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Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Mercury Assessment and Potential for Bioaccumulation Study
Study Plan Section 5.7

Final Study Plan

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

July 2013

5.7. Mercury Assessment and Potential for Bioaccumulation Study

On December 14, 2012, Alaska Energy Authority (AEA) filed with the Federal Energy Regulatory Commission (FERC or Commission) its Revised Study Plan (RSP), which included 58 individual study plans (AEA 2012). Included within the RSP was the Mercury Assessment and Potential for Bioaccumulation Study, Section 5.7. RSP Section 5.7 focuses on the potential for mercury methylation to occur in the Project reservoir, will use modeling to estimate potential methylmercury concentrations in fish and will assess potential pathways for methylmercury to migrate to the surrounding environment.

On February 1, 2013, FERC staff issued its study determination (February 1 SPD) for 44 of the 58 studies, approving 31 studies as filed and 13 with modifications. On April 1, 2013 FERC issued its study determination (April 1 SPD) for the remaining 14 studies; approving 1 study as filed and 13 with modifications. RSP Section 5.7 was one of the 13 approved with modifications. In its April 1 SPD, FERC recommended the following:

Use of Harris and Hutchinson and EFDC Models for Mercury Estimation

- *We recommend that AEA use the more sophisticated Phosphorus Release Model to predict peak methylmercury levels in fish tissue, regardless of the outcome of the other two models.*

Mercury Effects on Riverine Receptors

- *We recommend that AEA include likely riverine receptors (i.e., biota living downstream of the reservoir that may be exposed to elevated methyl mercury concentrations produced in the reservoir and discharged to the river) as part of the predictive risk analysis. The additional study element would have a low cost (section 5.9(b)(7)) because AEA would simply add consideration of additional receptors to the existing analysis. This information is necessary to evaluate potential project effects downstream of the reservoir (section 5.9 (b)(5)).*

Prediction of potential methylmercury production and bioaccumulation in riverine receptors will be based on mutliple models with increasing levels of complexity. Estimating methylmercury production using multiple tools is expected to improve prediction of potential for bioaccumulation by: 1) verifying each outcome using multiple tools, and 2) using predictive output from individual models to inform the pathways analysis. Assessment of current background mercury concentrations in fish tissue is a reference against which impact of operational scenarios will be compared. Use of lower trophic levels (e.g., periphyton and benthic macroinvertebrates) to determine potential of mercury bioaccumulation show weaker relationship with potential impact from mercury methylation and conditions that increase methylation. A more stable signal within the biological community has been through correlation of fish tissue concentrations and organic decay rates. Predictions for impact of methylmercury bioaccumulation downstream of the reservoir will be based on comparison of fish tissue, sediment, pore water, and surface water concentrations to pre-project conditions. Increased concentrations of methylmercury predicted to occur in any of these media at downstram sites from the reservoir will be analyzed using the pathways analysis model to determine factors and mechanisms by which transfer occurs. Riverine receptors that contribute to bioconcentration of methylmercury in fish tissue will be identified through examination of feeding habits of fish that consume these receptors and through water quality conditions that are known to promote bioaccumulation of methylmercury in periphyton and benthic macroinvertebrates.

AEA has included FERC's modification requests in this Final Study Plan**.**

5.7.1. General Description of the Proposed Study

Many studies have documented increased mercury concentrations in fish and wildlife following the flooding of terrestrial areas to create hydroelectric reservoirs. The purpose of this study is to assess the potential for such an occurrence in the proposed Project area.

Based on several studies, the mercury that is found in newly formed reservoirs originates predominantly from inundation of organic soils. Receptors are and will be present in the inundation area (macroinvertebrates, fish, birds, etc.). Mercury methylation in reservoirs is a fairly well understood process, and numerous models exist to predict the occurrence and magnitude of the phenomena.

Given these known factors, key questions that need to be answered by this study include the following:

1) Whether conditions within the reservoir will cause mercury methylation from this source.
2) The concentrations of methylmercury that might occur.
3) Whether a mechanism exists (fish and small invertebrates living in the methylation zone) to transfer that methylmercury to wildlife, resulting in detrimental impacts.

Based on these questions, specific objectives of this study are as follows:

- Summarize available and historic water quality information for the Susitna River basin, including data collection from the 1980s Alaska Power Authority (APA) Susitna Hydroelectric Project.
- Characterize the baseline mercury concentrations of the Susitna River and tributaries. This will include collection and analyses of vegetation, soil, water, sediment pore water, sediment, piscivorous birds and mammals, and fish tissue samples for mercury.
- Utilize available geologic information to determine if a mineralogical source of mercury exists within the inundation area.
- Map mercury concentrations of soils and vegetation within the proposed inundation area. This information will be used to develop maps of where mercury methylation may occur.
- Use the water quality model to predict where in the reservoir conditions (pH, dissolved oxygen, turnover) are likely to be conducive to methylmercury formation.
- Use modeling to estimate methylmercury concentrations in fish.
- Assess potential pathways for methylmercury to migrate to the surrounding environment.

- Coordinate study results with other study areas, including fish, instream flow, and other piscivorous bird and mammal studies.

5.7.2. Existing Information and Need for Additional Information

The process by which mercury enters ecosystems is fairly well understood. Inorganic mercury from the atmosphere is deposited in lakes and rivers. Where conditions are right (anoxic, available sulfur), inorganic mercury can be converted by bacteria to methylmercury. Transfer of elemental mercury occurs from atmospheric deposition to surface water, and surface water to sediments. Production of methylmercury, mediated by bacterial activity is promoted or suppressed by one or combination of several factors in the aquatic environment.

Factors known to enhance methylation of mercury either in surface water or sediment are the following:

- Presence of aquatic vegetation and low oxygen concentrations
- Increased nutrients, temperature, microbial respiration, and dissolved organic carbon
- Neutral to low pH

Factors known to suppress methylation of mercury either in surface water or sediment are as follows:

- High oxygen concentrations
- Presence of sulfides and acid-volatile sulfides
- Presence of Selenium in sediments

Transfer of bioaccumulated mercury outside of the aquatic environment occurs between top of food chain animals with consumption of aquatic organisms by terrestrial animals.

At each level in a food chain, from bacteria to plankton, small fish, larger fish, and ultimately piscivorous terrestrial wildlife and humans, organisms take in more mercury than they excrete thereby accumulating the excess. This results in elevated concentrations of methylmercury at higher trophic levels. Fish-eating birds and mammals can suffer a wide range of impacts from accumulated methylmercury, including behavioral, neurochemical, hormonal, and reproductive effects.

While this process occurs all over the world in natural wetlands, it can be especially acute in newly formed reservoirs. This is because organic-rich soils can absorb mercury from the atmosphere over decades, and their degradation at the bottom of the reservoir will generate a spike in methylmercury production (Stokes and Wren 1987; Bodaly et al, 1984; Bodaly el al. 2007; Rudd, 1995; Hydro-Quebec 2003).

Many studies have documented increased mercury levels in fish following the flooding of terrestrial areas to create hydroelectric reservoirs (Bodaly et al. 1984; Bodaly et al 1997; Bodaly et al 2004; Bodaly et al. 2007; Rylander et al. 2006; Lockhart et al 2005; Johnston et al. 1991; Kelly et al. 1997; Morrison 1991b). Increased mercury concentrations have also been noted at other trophic levels within aquatic food chains of reservoirs, such as aquatic invertebrates (Hall et al. 1998). These problems have been particularly acute in hydropower projects from northern climates including Canada and Finland (Rosenberg et al. 1997). When boreal forests with large surface-area-to-volume ratios are flooded, substantial quantities of organic carbon and mercury stored in vegetation biomass and soils become inputs to the newly formed reservoir (Bodaly et al. 1984; Grigal 2003; Kelly et al. 1997). This flooding accelerates microbial decomposition, causing high rates of microbial methylation of mercury. Studies have shown this increase is temporary, lasting between 10 and 35 years (Hydro-Quebec 2003; Bodaly et al. 2007), whereupon methylmercury concentrations return to background levels. It should be noted that background methylmercury concentrations are rarely zero, and many natural water bodies have shown elevated concentrations of methylmercury.

Inorganic mercury deposition from the atmosphere is not a significant source of mercury concentrations that are elevated above background; however, it can be a source of background mercury concentrations. For example, Rudd (1995) has shown that just 0.3 and 3% of the mercury in a reservoir is derived from precipitation, the remainder from inundated fine organic soil particles. As explained in Section 5.7.1, the goal of this study is to quantify mercury resulting from filling the reservoir, not necessarily background mercury.

Background mercury concentrations are better predicted from studying mercury levels in nearby natural lakes, not quantifying atmospheric deposition. Background lake studies are included as part of the fish tissue sampling (see Section 5.7.4.2.6).

Mercury in organic soils is common. Background concentrations in organic soils of the Kuskokwim area of Alaska were found to be 0.10 to 1.2 parts per million (ppm) (Bailey and Gray 1997; Gray et al 2000); however, this area is well known to have large ore bodies of cinnabar, a mercury ore. Soils in Norway and Sweden were found to have mercury concentrations only as high as 0.24 ppm (Lindqvist 1991). In the United States, the mean concentrations reported from organic soils and loamy soils are 0.28 ppm and 0.13 ppm, respectively (Kabata-Pendias and Pendias 1992). Background concentrations for organic soils in Canada as high as 0.40 ppm have been reported (Kabata-Pendias and Pendias 1992). Shacklette and Boerngen (1984) report an average value of 0.058 ppm in all soil types in the contiguous United States.

In organic soils, mercury is mainly present in its inorganic form; the methylated form usually represents less than 1 percent of the total. Mercury does not appear to be mobile in soils, where it is firmly bound to the humus (Hydro-Quebec 2003).

Methylmercury can be detected in nearly every fish analyzed, from nearly any water body in the world. This is because the primary source of mercury to most aquatic ecosystems is deposition from the atmosphere. Mercury deposition worldwide has been steadily increasing due to the widespread burning of coal. In 2007, an international panel of experts concluded, “remote sites in both the Northern and Southern hemispheres demonstrate about a threefold increase in Hg deposition since preindustrial times” (Lindberg et al. 2007). Lakes at Glacier Bay, Alaska, have shown that current rates of atmospheric mercury deposition are about double what was observed in pre-industrial times (Engstrom and Swain 1997).

Mercury of non-atmospheric origin has been occasionally found in water bodies. The source can be industrial processes, mercury mining, or simply the presence of sulfate-rich mercury ores, which occur in very limited areas. In the study area, no mining has occurred, and there are no industrial sources. Point sources have been documented on the Kuskokwim River in Alaska, but are relatively rare, and are associated with known sulfate-rich ore bodies (Saiki and Martin 2010; Gray et al 2000). Based on the available geologic information, the inundation area consists largely of diorite and granodiorite, which are not typically associated with massive sulfide mineral deposits. For this reason, such a point source appears to be unlikely in the inundation area for the dam.

In areas that lack the necessary mercury mineralization, the mercury concentration in parent geologic materials is typically very low, and cannot explain the mercury concentrations observed in sediment in aquatic ecosystems (Fitzgerald et al. 1998; Swain et al. 1992; Wiener et al. 2006).

Historical mercury data from the study area are limited. Some samples were collected during previous studies of the APA Susitna Hydroelectric Project in the 1980s (AEA, 2011). This consisted of the collection of water samples at Gold Creek (RM 136) in 1982. Total mercury was found to be 0.12 micrograms per liter (µg/L) in turbid, summer water, and 0.04 µg/L in the clear, winter water (AEA, 2011). The same results were found downriver at Susitna Station (RM 26).

Frenzel (2000) collected sediment samples from the Deshka River and Talkeetna River, as well as from Colorado Creek and Costello Creek, which are tributaries to the Chulitna River (Table 5.7-1). Based on these results, mercury concentrations in the drainage appear to be elevated over the national median, and appear to vary significantly by drainage. The report indicated that both Colorado and Costello Creeks appear to drain a portion of Denali National Park and Preserve that is highly mineralized, which likely causes the higher than background mercury concentrations. Previous studies (St. Louis et al. 1994) have shown that methylmercury occurrence is positively correlated with wetland density, and the Deshka River has significantly more wetlands in the drainage than other tributaries to the Susitna River.

Additional samples were collected by Frenzel (2000) of slimy sculpin from the Deshka River, Talkeetna River, and Costello Creek (Table 5.7-2). Whole fish samples tend to underestimate the presence of methylmercury, given that this compound concentrates in muscle tissue.

Samples of fish tissue and sediment from the Deshka River and Costello Creek were speciated for metallic mercury and methylmercury (Table 5.7-3). As anticipated, the ratio of methylmercury to inorganic mercury in the Deshka River is relatively high due to extensive wetlands in the drainage area. Costello Creek was found to have a higher inorganic mercury component due to possible mineralogical sources of mercury in the drainage area.

Overall mercury concentrations in water were also found to be positively correlated with the turbidity of the water. Very little mercury was found in filtered water samples (Frenzel 2000). This is consistent with methylmercury being strongly bound to organic particles.

These results are in agreement with the results from Krabbenhoft et al. (1999). In nationwide mercury sampling, in a wide array of hydrological basins and environmental settings, wetland density was found to be the most important factor controlling methylmercury production. It was also found that methylmercury production appears proportional to total mercury concentrations only at low total mercury levels. Once total mercury concentrations exceed 1,000 nanograms per gram (ng/g), little additional methylmercury was observed to be produced. Atmospheric deposition was found to be the predominant source for most mercury. Subbasins characterized as mixed agriculture and forested had the highest methylation efficiency, whereas areas affected by mining were found to be the lowest.

A more recent study has been done by the Alaska Department of Environmental Conservation's Department of Environmental Health (ADEC 2012). ADEC is currently analyzing salmon (all five species) as well as other freshwater species for total mercury in the Susitna River drainages (Table 5.7-4). These results appear to be consistent with those in other areas of the state.

5.7.3. Study Area

Water quality and sediment samples will be collected at the sites identified in Table 5.7-5. The study area begins at RM 15.1 and extends past the proposed dam site to RM 233.4. Tributaries to the Susitna River will be sampled and include those contributing large portions of the lower river flow such as the Talkeetna, Chulitna, Deshka, and Yentna rivers. Also included are smaller tributaries such as Gold, Portage, Tsusena, and Watana creeks, and the Oshetna River. These sites were selected based on the following rationale:

- Adequate representation of locations throughout the Susitna River and tributaries above and below the proposed dam site for the purpose of a baseline mercury characterization.
- Location on tributaries where proposed access road crossing impacts might occur during and after construction (upstream/downstream sampling points on each crossing).
- Consultation with licensing participants including co-location with other study sites (e.g., instream flow, ice processes).
- Sites that are in the Susitna River mainstem, tributary, or slough locations, most of which were monitored in the 1980s.

The proposed study will describe impacts from road crossings on mercury concentrations. Several access road corridors have been identified, one of which will be utilized to access the proposed dam site. Road crossings are expected to impact streams at each of the crossings and these locations will be surveyed for toxics concentrations above background in sediment and surface water.

Soil and vegetation samples will be collected from the proposed inundation area. Piscivorous birds and mammals, and fish samples will be collected from a variety of drainages in the study area; however, the focus will be on the proposed inundation area for the dam to establish background concentrations of methylmercury in fish prior to site development.

5.7.4. Study Methods

This study responds to comments from NMFS and USFWS, among other licensing participants. Originally the study components described here were spread into several other sections of the overall study plan. They have been consolidated here to provide an overview of the proposed mercury assessment and bioaccumulation plans.

This study consists of six study components:

- Summarize available information for the Susitna River basin, including data collection from the 1980s APA Susitna Hydroelectric Project, and existing geologic information to determine if a mineralogical source of mercury exists within the inundation area.
- Collect and analyze background vegetation, soil, water, sediment, sediment pore water, piscivorous birds and mammals, and fish tissue samples for mercury. This will include

mapping vegetation types and the lateral extent, thickness, and mercury concentrations of soils within the proposed inundation area. These data will be used to provide background concentrations for mercury, but will also help evaluate potential mitigation methods (soil and vegetation removal) should that become necessary.

- Use the water quality model to predict where in the reservoir conditions (pH, dissolved oxygen, turnover) are likely to be conducive to methylmercury formation (see Section 5.6).
- Utilize specialty models to predict potential fish methylmercury concentrations.
- Assess potential pathways for mercury movement from different areas of methylmercury formation to the surrounding environment.
- Prepare a technical report on analytical results, modeling, and mercury pathway assessment.

5.7.4.1. Summary of Available Information

Existing literature will be reviewed to summarize the current understanding of the occurrence of mercury in the environment. Much of that work has already been performed as part of this work plan and during previous studies (URS 2011) for this project. This review will include the following:

- A summary of 1980s APA Susitna Hydroelectric Project water quality studies, including data.
- Data collected in Alaska by both USGS and ADEC.
- A summary of the findings during development of other cold region hydroelectric projects.

5.7.4.2. Collection and Analyses of Soil, Vegetation, Water, Sediment, Sediment Pore Water, Piscivorous Birds and Mammals, and Fish Tissue Samples for Mercury

Data will be collected from soil, vegetation, surface water, sediment pore water, sediment, piscivorous birds and mammals, and fish tissue. Each of these media has been carefully selected on the following basis:

1. Applicability. Does measurement of background mercury contributions in the specified media contribute to understanding and predicting methylmercury concentrations after impoundment?
2. Measurability. Can we collect accurate data? Is the data representative of what is occurring in the environment? Will we be able to collect the same data post-impoundment?
3. Impact. Is the media likely to be impacted by the impoundment? Will the sampling damage the resource?

At this time there are media not being sampled as part of this study plan because it violates one of more of these decision points. The following is a summary of the most important media we are not sampling, and the reasoning for their exclusion from the sampling program:

Macroinvertebrates. Current mercury concentrations in macroinvertebrates are poor indicators post impoundment methylmercury concentrations in fish and wildlife, and most methylmercury models do not utilize this data for that reason (Harris and Hutchison, 2008; Hydro Quebec, 2003, etc.).

There appears to be no predictive model that can utilize current macroinvertebrate methylmercury concentration to predict future macroinvertebrate concentrations. Rennie et al (2011) has developed a predictive model for benthic macroinvertebrates, but not for other macroinvertebrates. Modeling of methylmercury in benthic invertebrates is of limited value, given these organisms are primarily predated by fish, which are already being modeled elsewhere in the study.

Methylmercury concentrations in macroinvertebrates can vary significantly by species, location, life stage, feeding behavior, and fish predation (Henderson et al, 2011). Sample mass can also be an issue. Even with the relatively low mass required for analyses, macroinvertebrates often require mixing of several individuals specimens, or even species, sometimes from collection locations far apart, into a single sample analytical result.

We are aware of only one study (Gerrard and St Louis, 2001) where terrestrial wildlife has been directly impacted by methylmercury in macroinvertebrates post-impoundment, bypassing migration via fish. However, while that study showed an approximate doubling of methylmercury concentrations in the swallows, they found no overt toxicological affects. In fact increased dipteran productivity (the primary food source of tree swallows) after reservoir creation resulted in earlier nest initiation, larger eggs, and faster growth rates of wing and bill length in nestlings.

Sampling of macroinvertebrates would need to be conducted based on pathway analysis to define methylmercury generation and potential bioexposure routes. Current macroinvertebrates communities may have little bearing on post impoundment communities.

Methylmercury in fish tissues is generally an order of magnitude higher than that of their food sources (Rennie et al, 2011). Therefore methylmercury is typically not damaging to macroinvertebrates, and may not be damaging to their predators due to the position at a lower trophic level than piscivorous fish, birds, and mammals. Well-developed predictive models for fish and piscivorous wildlife should be generally protective of wildlife that feed directly on macroinvertebrates. Sampling for fish, piscivorous birds, and aquatic wildlife is planned in this study.

In summary, macroinvertebrate sampling at this time would appear to have limited applicability, in that it does not contribute significantly to predicting future methylmercury concentrations or impacts. There are concerns regarding whether that data can be collected and interpreted accurately, and other studies are focused on more sensitive and easily measured methylmercury impacts.

Atmosphere. As illustrated in Figure 5.7-1, mercury cycles between the water soil, and atmosphere. Net accumulation rates are low. Also, the rate and amount of atmospheric deposition doesn’t depend on whether the water body is a natural lake or reservoir.

Previous studies have found that increases in methylmercury concentrations in a reservoir after filling are not related to atmospheric deposition. As previously stated, Rudd (1995) has shown that just 0.3 and 3% of the mercury in a reservoir is derived from precipitation, the remainder from inundated fine organic soil particles. While inorganic mercury deposition from the atmosphere is not a significant source of mercury concentrations that are elevated above background, it can be a source of background mercury concentrations. The goal of this study is to quantify mercury resulting from filling the reservoir, not necessarily background mercury.

Background mercury concentrations are better predicted from studying mercury levels in nearby natural lakes, not quantifying atmospheric deposition. Background lake studies are included as part of the fish tissue sampling.

Mercury in reservoirs typically isn't source limited, but is related to methylation rates in the reservoir. The water quality model will predict methylation rates in the reservoir (Section 5.6.4.8).

In summary, mercury deposition from the atmosphere represents an impact not related to creation of the reservoir. Measurements of atmospheric deposition are unlikely to advance our understanding and prediction of methylmercury concentrations after impoundment. The media (air) is unlikely to be impacted by filling of the reservoir.

Large Terrestrial Wildlife. Large terrestrial wildlife such as bears and foxes can consume fish and even piscivorous birds, however it is not their primary food source in the area, therefore net accumulation of methylmercury should be relatively low. Population density is anticipated to be low, and food sources may include areas well outside the drainage. The proposed study includes sampling of lower trophic levels (fish and birds), which should be protective of these apex predators.

Salmon. Limited numbers of salmon (estimated at 30 to 50) are currently in the inundation zone. Sampling a sufficient number of these fish to generate statistically usable data would be harmful to the fish run. As a small run, it currently serves as a very limited food source to the area. Salmon typically have higher mercury concentrations than resident fish, however, this mercury is predominately oceanic in origin.

The following sections describe these planned study components. A Quality Assurance Project Plan/Sampling and Analysis Plan (QAPP/SAP) has been developed for the Mercury Assessment and Potential for Bioaccumulation Study (Attachment 5-3). This QAPP/SAP includes specific detail describing study design, sampling procedures, and determining quality of data collected that satisfy objectives. This document is a required document when generating environmental data intended for use in making regulatory decisions. The QAPP/SAP ensures that defensible and high quality data is generated in this study by establishing performance goals and a process for evaluation of each of the study elements.

5.7.4.2.1. Vegetation

The principal concern for the vegetation portion of this study is to determine the mass of organics and mercury concentrations in the reservoir area. Plant species differ in their ability to take up mercury. At the Red Devil and Cinnabar Creek mines, alders and willows concentrate mercury at levels as much as 20 times higher than those in the other species collected in this study (Baily and Gray 1997). The mechanism of mercury uptake and reason for variation in mercury uptake by species is unclear. Siegal et al. (1985, 1987) have suggested that some species are mercury accumulators, whereas other plant species release their absorbed mercury as mercury vapor and thus lower their total concentration of mercury. Overall, leaves and needles have been found to hold the greatest accumulations of mercury in Alaska plants (Baily and Gray 1997).

The degradation rate for organic materials in water seems to be a primary source of the spike in methylmercury concentrations after filling of a reservoir (Hydro-Quebec 2003). Only the green part of the vegetation (leaves of trees and shrubs as well as forest ground cover) and the top centimeters of humus decompose quickly. Tree branches, trunks and roots, as well as deeper humus, remain almost intact decades after flooding (Morrison and Thérien 1991). Previous studies by Hydro-Quebec have shown that woody debris, even if it contains mercury, is not a problem for mercury methylation because the decay rate is slow in cold water (Hydro-Quebec 2003).

Based on these studies, up to 50 samples will be collected from various plants within the proposed inundation area. Studies are currently being completed on the distribution of types of species in the inundation zone, thus this information is currently unavailable. The sampling will be biased toward total vegetative mass, that is to say species that are present in the inundation area at low frequency and size may not be sampled, because even if these plants contain mercury, their contributions to mercury methylation will be low. Multiple samples (five to seven) will be collected at different locations for each species in the inundation area. Based on the available preliminary data, it is anticipated that a majority of the samples will consist of alder *(Alnus crispa),* willow *(Salix* sp.), white spruce *(Picea glauca),* cottonwood *(Populus balsamifera),* black spruce *(Picea mariana),* paper birch *(Betula papyrifera), and* dwarf birch *(Betula nana).* Leaves and needles will be collected.

Additional details of the sampling methods are provided in a combined Sampling and Analysis Plan (SAP) and the Quality Assurance Project Plan (QAPP) for this study.

5.7.4.2.2. Soil

Studies have found that the primary source of mercury to new reservoirs was the inundated soils (Meister et al. 1979), especially the upper organic soil horizon, which often has higher mercury levels than the lower inorganic soil layers (Bodaly et al. 1984). Measuring the thickness and mercury content of these soils prior to inundation may allow predictions of possible mercury methylation, and assist with evaluating potential mitigation methods, if necessary.

To the extent possible, soil samples are coincident with vegetative samples. The primary concern is to document the thickness and extent of organic rich soils, because these soils will have the highest concentrations of mercury and will provide most of the organic material resulting in the generation of methylmercury.

Additional details of the sampling methods are provided in a combined SAP and the QAPP for this study.

5.7.4.2.3. Water

The purpose of the water sampling is to collect baseline water quality information to support an assessment of the effects of the proposed Project operations on water quality in the Susitna River basin.

Mercury in water will be tested monthly during the summer along with two sampling events during the winter. Mercury has been shown to vary in concentrations throughout the year (Frenzel 2000).

Water samples will be collected at the locations shown on Table 5.7-5. The proposed spacing of the sample locations follows accepted practice when segmenting large river systems for development of Total Maximum Daily Load (TMDL) water quality models. Water sampling during winter months will be focused on locations where flow data are currently collected, or were historically collected by USGS. Water samples will be analyzed for the parameters reported in Table 5.7-6.

Grab samples will be collected along a transect of the stream channel/water body, using methods consistent with ADEC and EPA protocols and regulatory requirements for sampling ambient water and trace metal water quality criteria. Mainstem areas of the river not immediately influenced by a tributary will be characterized with a single transect. Areas of the mainstem with an upstream tributary that may influence the nearshore zone or that are well-mixed with the mainstem will be characterized by collecting samples at two transect locations: in the tributary and in the mainstem upstream of the tributary confluence. Samples will be collected at 3 equi-distant locations along each transect (i.e. 25% from left bank, 50% from left bank, and 75% from left bank). Samples will be collected from a depth of 0.5 meters below the surface as well as 0.5 meters above the bottom. This will ensure that variations in concentrations, especially metals, are captured and adequately characterized throughout the study area.

These samples will be collected on approximately a monthly basis (four samples from June to September). The period for collecting surface water samples will begin at ice break-up and extend to beginning of ice formation on the river. Limited winter sampling (once in December, and again in March) will be conducted where existing or historic USGS sites are located.

Review of existing data (URS 2011) indicates that few exceedances occur with metals concentrations during the winter months. If the 2013 data sets suggest that mercury concentrations exceed criteria or thresholds, then an expanded 2014 water quality monitoring program will be conducted to characterize conditions on a monthly basis throughout the winter months.

Variation of water quality in a river cross-section is often significant and is most likely to occur because of incomplete mixing of upstream tributary inflows, point-source discharges, or variations in velocity and channel geometry. Water quality profiles at each location on each transect will be conducted for field water quality parameters (e.g., temperature, pH, dissolved oxygen, and conductivity) to determine the extent of vertical and lateral mixing. Additional details of the sampling methods are provided in a combined SAP and the QAPP for this study.

5.7.4.2.4. Sediment and Sediment Pore Water

In general, all sediment samples will be taken from sheltered backwater areas, downstream of islands, and in similar riverine locations in which water currents are slowed, favoring accumulation of finer sediment along the channel bottom. Samples will be analyzed for mercury (Table 5.7-6). In addition, sediment size and total organic carbon (TOC) will be included to evaluate whether these parameters are predictors for elevated mercury concentrations. Samples will be collected just below and above the proposed dam site. Additional samples will be collected near the mouth of tributaries near the proposed dam site, including Fog, Deadman, Watana, Tsusena, Kosina, Jay, and Goose creeks, and the Oshetna River. The purpose of this sampling will be to determine where metals, if found in the water or sediment, originate in the drainage.

Mercury occurrence is typically associated with fine sediments, rather than with coarse-grained sandy sediment or rocky substrates. Therefore, the goal of the sampling will be to obtain sediments with at least 5 percent fines (i.e., particle size <63 µm, or passing through a #230 sieve).

Surficial sediment sampling will be conducted with a Van Veen sampler lowered from a boat by a power winch. This sampling device collects high-quality sediment samples from the top four to six inches of sediment. Three sediment samples will be collected at each of the sites sampled. These three samples will be collected and analyzed separately to characterize the presence of mercury and generate statistical summaries for site characterization. A photographic record of each sediment sample will be assembled from images of newly collected material.

Care will be taken to ensure the following:

- The sampler will not be overfilled with sediment.
- The overlying water is present when the sampler is retrieved.
- At least two inches of sediment depth is collected.
- There is no evidence of incomplete closure of the sampling device.

If a sediment sample does not meet all of the criteria listed above, it will be discarded and another sample will be collected.

Sediment interstitial water, or pore water, is defined as the water occupying the space between sediment particles. Interstitial waters will be collected from sites listed above and separated from sediments in the field house laboratory using a pump apparatus to draw pore water from each of the replicate samples. Filtering of samples will utilize a 0.45-µm pore size filter in both the lab apparatus and field apparatus. In some cases, pore water may be drawn from sediment samples in the field by using 100-milliliter (mL) syringes immersed in the dredge sample once a sediment sample is collected in a sample jar. These would be cases where sediment samples have slightly coarser particle sizes and pore water extraction in the field is possible. In other instances, where sediment samples have finer particle sizes requiring more time to draw samples for laboratory analysis, these samples will be transferred to the field laboratory for pore water extraction.

Additional details of the sampling methods are provided in a combined SAP and QAPP for this study.

5.7.4.2.5. Piscivorous Birds and Mammals

The potential impacts of methylmercury on upper trophic level species can by influenced by a variety of factors including animal behavior and physiology (e.g., foraging behavior, diet composition) and physical/chemical properties of the receiving environment (e.g., organic carbon content, anaerobic conditions, sulfides, etc.). Fish, in particular, absorb methylmercury efficiently from dietary sources and store this material in organs and tissues (U.S. EPA, 1997). Because fish are the primary source of methylmercury migration into the terrestrial ecosystem, this evaluation focuses on the impact of methylmercury generated in the proposed reservoir on fish-eating (piscivorous) upper trophic species.

5.7.4.3. Bird Species

Waterbirds such as loons, grebes, terns, and belted kingfishers consume varying amounts of small fish. Small fish tend to have lower mercury concentrations than larger fish. Previous studies have shown that mercury levels in waterbirds are highly variable (Braune et al. 1999; Langis et al. 1999). This variability results from the propensity of waterbirds to migrate between drainages, and the variability of mercury concentrations between drainages and food sources. Because of dietary preferences, the belted kingfisher and loon are likely to be a more conservative indicator species than grebe and other aquatic bird species that could be exposed to mercury.

For raptors, ospreys typically consume a diet exclusively of fish, whereas bald eagles feed on fish, birds and other animals including carrion (Watson and Pierce 1998). These birds have a long life span (15 to 30 years in the wild), so they are likely to have the opportunity to accumulate significant amounts of mercury throughout their lifespans. A study in northern Quebec found that ospreys nesting near reservoirs had high burdens of methylmercury in their muscle tissues (DesGranges et al. 1998). However, the ospreys there did not appear to suffer reproductive problems that are typical of high methylmercury exposure, and it has been suggested that the tolerance of fish-eating raptors to this compound may be higher than other species (DesGranges et al. 1998).

Predicting site-specific mercury exposure in raptors from feather or tissue residue concentrations is difficult because that they tend to feed over wide ranges (osprey are migratory), and that while both species feed on salmon, eagles tend to favor this type of fish. Salmon mercury concentrations are generally lower than other species of fish, but are typically only available seasonally in freshwater environments. This means that mercury concentrations in raptors may vary seasonally as well. In addition, salmon are not anticipated to be in the area after completion of the reservoir.

5.7.4.4. Aquatic Mammal Species

Aquatic furbearers that eat fish are at the highest risk of accumulating mercury. River otter and mink, both of which occur in the study area at low numbers, can accumulate the highest concentrations of mercury in their body tissues (Yates et al, 2005). As with birds, predicting how methylmercury in the aquatic food chain will affect mammal populations is difficult. The concentration of methylmercury in mammal tissue depends on diet, range, and longevity of the animal. Studies have documented mercury levels in river otter ranging from 0.89 to 36.0 µg/g wet weight in muscle tissue, and from 0.02 to 96.0 µg/g wet weight in liver tissue (Wren et al. 1980). Mink have similar mercury levels, ranging from 0.71 to 15.2 µg/g wet weight in muscle tissue and from 0.04 to 58.2 µg/g wet weight in liver tissue. Because mink and otter represent an aquatic and terrestrial species, both species will be considered as part of this study.

5.7.4.5. Sampling Program

There are two significant challenges to the proposed sampling program. The first is that the populations of most piscivorous birds and aquatic mammals are relatively small in the proposed study area. For that reason, sampling efforts are likely to collect few samples, or may be entirely unsuccessful for some species. From a statistical standpoint, low sample returns (< 5 samples), coupled with high variability in methylmercury concentrations, and may reduce the accuracy of results and conclusions for this study. In addition, damaging relatively small populations of these species as part of this study is undesirable, and therefore non-destructive sampling methods are preferred.

The second challenge is that some species may be feeding in areas outside the area of project effects. Species that feed in more than one area may be exposed to widely varying methylmercury dietary loads that are not specific to the inundation zone.

To compensate for these problems, the proposed study will:

1) Utilize data obtained in other studies on background concentrations of methylmercury in natural northern environments.
2) Utilize samples in the muscle and liver of various fish species and from feathers and fur, where it does not degrade quickly (Thompson, 1996; Strom 2008). These types of samples can be collected without harvesting or even harassing the species being sampled.

Feathers will be collected from nests of raptors (principally bald eagles, given that ospreys are rare in the study area), loons, grebes, arctic terns, and kingfishers found during the wildlife surveys planned for 2013 and 2014. Feathers from raptors and waterbirds will only be collected after the nests have been vacated for the season. Belted Kingfisher feathers will be collected from borrows during the planned survey of colonially nesting swallows.

Fur samples from river otters and mink will be sought from animals harvested by trappers in the study area; river otter furs must be presented to ADF&G for sealing, at which time fur samples can be obtained from animals known to have been harvested in or near the study area. In view of the low level of trapping expected to occur in the area, however, it is possible that this approach will yield few samples. If this approach does not yield fur samples in 2013, fur will be collected by placing hair-snag "traps" at or near the mouths of tributaries near the proposed dam site, including Fog, Deadman, Watana, Tsusena, Kosina, Jay, and Goose creeks, and the Oshetna River.

Studies have shown that a vast majority of the mercury found in fur and feathers will consist of methylmercury, therefor the analyses will be for total mercury only (Evers et al 2005). Samples will be analyzed using Environmental Protection Agency (EPA) Method 7473. Additional details on the sampling are included as part of the SAP/QAPP (Attachment 5-1).

5.7.4.6. Predictive Risk Analyses

A predictive risk analysis is likely to be a better indicator of potential mercury impacts on the terrestrial environment than measured concentrations of mercury at the project site, since the number of samples that may be collected will be low, and methylmercury concentrations in fur and feathers can change seasonally (U.S. EPA, 1997). In addition, mercury sequestration in feathers may not be a good indicator of current or relevant exposure levels. For example, a study measuring feather mercury concentrations in seabirds during various growth and development stages of the birds suggest that in seabirds molting may be an efficient means of eliminating mercury (Becker et al., 1994; Burger et al., 1994).

The potential impacts of the Project on mercury levels on piscivorous birds and aquatic furbearers will be assessed using a risk characterization approach. This approach uses exposure and toxicity assessments to link a chemical of potential concern, in this case methylmercury, with adverse ecological effects (known as the toxicity reference value or TRV). The hazard quotient (HQ) is the ratio of average anticipated concentration of mercury being ingested to the known concentration where adverse effects may occur. It will be calculated for all species for which significant samples are available.

The global assumptions and limitations of the mercury models are as follows:

- The reservoir is flooded and mercury baseline is measured as Day 1 of operation.
- Herbivores and omnivores accumulate less total mercury in tissue than piscivores, therefore this type of assessment is protective of other terrestrial species.
- Mercury concentrations in fish are expected to peak in 3 to 7 years after filling of the reservoir.
- Fish concentrations will be predicted using other modeling methods outlined in Section 5.7.4.2.6.
- Because total mercury levels in piscivores are highly correlated with the ingestion rates of fish, total mercury bioaccumulation will approximate the rate of increase and decline in fish.

In order for the predicted exposure to be compared against the TRV, the daily intake (D) will be calculated. D is defined as the amount of chemical an organism is exposed to on a mg/kg body weight/day basis and is normalized for body mass. Because the sediment and water intake of mercury is likely to be minimal as compared to the food ingestion pathway, only dietary intake will be quantified. The formula for calculating D is as follows:

$$D = \frac{F_{site} \times [(IF \times EPC \times PF)]}{BW}$$

Where:

- IF is the Intake Factor (kg fish/kg body weight per day)
- EPC is the Exposure Point Concentration (mg methylmercury/kg fish)
- PF is portion of total food containing a particular chemical of concern.
- BW = body weight (kg)
- F_{site} is the fraction of total ingestion from the site.

The IF is calculated using the ingestion rate (IR) of fish (kg/day) on a dry weight basis. The model can be adjusted to account for the consumption of piscivorous and non-piscivorous fish species.

TRV values for mercury incorporated a chronic lowest-observed adverse effects level threshold for adverse effects to reproduction, growth, and/ or survival. As previously stated, the HQ =D/TRV. Typically, a HQ >1 indicates that the exposure concentration has surpassed the threshold and adverse effects are possible. A HQ < 1 means the exposure concentration has not surpassed the threshold and consequently adverse effects are unlikely to occur. These values will be derived from the extant literature. For example, USEPA (1997) set reference doses for methylmercury in avian and mammalian wildlife at 21 and 18 µg/kg body weight per day, respectively. It also suggested the wildlife criterion as measured in water for several key species as follows:

Species	Methylmercury in water (pg/L)
Kingfisher (*Ceryle alcyon*)	27
Mink (*Mustela vison*)	57
Loon (*Gavia immer)*	67
Osprey (*Pandion haliaetus*)	67
River otter (*Lutra canadensis*)	42
Bald eagle (*Haliaeetus leucocephalus*)	82

pg/L= picograms per liter

5.7.4.6.1. Fish Tissue

Methylmercury is ubiquitous in the environment, and can be found in fish throughout Alaska. The primary concern of this study is not to catalogue this source of mercury in the environment; rather, it is to evaluate the potential for increasing mercury concentrations above background due to filling of the reservoir.

Methylmercury bioaccumulates, and the highest concentrations are typically in the muscle tissue of adult predatory fish. Targeting adult fish is a good way of monitoring methylmercury migration to the larger environment. While it may be possible for methylmercury generated by the reservoir to affect other species, there does not appear to be any pathway by which this could happen without also affecting fish. Avian species have the potential to bypass fish by feeding on small fish species and macroinvertebrates; however, bird species can move between drainages and sources of mercury, and it is difficult to determine what contributions may be from the reservoir or from outside sources.

Target fish species in the vicinity of the Susitna-Watana Reservoir will be Dolly Varden, arctic grayling, stickleback, long nose sucker, whitefish species, lake trout, burbot, and resident rainbow trout. If possible, filets will be sampled from seven adult individuals from each species. The larger number of samples from existing fish species will allow for some statistical control over the results.

For comparison purposes, Hydro-Quebec, in their extensive study of methylmercury impacts from existing reservoirs, collected 131 lake trout from 7 lakes over a period of 22 years (Hydro Quebec, 2003). This comes to less than 1 fish per water body per year. AEA is proposing collecting many more fish over a shorter period of time.

Methylmercury concentrations in fish vary predominately by species, age, water body size, and location. For example, ADEC has reported statewide concentrations of methylmercury in pike to be 420 ppb (n =532), while in arctic grayling it is 84 ppb (n=44) (ADEC 2012), a 400%

difference. Increases in methylmercury above background post impoundment are typically measured in units of 100% (Harris and Hutchison, 2008).

There is a well-known positive correlation between fish size (length and weight) and mercury concentration in muscle tissue (Bodaly et al. 1984; Somers and Jackson 1993). Larger, older fish tend to have higher mercury concentrations. These fish will be the targets for sampling. Body size targeted for collection will represent the adult phase of each species life cycle. For stickleback, whole fish samples will need to be used.

Collection times for fish samples will occur in August and early September. Intensive studies of methylmercury concentrations in the zooplankton of boreal lakes (Garcia et al. 2007) has shown that average methylmercury concentrations increased by 48% between spring and mid-summer, and decreased by just 12% between mid and late summer. This is very consistent with Bodaly et al (1993) which showed that methylmercury concentrations in fish, when controlled for age and reservoir size, were strongly related to shallow water temperatures. As water temperatures are reduced, methylmercury concentrations in fish tissue also tend to decrease. Therefore the proposed sampling period should represent the highest concentrations of methylmercury in fish tissue, and also the most likely time when the fish may be harvested by terrestrial wildlife.

Samples will be analyzed for methyl and total mercury (Tables 5.7-6). It is anticipated that most of the mercury found in the fish with be methylmercury. Liver samples will also be collected from burbot and analyzed for mercury and methylmercury. Salmon will not be sampled. Preliminary data suggests that approximately 30 Chinook (king) salmon spawn in the Watana area. Collecting a sufficient number of samples from this resource would seriously deplete it. Instead, sampling data from ADEC will be used to evaluate mercury concentrations in this resource (ADEC 2012). It should be noted that most of the mercury in salmon is oceanic in origin.

Field procedures will be consistent with those outlined in applicable ADEC and/or EPA sampling protocols (USEPA 2000). Clean nylon nets and polyethylene gloves will be used during fish tissue collection. Species identification, measurement of total length (mm), and weight (g) will be recorded, along with sex and sexual maturity. If possible, efforts will be made to determine the age of the fish, including an examination of otoliths and scales.

It is possible that adult fish of all species may not be present or available in the drainage. In this case, younger fish may be sampled. To eliminate the bias associated with differences in fish size, appropriate statistical procedures will be used to determine the mean mercury concentration for a specific fish size (Hydro Quebec 2003).

Additional details of the sampling methods are provided in a combined SAP and the QAPP for this study.

5.7.4.7. Modeling

Reservoir impoundments have been documented to cause significant increases in fish mercury levels by factors that generally ranged from 3 to 7 (Hydro-Quebec 2003). The phenomenon is temporary, and mercury concentrations generally returned to baseline values after 7 to 30 years.

Reservoir construction involves raising the water level and flooding a large quantity of terrestrial organic matter (vegetation and the surface layers of soils). During the early years of a reservoir's existence, this organic matter is subject to accelerated bacterial decomposition, which increases methylation of the mercury accumulated in the soil from the atmosphere. The production of methylmercury is governed by the amount and type of flooded organic matter and by biological and physical factors such as bacterial activity, water temperature, oxygen content of the water, etc.

Part of the methylmercury produced is released into the water column where it may be transferred to fish via zooplankton. Insect larvae feeding in the top centimeters of flooded soils can assimilate the methylmercury available and transfer it to fish (Figure 5.7-2).

There is evidence that mercury concentrations in fish correlate closely with environmental parameters such as pH (Qian et al. 2001; Ikingura and Akagi 2003), organic carbon (Cope et al. 1990; Suns and Hitchin 1990; Driscoll et al. 1995), and wetland area (Greenfield et al. 2001). However, because fish assimilate the vast majority of their mercury burden from their diet, such correlations are indirect (Westcott and Kalff 1996; Lawson and Mason 1998). It is, however, possible to predict the potential for mercury methylation based on the pH, dissolved oxygen content, organic carbon, and wetland area of an individual drainage.

There are several ways to predict the occurrence of methylmercury in a newly formed reservoir. One way is to model the physical conditions that create methylation of mercury. If the conditions for methylation are present (low DO, low pH, organic content, etc.), then it is presumed that methylation will occur, and the methylmercury will be transferred outside the reservoir. This type of modeling will be done as part of the model for the reservoir (see Section 5.6 Water Quality Modeling Study). This type of modeling does not predict specific impacts to the ecosystem, but merely suggests that such impacts could occur, and where in the reservoir methylmercury may be forming. Such an approach has considerable value in evaluating potential mitigation measures.

The other way of predicting the occurrence of methylmercury is to model concentrations in fish tissue after filling of the reservoir. Schetagne et al. (2003) found a strong correlation between the ratio of flooded area, the mean annual flow through of the reservoir, and maximum mercury concentrations in fish tissue. This approach was further refined by Harris and Hutchinson (2008) to provide a predictive tool for methylmercury concentrations in fish. Regression calculations using historical data from multiple reservoirs have determined the coefficients that control these equations. The drawback to these models is that they only predict peak methylmercury concentrations, not when these concentrations will occur or subside.

Phosphorous release modeling is a semi-empirical way to derive the same result, but has the added benefit of being able to predict when peak methylmercury concentrations will occur, and when they are likely to subside (Hydro-Quebec 2003). Unfortunately, they require considerably more input parameters, which can create additional uncertainty in the results.

5.7.4.7.1. Harris and Hutchison Model

The model assumes that the primary source of methylmercury in a new reservoir is the flooded terrain, while the primary methylmercury removal mechanism is outflow/dilution. The highest methylmercury concentrations in fish are therefore associated with reservoirs that flood large areas, but have low flow-through.

The formula is as follows:

Peak Increase factor = 1 + K_1 x <u>Area Flooded</u>

$$Q + K_2 \times (\text{Area Total})$$

Where

Peak increase factor = peak increase factor in fish methylmercury over background

Area flooded = flooded area (km^2)

Q = mean annual flow (km^3/yr.)

K_1 = regression coefficients (km/yr.)

K_2 = regression coefficients (1/yr.)

Area total = Total reservoir area (km^2)

The values of K1 and K2 are adjusted for piscivorous and non-piscivorous species of fish. The use of area in the denominator reflects an assumption that methylmercury removal mechanisms other than outflow are primarily related to area (e.g., photodegradation, burial and sediment demethylation) rather than volume. This approach has been calibrated and tested in the field, with good results (Harris and Hutchinson 2008). This method will be used to estimate methylmercury concentrations in fish at the proposed reservoir.

5.7.4.8. Phosphorous Release Model

The more complex method of estimating methylmercury impacts was pioneered by Messier et al. (1985) based on the phosphorus release model of Grimard and Jones (1982), whole-ecosystem reservoir experiments at the Experimental Lakes Area (ELA) in Ontario, Canada (Bodaly et al. 2005), and confirmed by decades-long studies of reservoirs by Hydro-Quebec (2003). It predicts peak fish mercury levels and the timing of the response to flooding. The model pays special attention to flood zone characteristics, because decomposition after flooding is a key driver for increases in methylmercury levels in new reservoirs.

Studies have shown that a simple model cannot explain all the differences observed between reservoirs with regard to maximum fish mercury levels (Hydro-Quebec 2003). The filling time is another important factor in determining the maximum levels in fish; several authors have demonstrated that mercury is released into the water column very rapidly when organic matter from soils and vegetation is flooded (Morrison and Thérien 1991; Kelly et al. 1997). Chartrand et al. (1994) showed that the changes in reservoir water quality correspond to bacterial decomposition of organic matter (as does mercury release) and peak two or three years after impoundment in reservoirs filled in one year or less, but after six to ten years in impoundments that took 35 months to fill. Thus, a longer filling time leads to lower peak values, but prolongs the period of elevated mercury levels.

The percentage of flooded land area located in the drawdown zone is another important factor because it is an indicator of the active transfer of methylmercury to fish by periphyton and benthic organisms. In fact, this transfer can occur for over 14 years in shallow areas that are rich in flooded organic matter and protected from wave action (Tremblay and Lucotte 1997). Where forest soil cover is thin, wave action along the exposed banks of the drawdown zone quickly erodes the mercury-rich organic matter and deposits it in deeper, colder areas that are less conducive to methylation. This erosion considerably reduces the area of flooded soil that still has organic matter colonized by the benthic organisms responsible for much of the transfer of methylmercury to fish. Therefore, the larger the percentage of flooded land area in a reservoir drawdown zone, the smaller and shorter in duration the increase in fish mercury levels is likely to be. Colder water and the vegetation and soil cover that contained less decomposable organic matter (Association Poulin Thériault-Gauthier & Guillemette Consultants Inc. 1993) may also help mitigate the increase in fish mercury levels.

The Hydro-Quebec model is semi-empirical, not mechanistic: decaying organic material releases phosphorous at a set rate (the phosphorus release curve), which controls decomposition of the organic material in the inundation zone. This turns out to be a fairly accurate measure of the bioavailability of mercury for fish, and can be used to predict mercury concentrations in muscle tissues.

The basic equation used by Hydro-Quebec is as follows:

$$V\,(P_r)_t = \frac{P_i}{\text{Ø}} \times (1-e^{-\text{Ø}t}) + \frac{rB}{\alpha - r} \times \left(\frac{e^{-rt}-e^{-\text{Ø}t}}{\text{Ø}-r} + \frac{e^{-\text{Ø}t}-e^{-\alpha t}}{\text{Ø}-r} \right) + V\,(P_r)_0 e^{-\text{Ø}t}$$

Where:

V	=	Reservoir volume (m^3)
P_r	=	Concentration of total phosphorous in the reservoir at time t (mg/m^3)
t	=	time in years after reservoir filling
Pi	=	Total phosphorous from inflows (mg/yr.)
Ø	=	The sum of the sedimentation coefficient and the flushing coefficient (r)
r	=	The reservoir flushing coefficient (per year)
α	=	The phosphorous release coefficient = ½(365/X)
X	=	The half-life of the organic matter in days
B	=	$\alpha(I_t)S_{max}$
S_{max}	=	Maximum surface area flooded (m^3)
T	=	Time (year)

When solved for Pr, this allows for the calculation of the amount of decomposable organic matter (mgC/m2) at a specific time (It), calculated by:

$$I_t = (P_r)_0 + 4((Pr)_t - (P_r)_0)$$

Where It is the decomposition factor at the time t. This result can then be used to calculate mercury concentrations in non-piscivorous (NP) species and piscivorous (P) species of fish:

$$(Hg_{np})_t = (Hg_{np})_{t-1} \times \frac{(1)}{(2^{365/u})} + dI_t$$

Where:

Hg_{np} = mercury concentration in non-piscivorous muscle tissue (mg/kg)
u = half-life of mercury in fish (days). This is typically set at 700 days in northern climates, but can be adjusted.
d = a transfer factor

For the predatory species, the decomposition factor was replaced by a factor (f) for mercury transfer from the prey to the predator:

$$(Hg_p)_t = (Hg_p)_{t-1} \times \frac{(1)}{(2^{365/u})} + f(Hg_{np})_t$$

Where Hgp = mercury concentration in piscivorous muscle tissue.

These formulas have been tested, and found to be very effective in predicting mercury concentrations in fish tissue (Figure 5.7-2). Note that the predictions generally tend to overestimate the changes actually recorded. This situation reflects a conscious choice on the part of the developers of the formula to be conservative with their predictions.

The phosphorous release model will be used to predict peak methylmercury levels in fish tissue.
Pathway Assessment

Assessment of the potential pathways for mercury in the environment will be based on readily available literature (Hydro-Quebec 1993; Johnston et al. 1991; Therriault and Schneider 1998), and additional mercury studies, to ensure the most applicable methods are used to meet Project needs. The goal of the pathway assessment will be to evaluate the potential pathways for methylmercury to move into the ecosystem, both from the reservoir and downstream of the reservoir.

The pathway assessment will incorporate both existing conditions, and conditions with the reservoir and dam in place. The reservoir representation will be developed based on the local bathymetry and dimensions of the proposed dam. The Water Quality Modeling Study (Section 5.6) provides for a three-dimensional model to be developed for the proposed reservoir to represent the spatial variability in hydrodynamics and water quality in longitudinal, vertical, and lateral directions. The model will be able to simulate flow circulation in the reservoir, turbulence mixing, temperature dynamics, nutrient fate and transport, interaction between nutrient and algae, and potentially sediment and metal transport.

5.7.4.9. Technical Report on Analytical Results and Mercury Assessment

The technical report will include a description of the study goals and objectives, assumptions made, sample methods, analytical results, models used, and other background information. Field data, laboratory report, and quality assurance information will be attached. Mercury will be modeled using three methods:

1. Water quality modeling of the reservoir will predict whether the conditions for the formation of methylmercury will be present, and where in the reservoir this may occur.

2. The linear model of Harris and Hutchinson (2008) to provide an initial prediction of peak mercury concentrations in fish.
3. The phosphorous release model will be used to evaluate when peak methylmercury production may occur.

The report will include a conceptual model showing mercury inputs to the reservoir, mercury methylation, mercury circulation among different media (fish, air, water, sediment, etc.), and bioabsorption and transfer. Strategies to manage mercury methylation, bioaccumulation, and biomagnification will be reviewed (Mailman et al. 2006).

Sediment, water, and tissue results from toxics analysis will use the federal NOAA Screening Quick Reference Tables (SQuiRTs). These are thresholds used as screening values for evaluation of toxics and potential effect to aquatic life in several media and will be implemented where ADEC water quality, sediment, or tissue criteria are not available.

An example for SQuiRT values can be found at the following website:

http://mapping2.orr.noaa.gov/portal/sanfranciscobay/sfb_html/pdfs/otherreports/squirt.pdf

Specific thresholds and criteria for toxics in each of the media are included in a QAPP.

Coordination will occur with the instream flow, ice processes, productivity, and fish studies to obtain information needed to reflect the results of this study in the context of the various Project scenarios.

5.7.5. Consistency with Generally Accepted Scientific Practice

Field sampling practices proposed in this study are consistent with ADEC (2003, 2005); USGS (Ward and Harr 1990); Edwards and Glysson 1988); and EPA (USEPA 2000). Results will be compared to established NOAA cleanup levels (NOAA 2012). Studies, field investigations, laboratory testing, engineering analysis, etc. will be performed in accordance with general industry-accepted scientific and engineering practices. The methods and work efforts outlined in this study plan are the same or consistent with analyses used by applicants and licensees and relied upon by FERC in other hydroelectric licensing proceedings.

The Clean Water Act Section 401 Water Quality Certification process includes a baseline assessment of mercury conditions and will determine if existing conditions will result in a potential for bioaccumulation. The monitoring strategy used in this study follows scientifically accepted practice for identifying impacts to water quality and will be used for Project certification. ADEC and USGS are currently pursing similar sampling programs for fish tissue in the state (ADEC 2012; Frenzel 2000; and Krabbenhoft et al. 1999).

FERC has a long history of performing similar studies during hydroelectric permitting, including most recently at the Middle Fork American River Project (FERC Project No. 2079) in 2011; and Yuba County Water Agency Yuba River Development Project (FERC Project No. 2246).

5.7.6. Schedule

The study elements will be completed in several stages and based on the timeline shown in Table 5.7-7. Water quality monitoring will start in March 2013, and continue periodically throughout the remainder of the year. Sediment and fish tissue sampling will occur in July and August.

Bird and aquatic furbearer samples will be collected in the third quarter of 2013. Some fish tissue samples have already been collected in 2012; the remainder will be collected in the third quarter of 2013. The initial study report will be completed by December 2014, with the final due in the first quarter of 2015. Additional follow-up studies will be performed between these two dates, as necessary.

5.7.7. Relationship with Other Studies

A flow chart (Figure 5.7-3) describing interdependencies outlines origin of existing data and related historical studies, specific output for each element of the Water Quality studies, and where the output information generated in the Water Quality studies will be directed. This chart provides details describing the flow of information related to the Water Quality studies, from historical data collection to current data collection. Data were examined in a Water Quality Data Gap Analysis (URS 2011) and this information was used, in part, to assist in making decisions about the current design for the Water Quality Monitoring studies and for ensuring that the current modeling effort would be able to compare the 1980s study results with current modeling results.

Integral portions of this interdependency chart are results from the Ice Processes Study and from the Fish and Aquatic Instream Flow Study. The Ice Processes Study will support water quality model development (Study Plan 5.6) with information about timing and conditions for ice formation and ice break-up. The Fish and Aquatic Instream Flow Study represents the effort to develop a hydraulic routing model that will be coupled with the EFDC water quality model. Water quality monitoring efforts for field parameters, general chemistry, and metals (including mercury) will be used as a calibration data set for developing the predictive EFDC model.

5.7.8. Level of Effort and Cost

The estimated cost for the proposed work in 2013 and 2014, including planning and reporting is approximately $500,000. This presumes that the costs for sampling and analyses all non-biological media are covered within the water quality costs.

5.7.9. Literature Cited

ADEC. 2005. Water Quality Assessment and Monitoring Program. Alaska Department of Environmental Conservation: Division of Water. Juneau, Alaska. 58p.

ADEC. 2012. Mercury concentration in fresh water fish Southcentral Susitna Watershed. Personal communication with Bob Gerlach, VMD, State Veterinarian. June 2012.

Alaska Energy Authority (AEA). 2011. Pre-Application Document: Susitna-Watana Hydroelectric Project FERC Project No. 14241. Volume I of II. Alaska Energy Authority, Anchorage, AK. 395p.Arctic Environmental Information and Data Center (AEIDC), 1985. Preliminary draft impact assessment technical memorandum, Volume 1. Main text.

Association Poulin Thériault - Gauthier & Guillemette Consultants Inc. 1993. *Méthode de caractérisation de la phytomasse appliquée aux complexes Grande-Baleine et La Grande*. Report by Association Poulin Thériault - Gauthier & Guillemette Consultants Inc. for Hydro-Québec. 152 p. and appendices.

Bailey, E.A., and Gray, J.E. 1997. Mercury in the terrestrial environment, Kuskokwim Mountains region, southwestern Alaska, in Dumoulin, J.A. and Gray J.E., ed., Geologic studies in Alaska by the U.S. Geological Survey, 1995: U.S. Geological Survey, Professional Paper 1574, p. 41-56.

Becker, P.H., Henning, D., and Furness, R.W. 1994. Differences in mercury contamination and elimination during feather development in gull and tern broods. Arch. Environ. Contam. Toxicol. 27:162-167.

Bodaly, R.A., Hecky, R.E., and Fudge, R.J.P. 1984. Increases in fish mercury levels in lakes flooded by the Churchill River diversion, northern Manitoba. Can. J. Fish. Aquat. Sci. 41: 682–691.

Bodaly, R.A., J.W.M. Wudd, R.J.P. Fudge, and C.A. Kelly. 1993. Mercury concentrations in fish related to size. Can. Jounal of Fish. Aquat. Sci. SO: 980-987.

Bodaly, R.A., St. Louis, V.L., Paterson, M.J., Fudge, R.J.P., Hall, B.D., Rosenberg, D.M., and Rudd, J.W.M., 1997, Bioaccumulation of mercury in the aquatic food chain in newly flooded areas, in Sigel, A., and Sigel, H., eds., Metal ions in biological systems: Mercury and its effects on environment and biology: New York, Marcel Decker, Inc., p. 259-287.

Bodaly R.A., Beaty K.G., Hendzel L.H., Majewski A.R., Paterson M.J., Rolfhus K.R., Penn A.F., St. Louis V.L., Hall B.D., Matthews C.J.D., Cherewyk K.A., Mailman M., Hurley, J.P., Schiff S.L., Venkiteswaran J.J., 2004. Experimenting with hydroelectric reservoirs, Environmental Science & Technology, American Chemical Society. pp. 346A-352A.

Bodaly, R.A., Beaty, K.G., Hendzel, L.H., Majewski, A.R., Paterson, M.J., Rolfhus, K.R., Penn, A.F., St.Louis, V.L., Hall, B.D., Matthews, C.J.D., Cherewyk, K.A., Mailman, M., Hurley, J.P., Schiff, S.L., and Venkiteswaran, J.J.. 2005. Mercury and the FLUDEX project: response. Environ. Sci. Technol. 39: 185A-186A.

Bodaly R.A., Jansen W.A., Majewski A.R., Fudge R.J.P., Strange N.E., Derksen A.J., Green D.J. 2007. Post impoundment time course of increased mercury concentrations in fish in hydroelectric reservoirs of Northern Manitoba, Canada. Arch. Environ. Con tam. Toxicol. 53:379-389.

Braune, B.; Muir, D.; DeMarch, D.; Gamberg, M.; Poole, K.; Currie, R.; Dodd, M.; Duschenko, W.; Eamer, J.; Elkin, B.; Evans, M.; Grundy, S.; Hebert, C.; Johnstone, R.; Kidd, K.; Koenig, B.; Lockhart, L.; Marshall, H.; Reimer, K.; Sanderson, J.; Shutt L.; 1999. Spatial and Temporal Trends of Contaminants in Canadian Arctic Freshwater and Terrestrial Ecosystems: A Review. Science of the Total Environment, Volume 230, Issues 1–3, 1 June 1999, Pages 145-207.

Burger, J., I.C.T. Nisbet and M. Gochfeld (1994). Heavy metal and selenium levels in feathers of known-aged common terns (Sterna hirundo). Arch. Environ. Contam. Toxicol. 26:351-355.Bodaly R.A., Hecky R.E., Fudge R.J.P. 1984. Increases in fish mercury levels in lakes flooded by the Churchill River Diversion, Northern Manitoba. Can. J. Fish. Aquat. Sci. 41:682-691.Chartrand, N., Schetagne, R., Verdon, R. 1994. *Enseignements tirés du suivi environnemental au complexe La Grande*. 18th Congress of the International Commission on Large Dams, Durban (South Africa). Paris: International Commission on Large Dams. p. 165-190.

Cope, W.G., Wiener, J.G., and Rada, R.G. 1990. Mercury accumulation in yellow perch in Wisconsin seepage lakes — relation to lake characteristics. Environ. Toxicol. Chem. 9: 931–940.

DesGranges, J.L.; Rodrigue, J., Tardif, B.; and Laperle M., 1998. Mercury Accumulation and Biomagnification in Ospreys (Pandion haliaetus) in the James Bay and Hudson Bay Regions of Québec. Archives of Environmental Contamination and Toxicology. Volume 35, Number 2 (1998), 330-341, DOI: 10.1007/s002449900384.

Driscoll, C.T., Blette, V., Yan, C., Schofield, C.L., Munson, R., and Holsapple, J. 1995. The role of dissolved organic carbon in the chemistry and bioavailability of mercury in remote Adirondack lakes. Water Air Soil Pollut. 80: 499–508.

Edwards, T.K., and D.G. Glysson. 1988. Field methods for measurement of fluvial sediment. U.S. Geological Survey Open-File Report 86-531, 118 p.

Engstrom, D.R., and Swain, E.B. 1997, Recent declines in atmospheric mercury deposition in the Upper Midwest: Environmental Science and Technology, v. 31, no. 4, p. 960-967.

Evers, D. Burgess, N. Champux, L. Hoskins, B. Major, A. Goodale, W., Taylor, R. Poppenga, R. and Daigle, T., 2005. Patterns and interpretation of mercury exposure in freshwater avian communities in northeastern North America. Exotoxicology 14: 193-221.

Fitzgerald, W.F., Engstrom, D.R., Mason, R.P., and Nater, E.A. 1998. The case for atmospheric mercury contamination in remote areas: Environmental Science and Technology, v. 32, no. 1, p. 1-7.

Frenzel, S.A. 2000. Selected Organic Compounds and Trace Elements in Streambed Sediments and Fish Tissues, Cook Inlet Basin, Alaska. USGS Water-Resources Investigations Report 00-4004. Prepared as part of the National Water-Quality Assessment Program.

Garcia. E., Carignan, R. and Lean, D.R.S. 2007. Seasonal and inter-annual variations in methyl mercury concentrations in zooplankton from boreal lakes impacted by deforestation or natural forest fires. Environ Monit Assess 131:1–11.

Gray J.E., Theodorakos P.M., Bailey E.A., Turner R.R., 2000. Distribution, speciation, and transport of mercury in stream-sediment, stream-water, and fish collected near abandoned mercury mines in southwestern Alaska, USA. Science of the Total Environment 260:21-33.

Greenfield, B.K, Hrabic T.R., Harvey C.J. Carpenteer S.R. 2001. Predicting mercury levels in yellow perch. Use of water chemistry, tropi ecology and spatial traits. Can J. Fish Aquat. Scie. Vol 58 : 1419 –1429.

Grigal D.F., 2003. Mercury sequestration in forests and peatlands: a review. *Journal of Environmental Quality* 32:393-405.

Grimard, Y., Jones, H. G. 1982. Trophic upsurge in new reservoirs: a model for total phosphorous concentration, *Canadian Journal of Fisheries and Aquatic Sciences*, Vol. 39 (1982). p. 1473-1483.

Hall, B.D., Rosenberg D.M., Wiens A.P. 1998. Methylmercury in aquatic insects from an experimental reservoir. *Can. J. Fish. Aquat. Sci*. 55:2036-2047.

Harris, R., and Hutchinson, D., 2008. Lower Churchill Hydroelectric Generation Project Environmental Baseline Report: Assessment of the Potential for Increased Mercury Concentrations. Prepared by Tetra Tech Inc. March 4, 2008.

Henderson, B.L., Chumchal, M.M., Drenner, R.W., Deng, Y., Diaz, P., and Nowlin, W.H. 2011. Effects of Fish on mercury contamination of macroinvertebarte communities of grassland ponds. Environmental Toxicology and Chemistry, Vol. 31, No. 4, pp. 870–876, 2012.

Hydro-Quebec. 1993. Grande-Baleine complex. Feasibility study. Part 2: Hydroelectric complex. Book 6: Mercury, Hydro-Quebec, Montreal, Quebec.

Hydro-Quebec. 2003. Environmental Monitoring at the La Grande Complex Summary Report 1978–2000: Evolution of Fish Mercury Levels. Joint Report: Direction Barrages et Environment Hydro-Quebec Production and Groupe Conseil, Genivar Inc. December 2003.

Ikingura, J.R., and Akagi, H. 2003. Total mercury and methylmercury levels in fish from hydroelectric reservoirs in Tanzania. Sci. Total Environ. 304: 355–368.

Johnston, T.A., Bodaly R.A., Mathias J.A. 1991. Predicting fish mercury levels from physical characteristics of boreal reservoirs. Can. J. Fish. Aquat. Sci. 48:1468-1475.

Kabata-Pendias, A., Pendias H., 1992. Trace elements in soils and plants. 2nd ed. CRC Press, Inc., Boca Raton, Florida, pp. 365.

Kelly C.A., Rudd J.W.M., Bodaly R.A., Roulet N.P., St. Louis V.L., Heyes A., Moore T.R., Schiff S., Aravena R., Scott K.J., Dyck B., Harris R., Warner B., Edwards G. 1997. Increases in fluxes of greenhouse gases and methylmercury following flooding of an experimental reservoir. Environmental Science & Technology 31:1334-1344.

Krabbenhoft, D.P., Wiener, J.G., Brumbaugh, W.G., Olson, M.L., DeWild, J.F., and Sabin, T.J. 1999. A national pilot study of mercury contamination of aquatic ecosystems along multiple gradients, in Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Charleston, South Carolina, March 8-12, 1999— Volume 2, Contamination of hydrologic systems and related ecosystems: U.S. Geological Survey Water-Resources Investigations Report 99-4018B, p. 147-162.

Langis, R., Langlois, C. and Morneau, F., 1999. Mercury in birds and mammals. In M. Lucotte, R. Schetagne, N. Therien, C. Langlois and A. Tremblay (eds). Mercury in the Biogeochemical Cycle. pp. 131–144. Springer, Germany.

Lawson, N.M., and Mason R.P. 1998. Accumulation of mercury in estuarine food chains. *Biogeochemistry*. 40:235–247.

Lindberg, S., Bullock, R., Ebinghaus, R., Engstrom, D., Feng, X., Fitzgerald, W., Pirrone, N., Prestbo, E., and Seigneur, C., 2007. A synthesis of progress and uncertainties in attributing the sources of mercury in deposition: Ambio, v. 36, no. 1, p. 19-32.

Lindqvist, O., 1991. Mercury in the Swedish environment: 9. Mercury in terrestrial ecosystems bioavailability and effects. Water, Air, and Soil Pollution, 55(1–2):101–108.

Lockhart, W.L., Stem G.A., Low G., Hendzel M., Boila G., Roach P., Evans M.S., Billeck B.N., DeLaronde J., Friesen S., Kidd K.A., Atkins S., Muir D.C.G., Stoddart M., Stephens G., Stephenson S., Harbicht S., Snowshoe N., Grey B., Thompson S., DeGraff N., 2005. A history of total mercury in edible muscle of fish from lakes in northern Canada. Science of the Total Environment 351-352:427-463.

Mailman, M., Stepnuk L., Cicek N., Bodaly R.A. 2006. Strategies to lower methylmercury concentrations in hydroelectric reservoirs and lakes: A review. Science of the Total Environment 368:224-235.

Meister, J.F., DiNunzio J., Cox J.A. 1979. Source and level of mercury in a new impoundment. *Journal of the American Water Works Association* 71:574-576.

Messier, D., Roy, D. and Lemire R., 1985. Reseau de surveillance ecologique du complexe La Grande 1978-1984. Evolution du mercure dans la chair des poissons. Societe d'energie de la Baie James. 179 pages.

Morrison, K. and Thérien, N. 1991. Influence of Environmental Factors on Mercury Release in Hydroelectric Reservoirs, Montréal, Quebec, Canadian Electrical Association, 122 p.

Morrison, K., Thérien, N. 1991b. Experimental evolution of mercury release from flooded vegetation and soil. Water, Air and Soil Pollution, Vol. 56 (1991). p. 607-619.

National Oceanic and Atmospheric Administration (NOAA). 2012. Screening Quick Reference Tables (SQuiRTs), National Oceanic and Atmospheric Administration, Office of Response and Restoration, http://response.restoration.noaa.gov/sites/default/files/SQuiRTs.pdf.

Qian, S.S., Warren-Hicks, W., Keating, J., Moore, D.R.J., and Teed, R.S. 2001. A predictive model of mercury fish tissue concentrations for the southeastern United States. Environ. Sci. Technol. 35: 941–947.

Rosenberg, D.M., Berkes F., Bodaly R.A., Hecky R.E., Kelly C.A., Rudd J.W.M. 1997. Large scale impacts of hydroelectric development. Environ. Rev. 5:27-54.

Rudd, W.M., 1995. Sources of Methyl Mercury to Freshwater Ecosystems : A Review. Plenary address to the International Conference on Mercury as a Global Pollutant. Publication #10 of the Experimental Lakes Area Reservoir Project (ELARP).

Rylander, L.D., Grohn J., Tropp M., Vikstrom A., Wolpher H., De Castro e Silva E., Meili M., Oliveira L.J. 2006. Fish mercury increase in Lago Manso, a new hydroelectric reservoir in tropical Brazil. *Journal of Environmental Management* 81:155-166.

Saiki, M.K., and Martin, B.A. 2010. Mercury concentrations in fish from a Sierra Nevada foothill reservoir located downstream from historic gold-mining operations Environ. Monit. Assess 163:313–326.

Schetagne, R., J. Therrien, J. and R. Lalumière. 2003. Environmental Monitoring at the La Grande Complex. Evolution of Fish Mercury Levels. Summary Report 1978–2000.

Direction Barrages et Environment, Hydro-Québec Production and Groupe Conseil GENIVAR inc. 185 p. and appendix.

Shacklette, H.T., and Boerngen, J.G. 1984. Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States. USGS Professional Paper 1270.

Siegal, S.M., Siegal, B.Z., Lipp, C., Kruckeberg, A., Towers, G.H.N., and Warren, H. 1985. Indicator plant-soil mercury patterns in a mercury-rich mining area of British Columbia: Water, Air, and Soil Pollution, v. 25, p. 73-85.

Siegal, S.M., Siegal, B.Z., Barghigiani, C., Aratani, K.. Penny, P., and Penny, D., 1987. A contribution to the environmental biology of mercury accumulation in plants: Water, Air, and Soil Pollution, v. 33, p. 65-72.

Somers, K.M. and D.A. Jackson. 1993. Adjusting mercury concentration for fish-size covariation: a multivariate alternative to bivariate regression. Can. J. Fish. Aquat. Sci. 50: 2388-2396.

St. Louis, V. L., Rudd, J.W.M, Kelly, C.A., Beaty, K.G., Bloom, N.S. and Flett, R.J. 1994. The importance of wetlands as sources of methylmercury to boreal forest ecosystems. Can. J. Fish. Aquat. Sci. 51: 1065–1076.

Stokes, P. M., and Wren, C. D. 1987. Bioaccumulation of mercury by aquatic biota in hydroelectric reservoirs: A review and consideration of mechanisms. In Lead, Mercury, and Arsenic in the Environment (T. C. Hutchinson and K. M. Meema, Eds.), pp. 255–278. John Wiley and Sons, New York.

Strom SM., 2008. Total mercury and methylmercury residues in river otters (Lutra canadensis) from Wisconsin. Arch Environ Contam Toxicol. 2008 Apr;54(3):546-54. Epub 2007 Oct 10.

Suns, K., and Hitchin, G. 1990. Interrelationships between mercury levels in yearling yellow perch, fish condition and water-quality. Water Air Soil Pollut. 50: 255–265.

Swain, E.B., Engstrom, D.R., Brigham, M.E., Henning, T.A., and Brezonik, P.L. 1992. Increasing rates of atmospheric mercury deposition in midcontinental North America: Science, v. 257, p. 784-787.

Therriault, T.W. and Schneider, D.C. 1998. Predicting change in fish mercury concentrations following reservoir impoundment. Environmental Pollution 101:33-42.

Thompson, D. R. 1996. Mercury in birds and terrestrial mammals. In Beyer, W.N., G.H. Heinz, and A.W. Redman-Norwood (eds.). Environmental contaminants in wildlife: interpreting tissue concentrations. Lewis Publ., Boca Raton, FL. 341-356.

Tremblay, A. and Lucotte, M. 1997. Accumulation of total mercury and methylmercury in insect larvae of hydroelectric reservoirs. Can. J. Fish. Aquat. Sci. 54: 832-841.

URS 2011. AEA Susitna Water Quality and Sediment Transport Data Gap Analysis Report. *Prepared by* Tetra Tech, URS, and Arctic Hydrologic Consultants. Anchorage, Alaska. 62p.+Appendixes.

U.S. Environmental Protection Agency (USEPA), 1997a. Mercury Study Report to Congress Volume I: Executive Summary. December 1997. EPA-452/R-97-003.

USEPA, 1997b. Volume VI: An Ecological Assessment for Anthropogenic Mercury Emissions in the United States. Office of Air Quality Planning & Standards and Office of Research and DevelopmentEPA-452/R-97-008, December.

USEPA. 2000. Guidance for Assessing Chemical Contaminant Data for use in Fish Advisories: Volume 1 Fish Sampling and Analysis, 3rd Edition. EPA-823-B-00-007. United States Environmental Protection Agency, Office of Water. Washington, D.C. 485p.

Ward J.C., Harr, C.A. 1990. Methods for collection and processing of surface-water and bed material samples for physical and chemical analyses. U.S. Geological Survey Open-File Report 90-140. 71.

Watson, J.W., and Pierce, D.J, 1998. Ecology of bald eagles in western Washington with an emphasis on the effects of human activity. Final Report, Washington Department of Fish and Wildlife, Olympia, Washington, USA.

Westcott, K. and Kalff, J. 1996. Environmental Factors Affecting Methyl Mercury Accumulation in Zooplankton. Can. J. Fish. Aquat. Sci. 53: 2221–2228.

Wiener, J.G., Knights, B.C., Sandheinrich, M.B., Jeremiason, J.D., Brigham, M.E., Engstrom, D.R., Woodruff, L.G., Cannon, W.F., and Balogh, S.J. 2006. Mercury in soils, lakes, and fish in Voyageurs National Park (Minnesota)—Importance of atmospheric deposition and ecosystem factors: Environmental Science and Technology, v. 40, p. 6261-6268.

Wren, C.D., MacCrimmon, H.R., Frank, R. and Suda, P., 1980. Total and methylmercury levels in wild mammals from the Precambrian Shield area of south central Ontario. Bull. Environ. Contam. Toxicol. 25, 100–5.

Yates, D.E., Mayack, D.T., Munney, K., Evers, D.C., Major, A., Tranjit, K., and Taylor, R.L., 2005. Mercury Levels in Mink (Mustela vison) and River Otter (Lontra canadensis) from Northeastern North America. Ecotoxicology, 14, 263–274, 2005.

5.7.10. Tables

Table 5.7-1. Sediment Results from the Susitna River Drainage

Location	Mercury (µg/g dry weight)
Talkeetna River	0.04
Deshka River	0.46
Colorado Creek	0.18
Costello Creek	0.23
National median value	0.06

From Frenzel (2000)

Table 5.7-2. Whole Body Slimy Sculpin Results from the Susitna River Drainage

Location	Mercury (µg/g dry weight)
Talkeetna River	0.08
Deshka River	0.11
Costello Creek	0.08

From Frenzel (2000)

Table 5.7-3. Speciated Mercury Results from Susitna River Drainage (µg/g dry weight)

Location	Sediment		Fish	Water	
	Inorganic mercury	Methylmercury	Inorganic mercury	Inorganic mercury	Methylmercury
Deshka River	0.021	0.00510	0.246 (SS)	Not sampled	Not sampled
Costello Creek	0.169	0.00004	0.101 (DV)	0.00497	0.00002

SS = whole slimy skulpin
DV = Dolly Varden fillet
From Frenzel (2000)

Table 5.7-4. Summary of ADEC Data for Mercury in Fish Tissue, Susitna River Drainage

Species	Number of Samples	Mean	Std. Deviation
Arctic Char	3	0.21000	0.052915
Burbot	1	0.09400	0
Grayling	18	0.10239	0.033477
Northern Pike	98	0.21071	0.206272
Salmon – Pink	16	0.25813	0.051279
Salmon – Red	14	0.02907	0.017398
Salmon – Silver	5	0.09520	0.053905
Stickleback – Nine Spine*	1	0.07600	0
Stickleback – Three Spine*	2	0.07350	0
Lake Trout	3	0.38000	0.319531
Rainbow Trout	27	0.11187	0.086007
Whitefish - Round	7	0.10929	0.048623

Concentrations in mg/kg. * indicates sample analyzed as whole body composite sample. All other fish samples analyzed as skinless fillets. Samples that were below detection limits were listed as 1/2 of detection limit. NOTE: If Std. Dev. is listed as 0, all the samples were below detection limits (ADEC, 2012).

Table 5.7-5. Proposed Susitna River Basin Mercury Monitoring Sites

Susitna River Mile	Description	Susitna River Slough ID	Latitude (decimal degrees)	Longitude (decimal degrees)
25.8	Susitna Station	NA	61.5454	-150.516
28.0	Yentna River	NA	61.589	-150.468
29.5	Susitna above Yentna	NA	61.5752	-150.248
40.6	Deshka River	NA	61.7098	-150.324
55.0	Susitna	NA	61.8589	-150.18
83.8	Susitna at Parks Highway East	NA	62.175	-150.174
97.2	Talkeetna River	NA	62.3418	-150.106
98.5	Chulitna River	NA	62.5574	-150.236
103.0	Talkeetna	NA	62.3943	-150.134
120.7	Curry Fishwheel Camp	NA	62.6178	-150.012
136.8	Gold Creek	NA	62.7676	-149.691
138.6	Indian River	NA	62.8009	-149.664
138.7	Susitna above Indian River	NA	62.7857	-149.651
148.8	Susitna above Portage Creek	NA	62.8286	-149.379
148.8	Portage Creek	NA	62.8317	-149.379
184.5	Susitna at Watana Dam site	NA	62.8226	-148.533
223.7	Susitna near Cantwell	NA	62.7052	147.538

Table 5.7-6. List of parameters and frequency of collection.

Media	Analyses	Frequency of Collection	Holding Time
Surface Water, sediment pore water	Total and methylmercury (EPA-1631E and 1630)	Monthly	48 hours
Soil, Sediment	Total mercury (EPA 1631E)	One Survey-summer	28 days
Avian, Terrestrial Furbearers, and Fish Tissue	Total and methylmercury (EPA-1631E and 1630)	One Survey-late summer	48 hours

Table 5.7-7. Schedule for Implementation of the Mercury Assessment and Potential for Bioaccumulation Study.

Activity	2012				2013				2014				2015
	1 Q	2 Q	3 Q	4 Q	1 Q	2 Q	3 Q	4 Q	1 Q	2 Q	3 Q	4 Q	1 Q
Water Quality Monitoring (monthly)							▬	▬					
Soil and Vegetation Sampling							▬						
Sediment Sampling							▬						
Bird and Aquatic Furbearer Sampling							▬						
Fish Tissue Sampling			▬				▬						
Data Analysis and Management								▬	▬				
Initial Study Report									Δ				
Follow-up studies (as needed)										▪▪▪	▪▪▪	▪▪▪	
Updated Study Report													▲

<u>Legend:</u>

▬ Planned Activity
▪▪▪ Optional Activity

Δ Initial Study Report
▲ Updated Study Report

5.7.11. Figures

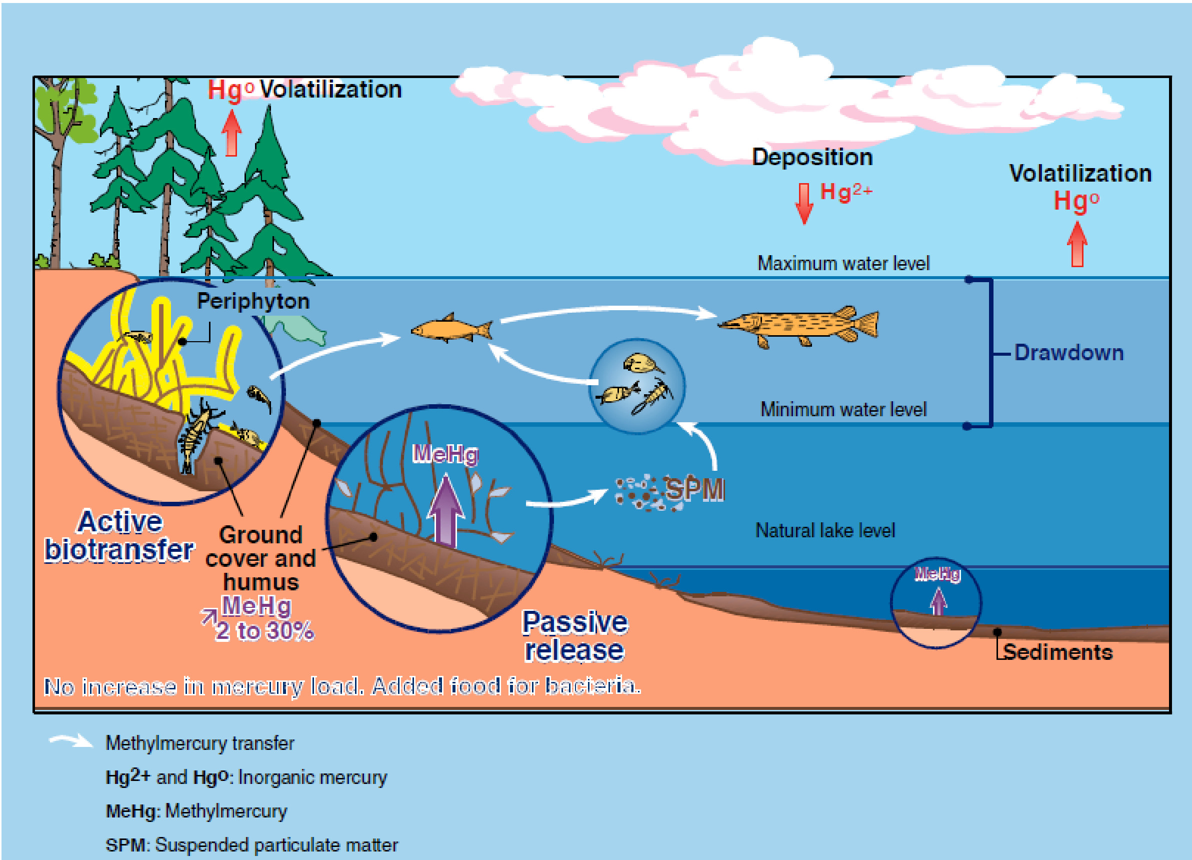

Figure 5.7-1. Transfer of Methylmercury to Fish Shortly after Impoundment from Hydro-Quebec (2003).

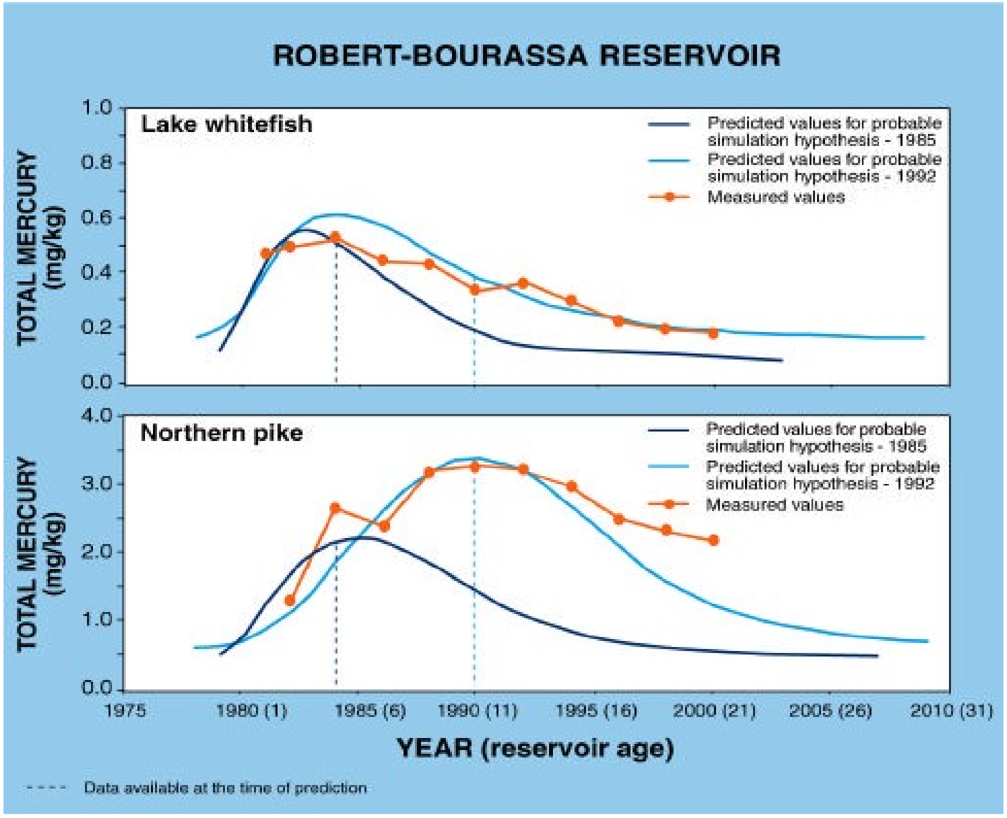

Figure 5.7-2 Example of Predicted and Actual Mercury Concentrations in Fish (from Hydro-Quebec 2003).

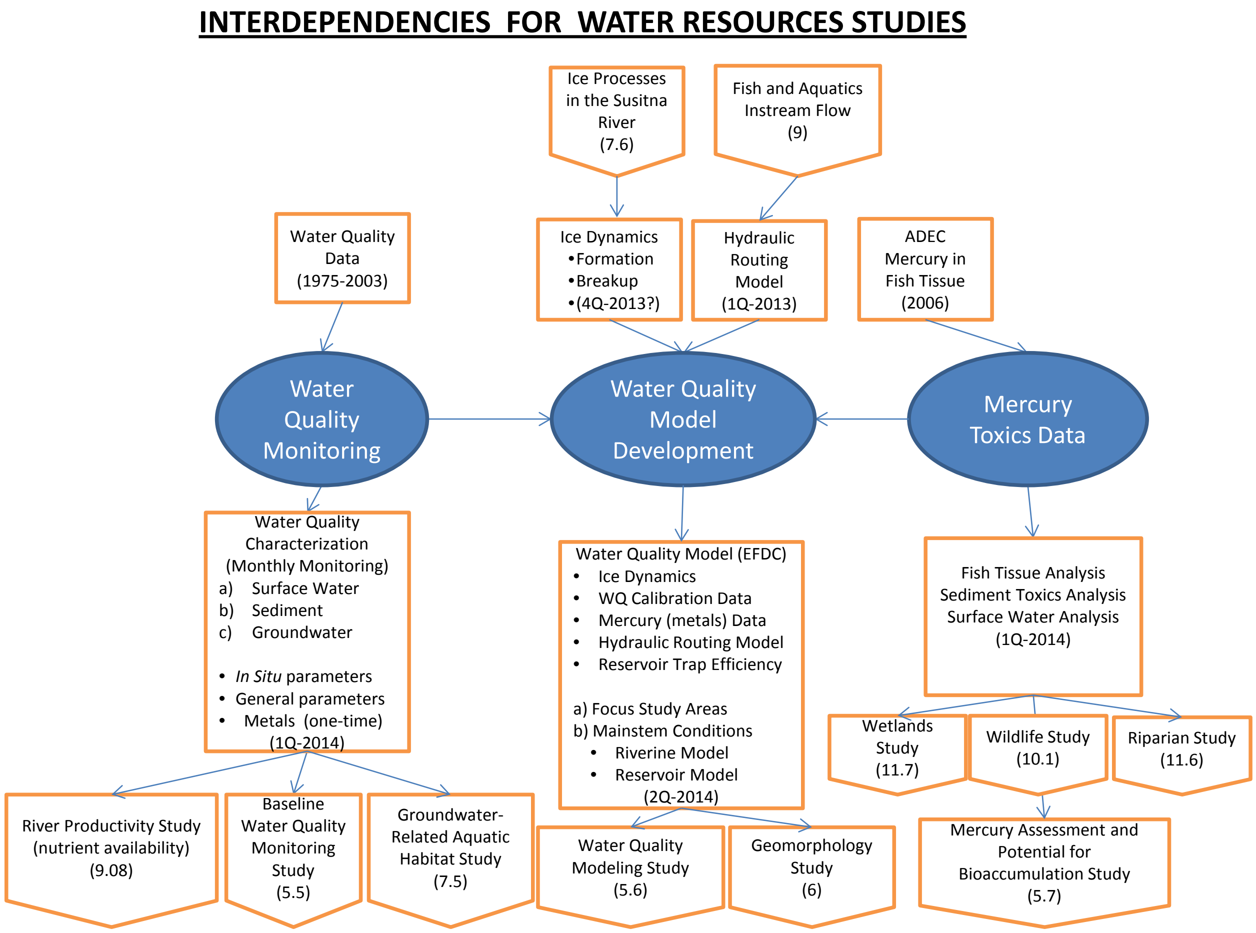

Figure 5.7-3. Interdependencies for water resources studies.