few decades, this remains a very complex issue. The unique combinations of site-specific parameters create uncertainty in predictions with respect to the magnitude of mercury concentrations in environmental media and how long they remain elevated above background.

The following sections provide an introduction to the key factors known to strongly influence the prevalence of mercury in various aquatic systems and are compared with site-specific data collected in summer 2016 to provide context.

2.3. Site-Specific Factors Relevant for Predicting Changes in Fish Mercury Concentrations

The rate and duration of methylmercury generation is influenced by many site-specific physical, chemical, and ecological factors, both in natural systems and in new reservoirs. The most important factors are baseline mercury concentrations in environmental media, hydraulic residence time, flooded area relative to original area, pH of water/sediment, the amount and chemical composition of the newly flooded soil and fish community structure. Specific dynamics surrounding the creation of the new 'reservoir' will alter these relationships, ultimately resulting in elevated production of methylmercury and food web mediated bioaccumulation by fish.

The vast majority of reservoirs in Canada have been created within boreal forest habitats, especially in Manitoba (Bodaly et al. 2007), Ontario (Hall et al. 2007) and Quebec (Tremblay et al. 1998b, Schetagne et al. 2003), although a few have also been created in Newfoundland (Harris and Hutchinson 2007), and British Columbia (Stockner et al. 2001). However, to our knowledge, no 'reservoirs' have been created strictly within an Arctic ecosystem. Thus, there is uncertainty about how specific physical (e.g., permafrost), climatic and ecological features may influence these reasonably well known dynamics from more southerly areas. For example, there is a long ice-cover period in Arctic lakes which will influence oxygen concentration and pH in particular, in a direction that may exacerbate methylmercury production. On the other hand, cold water temperatures, freezing of shorelines to a maximum depth of 2 m at end of winter, oligotrophic status and short food web may reduce the rate of methylmercury generation. Thus there is some uncertainty regarding how these factors interact and influence the end result. In the case of Whale Tail Lake (South Basin) however, the most important factor is the relatively short duration of flooding of adjacent terrestrial soils (Section 1.3), prior to a return to baseline water levels. This is likely the most important factor dictating mercury methylation dynamics and is discussed as part of the mercury modeling process.

As part of our weight-of-evidence approach, this section discusses the factors that control or influence methylmercury generation and bioaccumulation, based on well-established relationships in other reservoirs based on the scientific literature. This, combined with the modeling, will put site-specific conditions found in Whale Tail Lake in perspective, to enable us to predict the most likely scenario with respect to magnitude and duration of changes to mercury concentrations in environmental media and fish in particular.

2.4. Baseline Terrestrial Media

Organic soils in flooded terrestrial habitats are the medium for bacterially-mediated mercury methylation and mobilization of methylmercury into aquatic food chains. The main 'ingredients' or drivers to methylation are the concentration of inorganic mercury (mg Hg/ha) and the biomass of carbon (metric tonnes C/ha) in organic soils. Vegetation tends to play a lesser role in this process as the bulk of the 'raw ingredients' are in the soil, not overlying plants of which a very small proportion (<2%) is methylmercury (Rasmussen 1995, Grigal 2003). While mercury in plants was not measured, concentrations are lower than in soil, in the order of <0.005 to 0.019 mg/kg dry weight).

Following inundation the bulk of mercury methylation occurs in the top 5 – 10 cm of the litter, fermentation and humus soil horizons (Coleman et al. 1999). The amount of easily decomposable or bioavailable 'labile' carbon in this layer is also a key parameter to mercury methylation. While this has been well studied in reservoirs within forested areas where there is better defined 'soil', the composition of Arctic soils are different, with a higher amount of muskeg/peat as well as lichen and moss. Because of the influence of permafrost (permanently frozen ground within 1 m of surface), the surface soils tend to be quite wet, especially around lake margins in low-lying areas. Organic soils occur where water has accumulated to such a degree that decomposition has been considerably depressed, resulting in an accumulation of organic material, called peat. These kinds of peat-rich soils contain abundant organic material as well as mercury and tend to contribute more to mercury methylation production rates than upland soils, as has been demonstrated at the Experimental Lakes Area (ELA) in northwestern Ontario (e.g., Bodaly and Fudge 1999, Kelly et al. 1997, Bodaly et al. 2004, Hall and St. Louis 2004, Hall et al. 2005).

In addition, certain plant species such as lichen and moss (Zhang et al. 1995, Evans and Hutchinson 1996) are well known to accumulate and sequester atmospheric mercury at far higher concentrations than other plants. As such lichen are often used as sentinel species to track atmospheric quality, especially for mercury (e.g., Evans and Hutchinson 1996). Thus, the composition of plant / soil material in Arctic soils may be associated with higher availability of inorganic mercury than other soil types found in drier, forested and upland habitats.

Four soil samples were collected from the top ~ 5 cm beneath the surface litter layer from representative habitat around Whale Tail Lake, within the proposed inundation zone (**Figure 2-1**). Soils were analysed for organic content (%) and total metals concentration, including total mercury and methylmercury. Soil pH ranged from 5.8 – 6.7 in the four samples which is fairly typical for soils in non-coniferous settings.

Moisture content was ~10% which is reasonably dry. Total organic carbon content ranged from 17 – 48% (**Table 2–1**), confirming the highly organic nature of the thin soils in this Arctic region.

With respect to mercury, three of the four samples were below the laboratory detection limit (DL) for mercury (<0.005 mg/kg dry weight) with one sample above the DL (0.0066 mg/kg dw). These concentrations are quite low and consistent with the low range of mercury concentrations found in soils (0.01 mg Hg/kg) measured elsewhere from background, non-mineralized areas (e.g., McKeague and Kloosterman 1974, Rasmussen 1994, Lodenius 1994).

Because total mercury content of soil is most frequently associated with organic matter content it is a bit surprising that mercury content of the soil here is so low. This is probably a reflection of the fairly recent soil development timeframe post-glaciation and perhaps low atmospheric mercury concentrations in this region of the Arctic.

Methylmercury concentration measured from each of the soil samples was less than the DL (<0.00005 mg/kg dw) for three samples and just over the DL (0.000053 mg/kg) in the soil sample with a detectable mercury concentration (**Table 2–1**). This result confirms that the proportion of the total concentration that is present as methylmercury is less than 1%, which is on the low end of what is characteristic of terrestrial soils (Grigal 2003). These data suggest that mercury and methylmercury concentrations in terrestrial soils of the Whale Tail area proposed for inundation are very low.

Soil pH is an important determinant as to the bioavailability of mercury bound to carbon in soil. While at reduced pH (<6) under slightly acidic conditions, such as may exist under a coniferous forest soil canopy (e.g., conditions under which most northern Canadian reservoirs have been created) mercury reacts somewhat different than other metals. Rather than being mobilized, mercury tends to become immobilized because acidic conditions reduce degradation of organic material and favors condensation of humic acids, to which mercury becomes bound. Here, soil pH is above this threshold which may favor greater bioavailability; however, the very low concentration of mercury in the soil may minimize this as a factor.

2.5. Baseline Aquatic Media

Key parameters in the physical aquatic environment that influence generation and bioaccumulation of methylmercury are hydrology, limnology and specific water and sediment chemistry parameters (e.g., Weiner et al. 1990, Greenfield et al. 2001, Bodaly et al. 2004). Hydrology, including water residence or turnover time and the ratio of original lake area to flooded area are discussed within the modeling section of this report. These are highly influential factors that are probably the most important drivers behind methylation, in concert with water and sediment quality parameters as discussed below.

Among the water chemistry factors that have been demonstrated to be correlated with increases in fish mercury concentrations, the most important are pH (negative), DOC/TOC (positive), sulphate (positive) and labile carbon / carbon biomass in flooded soil (positive). While few studies have attempted to determine the fraction of carbon in flooded soils that is labile (i.e., easily available, most amenable to contributing to methylation, as discussed above) relative to refractory (i.e., less available). The most reliable surrogate for this is the amount (% or ha) of flooded wetland, which is correlated with peat / muskeg soils. Relationships between chemical factors in water and soil/sediment and relationships with mercury concentrations in environmental media, based on the literature are explored here.

2.5.1. Water Chemistry

Water pH is one of the most important determining factors in the rate of mercury methylation. Slightly acidic water (i.e., lower pH; <6.5) appears to favor methylation, ultimately resulting in elevated fish mercury concentrations in low pH reservoirs compared to fish from circumneutral lakes and reservoirs (Scheuhammer and Graham 1988, Grieb et al. 1990, Wiener et al. 1990, Gorski 2003, Simonin et al. 2008, Greenfield et al. 2001). Water pH in excess of 7.0 has been associated with a lower magnitude of increase in methylmercury concentrations in environmental media in new reservoirs, including fish.

Within Whale Tail Lake, pH was measured between 6.5 and 6.8 in 2016, placing the lake as slightly acidic, but still above the threshold where methylation is stimulated (**Table 2–2**). Mammoth Lake had a similar pH (6.4 – 6.8) as did A20 (pH 6.5) and A76 (6.7 – 6.8) (**Figure 1-2**). Water pH in the project lakes is intermediate between circumneutral (pH 7.0) and the threshold where pH favors methylation (6.5). Thus, the influence of pH as a factor that enhances methylation appears to be minor and should not play a large role with respect to stimulation of mercury methylation.

Elevated dissolved organic carbon (DOC) concentration is also known to stimulate methylmercury production. Ravichandran (2004) reviewed interactions between mercury and dissolved organic matter, finding that DOM interacts very strongly with mercury, affecting its bioavailability, mobility and toxicity. In Whale Tail Lake, the dissolved and total organic carbon concentrations were similar at 2.3 mg/L in summer 2016 (**Table 2–2**), similar to both Mammoth (1.9 – 2.2 mg/L) and Nemo LakeS (2.0). These concentrations are lower than reservoirs with peak mercury concentrations >3x baseline, where DOC concentration was < 5.0 mg/L. Low DOC favors a low magnitude increase.

Sulphate (S04-) concentration in water has also been implicated in favoring methylation because sulphate provides an important nutrient for sulphate-reducing bacteria (SRB). SRB are widely acknowledged as being primarily responsible for mediating the conversion of inorganic to methylmercury (Beaudoin et al. 1999). In 2016, sulphate concentration in Whale Tail Lake was 1.2 – 1.9 mg/L (**Table 2–2**), slightly lower than in Mammoth Lake (1.9 – 3.4 mg/L). Regardless, both of these concentration ranges are relatively low, much lower than the threshold of >5 mg/L that is purported to be positively correlated with methylation.

In reservoirs with a large relative percentage of wetland/peatland area relative to total flooded area, has been shown to be positively correlated with peak mercury concentrations >3x baseline. While we are uncertain about the relationship between moss / lichen / muskeg found in Arctic soils and 'wetlands' found in boreal forest settings of northern Quebec and Manitoba both have reasonably large quantities of wet, poorly metabolized soils, which may provide a good growth medium for SRB.

Finally, among baseline water quality parameters, inorganic and methylmercury concentrations are the only other parameters directly linked to the methylation process (Bodaly et al. 2004). Basically, there is a tendency for water bodies with elevated baseline mercury/methylmercury concentrations to be associated with elevated mercury concentrations in fish.

To provide perspective, total mercury (i.e., all forms, including inorganic and methylmercury) concentrations in remote, pristine lakes and rivers typically range in concentration from <1 – 3 ng/L (i.e., parts per trillion or 1,000 µg/L). In Whale Tail Lake, total mercury concentration in three samples from the mid water column was less than the laboratory DL of 0.5 ng/L (<0.00005 µg/L or 0.5 ng/L). Only one sample was equivalent to the DL at 0.5 ng/L. These are extremely low concentrations and indicative of the very oligotrophic nature of the water with low metals of all kinds.

Methylmercury concentration in water was similarly low, less than the DL of 0.05 ng/L in the single sample collected (**Table 2–2**). As a percentage of the total mercury concentration, methylmercury usually comprises between 1% and 10% of the total (Hurley et al. 1995, Krabbenhoft et al. 1999, St. Louis et al. 1995, Bodaly et al. 2004). Of the only detectable mercury concentrations in water, the ratio was 10% in Whale Tail. This value is consistent with what has been observed elsewhere when total and methylmercury concentrations are low and near the laboratory DLs.

Overall, the water quality data suggest that the peak fish mercury concentration in the Whale Tail Lake (South Basin) will be less than 3x baseline concentrations.

2.5.2. Sediment

Sediment mercury and methylmercury concentrations are also strong indicators of the potential for mercury methylation potential in the aquatic food web. The vast majority of methylmercury is naturally produced in the sediment by SRB as part of organic carbon decomposition. When new soils are flooded that contain 'new' sources of labile organic material and mercury, the bacterial decomposition process of these new 'sediments' further stimulates methylmercury generation. Methylmercury is released to the overlying water column and absorbed by plankton, as well as being readily taken up by benthic invertebrates living in or colonizing the new sediments. Thus the food web mediated transfer of methylmercury results in increased uptake and accumulation of mercury by fish (Hall et al. 1997).

Within sediment / soil, inorganic mercury is most common, mostly adhered to fine sediment and organic particles. A small amount of the total, usually around 1%, is methylmercury. The concentration of inorganic and methylmercury in sediments is correlated positively with small grain size (i.e., clay and silt, not sand/gravel), as well total organic carbon (TOC) particles, where inorganic mercury is sequestered. Thus the grain size and proportion of TOC in sediments is also an indicator of methylmercury generation potential and accumulation by fish.

Sediment from north and basin stations in 2015/2016 (6.5 – 9.0 m) was quite fine, dominated by silt / clay (76 – 97%) (**Table 2–3**). Total organic carbon (TOC) concentration ranged from 4.3% to 8.7% in 2015 and 2016. Sediments with a high amount of fines (>75%) and TOC >5% are relatively organic rich and provide favorable conditions for mercury methylation. However due to low sedimentation rates in Arctic systems, the TOC in the lake basin is likely 'old' and may not provide an ideal food source for SRB and mercury methylation.

Total mercury concentration in sediment from both basins of Whale Tail Lake in 2015 averaged 0.08 mg/kg within a narrow range (0.06 – 0.095 mg/kg) (**Table 2–3**). The range in 2016 from five stations in the south basin was also very similar (0.067 – 0.093) with a mean of 0.078 mg/kg. These concentrations are quite low relative to sediment mercury concentrations from other natural lakes and reservoirs. For example, in 'reference' lakes in undisturbed forests of northern Quebec, total mercury in sediment ranged from 0.03 – 0.35 mg/kg (Lucotte et al. 1999, Schetagne et al. 2003, 2005, Therien and Shetagne 2005). At the Experimental Lakes Area (ELA) in northwestern Ontario (Bodaly et al. 2004, Hall et al. 2005), sediment mercury concentration was also low (0.04 – 0.09 mg/kg) in regional lakes, similar to the range found at Whale Tail. These data indicated that sediment total mercury concentrations in Whale Tail Lake are relatively low, even for other pristine lakes elsewhere in Canada. These data suggest that atmospheric deposition of mercury and sequestration in sediments in this area is low.

Methylmercury concentration in five sediment samples in 2016 ranged from 0.00033 – 0.0010 mg/kg with a mean of 0.00059 mg/kg (**Table 2–3)**. These values comprised less than 1% of total mercury concentration (0.75%). These concentrations are low and percentage-wise are also on the low end of the scale for pristine watersheds. These data confirm that total and methylmercury concentrations in Whale Tail Lake sediments are low and similar to or less than sediment mercury concentrations in pristine lakes elsewhere in Canada.

2.5.3. Fish

The main influencing factors of fish mercury concentrations are methylmercury concentrations in prey, age and size of fish, growth rates, bioenergetics and reproduction (i.e., the latter two are means by which fish can eliminate methylmercury). Because methylmercury accumulated by fish is primarily acquired from dietary sources (Hall et al. 1997), body burden concentration is highly dependent on concentrations in their food, and trophic status. In general, fish mercury concentrations are highest in large predatory species, such as lake trout.

C. Portt and Associates (2015) conducted sampling for fish mercury concentrations in 2015 to characterize baseline conditions. Lake trout from a range of size classes were sampled from Mammoth Lake and Whale Tail Lake to allow for characterization of length-mercury relationships in each lake. In addition, composite samples of nine-spine stickleback were also sampled from each lake to characterize mercury concentrations in low trophic level fish. Results of baseline sampling are summarized in **Table 2–4**; key results were as follows:

- Lake trout – the size range of fish caught in Whale Tail Lake (mean 470 mm) was generally larger than for Mammoth Lake (360 mm), a difference of 100 mm smaller. As expected based on the size discrepancy between the lakes, mean mercury concentration was higher in Whale Tail Lake (0.50 ppm (mg/kg) wet weight) than in Mammoth lake (0.21 ppm ww). The maximum baseline mercury concentration for lake trout was 2.19 ppm (mg/kg) wet weight (ww), which was from the largest fish captured from Whale Tail (890 mm).
- Nine-spine stickleback – fish sizes[1] and mercury concentrations were similar between the two lakes. Mercury concentrations (in composite samples of several whole fish) in these low-trophic level fish were expectedly low, ranging from 0.05 to 0.08 mg/kg ww in Whale Tail Lake.

Given the known relationship between fish size and mercury, meaningful comparisons of temporal or spatial patterns can only be made if statistical models are applied to the data to allow the estimation of mercury concentrations for a specific size fish. Most modelling is conducted using the convention of species-specific "standardized" sizes for consistency across studies. While different statistical tools can be used to model length-mercury relationships, polynomial regression analysis (e.g., Tremblay et al. 1998b) was used to model length-mercury relationships in lake trout and estimate mercury concentrations (for the standardized size of 550 mm) in Mammoth and Whale Tail Lake (**Figure 2-2**). Differences identified between Mammoth and Whale Tail lakes appear to be an artefact of the generally smaller fish caught at Mammoth. The model fit for Mammoth Lake is strongly influenced by the two largest fish, both of which are positioned below the Whale Tail Lake model fit (i.e., lower mercury concentrations for their size) but are within the range of variability seen for Whale Tail Lake. Thus, the reported differences are not likely due to systematic differences between the two lakes.

Notwithstanding, the main objective here is to characterize baseline mercury concentrations in lake trout from Whale Tail Lake to support this study. A 550-mm standardized size lake trout is estimated to have a mercury concentration of 0.58 mg/kg wet muscle with a 95% confidence interval extending from 0.51 to 0.66 mg/kg (**Figure 2-2**). Baseline study results show that the likely age of a 550-mm lake trout would be approximately 25 years (C. Portt and Associates 2015), indicating a very slow growth rate. This is considerably older than similarly sized lake trout from non-Arctic regions of Canada. For the example lakes shown in the comparative growth rate table for lake trout in Scott and Crossman (1973), 550 mm is attained as early as the 6+ cohort and as late as the 18+ cohort, depending upon latitude (and lake water temperature). The implications of slow growth on rate of bioaccumulation of tissue mercury is discussed further in **Section 0**.

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[1] Note that the tissue samples were comprised of a number of fish

Table 2-1. Soil chemistry results from the 2016 sampling program, Whale Tail Pit Mercury Assessment.

	CCME Soil Quality Guideline[1]	2016 Soil Samples - Whale Tail Pit Flood Zone							
		WTS-SOIL-1	WTS-SOIL-2	WTS-SOIL-3	WTS-SOIL-4	Summary Statistics			
		18-Aug-16	18-Aug-16	18-Aug-16	18-Aug-16	**Min**	**Max**	**Mean**	**Stdev**
Physical & Organic Parameters									
Moisture (%)		8.8	9.9	9.7	11	8.8	11	9.8	0.96
pH		6.7	6.1	6.4	5.8	5.8	6.7	6.3	0.38
Total Organic Carbon (% dw)		0.30	0.27	0.17	0.49	0.17	0.49	0.31	0.13
Speciated Metals (mg/kg dw)									
Methyl Mercury		*<0.000050*	*<0.000050*	*<0.000050*	0.000053	0.000053	0.000053	0.000053	-
Total Metals (mg/kg dw)									
Aluminum		6380	7860	7470	6660	6380	7860	7093	690
Antimony	20	*<0.10*	*<0.10*	*<0.10*	*<0.10*	*<0.10*	*<0.10*	*<0.10*	*<0.10*
Arsenic	12	2.9	3.8	3.2	3.5	2.9	3.8	3.3	0.36
Cadmium	10	0.034	0.041	0.031	0.039	0.031	0.041	0.036	0.0
Calcium		2830	2860	2710	2580	2580	2860	2745	128
Chromium (total)	64	25	37	37	29	25	37	32	6.1
Cobalt	50	5.2	7.5	6.6	5.8	5.2	7.5	6.3	1.0
Copper	63	4.6	7.6	6.5	4.5	4.5	7.6	5.8	1.5
Iron		14300	16900	15700	15700	14300	16900	15650	1063
Lead	140	5.7	6.3	5.6	6.0	5.6	6.3	5.9	0.31
Lithium		7.7	9.4	9.1	8.6	7.7	9.4	8.7	0.74
Magnesium		3670	4870	4700	3610	3610	4870	4213	665
Manganese		219	270	239	243	219	270	243	21
Mercury	6.6	*<0.0050*	*<0.0050*	*<0.0050*	0.007	*<0.0050*	0.007	0.007	-
Molybdenum	10	0.27	0.39	0.50	0.40	0.27	0.50	0.39	0.094
Nickel	45	15	24	23	18	15	24	20	3.9
Phosphorus		525	539	505	542	505	542	528	17
Potassium		1000	1090	1010	940	940	1090	1010	62
Selenium	1	*<0.20*	*<0.20*	*<0.20*	*<0.20*	*<0.20*	*<0.20*	*<0.20*	-
Zinc	200	26	33	27	28	26	33	28	3.0

Notes:

[1] CCME (Canadian Council of Ministers of the Environment) Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health (Residential/Parkland).

123 Bold italicized concentrations exceed the soil quality guideline.

Italicized numbers are below detection limits.

Table 2-2. Water chemistry data for the Lake stations, Whale Tail Pit Baseline, 2016.

Lake	Aquatic Life	Whale Tail Lake (WTS)							
Station	Guidelines								
Area-Replicate ID		WTS-07	WTS-08	WTS-09	WTS-10	WTS-11	WTS-12	WTS-13	WTS-14
Depth (m)	CCME[1]	3	3	3	3	3	3	3	3
Date		24-Apr-16	24-Apr-16	28-Jul-16	28-Jul-16	17-Aug-16	17-Aug-16	11-Sep-16	11-Sep-16
Physical Tests (mg/L)									
Conductivity (µS/cm)		32.0	32.2	24.3	24.3	25.9	26.8	30.4	29.0
Hardness		11.4	11.7	8.9	9.1	9.7	9.8	10.2	10.4
pH (Laboratory)	6.5 - 9.0	6.87	6.61	6.55	6.55	6.84	6.82	6.79	6.75
Total Suspended Solids		*<1.0*	*<1.0*	*<1.0*	*<1.0*	*<1.0*	*<1.0*	*<1.0*	*<1.0*
Total Dissolved Solids		22	22	27	28	18	20	21	21
Turbidity (NTU)		0.15	0.16	0.35	0.33	0.27	0.28	0.25	0.35
Organic / Inorganic Carbon (mg/L)									
Dissolved Organic Carbon		2.3	2.2	2.0	2.2	2.2	2.1	1.9	2.0
Total Organic Carbon		2.3	2.3	2.1	2.1	2.3	2.4	2.1	2.2
Methyl Mercury (µg/L)									
Total		-	-	-	-	-	*<0.00005*	-	-
Dissolved		-	-	-	-	-	*<0.00005*	-	-
Total Metals (mg/L unless stated otherwise)									
Aluminum[2]	***equation***	0.0056	0.0046	0.0118	0.0129	0.0072	0.0087	0.0084	0.0092
Antimony		*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*
Arsenic	0.005	0.00017	0.00017	0.00016	0.00017	0.00016	0.00016	0.00024	0.00021
Barium		0.0052	0.0051	0.0048	0.0049	0.0046	0.0050	0.0051	0.0053
Cadmium[2]	***equation***	*<0.0000050*	*<0.0000050*	*<0.0000050*	*<0.0000050*	*<0.0000050*	*<0.0000050*	*<0.0000050*	*<0.0000050*
Calcium		2.88	2.76	2.39	2.42	2.63	2.86	2.78	2.88
Chromium[3]	0.001	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	0.0001	0.0001
Cobalt		*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*	*<0.00010*
Copper[2]	***equation***	*<0.00050*	*<0.00050*	*<0.00050*	*<0.00050*	*<0.00050*	*<0.00050*	0.0006	*<0.00050*
Iron	0.3	*<0.010*	*<0.010*	0.026	0.027	0.014	0.019	0.019	0.020
Lead[3]	***equation***	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	0.00016	0.00035
Magnesium		1.04	1.00	0.72	0.73	0.78	0.83	0.83	0.81
Manganese[2]		0.0010	0.0011	0.0031	0.0031	0.0017	0.0022	0.0022	0.0021
Mercury (µg/L)	0.026	*<0.0050*	*<0.0050*	*<0.0050*	*<0.0050*	*<0.0050*	*<0.0050*	*<0.0050*	*<0.0050*
Mercury (ultra low DL [µg/L))	0.026	-	-	-	-	-	*<0.00050*	-	-
Molybdenum	0.073	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	0.0002
Nickel[2]	***equation***	0.0007	0.0007	0.0008	0.0008	0.0006	0.0006	0.0012	0.0008
Phosphorus		*<0.050*	*<0.050*	*<0.050*	*<0.050*	*<0.050*	*<0.050*	*<0.050*	*<0.050*
Potassium		0.54	0.50	0.39	0.42	0.43	0.45	0.50	0.50
Selenium	0.001	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*	*<0.000050*
Zinc[4]	0.030	*<0.0030*	*<0.0030*	*<0.0030*	*<0.0030*	*<0.0030*	*<0.0030*	*<0.0030*	*<0.0030*

Notes:

[1] CCME (Canadian Council of Ministers of the Environment) Canadian Water Quality Guidelines for the Protection of Aquatic Life, 1999, updated up to 2015.

[2] "***equation***" means that CCME guidelines (or thresholds) are calculated based on an equation which is either pH or hardness dependent. The ammonia and aluminum (t & d) guidelines vary with pH; the cadmium, copper, lead, manganese, nickel and zinc guidelines vary with hardness.

[3] Chromium CCME guideline is for Cr VI.

123	Shaded concentrations exceed the CCME aquatic life guidelines.
123	Bordered concentrations exceed the GCDWQ.

Italicized numbers are below detection limits.

"-" not collected.

Table 2-3. Conventional sediment grab chemistry, particle size, and total metals concentrations, Whale Tail Pit Baseline, 2016.

	CCME (2002) Guideline[2]		Whale Tail Lake South Basin (WTS)								
			WTS-1	WTS-2	WTS-3	WTS-4	WTS-5	Summary Statistics			
	ISQG	**PEL**	12-Aug-16	12-Aug-16	12-Aug-16	12-Aug-16	12-Aug-16	**Min**	**Max**	**Mean**	**Stdev**
Physical & Organic Parameters											
Moisture (%)			84	85	88	89	86	84	89	86	2.3
pH			6.3	5.9	5.8	5.9	6.4	5.8	6.4	6.1	0.26
Total Organic Carbon (% dw)			4.9	4.3	6.8	7.9	4.7	4.3	7.9	5.7	1.6
Particle Size											
% Gravel (>2mm)			*<0.10*	*<0.10*	*<0.10*	*<0.10*	*<0.10*	0.0	0.0	*<0.10*	-
% Sand (2.00mm - 0.063mm)			3.3	4.4	4.2	2.2	4.0	2.2	4.4	3.6	0.88
% Silt (0.063mm - 4µm)			80	79	78	78	76	76	80	78	1.6
% Clay (<4µm)			17	17	18	20	20	17	20	18	1.6
Plant Available Nutrients (mg/kg d											
Available Sulfate-S			32	22	26	21	44	21	44	29	9.4
Speciated Metals (mg/kg dw)											
Methyl Mercury			0.000592	0.000333	0.000998	0.000457	0.000605	0.00033	0.00100	0.00060	0.00025
Total Metals (mg/kg dw)											
Aluminum			14500	15100	16100	17200	17800	14500	17800	16140	1383
Antimony			0.22	0.20	0.19	0.21	0.32	0.19	0.32	0.23	0.053
Arsenic*	5.9	17	***115***	***112***	***14***	***8.5***	***93***	***8.5***	***115***	***69***	***53***
Barium			99	104	108	132	111	99	132	111	13
Cadmium*	0.6	3.5	0.23	0.24	0.23	0.35	0.30	0.23	0.35	0.27	0.055
Calcium			1980	1960	3290	3480	3080	1960	3480	2758	733
Chromium*	37.3	90	***57***	***61***	***64***	***69***	***149***	***57***	***149***	***80***	***39***
Cobalt			24	20	7.6	8.0	12	7.6	24	14	7.4
Copper*	35.7	197	35	35	***37***	***39***	***59***	35	***59***	***41***	10
Iron			88000	82700	25200	20600	36500	20600	88000	50600	32300
Lead	35	91.3	12	12	13	12	17	12	17	13	2.3
Magnesium			5300	5640	6060	6750	8600	5300	8600	6470	1308
Manganese			3860	2850	278	286	339	278	3860	1523	1711
Mercury	0.17	0.486	0.079	0.068	0.082	0.068	0.093	0.068	0.093	0.078	0.011
Molybdenum			4.0	5.0	2.2	1.5	3.6	1.5	5.0	3.3	1.4
Nickel			64	61	58	59	100	58	100	68	18
Phosphorus			913	873	706	762	811	706	913	813	83
Potassium			2030	2120	2300	2490	2610	2030	2610	2310	243
Selenium			0.78	0.66	0.54	0.51	0.66	0.51	0.78	0.63	0.11
Sodium			137	157	169	197	150	137	197	162	23
Strontium			21	21	26	28	23	21	28	24	3.4
Vanadium			22	24	23	24	37	22	37	26	6.1
Zinc*	123	315	75	75	79	85	117	75	117	86	18

Notes:

[2] CCME (Canadian Council of Ministers of the Environment) Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, 1999, updated in 2002. ISQG = Interim freshwater Sediment Quality Guideline. ISQG = Interim sediment quality guideline; PEL = probable effect level.

123 Bold italicized concentrations exceed the ISQG guideline.

123 Bordered concentrations exceed the PEL guideline.

Italicized numbers are below detection limits.

Table 2–4. Baseline fish mercury concentrations in lake trout and nine-spine stickleback from Mammoth Lake and Whale Tail Lake.

Species	Lake	N	Length Range (mm)	Length Mean (mm)	Mercury Range (mg/kg wet)	Mercury Mean (mg/kg wet)
lake trout	Mammoth	25	215-700	360	0.07-1.07	0.21
lake trout	Whale Tail	21	159-860	469	0.08-2.19	0.50
stickleback	Mammoth	8	38-56	45	0.04-0.08	0.05
stickleback	Whale Tail	7	37-58	43	0.05-0.08	0.06

Figure 2-1: Sediment and soil sampling locations for the proposed Whale Tail Impoundment, 2016.

Version Date: 15 December 2016

Data Sources

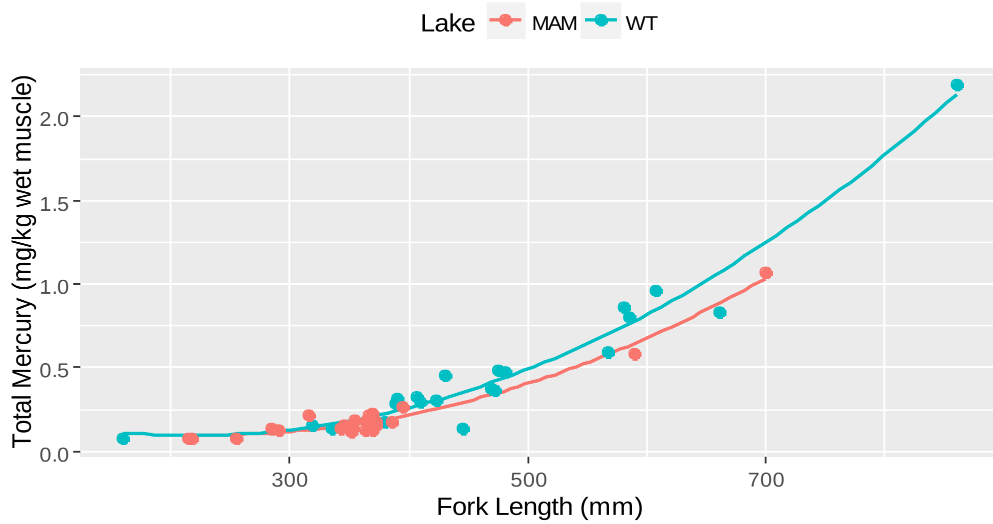
Projection: UTM 14 NAD83

Whale Tail Impoundment Mercury Assessment.

AZIMUTH

Figure 2-2. Mercury concentrations in lake trout from baseline sampling: (a) length-mercury relationships for Mammoth and Whale Tail lakes, (b) statistical comparison of position and shape coefficients (see text for explanation), (c) plot of mercury concentration and 95% confidence limits for standardized 550-mm lake trout in Mammoth and Whale Tail lakes, and (d) model-predicted values from above plot.

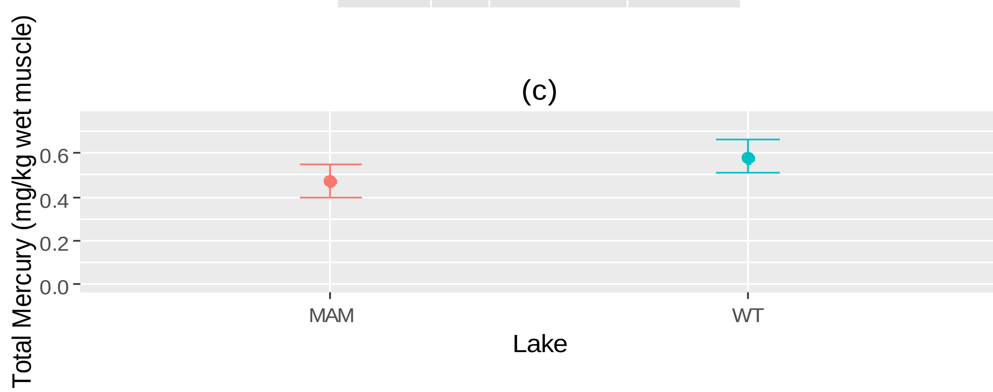
(a)



(b)

Lake	N	Position	Shape
MAM	25	b	a
WT	21	a	a

(c)



(d)

Lake	N	Std Length (mm)	Hg (ppm)	Hg (LCL)	Hg (HCL)
MAM	25	550	0.47	0.40	0.55
WT	21	550	0.58	0.51	0.66

3. PREDICTED CHANGES IN FISH MERCURY CONCENTRATIONS

This section presents two complementary approaches to predicting post-impoundment changes in fish mercury concentrations. The first approach (**Section 3.1**) compares the expected conditions in the proposed Whale Tail Lake South Basin with those associated with two types of Canadian reservoirs: (a) those where fish mercury concentrations generally increased by less than three times baseline concentrations and (b) those where fish mercury concentrations changes by more than three times baseline. The second approach (**Section 3.2**) uses empirical models founded on relationships derived from existing Canadian reservoirs to predict changes in fish mercury concentrations. Methods used follow recent best management practices developed in Ontario for small-scale hydropower projects (HESL 2016), including the application of modifying factors to account for the relatively short life span of the flooded Whale Tail Lake (South Basin). Modifying factors were developed two ways: (1) based on actual monitoring data from existing reservoirs and (2) based on scenarios run using a mechanistic (process-based) mercury model (RESMERC). To understand the implications of the results, predicted changes are presented within the context of allowable servings per month following Health Canada guidance (Health Canada 2007). A weight-of-evidence approach (**Section 3.3**) is used to integrate the two sets of results, including a discussion of key uncertainties and their likely influence on the predictions.

3.1. Comparative Assessment Using Canadian Reservoirs

A great deal of knowledge has been gained in Canada over the last 30 – 40 years regarding the underlying relationships between key physical, chemical and ecological factors that are positively correlated with the magnitude and duration of increase in fish mercury concentrations following impoundment. Recently, Azimuth was responsible for undertaking the Environmental Impact Statement for the Site C Clean Energy Project in BC. As part of this exercise, we examined these relationships in close detail. One of the products of this exercise was the 'Canadian Reservoirs Comparison Matrix' that was a chapter in the larger report entitled the Mercury Technical Synthesis Report, Vol. 2, Appendix J of the EIS (Azimuth 2012). The following discussion synthesizes those factors most closely associated with increases in fish mercury concentrations and puts local Whale Tail data, as discussed above, in context, to provide our assessment of where Whale Tail Lake 'stands' relative to other reservoirs.

Key factors were identified from seven Manitoba reservoirs (Keeyask, Limestone, Long Spruce, Notigi, Southern Indian Lake, Stephens, and Wuskwatim), five Quebec reservoirs (Caniapiscau, LG1, LG2 [Robert Bourassa], LG3, and Opinaca), two Labrador reservoirs (Gull and Muskrat) and Williston Reservoir (B.C.). Each of the reservoirs evaluated was placed into one of two categories, either 'low' or 'high', based on the magnitude of increase in fish Hg concentration relative to baseline, or reference data (i.e., nearby water bodies not influenced by flooding). A value of less than 3x above baseline was defined as producing a 'low' increase in fish mercury concentration, while an increase of more than 3x baseline was defined as a producing a 'high' increase in fish mercury concentration. The value of 3x baseline was chosen as a cutoff value, which is approximately half the increase in what is seen in most 'worst-case' scenario increase reservoirs (an increase of 6–7x baseline). A 3x increase factor is conservative, yet high enough that it is statistically distinguishable from baseline, and the return to baseline can be measured with greater precision (Azimuth 2012).

Table 3–1 summarizes the key parameters using site-specific data and assesses whether fish in the proposed Whale Tail Lake (South Basin) will fall either below ('low magnitude') or above ('high magnitude') a three times increase above baseline concentrations. Note that this assessment is based on reservoirs that have been created and maintained for at least a 20+ year period; a situation that does not apply to Whale Tail Lake (South Basin), with a 'life span' of only 4 years. Thus, this assessment is relatively conservative, notwithstanding the fact that the big 'pulse' of methylmercury generated at the bacterial level takes place during the first 2 – 3 years after inundation (Kelly et al. 1997, Bodaly et al. 2004).

Among the large number of factors considered, the most important physical factors associated with enhanced mercury methylation were:

- Total reservoir area – Larger reservoirs have fish with higher Hg concentrations and take longer to return to baseline or background (relative to nearby lakes). The size of the Whale Tail Lake (South Basin) is relatively small, with a good portion of the flooded soil being frozen over the winter, placing this lake into the '**low**' category increase (i.e., <3x increase).
- Ratio of total reservoir area (original area) – The higher the ratio, the greater amount of methylmercury that is generated. The predicated ratio for Whale Tail (South Basin) is less than 50%, putting it into the **low** increase category.
- Water residence time – Fish from longer residence time reservoirs have higher Hg concentrations that persist for a longer period. Given that Whale Tail water elevations will be raised and held, there is no export of methylmercury generated. This places this lake into the **high** increase category; the short duration of inundation may compensate for this to some extent, however.

The most important chemical factors were:

- Slightly acidic pH (<6.5) water and sediment is associated with higher Hg concentrations in fish. Whale Tail pH is slightly higher, but has low buffering capacity. We have therefore conservatively placed this lake into the **high** increase category.
- Higher total or dissolved organic carbon (TOC/DOC) concentrations in water (>5 mg/L) are weakly but positively correlated with the magnitude of increase in fish Hg. TOC/DOC in Whale Tail are well below this threshold, placing it into the **low** increase category. It is also noteworthy here that baseline total and methylmercury concentrations are very low, indicating a relatively low methylating environment.
- Labile or easily degradable carbon, best represented by the amount (% of total and/or hectares) of wetland within the reservoir has been found to be a key contributor to elevated mercury methylation rates. Arctic soils contain boggy, organic rich soils which are associated with elevated methylmercury generation. However, given our uncertainty about how Arctic soils will react, and considering the length of time during a year they may be frozen, we are uncertain as to which category Whale Tail Lake (South Basin) will fall for this parameter. As with water, it is also noteworthy that baseline mercury and methylmercury concentrations in sediment and soil are very low, again indicating a poor methylating environment.

The most important ecological factors are:

- Food chain length and diet – Lakes and reservoirs with a long food chain and higher dietary mercury concentrations in invertebrates and low trophic level fish are associated with higher increases in mercury. Food chain length in Whale Tail is quite short and we have no data on invertebrate concentrations. Despite this, the short food chain length of Arctic lakes would place Whale Tail in the **low** increase category.
- Fish age / growth – Reservoirs that are productive and encourage high growth of fish can diminish or 'dilute' the accumulation rate of methylmercury in tissue. This can often occur shortly after reservoir creation when a new source of nutrients is introduced. However, cold water temperatures and highly oligotrophic nature of these lakes may limit this as a factor. The large

age and slow growth of fish in Whale Tail will likely produce a 'lag' period between baseline and peak concentrations that may extend beyond the planned flood period. The effect of this lag may help to dampen the overall increase or bioaccumulation of methylmercury in larger fish as they are exposed to a combination of low and high mercury food once water levels in Whale Tail Lake (South Basin) have been restored. However, slow growth combined with elevated rates of exposure to dietary methylmercury will increase body burden concentrations, but not likely at a rate of 3x baseline because of the short duration of flooding and the dampening effect of slow growth / feeding rate. While there is a large amount of uncertainty, the increase in fish mercury should be less than 3x placing Whale Tail in the **low** category for fish age / growth.

In summary, marginally acidic pH and low turnover rate of water within the new impoundment would suggest that the increase in fish mercury concentrations in Whale Tail Lake (South Basin) would exceed 3x baseline. On the other hand, small reservoir area (and mitigating effect of a 2 m ice cover over adjacent flooded soils) and ratio of new vs original area size; low TOC/DOC in water, low baseline mercury concentrations in water, soil and sediment, frozen peripheral soil conditions, low carbon volume, low mercury concentration and short food chain length would all suggest a low (<3x) increase above baseline. There is probably too much uncertainty around growth / age parameters of fish because of the high uncertainty in how large fish will respond over the long-term. Thus, the weight-of-evidence based on what we have learned from other reservoir systems, we would predict a <3x increase in fish mercury concentrations above baseline. That assessment is made even assuming that the Whale Tail Lake (South Basin) would be in place for many more years than its current 4-year life span. Given that the duration of flooding is quite short (although the bulk of methylation in soils may occur during this time), the magnitude of increase will be less than a 3x increase above baseline concentrations.

3.2. Fish Mercury Modelling

3.2.1. Overview of Available Models

There are two main types of models available to help estimate post-impoundment fish mercury concentrations:

- Empirical – these models describe the data (e.g., fish mercury concentrations) using one or more variables (e.g., flooded area, flow rates) and are typically in the form of simple regression models.
- Mechanistic – these models are much more comprehensive and are based on the underlying biogeochemical processes (e.g., mercury cycling and bioaccumulation) that drive changes in fish mercury concentrations. They help understand how changes in mercury in fish occur over time.

While detailed process-based models have been developed for specific systems (e.g., Manitoba – RESMERC [Harris 2005]; Quebec – HQHG [Thérien 2006]), a substantial effort is required to broaden their applicability sufficiently for use in other areas (e.g., Site C British Columbia [Harris et al. 2012, Azimuth 2012]). Given the effort required to apply these models, they are typically only used at very large sites. However, the mechanistic RESMERC model was used in this assessment to run scenarios geared towards understanding how a shortened reservoir timeline would affect fish mercury concentrations, adapted to a northern impoundment with very slow fish growth rates (see **Section 3.2.4**).

A number of existing empirical models have been developed to predict peak fish mercury concentrations or peak increase factor. Johnston et al. (1991) quantified the relationship between degree of flooding and mercury in fish (northern pike [*Esox lucius*], walleye [*Sander vitreus*] and lake whitefish [*Coregonus* *clupeaformis*] using data on mercury in fish from boreal reservoirs in northern Manitoba. The degree of flooding was a key explanatory variable, likely due to higher rates of mercury methylation in newly flooded zones because of increased rates of decomposition of flooded organic carbon (Bodaly et al. 1997, Hecky et al. 1991). Bodaly et al. (2007) developed new models to predict peak fish mercury concentrations from northern Manitoba reservoirs based solely on flooded area. Schetagne et al. (2003) used an empirical model that also included a flushing coefficient. While flooded terrestrial area is a good indicator of available methylated mercury for fish, the annual volume of water flowing through the reservoir effectively dilutes mercury in the water column. Harris and Hutchinson (2008) modified the approach for application to the Lower Churchill River Project in Labrador and later to the Site C Clean Energy Project in British Columbia (Azimuth 2012).

Recently published *Best Management Practices for Small Hydropower and Methyl Mercury v2.0* (hereafter referred to as "Mercury BMP framework"; HESL 2016) identified the five most commonly applied empirical models for predicting post-impoundment mercury concentrations for northern pike and walleye for hydroelectric projects in Ontario. In addition to the Johnston et al. (1991) and Bodaly et al. (2007) models described above, the five include two Harris and Beals models (extensions of the Harris and Hutchinson 2008 models; one predicts peak increase factor and the other peak Hg concentration) and a model from Axor (as cited in HESL 2016). The Harris and Beals models and the Axor model all include flow as a parameter. These models provide a starting point for making quantitative predictions of changes in fish mercury concentrations for the Whale Tail Lake reservoir.

The mercury BMP framework (HESL 2016) recommends using all five empirical models to predict peak fish mercury concentrations following impoundment. The approach involves first calculating baseline fish mercury concentrations and associated variation for a standard length fish (e.g., a 550-mm northern pike or 400-mm walleye). The mean and variation of predicted post-impoundment fish mercury concentrations are derived using the average model prediction coupled with the baseline fish mercury variation.

The mercury BMP framework (HESL 2016) also includes the provision to incorporate modifying factors to account for site-specific conditions not included in the models. For Ontario hydropower projects, fish residency time in head ponds was included as an optional modifying factor that could be used to adjust the empirical model predictions. Following the same underlying logic, other site-specific modifying factors could also be used to adjust model predictions. That said, the semi-quantitative nature of the derivation and application of the modifying factors warrants caution in their application; uncertainties should be explicitly incorporated into the process where appropriate.

3.2.2. Approach for Whale Tail Lake (South Basin)

The mercury BMP framework (HESL 2016) was derived to support the derivation of defensible predictions of changes in fish mercury concentrations associated with small hydropower developments in Ontario. However, there were three main differences associated with proposed Whale Tail Lake (South Basin) that warranted implementing modifications of the mercury BMP framework:

- *Local flow regime* – Most reservoirs where fish mercury dynamics have been studied, including those which were used to derive the empirical models, are associated with hydroelectric power developments. By their very nature, these sites rely on substantial discharge to provide power. As described in **Section 1.3**, the proposed Whale Tail Lake (South Basin) is situated near the head of the watershed and will have much lower flows than hydroelectric developments. Early in the development is it is filling, there will be negligible outflow. Three of the five empirical models included in the mercury BMP framework explicitly include flow as a model parameter; model behavior in low flow conditions is explored in **Section 3.2.3** to determine whether they are suitable for use for the Whale Tail Lake (South Basin).

- *Target fish species* – Neither northern pike nor walleye occur in the Meadowbank region. Lake trout is the top predatory fish in Whale Tail and Mammoth Lakes but has a similar fish-based diet as pike and walleye. As none of the models directly predicts changes in mercury concentrations for lake trout, the peak-increase-factor (PIF) empirical models for both northern pike and walleye were used to estimate post-impoundment concentrations in lake trout. Post-impoundment lake trout mercury concentrations were be estimated by multiplying the PIF results by the baseline mercury concentrations for lake trout (**Section 3.2.5**).
- *Reservoir Timeline* – As described in **Section 1.3**, unlike most reservoirs, which are filled and then used for decades, the planned life span of the Whale Tail Lake (South Basin) (i.e., time from start of filling to end of draining) is just over four years. As discussed in **Section 2.2**, the temporal pattern in fish mercury concentrations seen at most reservoirs includes an initial increase to a peak (e.g., by 4 to 12 years), followed by a gradual decrease to baseline or near-baseline concentrations (e.g., by 15 to 30 years after impoundment). Given that the empirical models predict peak fish mercury concentrations regardless of when they occur (i.e., they could occur years after the Whale Tail Lake [South Basin] has returned to baseline water elevations), modifying factors were developed to adjust (reduce) the empirical model peak fish mercury predictions to account for the shortened life span. Two derivation methods were used for the modifying factors: (1) based on actual monitoring data from existing reservoirs and (2) based on scenarios run using the mechanistic RESMERC mercury model (**Section 3.2.4**). This modifier is applied to the empirical model results in **Section 3.2.5**.

3.2.3. Empirical Model Assessment

As described in **Section 3.2.1**, the mercury BMP framework (2016) presented five "recognized" models for changes in fish mercury concentrations, three of which include flow as a model parameter (hereafter referred to as "flow-based" models). As discussed in **Section 3.2.2**, however, water flow through the proposed Whale Tail Lake (South Basin) is relatively low (**Section 1.3**) and there is uncertainty regarding how the flow-based models behave when flows and export of methylmercury is low.

To address this uncertainty, we explored model behaviour across a range of flooding and discharge scenarios. While degree of flooding is a core parameter in all five models, it is expressed differently across each of the models. However, as the underlying information requirements (i.e., original area, flooded area, total area) are consistent across all models, we were able to show results of different models relative to a single expression of percent flooding (i.e., 100 x Area Flooded/Area Total). Similarly for discharge, which is expressed either as km^3/yr (Harris and Beals models) or m^3/s (Axor model), model results can be shown relative to one convention (km^3/yr) simply by applying a conversion factor between the two units. As discussed in **Section 3.2.2**, we focused on the PIF versions of the models (i.e., degree of change relative to baseline rather than peak concentration) so that we could apply results to lake trout.

Where PIF versions were not available, PIFs were calculated by dividing the model results (i.e., predicted peak mercury concentrations) by the model intercept coefficient (i.e., results of the model assuming no flooding). As the Harris and Beals model was developed in PIF and Peak Mercury Concentration versions, the latter was dropped from further assessment. Thus, the following four models were assessed across a range of percent flooding and flows (where applicable):

- Johnston et al. (1991) – predicts changes in fish mercury burden (µg Hg/fish) in standard sized northern pike (550 mm) or walleye (400 mm) based on degree of flooding. Peak mercury concentrations were derived by dividing burden results by the weight (g) of standard-sized northern pike or walleye. A PIF version was derived by dividing the peak mercury concentration prediction by the model's intercept coefficient. The final equation used is shown below:

$$PIF = {}^{(b_0 + b_1 \times PF)}\Big/_{W}\Big/_{b_0}$$

Where: PIF = peak increase factor (unitless), b_0 = intercept coefficient, b1 = slope coefficient, PF = 100 x flooded area/total area, and W = fish weight (g).

- Bodaly et al. (2007) – predicts peak mercury concentrations for standard sized northern pike (550 mm) and walleye (400 mm) based on degree of flooding. A PIF version was derived by dividing the peak mercury concentration prediction by the model's intercept coefficient. The final equation used is shown below:

$$PIF = {}^{(y_0 + a(1 - e^{-bx}))}\Big/_{y_0}$$

Where: PIF = peak increase factor (unitless), y_0 = intercept, a and b are regression coefficients, and x = 100 x flooded area/original area.

- Harris and Beals (2014, as cited in HESL 2016) – predicts the peak increase factor for standard sized northern pike (550 mm) and walleye (400 mm) based on degree of flooding and flow. The model is as follows:

$$PIF = k_1 \times \frac{A_f}{(Q + k_2 \times A_t)} + k_3$$

Where: PIF = peak increase factor (unitless); k_1, k_2 and k_3 are regression coefficients; Q = mean annual flow (km^3/yr); A_f = area flooded (km^2); and A_t = total area (km^2).

- Axor (2014, as cited in HESL 2016) – predicts peak mercury concentrations for standard sized walleye (400 mm) based on baseline mercury concentrations, flooded area and flow. A PIF version was derived by dividing the peak mercury concentration by the baseline mercury concentration. The final equation was a follows:

$$PIF = \left(Baseline\ Hg + \frac{0.62 \times ({}^{FA}/_{Q})}{0.55 \times ({}^{FA}/_{Q})^{0.97} + 0.4} \right) \Big/ Baseline\ Hg$$

Where: PIF = peak increase factor (unitless), Baseline Hg = pre-flood Hg concentration (µg/g wet muscle), FA = flooded area (ha), and Q = mean annual flow (m^3/s).

Model behaviour was explored across a range of conditions by model type. Results for the two models based on degree of flooding only are presented in **Figure 3-1**. Both models behave as expected under a no flooding scenario, with PIFs converging at 1 (i.e., equal to baseline mercury concentrations). The Johnston et al. model shows a steady increase in PIF across the range of percent flooding, with walleye increasing slightly faster than northern pike. The Bodaly et al. model is curvilinear, with PIF increases slowing down after about 50% flooding; northern pike increases are slightly higher than those predicted for walleye. Neither the Johnston et al. nor Bodaly et al. models showed unexpected behaviour across the range of percent flooding, so both were considered suitable for use predicting fish mercury changes for the proposed Whale Tail Lake (South Basin).

Results for the models with parameters for degree of flooding and flow are shown in **Figure 3-2** to **Figure 3-4**. When degree flooding and flow are both zero (**Figure 3-2**), the Harris-Beals model has PIF values of 1.33 for northern pike and 1.51 for walleye, clearly showing that they were not meant to cover this end of the spectrum. The influence of flow in the Harris-Beals models is seen clearly in **Figure 3-3**, with a substantial reduction in PIF for northern pike occurring with progressively higher flows. That said, there is virtually no difference between the zero flow scenario and the Whale Tail Lake (South Basin) scenario (0.00194 km^3/yr; ".WT" in plot). The Axor model (**Figure 3-4**) showed good behaviour when both percent flooding and flow were zero (i.e., PIF = 1), but exhibited strange results when degree of flooding and flows were low. For example, when flows are zero (n.b., where necessary, "zero" values were changed to extremely small values to prevent indeterminate math errors in the models), PIF values jumped from 1 to nearly 4.5 with only a modest 5% flooded, then changed very slowly to 5 at 95% flooded. Behaviour was less extreme for the Whale Tail scenario (0.00194 km^3/yr; ".WT" in plot), but still showed an unexpected dramatic rise in PIF values between 0 and 5% flooding followed by more subtle changes through to 95% flooding. In contrast, none of the scenarios with flows in excess of 0.1 km^3/yr showed the sharp initial rises seen in the zero flow and Whale Tail scenarios. The results for both the Harris-Beals and Axor models suggest that they were not intended to apply in no flow, or low flow conditions. Consequently, neither model was considered suitable for use predicting changes in fish mercury concentrations for the proposed Whale Tail Lake (South Basin).

3.2.4. Modifying Factor to Account for Short Reservoir Life

The vast majority of published information on reservoir-related fish mercury dynamics is for long-term hydroelectric power developments. While physico-chemical factors play a key role in determining peak mercury concentrations, the magnitude and timing of response differs across trophic levels (Bodaly et al. 2007, Schetagne and Therrien 2013). In general, methylmercury concentrations peak first in water, then cascade through the food chain over a lagged time period, with large predatory fish typically peaking 4 to 12 years after reservoir creation (Bodaly et al. 2007, Schetagne and Therrien 2013).

The planned life span of the proposed Whale Tail Lake (South Basin) reservoir is just over four years. To quantify the magnitude of influence of this shorter time frame on expected peak fish mercury concentrations (i.e., as a modifying factor to adjust the empirical model predictions), we looked at monitoring data from long-term studies of Canadian reservoirs and at modelling simulation results from the mechanistic RESMERC model.

3.2.4.1. Monitoring-based Modifying Factors

The monitoring data were from long-term studies conducted in Manitoba (Bodaly et al. 2007), Quebec (Schetagne and Therrien 2013) and Labrador (Jacques Whitford 2006). Peak increase factors (PIF) across all years (PIF.All) were calculated for northern pike and walleye for each reservoir by dividing the peak fish mercury concentration (across all years) by the respective pre-impoundment concentration (or regional background concentration where pre-impoundment data were not collected). To determine the influence of time on peak mercury concentrations, PIF values were also calculated for the first three (PIF.3) and five (PIF.5) years after impoundment (see rationale below). Note that the Labrador data set (Jacques Whitford 2006) contained insufficient data to contribute to this assessment. Temporal modifying factors (MF) were calculated to quantify the relative difference between the 3 and 5-yr PIFs and the PIF.All values; since the scales start at PIF = 1 (i.e., for no increase above baseline), the relative difference must be calculated by subtracting 1 from each PIF (e.g., MF.5 = [PIF.5 – 1]/[PIF.All – 1]). Conversely, application of the MF values to the empirical model results (Model.PIF) to obtain a time-modified PIF (MF.PIF) must also take the scale into consideration (e.g., MF.PIF = MF x [Mod.PIF – 1] + 1).

The rationale for selecting three and five year periods for this assessment was as follows:

- *Three-year period* – the creation and decommissioning of the proposed Whale Tail Lake (South Basin) are not instantaneous events. For example, it will take approximately two years to fill the impoundment and six months to return it back down to original lake levels (see **Section 1.3**). The impoundment will be 50% full or greater (based on area of flooded terrestrial habitat, not volume) for 39 months. This time period was rounded down to three years to better match the timing of fish sampling events in the Manitoba and Quebec data sets. Given that residual mercury will remain in the aquatic ecosystem after impoundment decommissioning (i.e., all media will not immediately revert to pre-impoundment mercury concentrations), PIFs and MFs based on this time period represent the most optimistic effect of reduced reservoir life span.
- *Five-year period* – this time period was selected to provide an allowance for the residual mercury to move through the system after decommissioning. Consequently, PIFs and MFs based on this time period are a more conservative estimate of the effects of reduced impoundment life span.

The results are presented in **Figure 3-5**. In most cases, PIF values were lower in the three and five-year time periods than across all years, highlighting that peak fish mercury concentrations generally occurred *after* the first three to five years of impoundment. MFs for the three-year period ranged from 0.24 (i.e., the change from baseline to PIF.3 was 24% of that seen from baseline to PIF.All) to 0.90; MFs for the five-year period ranged from 0.44 to 0.91. Given that the five-year period provides some allowance for continued elevated mercury after the impoundment is reverted back to the original lakes, those MFs were carried forward for application in the fish mercury predictions.

3.2.4.2. RESMERC-based Modifying Factors

Details regarding the RESMERC simulations are provided in **Appendix C**. Simulations were conducted using model calibrations for Robert Bourassa Reservoir (Quebec) and Notigi Reservoir (Manitoba). The effects of short life span on peak fish mercury concentrations were simulated by adjusting the water elevation profiles for each reservoir (i.e., follow the initial filling timeline, then return to pre-flood elevations after 4 years). MF values (called "adjustment factors" in **Appendix C**) were calculated by comparing the results of the modified flooding simulations (i.e., for a 4-yr flooding scenario) to the original (i.e., permanent flooding) simulations; the adjustment factors were calculated in relative terms, similar to the MF calculation equations shown in **Section 3.2.4.1**. The RESMERC outputs include results for a number of size/age classes for northern pike and lake whitefish. For the purposes of estimating the effects of a short life span on lake trout in Whale Tail Lake (South Basin), we focused on the results for the predatory species (i.e., northern pike).

The predicted effects of a 4-year flooding period varied according to fish size/age, with the greatest effects seen in older (larger) pike. On the upper end, MFs for the 19+ age class ranged from 0.56 to 0.75. MF values generally decreased with fish size/age, with no effect seen in young pike (i.e., 0+ in Robert Bourassa, 0+ through 4+ in Notigi).

Mercury assessments generally focus on fish of standardized size. One challenge is that the size selected can vary within species, does vary among species and can represent substantially different age classes. For example, the standardized size northern pike used in monitoring studies was 700 mm for Robert Bourassa Reservoir (Schetagne and Therrien 2013) and 550 mm for Notigi Reservoir (Bodaly et al. 2007). Interestingly, these would be 4+ to 5+ aged fish in these reservoirs, but a 550-mm lake trout in Whale Tail Lake would be approximately 25 years old (i.e., much slower growth rates) (**Section 2.5.3**). Faster growing fish (i.e., younger for a given size) have been shown to contain lower mercury concentrations (i.e., through growth dilution) relative to slower growing (i.e., older for a given size) fish (Simoneau et al.

2005, Lavigne et al. 2010). While that may be true in steady state situations, the results of the initial simulations (**Appendix C**) suggested that peak mercury concentrations in older fish were delayed relative to younger fish and therefore more likely to benefit from a shortened reservoir life span. Given the influence of size/age on the MF values, the following approach was used:

- *Effects of Short Life Span* – the MF estimates for a 550-mm northern pike were conservatively used for both Robert Bourassa and Notigi. This equated to the predictions for the 4+ age class for both reservoirs, or an MF of 0.87 for Robert Bourassa and 1.0 for Notigi.
- *Effects of Slow Growth Rates* – a third simulation was used to explore the effects of slow growth rates on MF values. Fish bioenergetics and growth rates for Robert Bourassa were modified based on the baseline fish growth data from Whale Tail and other lakes in the Meadowbank region (**Appendix C**). The results for the closest age class to the standardized size (550 mm) lake trout (i.e., the 19+ age class; RESMERC is limited to 20 age classes that range from 0+ to 19) was used to derive the MF of 0.71.

3.2.5. Application of Empirical Models and Modifying Factors

Consistent with the mercury BMP framework (HESL 2016), predicted changes in lake trout mercury concentrations for the proposed Whale Tail Lake (South Basin) were calculated as follows (results shown in **Figure 3-6**:

- *Establish of baseline fish mercury concentrations* – Standardized (for a 550-mm lake trout) tissue mercury concentrations for Whale Tail Lake were presented in **Section 2.5.3**. Mean baseline mercury concentration for a 550-mm lake trout was 0.58 mg/kg wet muscle; **Figure 3-6** shows the 95% confidence interval for that mean mercury concentration.
- *Empirical model results* – The Johnston et al. (1991) and Bodaly et al. (2007) model predictions for northern pike and walleye are presented in **Figure 3-6**. These assume a full life span reservoir. The mean of the model predictions was used as the starting point for predicting peak post-impoundment mercury concentrations for lake trout in Whale Tail Lake (South Basin) (see "1. Model Only" in **Figure 3-6**); the 95% confidence interval of baseline mercury concentrations in lake trout was then applied to the mean of the empirical models (extrapolated as a percent of the mean, so the range gets wider with higher mercury concentrations) (see "2. Mean & 95%CI" in **Figure 3-6**).
- *Monitoring-based Modifying Factor for short life span of impoundment* – The range of five-year MFs from the monitoring studies was applied to the mean model estimates to account for the expected lower peak mercury concentrations due to the short life span of the proposed Whale Tail Lake (South Basin) relative to long-term hydroelectric reservoirs upon which the empirical models are based (see previous section). Results show that a shorter life span is likely to reduce peak mercury concentrations, but that the magnitude of reduction can vary from small (corresponding to the MF of 0.91; see "3. Mean & 95%CI MF.Lo" in **Figure 3-6**) to substantial (corresponding to the MF of 0.44; see "4. Mean & 95%CI MF.Hi" in **Figure 3-6**).
- *Model-based Modifying Factor for short life span of impoundment* – The RESMERC simulation results for Notigi and Robert-Bourassa reservoirs were also applied to the mean model estimates to provide another estimate of the influence that a short reservoir timeline will have on peak fish mercury concentrations. The RESMERC-based results predicted an even more subtle effect on peak mercury results than the monitoring-based results (see "5. Mean & 95%CI MF.Notigi" and "6. Mean and 95%CI MF.Bourassa" in **Figure 3-6**). The results for the 19+ age class (the oldest age class in the RESMERC model) of the modified scenario for Robert Bourassa reservoir was used to derive a third RESMERC-based MF (**Appendix C**). The resulting MF was lower, which

translated into lower predicted concentrations (see "7. Mean and 95%CI MF.Bourassa Slow Growth" in **Figure 3-6**).

- *Final prediction range for empirical modelling approach with modifying factors* – The mean of all the monitoring-based and RESMERC-based MF-adjusted predictions was used as the weight-of-evidence based prediction of peak mercury concentrations in lake trout in the Whale Tail Lake (South Basin) (see "8. Weight of Evidence Prediction" in **Figure 3-6**). Uncertainty around that prediction was conservatively based on the maximum extent of all the MF-adjusted 95% confidence intervals (see further discussion of uncertainty in the next section).
- *Implications for fish consumption* – This information is intended to provide some context for interpreting the predicted magnitude of change in fish mercury concentrations with respect to 'means per week or month' that are permissible to stay within guidelines; it is not intended to be a comprehensive human health risk assessment. Health Canada guidance (2007) was followed to estimate the number of servings per month for adults in general and for women of child-bearing age. Key assumptions for the calculations were as follows:
    - Body weights for both groups were assumed to be 70.7 kg.
    - Tolerable daily intake for mercury (µg/kg bw/day) was 0.47 and 0.2 for adults in general and women of child-bearing age, respectively.
    - Serving size for both groups was 150 g.
    - A month was considered to contain 365/12 days (i.e., 30.4 days)

  Number of servings/month of lake trout (550 mm) based on baseline conditions would be approximately 12 and 5 for adults in general and women of child-bearing age, respectively. This would drop to 5 and 2 based on the mean weight-of-evidence prediction, but could be as low as 3 and 1 at the upper bound of the prediction range (see "Health Canada Servings/mth" in **Figure 3-6**).

3.3. Uncertainty Assessment

Key uncertainties, and their likely influence on the magnitude prediction, include:

- Arctic environment – This is a completely untested environment from a mercury perspective and there is no precedent or empirical data to draw from to assist in reducing uncertainty in these predictions. Cold year-round water temperatures and nutrient-poor oligotrophic status of the lakes will naturally reduce methylmercury generation and the rate it cascades upwards through the food web, because of energetic constraints on growth physiology. However, a relatively large amount of nutrients will likely be released upon impoundment from flooding of tundra habitat; this may increase lake productivity and make more Hg-enriched food available for growth.
- Ice rafting – Given the thick ice cover each year, previously unflooded soils may be frozen to the bottom of the ice. During spring melt, some of this soil may be rafted away and deposited into the middle of the lake – essentially transporting littoral zone carbon/soils to deeper portions of the lake where they are available for methylation beyond the four-year life span of the impoundment. The potential of this phenomenon is unknown – although it has been observed in northern Quebec and Manitoba reservoirs (Bodaly et al. 1987).
- Tundra soils – Tundra soils consist of boggy, peat soils with high organic content. We are uncertain about how labile the carbon is in these soils and therefore how amenable it is to

contributing to methylation. Should Arctic soils have greater labile carbon content, this may result in a slightly higher available nutrient source.

- Ice cover – During early and later months of impoundment, inundated areas laying in shallower portions of the impoundment will become frozen to the bottom of the ice and removed from the pool of soil/sediment available for methylation. While water level rise is predicted to be about 4 m, maximum ice thickness is about 2 m; so it is likely that some portion of the new impoundment will not contribute to methylation, depending on time of year.
- Interrupted Discharge – Extremely cold winters will halt all discharge between lakes and out of the Whale Tail Lake (South Basin) for up to six months per year. The effects of interrupted discharge patterns on this time scale is unknown.
- Cold water – Very cold water temperature nearly year round will reduce bacterial decomposition rates and hence, mercury methylation (Ullrich et al 2001, Lesoto et al. 2004).
- Slow fish growth – Lower metabolism, dietary ingestion and slow growth rates of fish in cold water in Arctic lakes explains the very great age (~25 y) of a 550-mm standardized size lake trout in Whale Tail Lake relative to other northern reservoirs. In addition, as the size of the lake / impoundment is doubled, fish and prey density will be reduced in half, making finding prey more difficult.
- Shortened reservoir life – Finally, while this has explicitly been factored in as a modifying factor, there is no empirical data from known case studies where this may have occurred. However, it is safe to assume that the magnitude of increase in fish mercury concentrations and the time required to return to baseline, will be lower in a short-life impoundment than in a full-life reservoir.

3.4. Final Conclusions

Both the Canadian reservoir matrix and modelling (empirical/RESMERC) approaches point to an increase in lake trout mercury concentration above baseline of between 2 and 3 times. The corroboration between these two complementary approaches provides added confidence in the overall predictions. Furthermore, the mechanistic RESMERC model simulations of the short life span of flooding at Whale Tail Lake (South Basin), which showed a reduction in peak fish mercury concentrations, also showed a quicker return to baseline conditions. While there are a number of uncertainties associated with these predictions, they were relatively balanced in how they might affect the predicted magnitude of change in lake trout mercury concentrations.

The implications of the predicted changes in fish mercury concentrations was explored on the basis of the number of servings/month of lake trout (for a 550 mm fish) following Health Canada guidance. The change in servings/month based for adults in general dropped from 12 (baseline) to 5 (mean prediction) or 3 (upper bound of prediction range). The change for women of child-bearing age dropped from 5 (baseline) to 2 (mean prediction) or 1 (upper bound of prediction range).

Temporal monitoring of fish mercury concentrations relative to flooding would not only provide useful information for environmental management, it would provide valuable insights into mercury dynamics in flooded northern aquatic environments. That said, measures would need to be taken (e.g., use of non-lethal sampling procedures) to ensure than any monitoring activities do not result in adverse effects to fish populations in this relatively small headwater system.

Table 3-1. Simplified Reservoirs Comparison Matrix - Relationship between low and high magnitude fish mercury increase parameters vs physical, chemical, ecological parameters.

Reservoir Characteristics	Low Magnitude Increase Reservoirs (Fish Mercury < 3 x Baseline)	High Magnitude Increase Reservoirs (Fish Mercury > 3 x Baseline)	Predicted Result for Whale Tail
Magnitude of Fish Mercury Increase above Baseline	Muskrat Falls, Gull Island (Nfld/Lab); Limestone, Long Spruce, Wuskwatim, Southern Indian Lake (all MB) for some fish species	LG-1, LG-2, LG-3, Opinaca, Caniapiscau Quebec; Southern Indian Lake, MB (for some species), Williston Reservoir BC	
Physical Parameters			
Total Reservoir Area	Reservoirs with low magnitude increase Typically ranging from 25 to < 200 $km^{2,}$	Typically very large reservoirs, flooding large amounts ot terrestial habitat, usually exceeding 1000 km2	Whale Tail flooded area = X km2 and falls into **low** increase category. However, the high ratio of flooded to unflooded is high, suggesting some uncertainty for this metric
Original:Flooded Area	Original to flooded area ratio in low magnitude increase reservoirs is typically <2x original size	Increase in reservoir area of >3x and in some cases >20x (Williston Reservoir, BC) strongly positively correlated with >3x increase in fish mercury concentration	Whale Tail predicted ratio is X.X and thus would fall into the upper end of the **low** increase category
Water Residence Time	A short residence time in reservoirs on the order days to less than 1 month results in low magnitude increase in fish	A residence time in reservoirs greater than 3 months or more typically results in a high magnitude increase in fish mercury	With a water residence time of X months, this places Whale Tail in the **high** increase category
Chemical Parameters			
pH	Reservoirs with a pH of 7.5 or greater in water is strongly associated with a low magnitude increase. This has been observed in Manitoba reservoirs (7.5 - 8.5), Williston (8.5); and Gull/Muskrat	A high fish mercury incrase is associated with a water pH of <6.5 in Quebec (LG1: 6.5, LG2, 6.2, and LG3, <6.5), Caniapiscau (5.8 - 6.4) and Opinaca (5.9 - 6.3)	Whale Tail Lake has baseline pH of 6.5 - 6.8, with a low buffering capacity. Water pH is slightly acidic, and nearer to the high mercury threshold than the low mercury threshold. Given low buffering capacity, Whale Tale falls marginally withing the **high** increase category.
TOC / DOC	Reservoirs with TOC/DOC concentrations less than 5 mg/L, such as Muskrat/Gull MB (2.6 - 4.6 mg/L) and Williston (2 - 3 mg/L) tend to be associated with a low increase in fish mercury	Reservoirs with elevated TOC (>5 - 10 mg/L) tend to be associated with elevated fish mercury, although the relationship is not strong. For example, LG-1 (6.4 mg/L), LG-2 (9-29 mg/L), LG3 (7-10 mg/L), Caniapiscaue and Opinaka (7-10 mg/L)	TOC/DOC of Whale Tail is low, <2.3 mg/L, firmly placing this lake into the **low** liklihood of elevated mercury in fish, with some uncertainty
Labile Carbon / % Wetland	While there are few good data for most reservoirs, the a % wetland of 3% or less is associated with low fish mercury increase	Several Quebec reservoirs with a high % of flooded wetland: LG1 and LG2 (5%), LG3 (10%), Caniapiscau (7%) and Opinaca (16%) nd in MB (SIL >5%) and large carbon pool (16 - 23 kg/m^2 in peat soils, 9 - 42 kg/m^2 in wetlands vs <7 kg/m^2 in podzol all have high fish mercury	We areuncertain as to how muskeg, tundra soils compare to wetland soils; given this uncertainey, there is a **moderate** potential for fish mercury concentrations to exceed 3x baseline.
Ecological Parameters			
Food Chain Length and Diet	Mercury data from other northern pre-impoundments ranged from 0.05 - 0.26 ppm in zooplankton from Muskrat (Nfld) and Peace River BC, of which 35% is MeHg; In benthos THg ranged from 0.2 - 0.57 (Muskrat) and 0.15 - 0.28 ppm (Peace) of which 20% is MeHg.. No Hg data available from Whaletail. However, Arctic food webs are quite short providing less opportunity for bioaccumulation, independing of age/growth	Mercury data from large reservoirs with large increases in fish Hg (PQ) have higher zooplakton and benthos mercury concentrations, ranging from 0.20 - 0.80 ppm depending on taxa, with similar % MeHg ratio. Again, food chain length and diet are similar between low and high increase reservoirs in these areas, and longer than an Arctic lake.	Strictly speaking, an Arctic lake has a shorter food chain length than temperate lakes and thus should have lower magnitude increase post-inundation. However, there are no invertebrate Hg data for Whale Tail so uncertainty is high.
Fish Age/Growth Parameters	Fish from large temperate reservoirs with high nutrient availability, ample food and good growth tend to have a low magnitude fish Hg increase because of rapid growth and high updake of nutrients - or 'growth dilution'	Reservoirs with lower nutrient inputs, less connectivity to tributaries and lakes, short residence time and less productive tend to have higher fish Hg concentrations. There is a lack of 'growth dilution' when fish grow slowly and accumulate more Hg over time	There is no precedent for this factor in an Arctic lake. However, given the great age and slow growth of resident fish and lack of growth dilution, Whale Tail may fall into the **high** increase category. Note however, this may be offset by the short duration of inundation before return to baseline

THg = total mercury; MeHg = methylmercury; dw = dry weight; MB = Manitoba, PQ = Quebec

Figure 3-1. Predicted Peak Increase Factor (PIF) from the Johnson et al. (".J") and Bodaly et al. (".B") models across a range of degrees of flooding for northern pike (550 mm; NRPK) and walleye (400 mm; WALL).

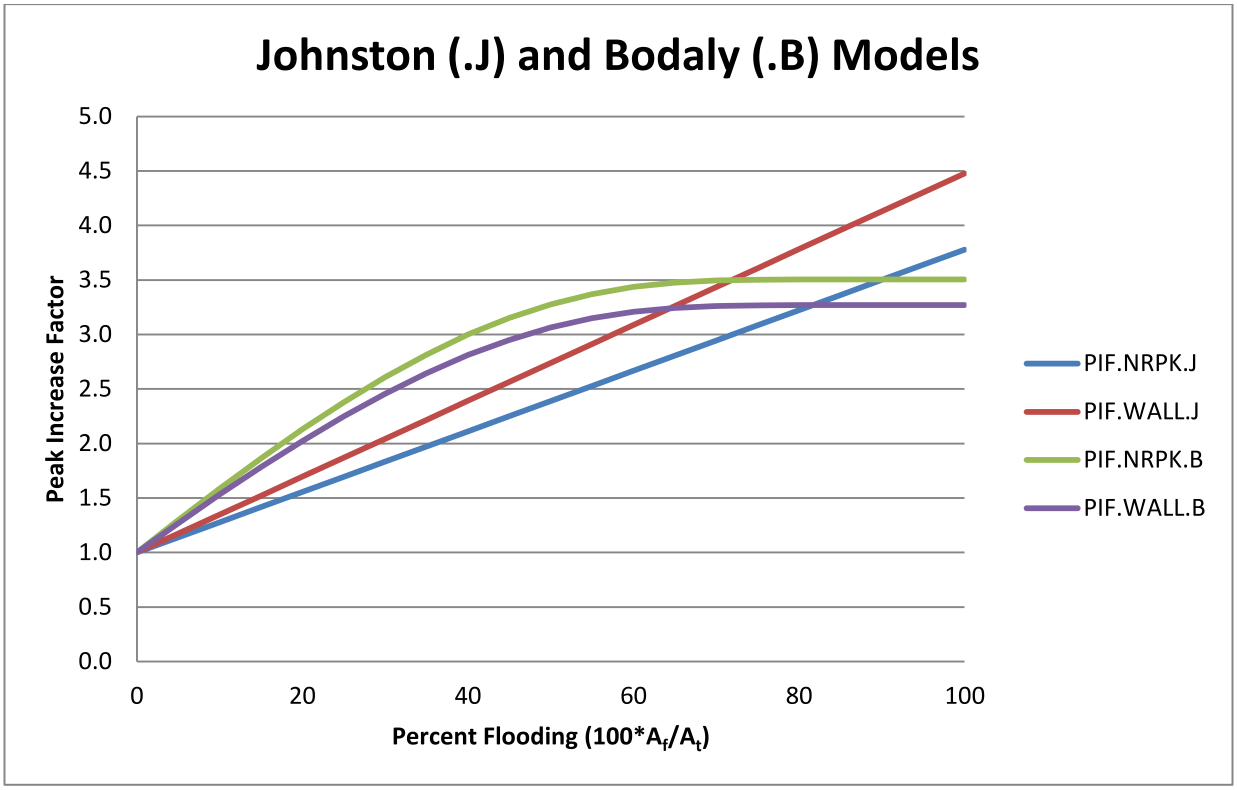


Figure 3-2. Predicted Peak Increase Factor (PIF) from the Harris-Beals (".HB") model across a range of degrees of flooding and no flow for northern pike (550 mm; NRPK) and walleye (400 mm; WALL).

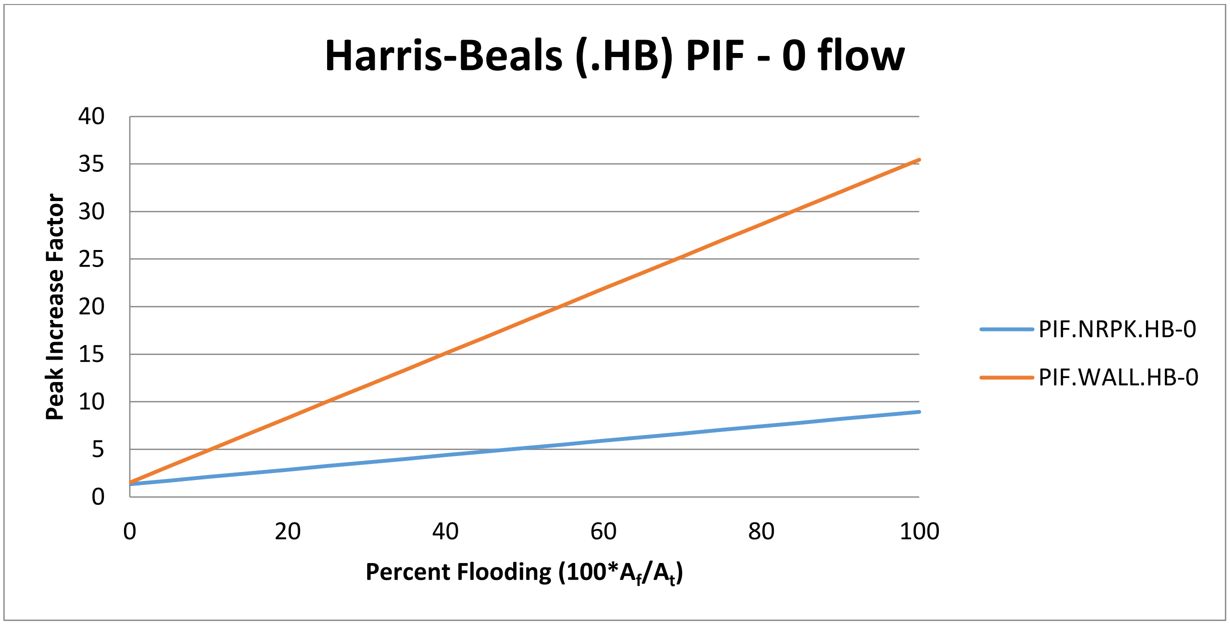


Figure 3-3. Predicted Peak Increase Factor (PIF) from the Harris-Beals (".HB") model across a range of degrees of flooding and flows for northern pike (550 mm; NRPK).

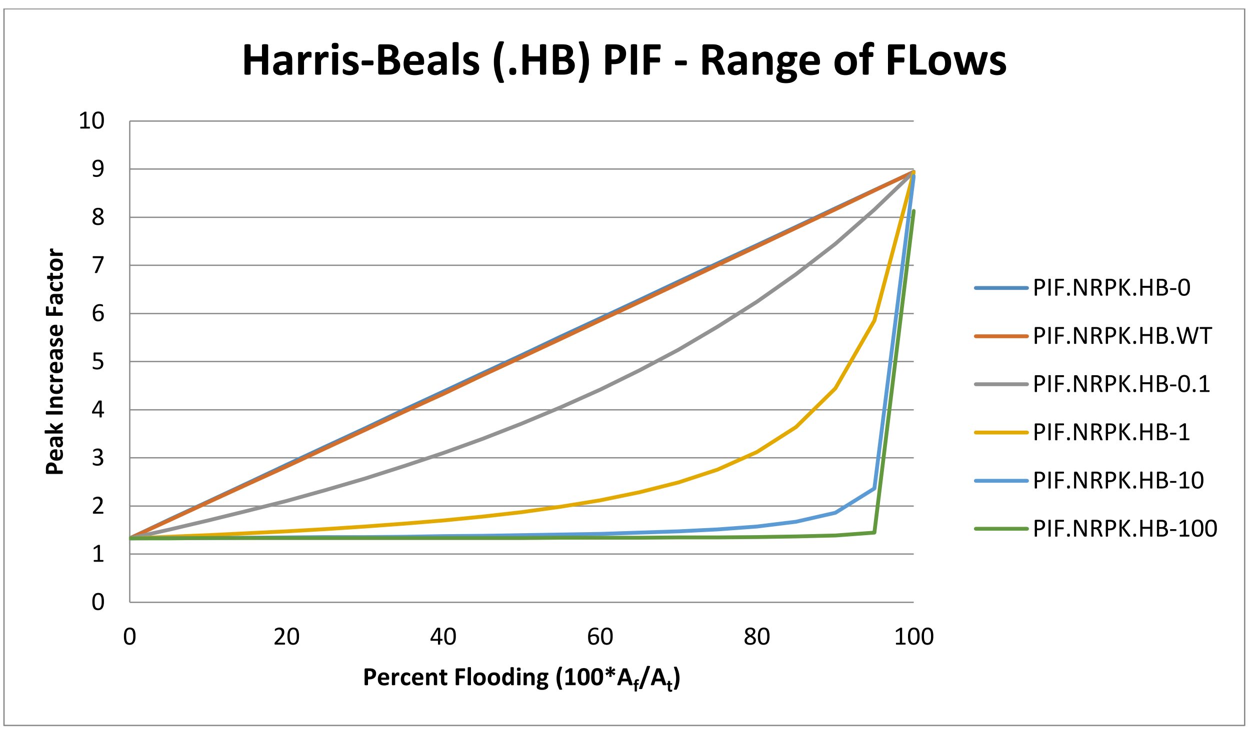


Figure 3-4. Predicted Peak Increase Factor (PIF) from the Axor (".A") model across a range of degrees of flooding and flows for walleye (400 mm; WALL).

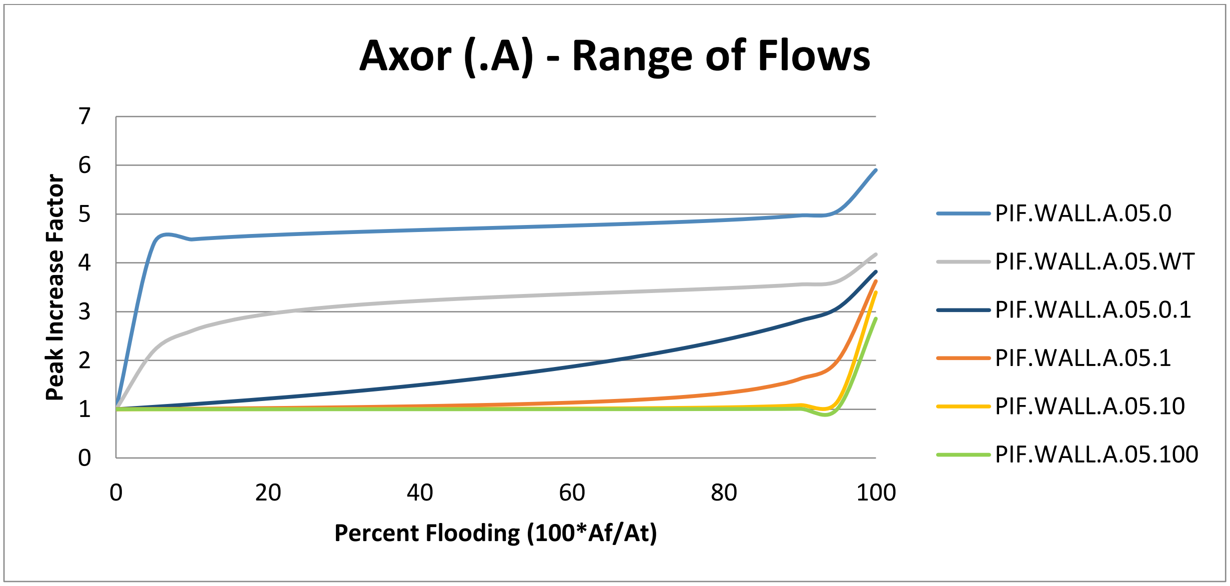
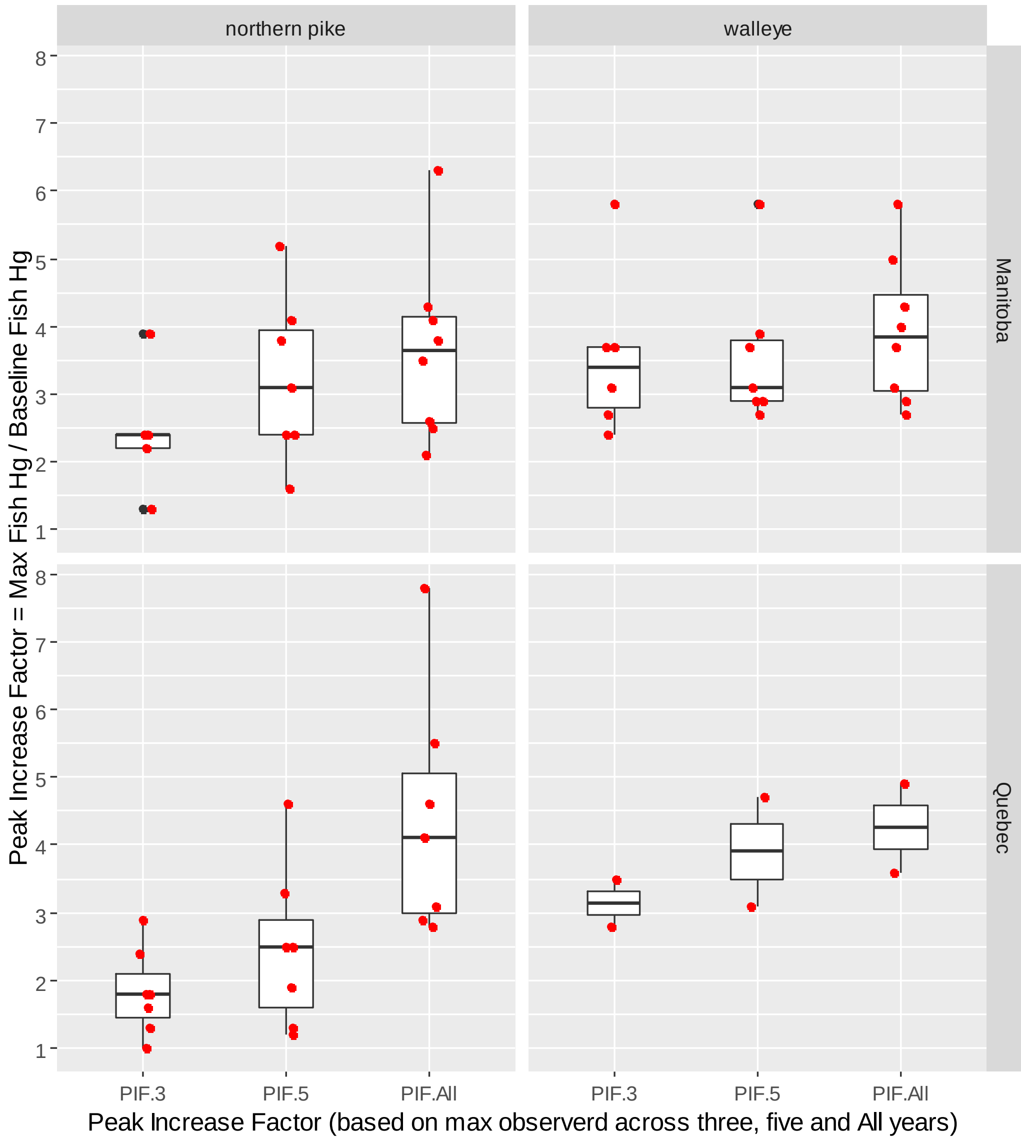


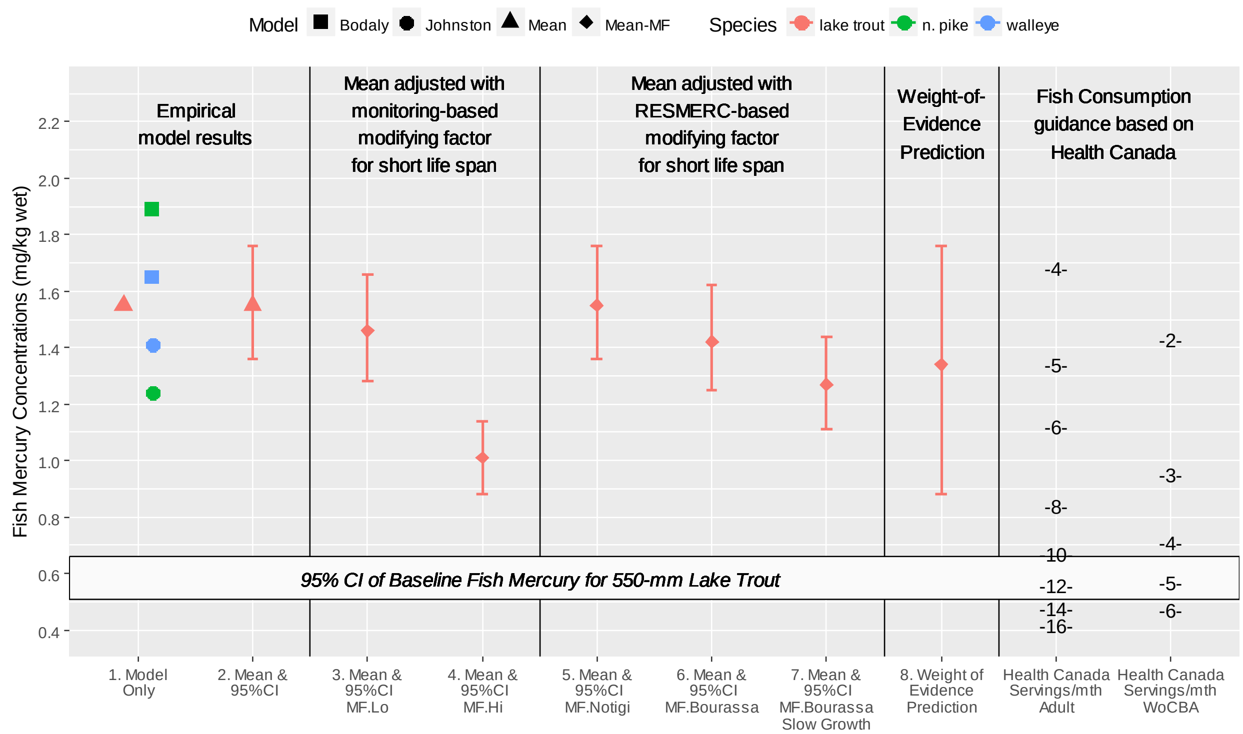
Figure 3-5. Comparison of peak increase factors (PIF) and temporal modifying factors (MF) for northern pike and walleye from Manitoba and Quebec reservoirs across the first three (PIF.3), five (PIF.5) and all years (PIF.All) after impoundment.



Mean PIFs and Modifying Factors (MF)

Species	Area	PIF.3	PIF.5	PIF.All	MF.3	MF.5
northern pike	Manitoba	2.4	3.2	3.6	0.54	0.85
northern pike	Quebec	1.8	2.5	4.4	0.24	0.44
walleye	Manitoba	3.6	3.6	3.9	0.90	0.90
walleye	Quebec	3.1	3.9	4.2	0.66	0.91

Figure 3-6. Predicted changes in lake trout (550 mm) mercury concentrations for the proposed Whale Tail Lake (South Basin) relative to baseline conditions and fish consumption (servings per month) guidance based on Health Canada.



Characteristics of Proposed Whale Tail Impoundment

	Values	Units	Source
Flooded Terrestrial Area	1.58	km^2	Golder (Appendix B)
Total Area	3.85	km^2	Golder (Appendix B)
Percent Flooding	41	percent	calculated
Mean Annual Flow	0.00194	km^3/yr	Golder (Appendix B)
Baseline Hg for 550-mm lake trout	0.58	mg/kg wet muscle	WTP Baseline
Weight for 550-mm lake trout	1800	g wet	WTP Baseline

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APPENDICES

APPENDIX A

Analytical Laboratory Results for Water, Sediment and Soil - ALS

AZIMUTH CONSULTING GROUP INC.
ATTN: Eric Franz
218 - 2902 West Broadway
Vancouver BC V6K 2G8

Date Received: 23-AUG-16
Report Date: 15-SEP-16 14:19 (MT)
Version: FINAL

Client Phone: 604-730-1220

Certificate of Analysis

Lab Work Order #: L1817642

Project P.O. #: NOT SUBMITTED
Job Reference: WTP AS AND HG ASSESSMENT
C of C Numbers: OL-2119
Legal Site Desc:

Brent Mack, B.Sc.
Account Manager

ALS ENVIRONMENTAL ANALYTICAL REPORT

	Sample ID	L1817642-1				
	Description	WATER				
	Sampled Date	17-AUG-16				
	Sampled Time	11:45				
	Client ID	WTS-12				
Grouping	**Analyte**					
WATER						
Total Metals	Mercury (Hg)-Total (ug/L)	<0.00050				
Dissolved Metals	Dissolved Mercury Filtration Location	FIELD				
	Mercury (Hg)-Dissolved (ug/L)	<0.00050				
Speciated Metals	Dissolved MeHg Filtration Location	FIELD				
	Methyl Mercury-Dissolved (ug/L)	<0.000050				
	Methyl Mercury-Total (ug/L)	<0.000050				

Reference Information

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**
HG-D-U-CVAF-VA	Water	Diss. Mercury in Water by CVAFS (Ultra)	APHA 3030 B / EPA 1631 REV. E

This analysis is carried out using procedures adapted from "Standard Methods for the Examination of Water and Wastewater" published by the American Public Health Association, and with procedures adapted from Method 1631 Rev. E. by the United States Environmental Protection Agency (EPA). The procedure may involve preliminary sample treatment by filtration (APHA 3030B) and involves a cold-oxidation of the acidified sample using bromine monochloride prior to a purge and trap concentration step and final reduction of the sample with stannous chloride. Instrumental analysis is by cold vapour atomic fluorescence spectrophotometry.

ALS Test Code	Matrix	Test Description	Method Reference**
HG-MEHG-DIS-GCAFS-VA	Water	Diss. Methyl Mercury in Water by GCAFS	EPA 1630

This procedure is carried out using the US EPA Method 1630. Water samples are distilled to isolate methyl mercury from the sample matrix. The distillate is analyzed by aqueous phase ethylation and purge and trap, followed by capillary gas chromatography. Highly selective and sensitive detection is achieved by Atomic Fluorescence Spectrometry (AFS) after pyrolytic decomposition of the GC eluent. Results are reported "as MeHg".

ALS Test Code	Matrix	Test Description	Method Reference**
HG-MEHG-TOT-GCAFS-VA	Water	Total Methyl Mercury in Water by GCAFS	EPA 1630

This procedure is carried out using the US EPA Method 1630. Water samples are distilled to isolate methyl mercury from the sample matrix. The distillate is analyzed by aqueous phase ethylation and purge and trap, followed by capillary gas chromatography. Highly selective and sensitive detection is achieved by Atomic Fluorescence Spectrometry (AFS) after pyrolytic decomposition of the GC eluent. Results are reported "as MeHg".

ALS Test Code	Matrix	Test Description	Method Reference**
HG-T-U-CVAF-VA	Water	Total Mercury in Water by CVAFS (Ultra)	EPA 1631 REV. E

This analysis is carried out using procedures adapted from Method 1631 Rev. E. by the United States Environmental Protection Agency (EPA). The procedure involves a cold-oxidation of the acidified sample using bromine monochloride prior to a purge and trap concentration step and final reduction of the sample with stannous chloride. Instrumental analysis is by cold vapour atomic fluorescence spectrophotometry.

** ALS test methods may incorporate modifications from specified reference methods to improve performance.

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
VA	ALS ENVIRONMENTAL - VANCOUVER, BRITISH COLUMBIA, CANADA

Chain of Custody Numbers:

OL-2119

GLOSSARY OF REPORT TERMS

Surrogate - A compound that is similar in behaviour to target analyte(s), but that does not occur naturally in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery.
mg/kg - milligrams per kilogram based on dry weight of sample.
mg/kg wwt - milligrams per kilogram based on wet weight of sample.
mg/kg lwt - milligrams per kilogram based on lipid-adjusted weight of sample.
mg/L - milligrams per litre.
< - Less than.
D.L. - The reported Detection Limit, also known as the Limit of Reporting (LOR).
N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.
UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.
Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.

ALS Environmental

Chain of Custody / Analytical Request Form
Canada Toll Free : 1 800 668 9878
www.alsglobal.com

21x2

COC #: OL-2119

Report To
Company: Azimuth Consulting Group Partnership
Contact: Eric Franz
Address: #218 - 2902 West Broadway
Vancouver, BC
Canada, V6K 2G8
Phone: 604-730-1220 Fax: 604-739-8511

Invoice To ☑Email ☑Mail
Company: Azimuth Consulting Group Partnership
Contact: Eric Franz
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Email: info@azimuthgroup.ca
Phone: 604-730-1220

Lab Work Order # (lab use only)

Reporting
Distribution: ☐Fax ☐Mail ☑Email
☐ Criteria on Report (select from Guidelines below)
Report Type: ☑Excel ☐Digital
Report Format:
Report Email(s): efranz@azimuthgroup.ca
gmann@azimuthgroup.ca
EDD Format:
EDD Email(s):

Project Info
Job #: WTP As and Hg Assessment
PO/AFE:
LSD:
Quote #: Q57023
ALS Contact: Brent Mack
Sampler: Eric Franz

Service Requested
◉ Regular (Standard Turnaround Times - Business Days) - R
○ Priority (3 Days) - surcharge will apply - P
○ Priority (2 Days) - surcharge will apply - P2
○ Emergency (1-2 day) – surcharge will apply - E
○ Same Day or Weekend Emergency - surcharge will apply - E2
○ Specify date required - X

Analysis Requests

Please indicate below Filtered, Preserved or both(F, P, F/P)

Sample #	Sample Identification (This will appear on the report)	Longitude	Latitude	Date	Time	Sample Type	Number of Containers	Mercury - Total (Ultra trace)	Mercury - Dissolved (Ultra trace)	Mercury, Methyl - Total	Mercury, Methyl - Dissolved
								~~F~~	~~F/P~~	P	F/P
	~~Whole Tail South Basin~~ WTS-12			17AUG16	11:45	Water	4	R	R	R	R

L1817642-COFC

Special Instructions/Comments
Ultra low samples were NOT preserved. HOLD all samples until receiving instructions on how to proceed with analysis.

The questions below must be answered for water samples (check Yes or No)
Are any sample taken from a regulated DW system? ☐Yes ☐No
If yes, please use an authorized drinking water COC
Is the water sampled intended to be potable for human consumption? ☐Yes ☐No

Guidelines

SAMPLE CONDITION (lab use only)
☐Frozen ☐Cold ☐Ambient ☐Cooling Initiated

SHIPMENT RELEASE (client use)			SHIPMENT RECEPTION (lab use only)				SHIPMENT VERIFICATION (lab use only)			
Released by:	Date:	Time:	Received by:	Date:	Time:	Temperature:	Verified by:	Date:	Time:	Observations:
Eric Franz	18AUG16	7:00	JC	AUG 2 3 2016	8:30	20,20 °C				☐Yes If Yes add SIF

330820048941/8933
PP 12:00 RS©

AZIMUTH CONSULTING GROUP INC.
ATTN: Eric Franz
218 - 2902 West Broadway
Vancouver BC V6K 2G8

Date Received: 29-AUG-16
Report Date: 23-SEP-16 18:02 (MT)
Version: FINAL

Client Phone: 604-730-1220

Certificate of Analysis

Lab Work Order #: L1822218

Project P.O. #: NOT SUBMITTED
Job Reference: WTP AS AND HG ASSESSMENT
C of C Numbers: OL-2125
Legal Site Desc:

Brent Mack, B.Sc.
Account Manager

ALS ENVIRONMENTAL ANALYTICAL REPORT

	Sample ID	L1822218-1	L1822218-2	L1822218-3	L1822218-4
	Description	Soil	Soil	Soil	Soil
	Sampled Date	18-AUG-16	18-AUG-16	18-AUG-16	18-AUG-16
	Sampled Time				
	Client ID	WTS-SOIL-1	WTS-SOIL-2	WTS-SOIL-3	WTS-SOIL-4
Grouping	**Analyte**				
SOIL					
Physical Tests	Moisture (%)	8.77	9.87	9.65	11.1
	pH (1:2 soil:water) (pH)	6.70	6.13	6.39	5.81
Organic / Inorganic Carbon	Total Organic Carbon (%)	0.296	0.273	0.169	0.487
Metals	Aluminum (Al) (mg/kg)	6380	7860	7470	6660
	Antimony (Sb) (mg/kg)	<0.10	<0.10	<0.10	<0.10
	Arsenic (As) (mg/kg)	2.92	3.75	3.20	3.50
	Barium (Ba) (mg/kg)	33.5	35.3	32.9	26.9
	Beryllium (Be) (mg/kg)	0.34	0.44	0.40	0.32
	Bismuth (Bi) (mg/kg)	0.21	0.21	<0.20	<0.20
	Boron (B) (mg/kg)	<5.0	<5.0	<5.0	<5.0
	Cadmium (Cd) (mg/kg)	0.034	0.041	0.031	0.039
	Calcium (Ca) (mg/kg)	2830	2860	2710	2580
	Chromium (Cr) (mg/kg)	25.1	37.4	37.3	29.4
	Cobalt (Co) (mg/kg)	5.20	7.52	6.55	5.78
	Copper (Cu) (mg/kg)	4.56	7.58	6.46	4.49
	Iron (Fe) (mg/kg)	14300	16900	15700	15700
	Lead (Pb) (mg/kg)	5.70	6.29	5.59	5.95
	Lithium (Li) (mg/kg)	7.7	9.4	9.1	8.6
	Magnesium (Mg) (mg/kg)	3670	4870	4700	3610
	Manganese (Mn) (mg/kg)	219	270	239	243
	Mercury (Hg) (mg/kg)	<0.0050	<0.0050	<0.0050	0.0066
	Molybdenum (Mo) (mg/kg)	0.27	0.39	0.50	0.40
	Nickel (Ni) (mg/kg)	15.1	23.6	22.6	18.4
	Phosphorus (P) (mg/kg)	525	539	505	542
	Potassium (K) (mg/kg)	1000	1090	1010	940
	Selenium (Se) (mg/kg)	<0.20	<0.20	<0.20	<0.20
	Silver (Ag) (mg/kg)	<0.10	<0.10	<0.10	<0.10
	Sodium (Na) (mg/kg)	107	108	197	79
	Strontium (Sr) (mg/kg)	26.8	28.1	26.6	23.4
	Thallium (Tl) (mg/kg)	0.068	0.078	0.064	0.076
	Tin (Sn) (mg/kg)	<2.0	<2.0	<2.0	<2.0
	Titanium (Ti) (mg/kg)	560	598	554	555
	Uranium (U) (mg/kg)	2.06	2.44	2.07	2.09
	Vanadium (V) (mg/kg)	14.7	19.0	17.1	12.2
	Zinc (Zn) (mg/kg)	25.6	32.5	26.8	28.1
	Zirconium (Zr) (mg/kg)	8.1	7.5	8.8	3.9
Speciated Metals	Methyl Mercury (mg/kg)	<0.000050	<0.000050	<0.000050	0.000053

Reference Information

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**
C-TIC-PCT-SK	Soil	Total Inorganic Carbon in Soil	CSSS (2008) P216-217

A known quantity of acetic acid is consumed by reaction with carbonates in the soil. The pH of the resulting solution is measured and compared against a standard curve relating pH to weight of carbonate.

C-TOC-CALC-SK	Soil	Total Organic Carbon Calculation	CSSS (2008) 21.2

Total Organic Carbon (TOC) is calculated by the difference between total carbon (TC) and total inorganic carbon. (TIC)

C-TOT-LECO-SK	Soil	Total Carbon by combustion method	SSSA (1996) P. 973-974

The sample is ignited in a combustion analyzer where carbon in the reduced CO2 gas is determined using a thermal conductivity detector.

HG-200.2-CVAF-VA	Soil	Mercury in Soil by CVAFS	EPA 200.2/1631E (mod)

Soil samples are digested with nitric and hydrochloric acids, followed by analysis by CVAFS.

HG-MEHG-GCAFS-VA	Soil	Methyl Mercury in Soil by GCAFS	EPA 1630

This procedure is carried out using a method published by Bloom et al (1997), using instrumental conditions adopted from draft US EPA Method 1630. Sediment/soil samples are treated with sulfuric acid, potassium bromide, and copper sulfate prior to extraction with DCM. A portion of the extract is back extracted into water and analyzed by aqueous phase ethylation and purge and trap followed by capillary gas chromatography. Highly selective and sensitive detection is achieved by Cold Vapour Atomic Fluorescence Spectrometry (CVAFS) after pyrolytic decomposition of the GC eluent. Results are reported "as MeHg".

MET-200.2-CCMS-VA	Soil	Metals in Soil by CRC ICPMS	EPA 200.2/6020A (mod)

Soil samples are digested with nitric and hydrochloric acids, followed by analysis by CRC ICPMS.

Method Limitation: This method is not a total digestion technique. It is a very strong acid digestion that is intended to dissolve those metals that may be environmentally available. This method does not dissolve all silicate materials and may result in a partial extraction. depending on the sample matrix, for some metals, including, but not limited to Al, Ba, Be, Cr, Sr, Ti, Tl, and V.

MOISTURE-VA	Soil	Moisture content	ASTM D2974-00 Method A

This analysis is carried out gravimetrically by drying the sample at 105 C for a minimum of six hours.

PH-1:2-VA	Soil	pH in Soil (1:2 Soil:Water Extraction)	BC WLAP METHOD: PH, ELECTROMETRIC, SOIL

This analysis is carried out in accordance with procedures described in the pH, Electrometric in Soil and Sediment method - Section B Physical/Inorganic and Misc. Constituents, BC Environmental Laboratory Manual 2007. The procedure involves mixing the dried (at <60°C) and sieved (No. 10 / 2mm) sample with deionized/distilled water at a 1:2 ratio of sediment to water. The pH of the solution is then measured using a standard pH probe.

** ALS test methods may incorporate modifications from specified reference methods to improve performance.

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
SK	ALS ENVIRONMENTAL - SASKATOON, SASKATCHEWAN, CANADA
VA	ALS ENVIRONMENTAL - VANCOUVER, BRITISH COLUMBIA, CANADA

Chain of Custody Numbers:

OL-2125

GLOSSARY OF REPORT TERMS

Surrogate - A compound that is similar in behaviour to target analyte(s), but that does not occur naturally in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery.
mg/kg - milligrams per kilogram based on dry weight of sample.
mg/kg wwt - milligrams per kilogram based on wet weight of sample.
mg/kg lwt - milligrams per kilogram based on lipid-adjusted weight of sample.
mg/L - milligrams per litre.
< - Less than.
D.L. - The reported Detection Limit, also known as the Limit of Reporting (LOR).
N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.
UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.
Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.

L1822218-COFC

COC #: OL-2125

ALS Environmental

Report To		Reporting		Service Requested
Company:	Azimuth Consulting Group Partnership	Distribution:	☐Fax ☐Mail ☑Email	⦿Regular (Standard Turnaround Times - Business Days) - R
Contact:	Eric Franz	☐Criteria on Report (select from Guidelines below)		○Priority (3 Days) - surcharge will apply - P
Address:	#218 - 2902 West Broadway Vancouver, BC Canada, V6K 2G8	Report Type:	☑Excel ☑Digital	○Priority (2 Days) - surcharge will apply - P2
		Report Format:		○Emergency (1-2 day) – surcharge will apply - E
		Report Email(s):	efranz@azimuthgroup.ca gmann@azimuthgroup.ca	○Same Day or Weekend Emergency - surcharge will apply - E2
				○Specify date required - X
Phone:	604-730-1220 Fax: 604-739-8511			
Invoice To	☑Email ☑Mail	EDD Format:		
Company:	Azimuth Consulting Group Partnership	EDD Email(s):		
Contact:	Eric Franz			
Address:	#218 - 2902 West Broadway Vancouver, BC Canada, V6K 2G8	Project Info		
		Job #:	WTP As and Hg Assessment	
		PO/AFE:		
Email:	info@azimuthgroup.ca	LSD:		
Phone:	604-730-1220	Quote #:	Q38011 and Q57024	
Lab Work Order # (lab use only)	L1822218	ALS Contact: Brent Mack	Sampler: Eric Franz	

Analysis Requests — Please indicate below Filtered, Preserved or both(F, P, F/P)

Sample #	Sample Identification (This will appear on the report)	Longitude	Latitude	Date	Time	Sample Type	Number of Containers	Metals - Mercury, Methyl	TOC	Total metals, pH, Moisture	Sulphate (nutrient)
	WTS-1			12 AUG 16		Soil/(Sed)/Waste	10	R			R
	WTS-2			12 AUG 16		Soil/(Sed)/Waste	10	R			R
	WTS-3			12 AUG 16		Soil/(Sed)/Waste	10	R			R
	WTS-4			12 AUG 16		Soil/(Sed)/Waste	10	R			R
	WTS-5			12 AUG 16		Soil/(Sed)/Waste	10	R			R
1	WTS-Soil-1			18 AUG 16		(Soil)/Sed/Waste	3	R	R	R	
2	WTS-Soil-2			18 AUG 16		(Soil)/Sed/Waste	3	R	R	R	
3	WTS-Soil-3			18 AUG 16		(Soil)/Sed/Waste	3	R	R	R	
4	WTS-Soil-4			18 AUG 16		(Soil)/Sed/Waste	3	R	R	R	

Special Instructions/Comments

HOLD SAMPLES PRIOR TO ANALYSIS - Contact Eric Franz or Gary Mann to confirm list of analytes.

The questions below must be answered for water samples (check Yes or No)

Are any sample taken from a regulated DW system? ☐Yes ☐No

If yes, please use an authorized drinking water COC

Is the water sampled intended to be potable for human consumption? ☐Yes ☐No

Guidelines

SAMPLE CONDITION (lab use only)

☐Frozen ☐Cold ☐Ambient ☐Cooling Initiated

SHIPMENT RELEASE (client use)			SHIPMENT RECEPTION (lab use only)				SHIPMENT VERIFICATION (lab use only)			
Released by: Eric Franz	Date: 18 AUG 16	Time: 19:50	Received by:	Date:	Time:	Temperature: °C	Verified by:	Date:	Time:	Observations: ☐Yes If Yes add SIF

APPENDIX B

Whale Tail Lake (South Basin) – Flooding & Dewatering Schedule – Golder Associates

Updated Flooding Schedule (Golder Associates)

Date	Total Inflow (Net from Evaporation)	Water Level (m)	Lake Area (m2)	Flooded Terrestrial Habitat (m2)	Flooded Aquatic Habitat (m2)	Storage (m3)
Jan 18	0	152.50	893,448	0		4,628,152
Feb 18	0	152.50	893,448	0		4,628,152
Mar 18	0	152.50	893,448	0		4,628,152
Apr 18	0	152.50	893,448	0		4,628,152
May 18	0	152.50	893,448	0		4,628,152
Jun 18	1,368,087	152.50	893,448	0		4,628,152
Jul 18	97,673	152.50	893,448	0		4,628,152
Aug 18	198,611	152.61	903,582	2,060	8,074	4,725,825
Sep 18	664,171	152.83	924,312	17,593	13,272	4,924,436
Oct 18	0	153.50	1,001,835	106,810	1,577	5,588,607
Nov 18	0	153.50	1,001,835	106,810	1,577	5,588,607
Dec 18	0	153.50	1,001,835	106,810	1,577	5,588,607
Jan 19	0	153.50	1,001,835	106,810	1,577	5,588,607
Feb 19	0	153.50	1,001,835	106,810	1,577	5,588,607
Mar 19	0	153.50	1,001,835	106,810	1,577	5,588,607
Apr 19	0	154.44	1,278,407	437,634	-52,675	6,710,607
May 19	0	154.98	1,496,787	743,172	-139,833	7,430,607
Jun 19	1,362,914	155.11	1,755,701	849,873	12,380	7,832,607
Jul 19	0	155.50	2,672,890	1,161,693	617,750	9,195,520
Aug 19	78,298	155.50	2,672,890	1,161,693	617,750	9,195,520
Sep 19	615,537	155.52	2,725,582	1,179,492	652,642	9,273,818
Oct 19	0	155.70	3,139,815	1,322,012	924,356	9,889,355
Nov 19	0	155.70	3,139,815	1,322,012	924,356	9,889,355
Dec 19	0	155.70	3,139,815	1,322,012	924,356	9,889,355
Jan 20	0	155.70	3,139,815	1,322,012	924,356	9,889,355
Feb 20	0	155.70	3,139,815	1,322,012	924,356	9,889,355
Mar 20	0	155.70	3,139,815	1,322,012	924,356	9,889,355
Apr 20	0	155.70	3,139,815	1,322,012	924,356	9,889,355
May 20	0	155.70	3,139,815	1,322,012	924,356	9,889,355
Jun 20	1,354,609	155.70	3,139,815	1,322,012	924,356	9,889,355
Jul 20	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Aug 20	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Sep 20	585,138	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Oct 20	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Nov 20	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Dec 20	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Jan 21	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Feb 21	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Mar 21	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Apr 21	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
May 21	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Jun 21	1,350,339	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Jul 21	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Aug 21	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Sep 21	585,138	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Oct 21	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Nov 21	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Dec 21	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Jan 22	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Feb 22	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Mar 22	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Apr 22	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
May 22	0	156.00	3,851,450	1,575,487	1,382,516	10,946,821
Jun 22	1,355,972	155.60	2,912,668	1,242,689	776,531	9,551,821
Jul 22	0	155.60	2,916,686	1,244,047	779,192	9,557,793
Aug 22	125,557	155.20	1,977,904	926,073	158,383	8,162,793
Sep 22	653,167	154.58	1,331,858	501,913	-63,503	6,893,350
Oct 22	0	154.04	1,128,039	256,807	-22,216	6,196,517
Nov 22	0	152.69	911,435	7,765	10,223	4,801,517
Dec 22	0	152.50	893,448	0	0	4,628,152
Jan 23	0	152.50	893,448	0		4,628,152
Feb 23	0	152.50	893,448	0		4,628,152
Mar 23	0	152.50	893,448	0		4,628,152
Apr 23	0	152.50	893,448	0		4,628,152
May 23	0	152.50	893,448	0		4,628,152
Jun 23	1,368,087	152.50	893,448	0		4,628,152
Jul 23	97,673	152.50	893,448	0		4,628,152
Aug 23	199,300	152.50	893,448	0		4,628,152
Sep 23	665,004	152.50	893,448	0		4,628,152
Oct 23	0	152.50	893,448	0		4,628,152
Nov 23	0	152.50	893,448	0		4,628,152
Dec 23	0	152.50	893,448	0		4,628,152

APPENDIX C

RESMERC Simulations – R. Harris Environmental

Predictions of Increases in Fish Mercury Concentrations Following a 4 Year Impoundment, Relative to Permanent Flooding – A Coarse Modeling Analysis

Technical Memorandum

Prepared by

David Hutchinson and Reed Harris
Reed Harris Environmental Ltd.
Oakville, ON

Prepared for:

Gary Mann
Azimuth Consulting Group
Vancouver, BC

February 14, 2017

1 Background

Fish mercury concentrations have been well documented to increase in connection with flooding in large new reservoirs (*e.g.* Schetagne and Therrien, 2013; Bodaly *et al.*, 2007; Verta *et al.* 1986). Peak Hg concentrations, especially in adult predatory fish can be, but are not always, up to 7 times greater than background levels (Bodaly *et al*., 2007; Schetagne *et al*., 2003) often exceeding the Canadian limit of 0.5 $\mu g\ g^{-1}$ for domestic commercial sale (Health Canada, 2007) in higher trophic level species such as northern pike or walleye (Figure 1c and d). Lower trophic level fish species such as lake whitefish tend to have lower concentrations (Figure 1a).

Fish mercury levels in new reservoirs increase due to the decomposition of easily degradable flooded organic matter (Figure 2). This leads to an increase in the activity of microbes that produce methylmercury, which then moves from sediments and water through the food web , representing most (>90%) of the mercury in fish muscle tissue. The duration of elevated fish mercury concentrations in boreal reservoirs typically lasts up to three decades. Importantly, fish mercury levels take years to reach peak concentrations, after which concentrations gradually decline towards background levels. Because flooding alters the characteristics of a waterbody, long term mercury concentrations in reservoirs may stabilize at concentrations different than occur pre-flood.

The rise and fall of fish mercury concentrations after flooding reflects the transient increase of decomposition and methylmercury production that occurs after flooding. Furthermore, increases in methylmercury concentrations first observed in sediments and water can take years to move through the food web. Peak concentrations occur later in higher trophic level species, and in older specimens for a given predatory species. This is because fish obtain most of their methylmercury via the diet. Most of the the increase in mercury concentration in a predator will not occur until concentrations increase in its prey.

Peak fish mercury levels in reservoirs on the Canadian Shield have been observed roughly 4-13 years after permanent flooding occurred. How high would fish mercury levels go if water levels returned to pre-flood elevations before peak fish levels associated with permanent flooding occurred? The proposed Whale Tail gold mining project in Nunavut, for example, would increase water levels for four years, followed by a return to pre-flood levels over a period of few months. This Technical Memorandum describes a coarse modeling analysis to examine the implications of a four year flood period on increases in fish mercury concentrations, relative to permanent flooding.

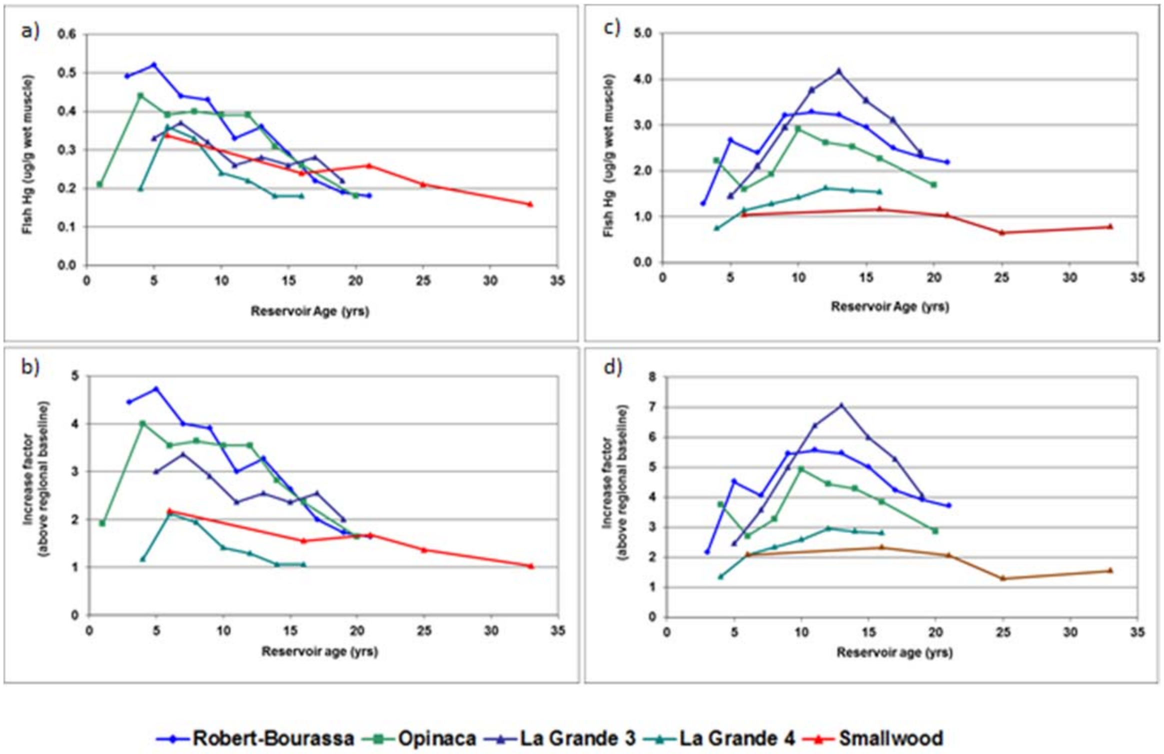

Figure 1. Hg levels observed in 400 mm lake whitefish and 700 mm northern pike as a function of reservoir age in Quebec and Labrador: a) concentrations in lake whitefish, b) relative increase above regional baseline concentrations in lake whitefish, c) concentrations in northern pike, d) relative increase above regional baseline concentrations in northern pike. Quebec baseline was 0.59 µg g^{-1} for the western sector and 0.55 µg g^{-1} for the eastern sector of the La Grande complex. Smallwood baseline was 0.5 µg g^{-1}, the average from Atikonak Lake and Shipiskan Lake. Quebec data from Schetagne *et al*. (2003). Smallwood Reservoir data from Jacques Whitford (2006) for Lobstick and Sandgirt Lakes. Limited sampling in Smallwood Reservoir during 1^{st} fifteen years after flooding may have missed peak.

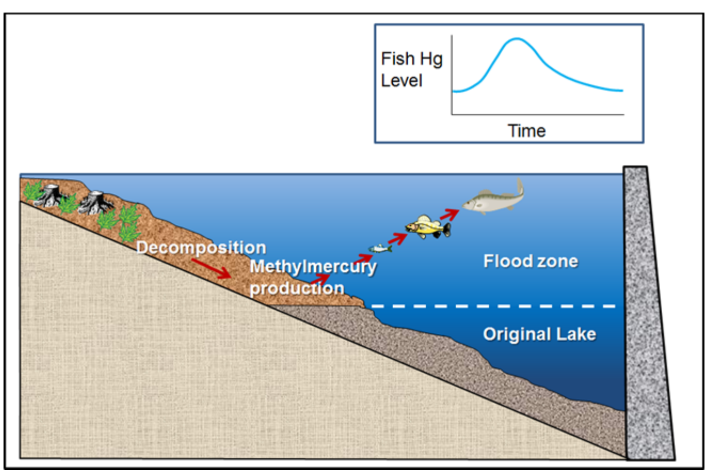

Figure 2. Conceptual diagram of increased decomposition, MeHg production and MeHg bioaccumulation following flooding

2 Modeling Approach and Scenarios

A mechanistic mass balance model of mercury cycling and bioaccumulation in new reservoirs was used for the analysis. The RESMERC model was originally developed as part of experimental reservoir studies at the Experimental Lakes Area (*e.g.* Bodaly et al., 2004; St. Louis et al., 2004; Hall et al. 2005), and later calibrated to fish mercury data from two full scale reservoirs: Robert Bourassa Reservoir in Quebec and Notigi Reservoir in Manitoba, as part of studies to predict fish mercury concentrations associated with the proposed Site C Reservoir in British Columbia (Harris *et al*., 2012). RESMERC was also applied to the Lower Churchill River Hydroelectric Development (Harris *et al*., 2010), now under construction. RESMERC predicts concentrations and fluxes of inorganic mercury and methylmercury in sediments, water, and the food web, including fish. Mercury concentrations in fish are predicted as a function of time, considering the timing of flooding as well as trophic structure, length of the food web, and fish growth rates. The model is well suited to examine the potential implications of a temporary flooding regime on the order of several years, and was used for this analysis.

Detailed site-specific RESMERC simulations were not conducted for Whale Tail Lake. Rather, the effects of a 4 year impoundment were assessed using previous simulations of Robert Bourassa and Notigi Reservoirs as starting points, modified to have temporary instead of permanent flooding, as shown in Figure 3 and Figure 4. Four years after filling began (and after full elevation was reached), water levels were lowered to pre-inundation levels over a period of 3 months, similar to the proposed water level reductions planned to Whale Tail Lake (shown in Figure 5). Reservoir filling patterns were not altered from the original simulations for Notigi and Robert Bourassa Reservoirs. Whale Tail Lake filling is proposed to take approximately two years. Filling took 1.0 and 2.6 years In Robert Bourassa and Notigi Reservoir simulations respectively.

A third scenario was developed based on the Robert Bourassa scenario. Modifications were made to the food web to be more representative of the Whale Tail Lake Region (Figure 6). The top level predator was changed from Northern Pike to Lake Trout by using species-specific bioenergetics inputs. This scenario also used fish growth rates for Lake Trout, Arctic Char and Round Whitefish that were more representative of the Whale Tail Lake region. Growth rates were initially adjusted to match regional observations on a weight vs age basis (left panels in Figure 6). Model inputs relating fish length to weight were then adjusted to provide reasonable estimates of growth on the bases of length versus age (right panels in Figure 6). Because trophic structure and fish diets were not changed from the Robert Bourassa simulation values, this scenario was effectively a test of the sensitivity of model results to changes in two factors (bioenergetics and growth), and was not a full simulation of the Whale Tail Lake food web.

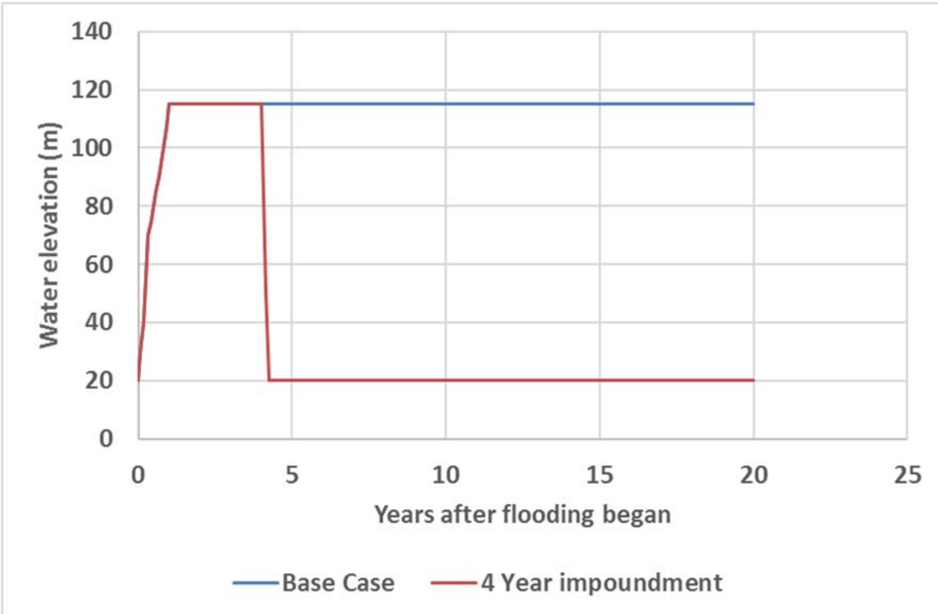

Figure 3. Water levels used for base case Robert Bourassa Reservoir simulation with permanent flooding, and for 4 year impoundment scenario.

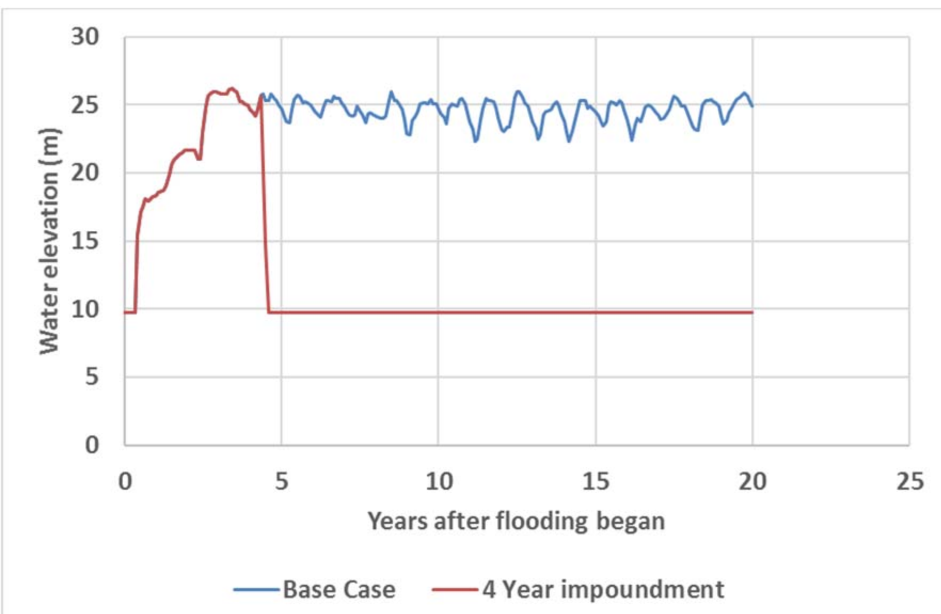

Figure 4. Water levels used for base case Notigi Reservoir simulation with permanent flooding, and for 4 year impoundment scenario.

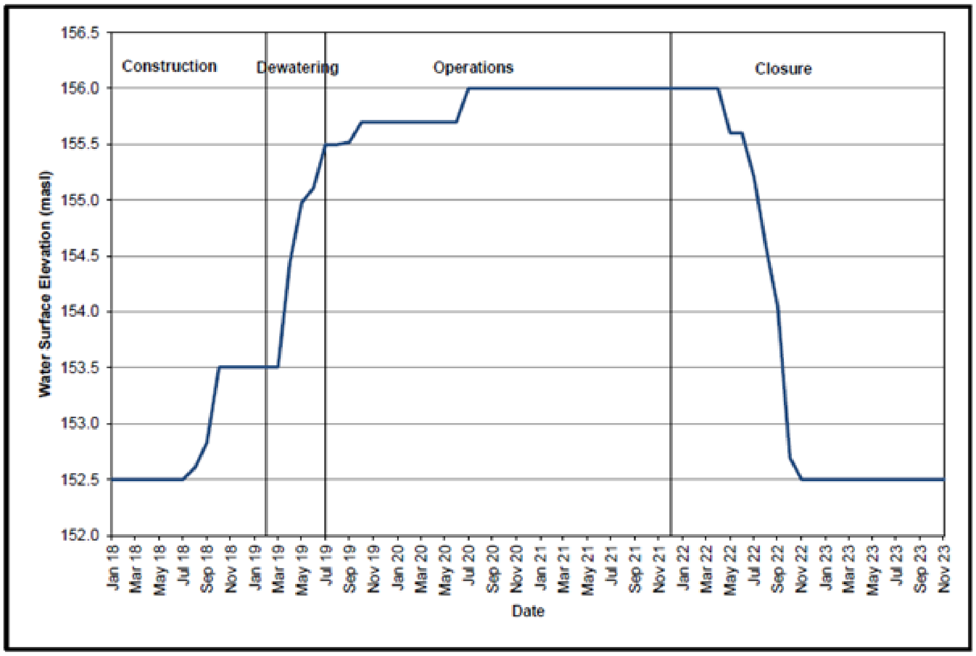

Figure 5. Proposed filling pattern for Whale Tail Lake (South Basin) Diversion. Provided by R. Baker.

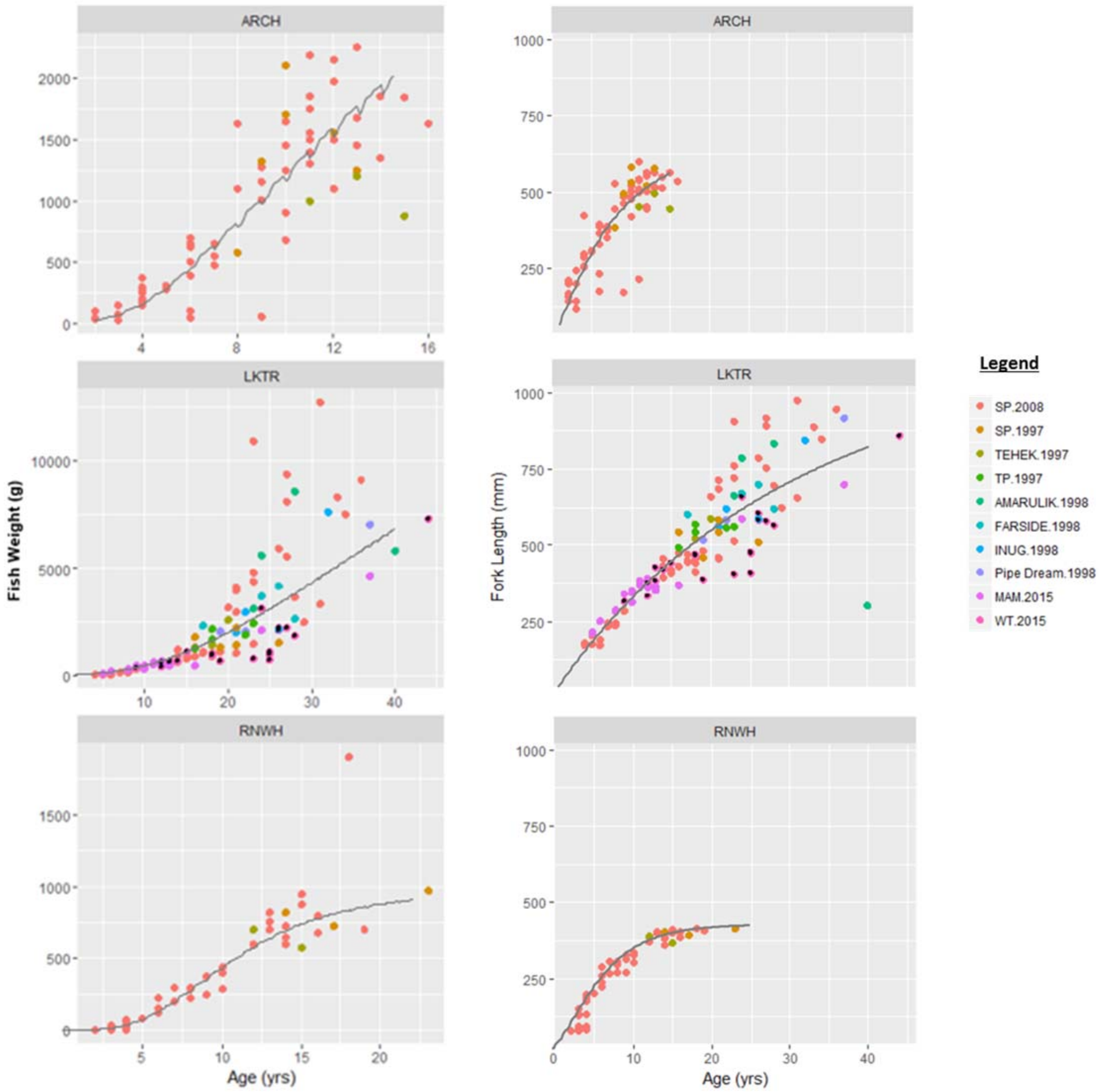

Figure 6. Predicted (lines) and observed (points) growth rates for Arctic Char (ARCH), Lake Trout (LKTR) and Round Whitefish (RNWH). SP = Second Portage Lake , TEHEK= Tehek Lake, TP = Third Portage Lake, MAM = Mammoth Lake, WT = Whale Tail Lake . Data from G. Mann, Azimuth Consulting Group Partnership**.**

Because the simulations did not fully represent conditions at Whale Tail Lake, the effects of a 4 year impoundment were compared to the effects of permanent flooding in relative terms. Predicted increases in fish mercury concentrations for a 4 year impoundment were divided by predicted increases with permanent flooding. A value of 0.8 would mean that the peak increase in fish mercury concentration for a 4 year impoundment would be 80% of the peak increase with permanent flooding. The equation used for this calculation was as follows:

$$\text{Adjustment Factor} = (PIF_{4yr}-1)/(PIF_{permanent\ flooding}-1)$$

Where

Adjustment Factor	= Effect of 4 yr impoundment on peak fish mercury concentration, relative to permanent flooding (dimensionless).
PIF_{4yr}	= Predicted maximum fish mercury concentration after flooding divided by predicted pre-flood concentration, for a scenario with 4 yrs of flooding.
$PIF_{permanent\ flooding}$	= Predicted maximum fish mercury concentration after flooding divided by predicted pre-flood concentration, for a scenario with permanent flooding.

The “minus 1” in the numerator and denominator of the calculation of the Adjustment Factor is included because the calculation estimates the effect of a 4 yr impoundment only in terms of the increase in fish mercury concentration, not the overall concentrations. This calculation could then be used to adjust predictions of the increase in fish mercury concentrations ($PIF_{permanent\ flooding}$) estimated with other tools.

3 Results and Discussion

Predicted effects of a 4 year impoundment on increases in peak fish mercury levels are summarized in Figures Figure 7-Figure 8 and Tables Table 1 - Table 3. Overall, a 4 year impoundment is predicted to produce less of an increase mercury concentrations in some but not all fish, when compared to permanent flooding. This predicted effect was more more evident in older predatory fish. For example, the increases in mercury concentrations predicted to occur with permanent flooding in age 19+ predatory fish would be adjusted using a multiplier ranging from 0.56 to 0.75 if predicting increases that would occur with the 4 year inundation scenarios tested. Peak concentrations would be adjusted used a multiplier ranging from 0.68 to 0.85. When the Robert Bourassa scenario was modified to use growth rates and bioenergetics constants more applicable to the Whale Tail region, a 4 year impoundment had less effect on predicited peak concentrations in Northern Pike, but the results were within the range predicted for the 1st two scenarios. A more complete representation of the Whale Tail Lake food web and local site conditions would be needed to fully explore site-specific influences on the effects of a 4 year impoundment.

In contrast to the predictions for adult Northern Pike, the adjustment factor applied to predicted increases in fish mercury concentrations in age 0+ to 2+ fish of any species simulated, and any age whitefish, ranged from 0.9 to 1.0 (*i.e*. little change compared to permanent flooding). The effects of a 4 year impoundment on peak mercury concentrations varied with species and age because of differences in the timing of peak concentrations that occur with permanent flooding, compared to when water levels were lowered back to pre-flood levels. If fish were predicted to reach peak concentrations within the first four years post-flood, there was no change in the peak level if water levels were lowered after 4 years. If peak concentrations were predicted to occur much later than 4 years after flooding, and were still rising when water levels were lowered, the predicted effects of a 4 yr impoundment were more evident. Lower trophic level fish are predicted and observed to reach peak concentrations sooner than higher trophic level predators. For predatory species, younger fish reach peak levels sooner than older fish. Both of these trends are related to the fact that fish obtain most of their methylmercury via the diet. Dietary increases in methylmercury concentrations must occur in prey items before an increase will occur in a predator, resulting in lag times between increase in trophic levels, and between younger and older predators who eat different size/age prey. These trends are shown in Figure 9, which plots predicted fish mercury concentrations versus time for the three scenarios, with permanent flooding (solid lines) and temporary flooding (dashed lines) for three age classes of fish (ages 2+, 9+, and 19+ years). The three panels on the right side of Figure 9 show model results for whitefish, which were closer to peak values 4 years post-flood than were the predators, shown on the left side of Figure 9. This partly demonstrates why the effects of a 4 year impoundment were greater for predators than prey fish. All age classes of whitefish were predicted to reach peak levels within about 5 years after flooding, which resulted in less variability in the predicted effect of a 4 year impoundment on prey fish than for predators, whose peak concentrations were predicted to occur from 3-15 years after flooding. Older age classes of piscivorous fish peaked later than younger age classes, demonstrating why the effects of a 4 year impoundment were more evident for older predatory fish.

The simulations also suggested that peak fish mercury levels would continue to rise for a period of time after water levels were lowered, although not to the same peaks that would occur with permanent flooding. The continued rise of fish mercury levels after water levels declined was associated with lag times predicted for methylmercury in higher trophic level biota to respond to changes in methylmercury production and concentrations in sediments, water, and lower trophic levels in the reservoir ecosystems. If peak fish mercury concentrations were estimated for a 4 year flood scenario simply by examining observed fish mercury levels in reseroirs at 4 years post-flood, peak concentrations would be slightly underestimated.

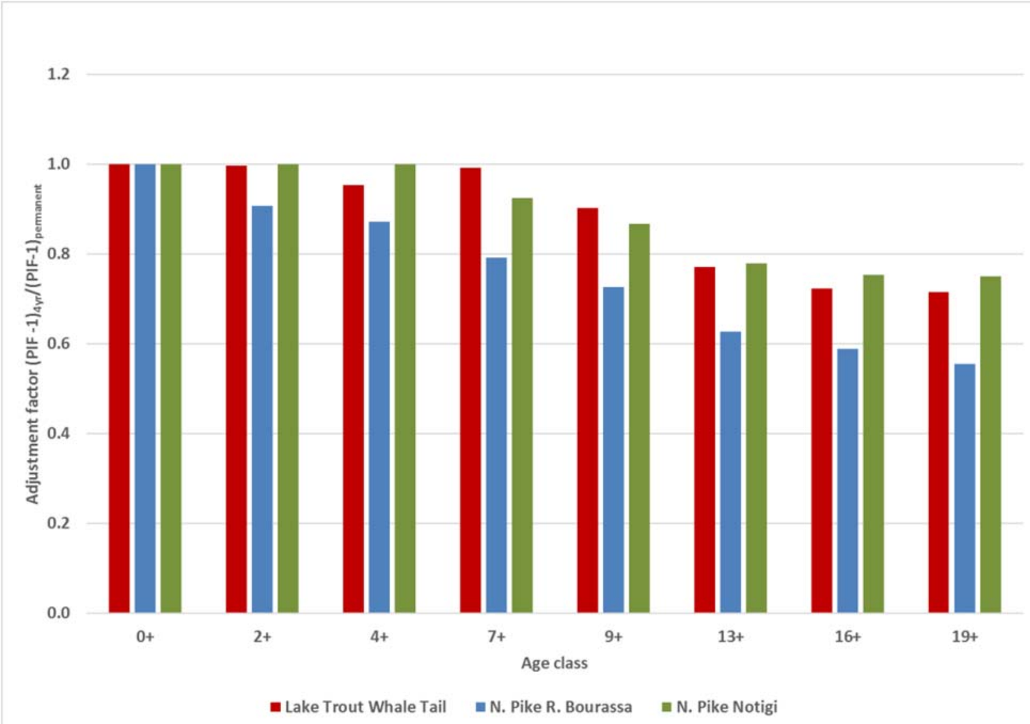

Figure 7. Predicted effects of a 4 year flood duration on peak mercury concentrations in top predators. Y axis values represent scaling factors to adjust peak increase factors applied to predictions with permanent flooding.

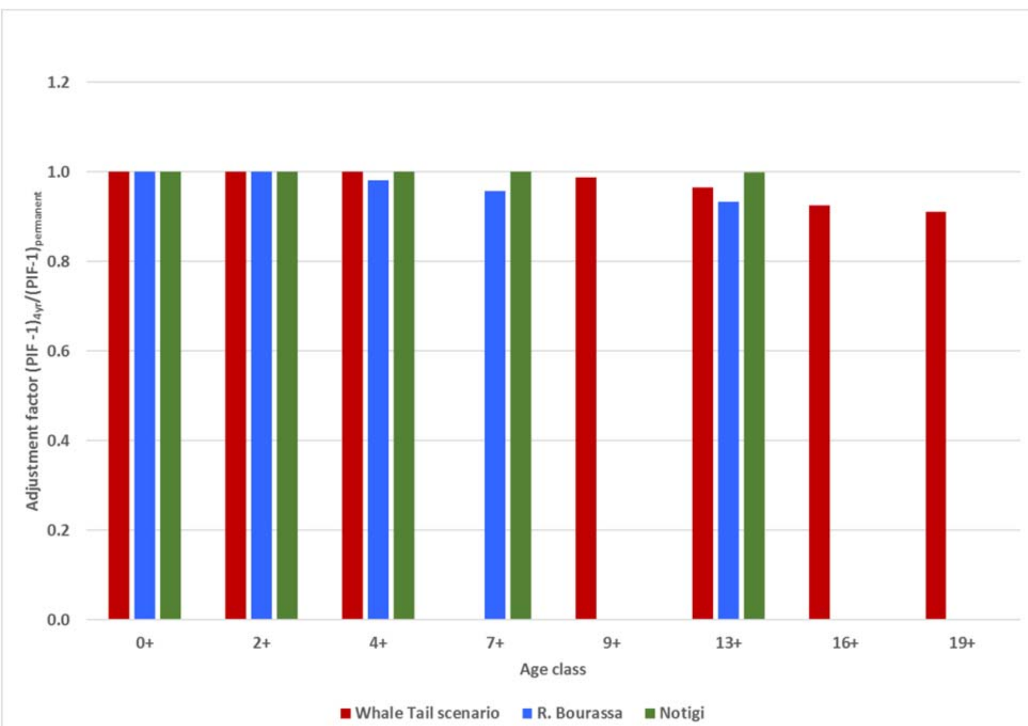

Figure 8. Predicted effects of a 4 year flood duration on peak mercury concentrations in Lake Whitefish. Y axis values represent scaling factors to adjust peak increase factors applied to predictions with permanent flooding.

Table 1. Predicted effects of a 4 year flood duration on peak mercury concentrations in Northern Pike and Lake Whitefish for Robert Bourassa Reservoir.

Species	Age Class (yr)	Length range (mm)	Ratio of predicted peak concentrations for 4 yr and permanent flooding ($PIF_{4yr}/PIF_{permanent}$)	Ratio of predicted increases in peak concentrations for 4 yr and permanent flooding $(PIF -1)_{4yr}/(PIF-1)_{permanent}$
Northern Pike	0+	35 - 205	1.00	1.00
	2+	332 - 419	0.92	0.91
	4+	493 - 555	0.90	0.87
	7+	638 - 680	0.83	0.79
	9+	701 - 736	0.77	0.73
	13+	782 - 807	0.71	0.63
	16+	817 - 839	0.69	0.59
	19+	841 - 859	0.68	0.56
Lake Whitefish	0+	25 - 123	1.00	1.00
	2+	193 - 240	1.00	1.00
	4+	279 - 313	0.98	0.98
	6+	336 - 362	0.96	0.96
	9+	393 - 413	0.95	0.93

Table 2. Predicted effects of a 4 year flood duration on peak mercury concentrations in Northern Pike and Lake Whitefish for Notigi Reservoir.

Species	Age Class (yr)	Length range (mm)	Ratio of predicted peak concentrations for 4 yr and permanent flooding ($PIF_{4yr}/PIF_{permanent}$)	Ratio of predicted increases in peak concentrations for 4 yr and permanent flooding $(PIF -1)_{4yr}/(PIF-1)_{permanent}$
Northern Pike	0+	0.1 - 32	1.00	1.00
	2+	134 - 271	1.00	1.00
	4+	460 - 646	1.00	1.00
	7+	952 - 1150	0.95	0.92
	9+	1245 - 1434	0.91	0.87
	13+	1689 - 1854	0.86	0.78
	16+	1910 - 2060	0.85	0.75
	19+	2060 - 2199	0.85	0.75
Lake Whitefish	0+	.2 - 25	1.00	1.00
	2+	92 - 171	1.00	1.00
	4+	250 - 343	1.00	1.00
	6+	410 - 502	1.00	1.00
	9+	608 - 690	1.00	1.00

Table 3. Predicted effects of a 4 year flood duration on peak mercury concentrations in Lake Trout and Whitefish for Robert Bourassa Reservoir, with modified fish bioenergetics and growth rates.

Species	Age Class (yr)	Length range (mm)	Ratio of predicted peak concentrations for 4 yr and permanent flooding ($PIF_{4yr}/PIF_{permanent}$)	Ratio of predicted increases in peak concentrations for 4 yr and permanent flooding $(PIF-1)_{4yr}/(PIF-1)_{permanent}$
Lake Trout	0+	14 - 50	1	1
	2+	89 - 121	1.00	1.00
	4+	157 - 187	0.96	0.95
	7+	251 - 278	0.99	0.99
	9+	309 - 334	0.92	0.90
	13+	414 - 436	0.81	0.77
	16+	484 - 505	0.78	0.72
	19+	549 - 567	0.78	0.71
Whitefish	0+	20 - 49	1	1
	2+	90 - 130	1.00	1.00
	4+	175 - 212	1.00	1.00
	7+	277 - 303	0.99	0.99
	9+	319 - 339	0.96	0.97
	13+	368 - 379	0.94	0.92
	14+	375 - 385	0.93	0.91

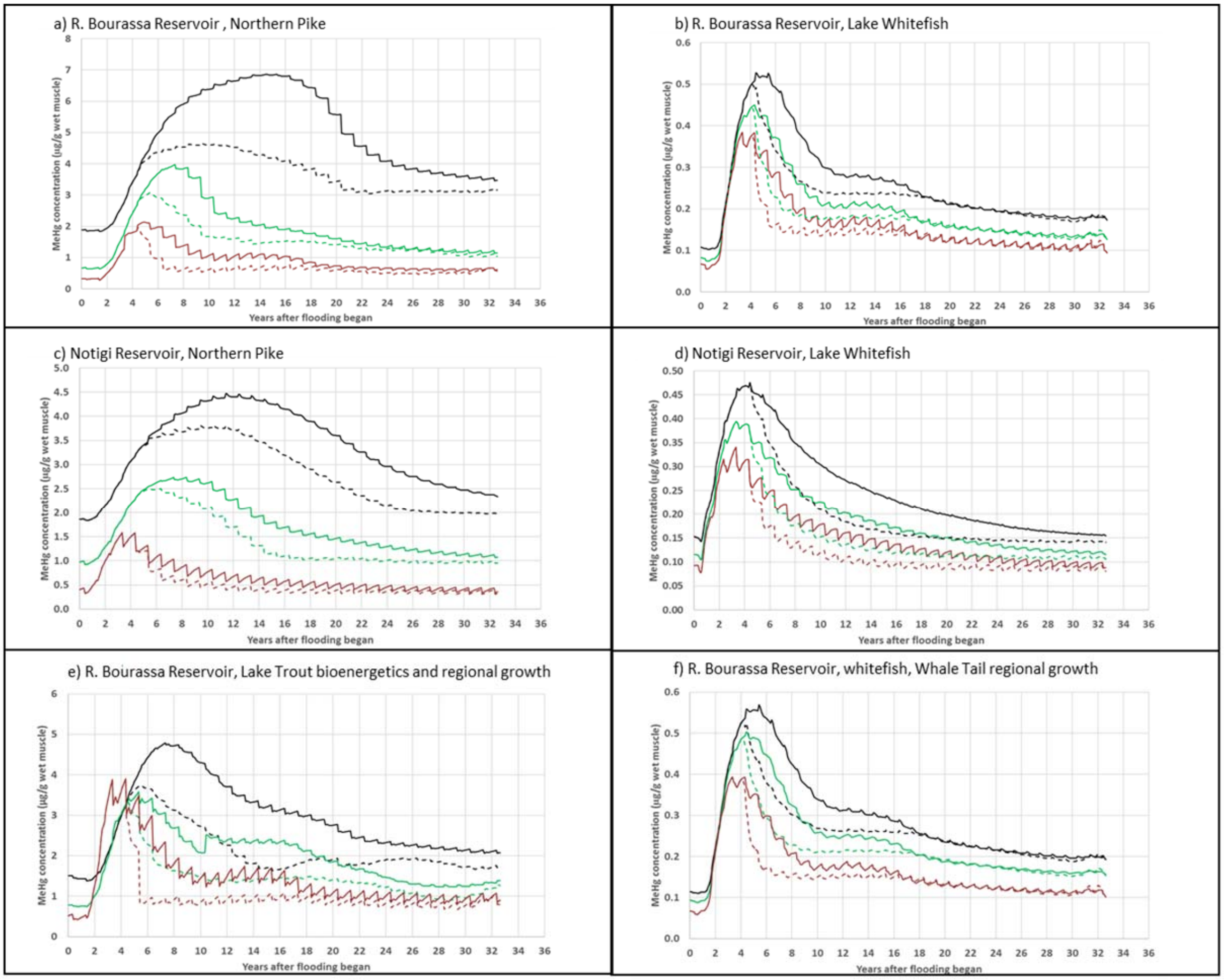

Figure 9. Predicted methylmercury concentrations versus tim in predatory and prey fish species for three reservoir scenarios. Black = age 19+ yrs, Green = age 9+ yrs, Red = Age 2+ yrs. Solid line = permanent flooding, dashed line = 4 yr impoundment.

4 Conclusions

Simulations were carried out to examine the potential effect of flooding for 4 years rather than permanently, in terms of peak fish mercury concentrations. Previous simulations of Robert Bourassa Reservoir in Quebec and Notigi Reservoir in Manitoba were modified such that water elevations returned to pre-flood levels after four years of flooding. Overall, the simulations predicted that a 4 year impoundment would produce less of an increase mercury concentrations in some but not all fish, relative to permanent flooding. The predicted effects varied by species and age and were more evident in older predatory fish. Increases in mercury concentrations predicted to occur with permanent flooding in age 19+ predatory fish would be lowered using a multiplier ranging from 0.56 to 0.75 if predicting increases that would occur with the 4 year inundation scenarios tested. In contrast, the adjustment factor applied to predicted increases in fish mercury concentrations in age 0+ to 2+ fish of any species simulated, and any age whitefish, ranged from 0.9 to 1.0 (*i.e.* little change compared to permanent flooding). Given that the scenarios tested are all hypothetical and do not have field data to test the accuracy of the predictions, the results are interpreted to suggest that a flooding period of 4 years would experience lower peak concentrations in adult predatory fish, but the results should not be assigned robust numerical accuracy.

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