CONTACT:
Shannon Gavin
shannon.gavin@mses.ca
403-241-8668

ADDRESS:
207 Edgebrook Close, NW
Calgary, AB, Canada
T3A 4W5

MSES
Management and Solutions in Environmental Science

Trans Mountain Expansion Project and Oil Spills: Power Analysis on Pacific Salmon Data

Prepared for Adams Lake Indian Band

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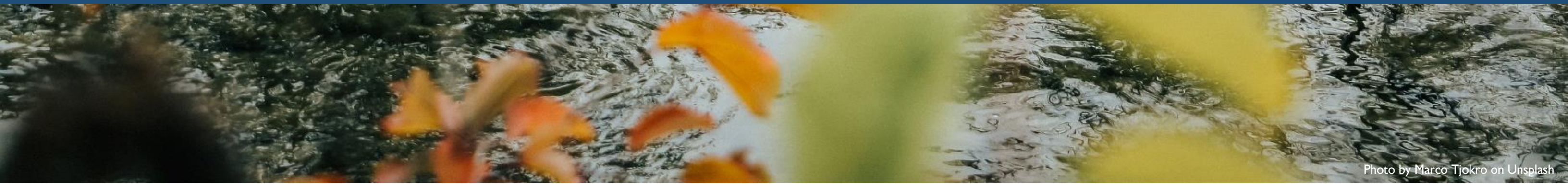

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List of Contributors

Dr. Megan Thompson	Surface Water Quality
Dr. Sarah Alderman	Fish Ecotoxicology
Dr. Kyle Wilson	Fisheries Ecologist
Mr. Sebastian Dalgarno	Computational Biologist
Dr. Joseph Thorley	Computational Biologist
Ms. Shannon Gavin, M.Sc., P.Biol.	Terrestrial Wildlife
Dr. Ave Dersch	Traditional Resource Use
Mr. Logan Boyer	Report Management

Executive Summary

Pacific salmon that migrate through Kamloops Lake and into the North Thompson River and Shuswap Lake complex are at risk from oil spills associated with the Trans Mountain Expansion pipeline project (TMX). These watersheds and salmon are culturally important to Adams Lake Indian Band (ALIB) members and the larger Secwépemc Nation (Kwusen Research and Media 2019). Salmon have an important role in the ecosystem as they provide a nutrient and food source for traditional users, and for a variety of plants and wildlife. Therefore, reductions in numbers or contamination of salmon can have consequences for the broader ecosystem. ALIB requested that Management and Solutions in Environmental Science (MSES) assist the community by conducting a technical study. The focus of the study was to examine whether existing scientific data would be able to detect potential impacts on salmon stocks in these watersheds if a spill were to occur associated with the TMX project.

The TMX project involves a twinning of the existing Trans Mountain pipeline with the construction of Line 2. The TMX will transport diluted bitumen, other conventional crude oils and diluent. Unlike conventional crude oil, bitumen is too thick to be pumped through pipelines, so it is diluted with either conventional light crude oil or a mix of natural gas liquids, to give it a thinner consistency. This is called diluted bitumen. There is less known about the toxicity of diluted bitumen to salmon compared to conventional crude oil. There is also less known about oil spills in freshwater systems compared to marine environments. Diluted bitumen has physical characteristics that make it more unpredictable in its behaviour when spilled into a freshwater ecosystem, relative to other crude oil types. The outcome of diluted bitumen exposure in salmon can include short term effects (acute effects) and long-term effects (chronic effects). The magnitude of these effects on salmon depends on the concentration and duration that fish are exposed to various constituents of the diluted bitumen.

The first step in our study was to review the existing scientific literature to provide background information for our analysis and to identify gaps in the existing state of knowledge on oil spills and its impacts to salmon. Critical knowledge gaps identified from this literature review are presented within the context of assessing impacts to salmon populations due to a pipeline spill. Populations of salmon are declining in the Fraser Basin and Thompson River Complex and the number of returning adults is highly variable among sites within and between years. Although there are five species of salmon (Coho, Pink, Chinook, Sockeye, and Chum) in the Fraser Basin watershed, our study focused on Chinook and Sockeye salmon populations. These populations provide major fishery resources to the ALIB and may be affected by the TMX project. The key difference between Chinook salmon and Sockeye salmon is their migratory behaviour; Chinook salmon rear in streams and spend three years at sea while Sockeye salmon rear in lakes and spend two years at sea. Given the differences in migratory behaviour of both these species, the timing and location of any potential oil spill will determine the magnitude of the potential impact to each species and each life stage (egg, fry, smolt, sub-adult, pre-spawning adult and adult).

The second step in our study was to complete a power analysis to test how precisely we could estimate the size of a hypothetical impact using currently available fisheries data as a baseline. We considered an extreme worst-case scenario wherein we assumed a large spatial extent for a spill and high concentrations of toxic substances. Our analysis considered that this worst-case scenario could occur under three different river flow conditions: high flow freshet, open water and winter under ice. The relative survival of salmon following a spill was estimated for each life stage for both species, and a mechanistic population

model was used to estimate resulting adult returns. We assumed that the spatial coverage from an oil spill would extend through the North Thompson, Thompson complex and Kamloops Lake. We did not directly assess impacts to salmon in the Shuswap Complex because based on our worst-case scenario, it was assumed that the Shuswap Complex salmon would be less impacted less than the North Thompson salmon. This does **NOT** mean that the Shuswap Complex salmon would be unaffected by an oil spill. We then used an empirical model in a power analysis to determine whether we could detect the impact of an actual spill from the available adult return data.

Below we provide a brief outline of key findings from our literature review and power analysis study.

Key Findings: Literature Review and Current State of Knowledge

- Knowledge gaps on what size/cohorts of juvenile salmon would use areas in the watershed that could be vulnerable to an oil spill event.
- Details are needed on the natal origins of juvenile salmon that use areas of the watershed that would be vulnerable during an oil spill event.
- Knowledge gaps regarding impacts to fish health from a bitumen spill include a lack of data on life stage-specific and species-specific sensitivities to diluted bitumen. Also, how long-term effects may influence salmon migration patterns and migratory behaviour.
- There is a lack of information regarding the transfer of contaminants in the food web, which has implications for the health of the broader ecosystem.
- Consequences of a decline in prey availability can lead to corresponding population declines in higher-order predators. Food web relationships are quite complex and there is still much more information needed to understand these interactions.
- A full list of knowledge gaps can be found in the summary table in Section 2.9 of this report.

Key Findings: Modelling Spill Scenario Impacts to Salmon and Power Analysis

- Negative impacts on Chinook and Sockeye salmon survival are likely to be greatest under winter conditions because the concentration of contaminants in the river water are at their highest under low stream flow, and because young vulnerable salmon life stages are still overwintering in the River.
- Based on our worst-case spill scenario, using our mechanistic model, we estimated the number of returning adults which was most directly impacted by the spill. The results suggest that a worst-case bitumen spill of 4,000 m^3 of diluted bitumen from the TMX Project could cause as much as a 71% and 73% reduction in the number of Chinook and Sockeye adult salmon, respectively, returning to the main stem North Thompson. The number of adults returning to the tributaries could be reduced by between 12% and 53% for Chinook and Sockeye, respectively.
- The power analysis considered whether available baseline adult return data for the North Thompson River would allow us to detect an oil spill given a reduction of up to 71% and 73% of returning adults.
- The existing fisheries data is too variable among sites within and between years to reliably detect changes in the number of returning adults due to an oil spill.

Recommendations

- Our analysis and results do **NOT** mean that an impact would be small on salmon BUT that the data on returning adults are not adequate to detect the impact of an oil spill on the number of returning adults.

- The current data on returning adults are not adequate to capture the variability in salmon abundance at the local scale.
- We suggest the following research is needed that would help inform our understanding of impacts from oil spills on salmon:
  - More extensive and comprehensive monitoring of suspended sediments, water temperature, and existing contaminants of potential concern.
  - Characterize distribution, origin, and abundance of juvenile salmon within the watershed, particularly for the smallest life history stages most vulnerable to spill impacts.
  - Define the timing and locations of juvenile habitat use in the watershed.
  - Establish reference values for effects from diluted bitumen exposure for different salmon species and life stages.
  - A full list of recommendations can be found in Table 11 in Section 4.1 of this report.

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Acronyms/Abbreviations

AER	Alberta Energy Regulator
ALIB	Adams Lake Indian Band
ANSCO	Alaska North Slope crude oil
AWB	Access Winter Blend
BC	British Columbia
BTEX	benzene, toluene, ethylene and xylene
CABIN	Canadian Aquatic Biomonitoring Network
CCME	Canadian Council of Ministers of the Environment
Cl-	chloride Ion
CLB	Cold Lake Blend
CLWB	Cold Lake Winter Blend
COPC	contaminants of potential concern
CU	conversion unit
cyp1A	cytochrome P450 1A
dilbit	Diluted bitumen
dpf	days post-fertilization
DFO	Fisheries and Oceans Canada
EC50	the effective concentration at which 50% of the population displays a sublethal endpoint of interest
EIA	Environmental Impact Assessment
EPA	United States Environmental Protection Agency
Eq	equilibrium

EROD	Ethoxyresorufin-O-deethylase
ES	early summer
FOSC	Federal On Scene Coordinator
FSC	food, social and ceremonial
g/L	grams per litre
K	carrying capacity
LC50	the concentration of a compound that is lethal for 50% of the exposed population
M	mortality
m^3	cubic metres
m^3/s	cubic metres per second
MAH	monocyclic aromatic hydrocarbons
mg/g	milligrams per gram
mg/L	milligrams per litre
MSES	Management and Solutions in Environmental Science
N	abundance
$Na+$	sodium ion
NTSB	National Transportation Safety Board
NTU	Nephelometric Turbidity Unit
PAC	polycyclic aromatic compounds
PAH	polycyclic aromatic hydrocarbons
QERA	Qualitative Ecological Risk Assessment
TMP	Trans Mountain Pipeline
TMX	Trans Mountain Expansion

TPAH	total polycyclic aromatic hydrocarbons
TPH-F	total petroleum hydrocarbons quantified using fluorescence
TSS	total suspended solids
USFWS	U.S. Fish and Wildlife Service
WAF	water-accommodated fraction
WCS	Western Canadian Select
wk	weeks
WSC	Water Survey of Canada
µg/L	micrograms per litre
µS/cm	microsiemens per centimetre

1.0 Introduction

Anadromous (migrating up rivers from the sea to spawn) Pacific salmon are ecologically, economically and socially important to the Fraser Basin. Salmon provide fishery resources to Indigenous peoples, commercial fishers, and recreational anglers throughout the region. The resilience of Pacific salmon, including Sockeye and Chinook, has been jointly challenged in recent decades by environmental stressors such as habitat loss and conversion, climate changes, overfishing, and pollution (Cohen, 2012). Cumulative effects from these stressors continue to impact freshwater, coastal, and marine ecosystems. As a consequence of these multiple challenges, Pacific salmon fisheries have declined in recent decades throughout much of British Columbia (Walters et al. 2019). Spatial impacts from different fishing communities on salmon populations can vary from one another. First Nations and Indigenous food, social, and ceremonial (FSC) fisheries often operate locally with "terminal-based" fishing in nearby streams, rivers, and lakes. For efficiency, commercial fisheries tend to operate at the "mixed-stock" level, fishing either the open ocean or coastline during larger aggregations of migrating adults. Recreational anglers can fish at both aggregate- (e.g., trolling from boats on BC coasts) and local-scales (e.g., fly-fishing in streams). Climate changes affect freshwater and marine habitats in different ways. Pacific decadal oscillations, El Nino and La Nina events, and other oceanic drivers can alter conditions for marine growth and survival. Climate changes can also alter precipitation (e.g. rain and snow) and other factors that affect the flow and temperatures of freshwater habitats. Activities from ongoing and new development projects are a concern, given the existing stressors to this fishery.

Adams Lake Indian Band (ALIB) have expressed their concerns with the proposed Trans Mountain Expansion pipeline project (TMX) which has the potential to impact Pacific salmon in the North Thompson River and Shuswap Lake complex in a variety of ways, including impacts associated with potential oil spills. These watersheds and salmon are culturally important to ALIB members and the larger Secwépemc Nation (Kwusen Research and Media 2019). There is an existing Trans Mountain Pipeline (TMP) on the landscape which was built in 1953 and continues to operate today. The TMX Project will twin this existing pipeline through the construction of Line 2. Currently the pipeline transports liquid hydrocarbon products, including crude oil and diluted bitumen. The location of the TMX Project in the North Thompson River valley, and crossing the Thompson River upstream of Kamloops Lake, will continue to be a cause for concern to land users and a source of risk to salmon. A paramount concern is a pipeline leak or spill that results in contamination of these water bodies. The increased capacity of the TMX Project compared to the existing TMP, along with the uncertainty around the impacts of diluted bitumen spills into freshwater, escalates concerns already voiced by Indigenous groups.

The goal of this report is to provide a comprehensive review of potential impacts and risks associated with oil spills to salmon stocks (e.g. Sockeye, Chinook), within the North Thompson River, Thompson River and Kamloops Lake area of the Fraser Basin. To do this, we have identified the following research questions.

Research Questions:

1) What is the state of knowledge about impacts of oil and/or diluted bitumen spills on Chinook and Sockeye salmon in freshwater systems, and specifically in the Thompson River complex?
2) Given specific hypothetical spill conditions, what are the potential impacts of a spill of a diluted bitumen product in the North Thompson River on Chinook and Sockeye salmon?

3) Using the available DFO data on numbers of returning adults, how precisely would we be able to quantify such an impact on the number of returning Chinook and Sockeye salmon adults?

Technical experts reviewed publicly available literature and empirical data related to freshwater oil spills, fish toxicity impacts, salmon populations, habitat use, distribution, and movements in the Fraser Basin. A hypothetical spill scenario was considered, and the potential effects on adult salmon returns was estimated using a population model. Quantitative population-based power analyses were completed to determine how much baseline data is required in order to detect a particular effect or level of impact from an oil spill. Understanding the adequacy of the current baseline data on salmon and its ability to be used in detecting impacts to these key resources is essential for the management and protection of this ecosystem.

1.1 Report Structure

This report is organized into two sections. Section 2.0 is a literature review of the current state of knowledge for salmon in the Thompson River complex and the known adverse effects of diluted bitumen exposure on fish (Research Question #1). Critical knowledge gaps identified from this literature review are presented within the context of assessing impacts to the salmon population in the event of a pipeline spill. Section 3.0 comprises an analysis of a hypothetical spill scenario. Here, an estimation of the nature and magnitude of the impact of a spill on salmon returns was estimated using a salmon population model (Research Question #2), and a statistical power analysis was used to determine whether the currently available baseline salmon data could be reliably used to identify such an impact (Research Question #3).

2.0 Part A: Current State of Knowledge and Literature Review

2.1 Study Area of Interest

Our study focused on the Thompson watershed within the larger Fraser Basin watershed in British Columbia (BC), Canada (Figure 1). The TMX pipeline route closely follows the North Thompson River for about 275 km from south of Albreda, BC to just west of Kamloops, BC, where it crosses the Thompson River upstream of Kamloops Lake (see Figure 2 below). The pipeline route deviates from the North Thompson River course briefly at the Clearwater, BC and Barrière, BC areas. The pipeline crosses the North Thompson River at least three times along this course, and also crosses tributaries of the North Thompson, including the Albreda, Blue and Clearwater Rivers (TMP ULC 2013, Volume 5C, Table 5.2, p. 5-4 and 5-5). South of Kamloops Lake, the pipeline route leaves the Thompson River mainstem and crosses through a portion of the South Thompson River Watershed and the Nicola River watershed before rejoining the Fraser River Mainstem at Hope, BC. The area of interest for this study includes the North Thompson, South Thompson and Thompson Rivers, as well as, Kamloops Lake.

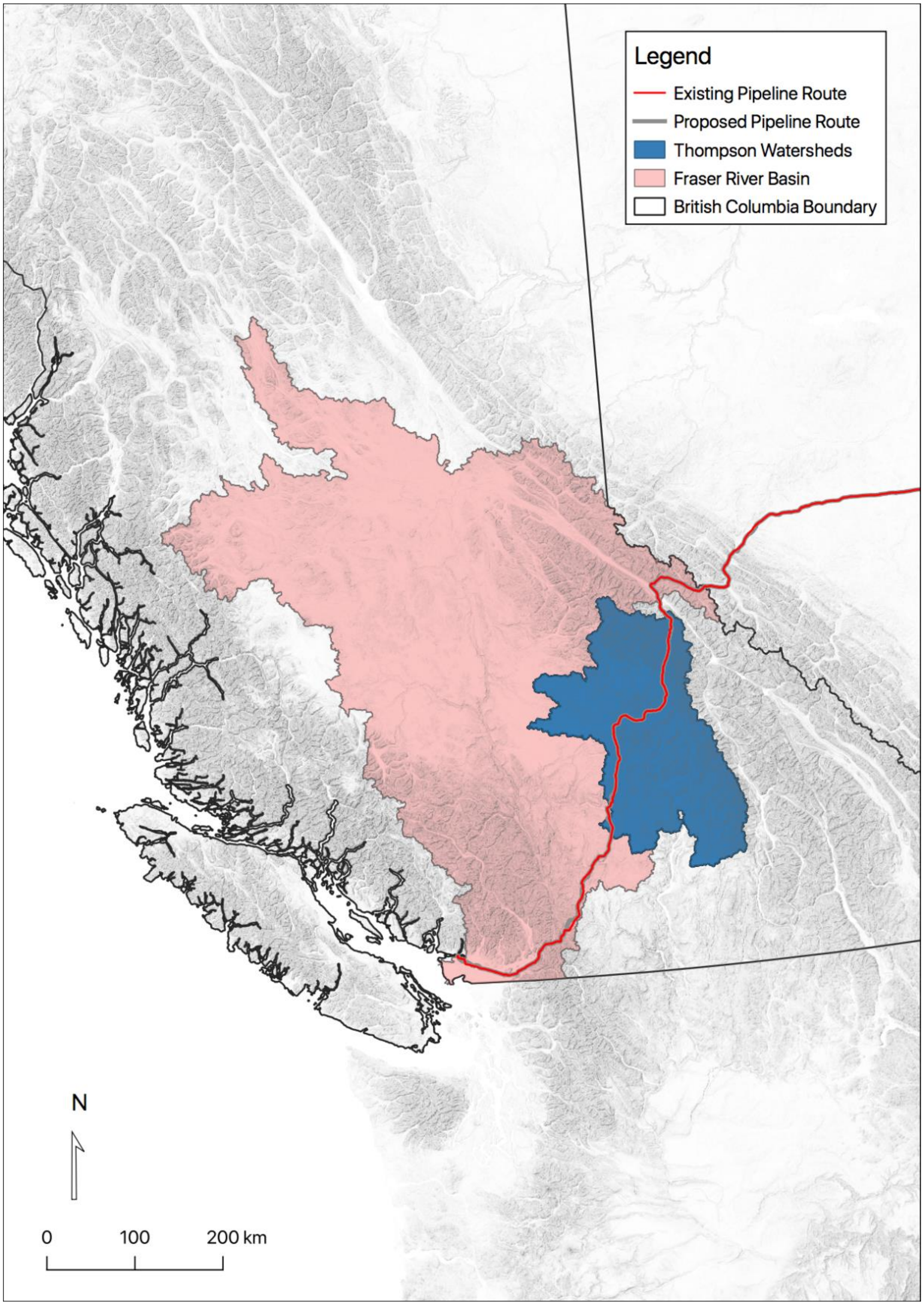

Figure 1. Map illustrating the Fraser River Basin with our Area of Interest highlighted in blue (Thompson watersheds). The existing and proposed TMX pipeline route overlays our study boundaries.

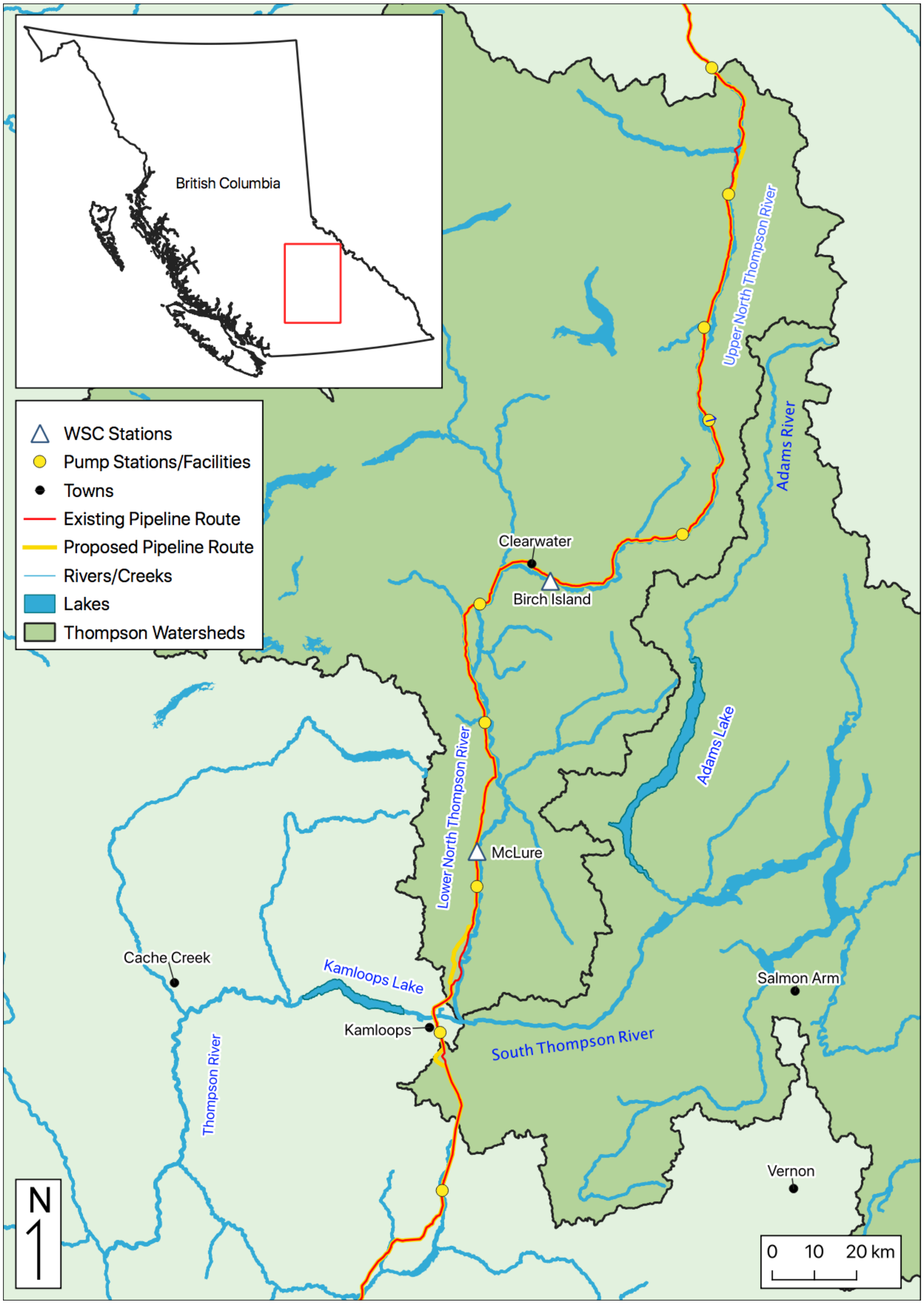

Figure 2. The Area of Interest for this study includes the North and South Thompson River watersheds, and the mainstem Thompson River downstream to Kamloops Lake. The TMX Line 2 route and facilities are also shown. Water Survey of Canada (WSC) flow monitoring stations on the North Thompson River Mainstem are shown.

Our Area of Interest does not include the smaller drainages south of Kamloops or the Nicola River watersheds for two reasons:

1. The stated interest in terms of potential impacts of a pipeline failure on salmon applies primarily to Thompson River salmon returns, and specifically in the Adams River and Adams Lake areas. Although these areas are within the Fraser River watershed, they constitute separate salmon conservation units/populations.
2. The potential for a pipeline failure and oil release that might occur south of Kamloops to reach the South Thompson and/or Thompson Rivers is less likely than a failure that might occur along the North Thompson River or at the Thompson River, as the watercourses and their valleys are smaller, and in some cases ephemeral, and there are several intervening lakes that can act as collection basins for spilled oil. It should be noted that impacts to these aquatic ecosystems from such a spill could be significant, but the potential for rapid transport of a spill downstream is somewhat moderated.

2.1.1 North Thompson River

The North Thompson River is a free-flowing system with a large contribution of meltwater coming from glacial or snow melt (Nordin 1993). Shoreline habitat surveys of the lower North Thompson River completed in the 1990's characterize the substrate as mainly fine sand gravels, with steep and often unstable banks (Hickey & Trask 1994). Vegetation, both riparian and instream, was not abundant except for macrophytes in side-channels and embayments where flows were relatively slow and open water temperatures might have been higher. High streamflow velocity and significant bedload sand transport and deposition were also noted in the mainstem (Hickey & Trask 1994). The North Thompson River has a moderate gradient for a large river, including an elevation change along the TMX route of 397 m over 275 km, with an average slope of approximately 0.14%.

The Water Survey of Canada (WSC) has two recently or currently active water flow monitoring stations on the North Thompson River: Birch Island (# 08LB047) and McLure (# 08LB064). Several tributaries are also monitored for stream flow at their mouths. Streamflow in the Thompson River is monitored at Kamloops (# 08LF023) and downstream of Kamloops Lake at Spences Bridge (#08LF051). At Birch Island, maximum historical discharge from 1960-2015 was about 950 m^3/s, recorded in July, while the median maximum for the same period was about 475 m^3/s and the minimum was about 15 m^3/s, recorded during the winter low flow (December through March). During any given year, localized peak discharges can occur, likely associated with storms (Figure 3).

Further downstream at McClure, the maximum historical discharge is much higher, at about 2750 m^3/s recorded in June between 1958 and 2018. The median maximum historical discharge at McClure is about 1450 m^3/s and the minimum discharge is less than 50 m^3/s during the winter low flow. Localized peaks in discharge are also apparent at this station but are more moderate compared to the maximum late spring/early summer discharges (Figure 4).

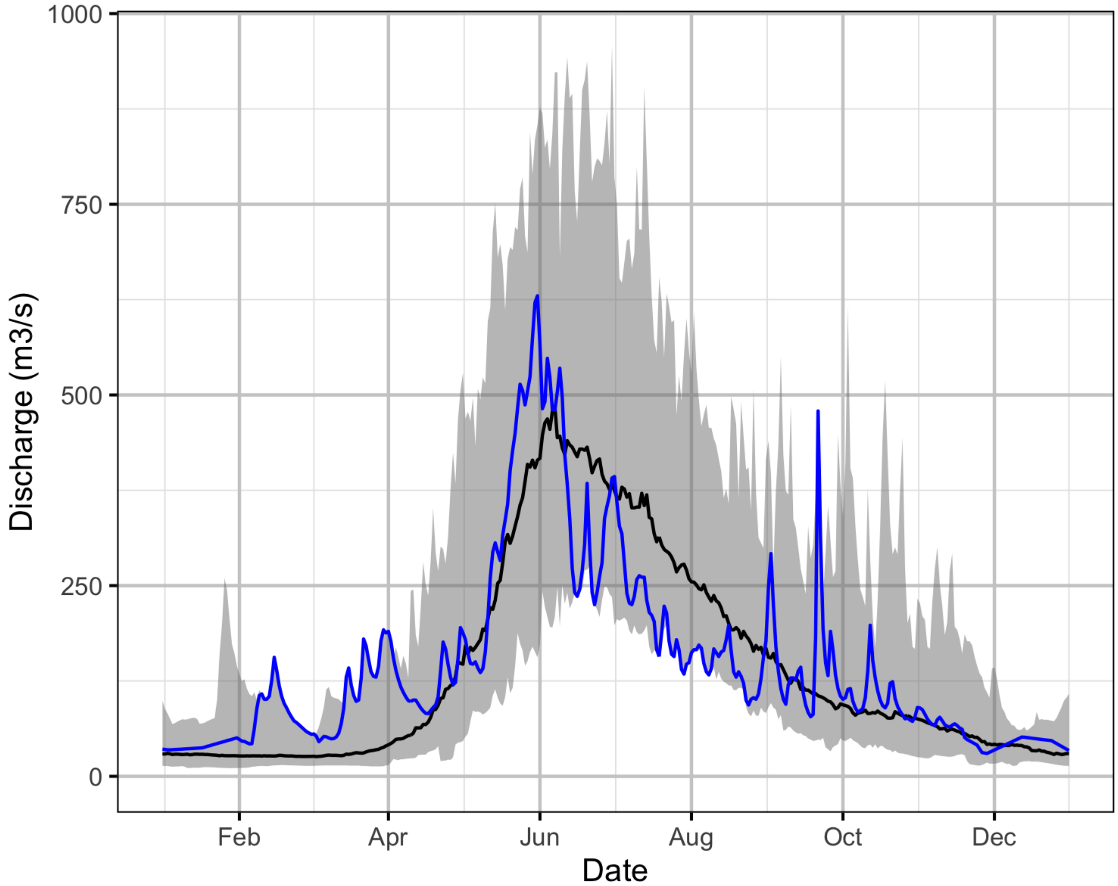

Figure 3. The North Thompson River daily discharge at Birch Island (08LB047) from 1960 to 2015. The grey ribbon indicates the minimum and maximum discharge, the black line the median discharge and the blue line the 2015 discharge.

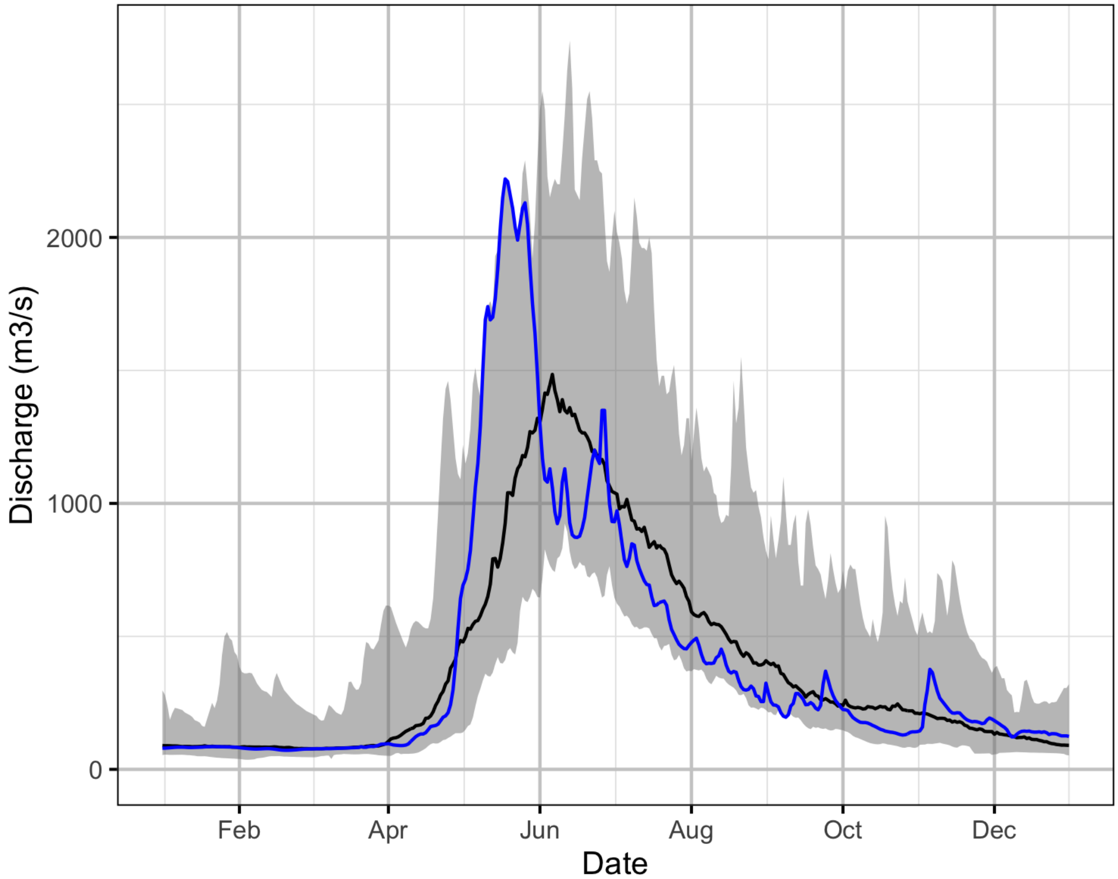

Figure 4. The North Thompson River daily discharge at McLure (08LB064) from 1960 to 2018. The grey ribbon indicates the minimum and maximum discharge, the black line the median discharge and the blue line the 2018 discharge.

An analysis of future changes in land use combined with climate change in the North Thompson River watershed indicated that mean annual flow is expected to increase by as much as 55% by 2070, and that peak flows were expected to occur earlier in the spring and be 20-30% higher by 2050 relative to 1981-2010 peak flows (Carlson et al. 2019). These changes in flow were predicted to occur mainly as a result of climate change, specifically increased precipitation, and were predicted for the North Thompson River and its tributaries. The authors point out that the "design flows" of infrastructure that crosses or is in close proximity to these watercourses, including pipelines, should take into account the potential for increases in peak flow resulting from climate change.

Available provincially collected water quality data for the North Thompson River are sparse, and the most recent data are in some cases decades old. At Birch Island (# 0600025) in July 1993, total suspended solids (TSS) was 11 mg/L and specific conductance was 56 µS/cm. At McLure (site # 0600002), in April 1980, TSS data are not available but turbidity was low at 2.8 Nephelometric Turbidity Units (NTU) and specific conductance was 106 µS/cm. Historical average TSS at McLure (1967-1977) is 44 mg/L in June. At North Kamloops (site # 0600164), much more recently collected samples from February 2020 indicate a specific conductance of 131 µS/cm, but no TSS or turbidity data are available. (data obtained from https://governmentofbc.maps.arcgis.com/apps/webappviewer/index.html?id=0ecd608e27ec45cd923bdcfeefba00a7, retrieved March 2020).

2.1.2 Thompson River

The Thompson River begins at the confluence of the South and North Thompson Rivers, and flows approximately 15km into Kamloops Lake, below which it continues to the Fraser River. At their confluence, the North Thompson River contributes about 60% and the South Thompson River about 40% of mean annual flow in the Thompson River (Nordin & Holmes 1992). Shoreline fish habitat surveys of the Thompson River upstream of Kamloops Lake noted extensive sand substrates in a predominantly straight channel (Hickey & Trask 1994). The flow is generally smooth, with some back-channel areas. Substrates were mainly fine particles (clay, mud, sand) (71%) or man-made with a small percentage of gravel and cobbles (13%). Fine particles also made up the majority of streambank materials along the Thompson River upstream of Kamloops Lake. Instream vegetation was recorded in this stretch of the River, but not in great abundance (Hickey & Trask 1994).

2.1.3 Kamloops Lake

Kamloops Lake is a long, narrow water body that is heavily influenced by Thompson River inflows (Nordin & Holmes 1992). Inflow turbidity peaks during high flows at the freshet period (high flow, early summer), and the lake acts as a sink for particulate material (Carmack et al. 1979). Documented historical water quality impacts on the lower Thompson River from discharge points upstream of Kamloops Lake further indicate the flow-through nature of the Lake and interconnectedness with the Thompson River (Nordin & Holmes 1992).

Kamloops lake is about 25 km long, 2.1 km wide and has a maximum depth of 143m (Nordin & Holmes 1992, Carmack et al. 1979). The inflow of the Thompson River upstream represents a sizeable fraction of the lake volume, so that bulk residence times are very short (the annual average is 60 days), and lake levels fluctuate significantly during periods of high river flow (Nordin & Holmes 1992, Carmack et al. 1979). The inflow water from the Thompson River enters Kamloops Lake and either moves through the lake mainly at the surface (in late spring and winter), or at a middle depth according to temperature stratification (in summer and early autumn), or along the bottom of the lake (during turnover conditions in spring and autumn)(Carmack et al. 1979).

2.1.4 Groundwater

There are mapped aquifers (i.e. underground layer of water-bearing permeable rock, rock fractures, gravel, sand, or silt), along the pipeline route in the area of interest. These are generally located at certain points along the North Thompson River (e.g., Blue River and Clearwater River confluences), and clustered around the Thompson River and lower South and North Thompson Rivers near Kamloops. There is limited groundwater data available for the northern North Thompson River valley (TMP ULC 2013, Volume 5C, Waterline Resources Inc. 2013).

According to the TMX Project Environmental Impact Assessment (EIA) (TMP ULC 2013), many of the aquifers along the North Thompson River are considered vulnerable to contamination. Aquifers may be considered vulnerable because they are shallow, porous and/or have high-permeability confining layers, among other factors (Liggett et al. 2011). This is important when considering how constituents from an oil spill might be transported through salmon habitats, as shallow aquifers are often connected to surface water and may serve as a pathway for contamination.

2.2 Importance of Salmon in the Ecosystem

Anadromous (migrating up rivers from the sea to spawn) Pacific salmon are ecologically, economically and socially important to the Fraser Basin. Salmon provide fishery resources to Indigenous peoples, commercial fishers, and recreational anglers throughout the region. Indigenous people in this region have fished for Pacific salmon since time immemorial, with archeological evidence of at least 9,000 years of food, social, and ceremonial fishing practices (Diaz 2019). Pacific salmon provide critical linkages between marine, coastal, freshwater and terrestrial ecosystems throughout the region by providing large pulses of biomass to the flora and fauna of the region. They are prey and predators to many aquatic and terrestrial animals including aquatic invertebrates, fishes, birds, bears, and marine mammals.

For terrestrial wildlife, the availability of salmon as a food source has implications for their overall fitness in terms of growth rates, litter sizes and reproductive timing and success (Ben-David 1996, Hilderbrand et al 1999). Higher salmon consumption by coastal bears has been shown to have improved their body condition, reproductive success and population densities compared to areas without access to salmon (Hilderbrand et al 1999, Service et al 2018). Population dynamics of other organisms are also influenced by the availability of salmon. For example, during the breeding season, insectivorous passerines (birds) have been found in greater densities along salmon streams compared to other streams (Gende et al 2002). This is thought to be associated with higher invertebrate densities feeding on the salmon carcasses (Gende et al 2002). Therefore, fluctuations in the availability of salmon to this ecosystem has ramifications for other species within the overall food web and broader ecosystem.

In addition, salmon have a role in contributing to the recycling of nutrients into the surrounding riparian and upland habitat via decomposition processes (Reimchen et al 2002). Increased nitrogen and phosphorus from decomposition support algae and primary production and contributes to soil nutrients and riparian vegetation growth (Gende et al 2004). Bears and other predator foraging activities often result in fish carcasses being left within the riparian and upland habitat (Quinn et al 2009). Up to 50% of the salmon biomass of returning adults may actually end up on the ground as a result of bear foraging activities (Gende et al 2004) which has benefits for the overall productivity of the ecosystem.

2.3 Salmon in the Fraser River Basin

All five Pacific salmon (e.g., Coho, Pink, Chinook, Sockeye, and Chum) and sea-run trout (e.g., Steelhead and Coastal Cutthroat Trout) are present in the Fraser River Basin, but this report will focus on two, Sockeye salmon (*Oncorhynchus nerka*) and Chinook (*Oncorhynchus tshawytscha*) salmon, as they provide major fishery resources to ALIB and may be affected by the TMX project. Sockeye and Chinook salmon have tremendous life history diversity throughout the Fraser Basin including the North Thompson watershed, the latter of which is the focus of this report.
The life cycles of Chinook and Sockeye salmon can both be broken into six life stages eggs, fry, smolt, sub-adult, pre-spawning adult and spawning adult (Figure 5). Eggs, fry, smolt, and sub-adults can all be considered juveniles (i.e., reproductively immature), but sub-adults reside only in the ocean. Salmon undertake at least four major migrations throughout their lives – three of which must be understood to assess potential TMX impacts on local salmon populations. First, salmon fry migrate downstream from natal streams into higher order streams or rivers for growth and rearing as they develop into smolts. For Sockeye salmon, fry migrate downstream into rearing lakes and, for Chinook salmon, fry migrate

downstream into larger streams or rivers. Second, salmon smolts migrate downstream to the estuary and open Pacific Ocean and develop into sub-adults. Third, salmon sub-adults migrate across the Pacific Ocean for growth and maturation and return to BC coastal waters as pre-spawning adults (this migration is not considered relevant to assessing TMX impacts). Last, pre-spawning adults migrate upstream to their natal streams and lakes as spawning adults.

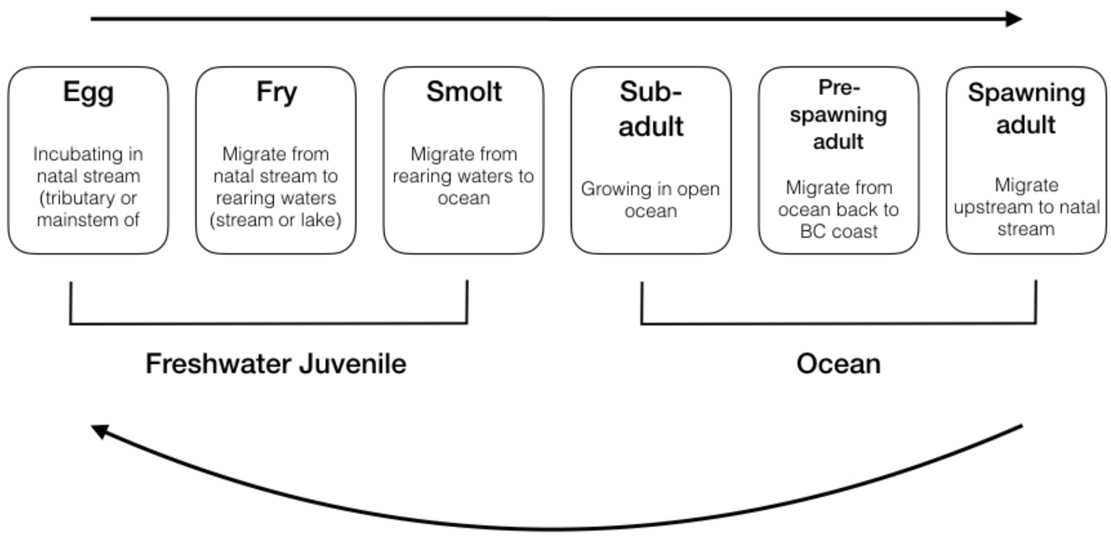

Figure 5. Illustration of the general life cycle of salmon including six life stages eggs, fry, smolt, sub-adult, pre-spawning adult and spawning adult.

Hence, both Sockeye and Chinook extensively rely upon interior BC freshwaters as juveniles for growth and rearing – the same freshwaters susceptible to human impacts like TMX. Each of these migration timings and usage of lakes and rivers can vary by species and natal Sockeye and Chinook populations. In the open ocean, sub-adult salmon grow and mature over several years before returning to their natal streams and lakes in the Fraser Basin for spawning, but this can also vary by cohorts. For example, ~90% of Fraser sockeye adults return at four-years old while 10% return at five years old, and this ratio varies by population (DFO 2018a).

Sockeye and Chinook salmon also exhibit spatial complexity in their movement across and usage within Fraser Basin watersheds. Sockeye and Chinook salmon use upper headwater streams, tributary rivers, large mainstem rivers, and lakes throughout the Fraser Basin. Overall, the Fraser Basin provides an important spawning and rearing area for sockeye globally, with over 150 natal areas that constitute 24 Conservation Units (CU) - ecologically and genetically unique populations that are defined by the Department of Fisheries and Oceans (DFO) for fisheries management. These CUs typically vary in spawning timing, spatial usage within the Basin, and rearing areas. Chinook Salmon in the Fraser Basin constitute 19 CUs, which group Chinook populations together based on geographic distribution, duration of freshwater residence as juveniles, oceanic distribution and dispersal, and timing of spawning migration (Burgner 1991). One-third of Chinook CUs are ocean-type, including upper Adam's River and Shuswap (Riddell et al. 2013) with the rest being stream-type. Since the 1950s, DFO monitors adult escapement (the number of returning spawning adults) for all CUs in the Basin of both Sockeye and Chinook, but sampling is not always at the scale of local spawning streams and rivers. In other words, sampling may or may not occur at the scale of spawning sites, with the result that there may be a mismatch between the monitoring data and the ecological dynamics of the salmon populations. This data is used year-to-year to adjust commercial and recreational fisheries management (catch) targets.

2.4 Salmon in the Area of Interest

Sockeye and Chinook salmon populations vary in how they use and move across the North Thompson watershed. These spatial usage patterns can be categorized by whether and how much salmon use three key habitats: (1) tributaries, headwater streams, and lakes outside of the TMX pipeline corridor, (2) the mainstem North Thompson River that the TMX pipeline follows, and (3) Kamloops Lake, where the North Thompson and South Thompson Rivers converge and the last catchment area for potential contaminants prior to higher-gradient downstream flows of the Thompson River. Given that there are dozens of local spawning and natal Sockeye and Chinook populations within the North Thompson Watershed that vary in local spawning and natal streams, we focused on reviewing how each of these populations might vary in terms of how many and which life stages use each of the above three habitats.

Sockeye salmon life histories were represented, for our purposes, in three unique groupings each with variable life histories (see details in Section 3.2.4). Tributary populations were defined as Sockeye populations where adults spawn in tributaries of the North Thompson River, but where fry rear in Kamloops Lake (as part of the North Thompson Conservation Unit). Mainstem populations were defined as sockeye populations that spawn in the mainstem North Thompson River and that rear in Kamloops Lake (as part of the North Thompson Conservation Unit). The last grouping were populations of the Barriere Conservation Unit where adults still pass through the mainstem North Thompson River on their way to spawning in the Barriere River, and fry rear in Barriere Lake. Juvenile Sockeye (from eggs to fry to smolts) spend approximately 18-24 months in freshwater (two springs, one winter) – most of this time is spent in their rearing lake, e.g., Kamloops Lake. In total, most Sockeye salmon in the North Thompson watershed express a four-year life cycle spending ~2 years in freshwater and ~2 years at sea.

Chinook salmon life histories were represented with two general groupings (see details in Section 3.2.4). First, the mainstem North Thompson River population where adult Chinook spawn in the mainstem river and fry also rear in the mainstem. The second grouping were the six tributary populations (Louis Creek, Finn Creek, Barriere River, Clearwater River, Mahood River, and Raft River) where adults pass through the North Thompson River on their way to spawn in their natal tributaries. Fry from tributary populations then migrate downstream, and some will rear in the North Thompson River. Juvenile Chinook (from eggs to fry to smolts) spend approximately 18-24 months in freshwater (two springs, one winter) – most of this time will be spent in their rearing stream or river (e.g., North Thompson River). Most Chinook salmon in the North Thompson watershed express a five-year life cycle spending ~2 year in freshwater and ~3 years at sea.

2.5 Potential Risks of TMX to Salmon

The TMX may pose a significant risk to the Sockeye and Chinook populations along the Fraser Basin by crossing much of their freshwater and estuarine habitats. The expansion to the existing pipeline follows and crosses several major rivers and tributaries of the Fraser Basin including the North Thompson River and just upstream from large Sockeye rearing lakes like Kamloops Lake. The pipeline may pose localized and downstream risks to salmon populations that include environmental contamination from oil spills, and habitat deterioration from infrastructure development and runoff. The forms and spatial extent of impacts from the TMX may vary due to the upstream and downstream connectivity of surface water, groundwater, nutrients, thermal energy (water temperature), and salmon throughout the Fraser Basin and nearby coastal waters. These impacts can include spills or disturbances that are localized to a few populations or watersheds or that broadly affect the entire portfolio of salmon populations throughout the Fraser Basin.

2.6 Current State of Knowledge on Diluted Bitumen in Freshwaters

2.6.1 What is diluted bitumen?

Bitumen is a "heavy" type of crude oil found in rich deposits throughout the oil sands region of Western Canada. Bitumen differs from conventional crude oils, which are classified as "light", because bitumen is very dense, thick, and sticky. The peanut butter-like consistency of raw bitumen makes it impossible to pump through pipelines. Therefore, before bitumen extracted from oil sands can be transported by rail and pipeline to oil refineries, it must first be mixed with lighter petroleum products to make it more liquid and able to flow. This modified crude oil is called diluted bitumen (or dilbit) and is one of the main products that is transported in the TMP.

2.6.2 Diluted bitumen composition

Diluted bitumen, like all crude oils, is a complex mixture of thousands of chemicals. The contaminants of potential concern present in crude oil include aliphatic (non-aromatic) hydrocarbons, naphthenic acids, and aromatic hydrocarbons. Each of these contaminant groups contains hundreds of unique chemicals. The toxicity of crude oil to fish is attributed to the aromatic hydrocarbon fraction. It is widely accepted that aromatic hydrocarbon toxicity in fish and other organisms has many root causes, and the nature of the toxic response depends on the specific chemical(s) involved, their concentrations, and the length of exposure. Aromatic hydrocarbons are divided into two groups:

- **Monocyclic aromatic hydrocarbons** (MAH) are the largest component of the volatile (easily evaporated) organic compounds in crude oil and are defined by having a chemical structure of a single 6-carbon benzene ring. Benzene, toluene, ethylene, and xylene (BTEX) comprise ~90% of the MAH in crude oil, and are considered acutely toxic to fish. The BTEX fraction dissipates quickly (24-96 h) via evaporation, and is a main driver of the acute toxic response to crude oil exposure (Kennedy, 2015).
- **Polycyclic aromatic hydrocarbons** (PAH; also frequently referred to as polycyclic aromatic compounds, PAC) are a diverse group of chemicals that contain 2 or more fused benzene rings. PAH can comprise as much as 10% of the total weight of diluted bitumen. The specific toxicity of a single PAH to fish is influenced by its molecular weight and solubility (ability to dissolve). Small molecular weight PAH (2-3 ring) are also a major contributor to the acute toxic response to crude oil exposure. These and other PAH compounds are also responsible for longer term chronic effects. Given the important roles that PAH play in crude oil toxicity, the sum total of measurable PAH (in µg per liter of oil) is typically used to describe crude oil exposure concentrations.

2.6.3 Behaviour of diluted bitumen in freshwaters

The fate of spilled oil products in freshwater ecosystems has not been as thoroughly studied as in marine environments. This information is particularly scarce for diluted bitumen products. Conventional crude oils generally do not sink in water, making the recovery after a spill more straightforward. Because diluted bitumen appears to have a greater propensity to sink to the sediments in aquatic systems, its specific impacts may be different from those of a conventional crude oil spill and its recovery may be more complex. A federal government status report issued in April 2018 indicates that the Government of Canada is funding ongoing studies of diluted bitumen in several federal departments, as is the oil and gas industry (DFO 2018b). That status report included a brief review of nine spills of oil into freshwater systems as well as one brackish estuary, of which four involved diluted bitumen products. Thirty-six laboratory experimental treatments were also reviewed in the report, all of which were conducted by Canadian or United States federal agencies. These reviews did not involve summary or comparative analyses that linked experimental findings to real-world observations, and the experimental findings had highly variable results. Generally, it was found that suspended sediments in water influenced the formation of oil-particle aggregates, and therefore sinking potential, although this varied with sediment type.

The status report authors indicated that the most important aspect of spill response is timing, and that a prompt response is the most important determinant of the ultimate fate of diluted bitumen spilled into aquatic systems (DFO 2018b). Conventional spill response measures were also generally seen as effective for diluted bitumen spills, although it was acknowledged that more rapid evaporative weathering processes of diluent and the inherent heavy nature of the bitumen itself means that changes in viscosity and density of diluted bitumen are more rapid than for conventional crude oils. The window of opportunity for application of oil recovery and spill countermeasures aimed at the water surface can range from hours to weeks, depending on the product and the site-specific conditions. In the case of diluted bitumen, this window is generally shorter, requiring a more rapid response before the properties of the oil change significantly. A helpful summary of the time of onset and relative importance of weathering mechanisms for conventional oil spilled into water are also shown in Figure 6 below. It is apparent from this figure that evaporation (particularly important for diluent), dissolution and dispersion are important short-term processes.

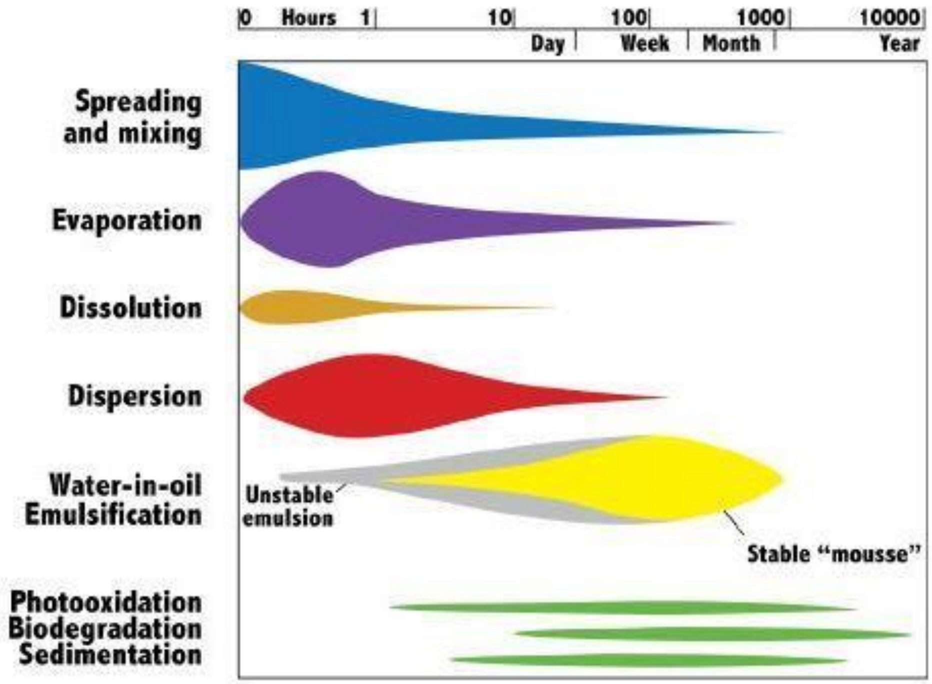

Figure 6. Time of onset and relative importance of weathering processes over time after an oil spill into water. The onset and magnitude of effect will vary with temperature and for different oils (note the time scale, which emphasizes the early onset of most processes) (figure and caption taken from Lee et al. 2015, Figure 2.4, p.77).

The status report also highlighted operational tools that were still required to enable the findings of scientific research to be integrated into spill response planning, preparation and operation, including more robust and comprehensive predictive models, summaries and comparisons between categories of known diluted bitumen blends (DFO 2018b).

Ongoing scientific research has included several studies that have attempted to predict how sunken bitumen may interact with the bottom of rivers and streams, in particular gravel beds, and whether it is likely to become embedded, or to travel downstream with the bedload of a watercourse. The findings have highlighted the importance of water temperature and stream velocity in determining where sunken bitumen will accumulate and/or become mobile.

Apart from these general observations, the status report identified several knowledge gaps regarding the fate and behaviour of diluted bitumen that is spilled into aquatic systems. These include:

- "*The fate and behaviour of diluted bitumen under low temperature and ice conditions;*
- *Physical, chemical and environmental processes that most influence diluted bitumen fate and behaviour;*
- *Natural weathering processes;*
- *Impacts of degradation and weathering on toxicity;*
- *The vulnerability of species to diluted bitumen blends;*
- *Methods to detect, track and monitor product movement when spilled;*
- *Processes for the formation and breakup of oil-mineral aggregates in the environment; and*

- *Further analysis of hydrocarbon composition present in fresh and weathered diluted bitumen blends*" (DFO 2018b, p. 18)

2.6.4 Freshwater Oil Spill Case Studies

The spill of crude oil into the Red Deer River that occurred in Alberta on June 7, 2012 provides helpful insight in determining the likely concentrations and behaviour of dissolved constituents derived from spilled oil in rivers and lakes. That spill was caused by high river flows stressing a pipeline at a watercourse crossing, and spatially comprehensive water quality data were collected for weeks afterward. The pipeline belonged to Plains Midstream Canada, and it had become exposed at the river crossing. Pipeline valves were closed within two hours of the initial indications of a spill, and 462.75 m^3 of crude oil was released. The spill entered the Red Deer River and was carried approximately 40 km downstream to the Glennifer Reservoir (AER 2014). A boom at the river mouth effectively stopped a significant amount of the spilled crude oil on the water surface from moving downstream and further into the reservoir. However, dissolved constituents, including light hydrocarbons (BTEX) and PAHs were measured in the reservoir water after less than two days. These dissolved constituents continued to be detected for the next 9 days of monitoring in the area and were described as moving downstream in a "pulse" that at times exceeded water quality guidelines for the protection of aquatic life (Teichreb 2013; AER 2012, 2014). Therefore, there is evidence that containing the physical oil product in a spill to freshwater does not equate to containment of potentially harmful dissolved hydrocarbon constituents, which are free to move further downstream. It is important to note that no sediment quality data are readily available from this spill monitoring effort.

Another spill of 3,190 m^3 of diluted bitumen and other crude oil product in July 2010 from an Enbridge pipeline near Marshall, Michigan, into a tributary of the Kalamazoo River (Talmadge Creek) occurred under high flow conditions. The spilled oil traveled about 65 km downstream over two days, and it affected both watercourses and riparian areas (Dollhopf et al. 2014; Fitzpatrick et al. 2015; FOSC 2016). Water quality data were collected following the spill for several months. PAH and BTEX concentrations in water measured in the affected area peaked at some sampling locations in the weeks after the spill, and some significantly exceeded water quality guidelines, in particular for benzene, toluene, benzo(a)pyrene and naphthalene (Michigan Department of Community Health 2013). By the fall of 2010 (October – December), the maximum measured concentrations of these constituents in the water was lower and at times undetectable, although toluene concentrations still exceeded guidelines at some locations. These constituents were then detected at lower concentrations in the winter of 2011 (January-April), but in the vast majority of samples collected (>95%, when they were measured). Only toluene concentrations exceeded guidelines during that time, but the pervasiveness of hydrocarbon detection across sampling locations indicates a system-wide input, possibly from impacted riparian and shoreline areas during snowmelt. Concentrations rose again slightly during the period May-August 2011, and fluoranthene in particular was measured at its highest concentrations during this time (Michigan Department of Community Health 2013). The variability in constituent concentrations over space and time indicates the complexity of estimating the magnitude and duration of contaminant exposures for aquatic organisms in the case of a spill, in particular where spilled oil is stranded in riparian areas and/or a portion of it sinks to the sediments.

A significant proportion of the spilled oil in the Marshall Spill became submerged in the Kalamazoo River, including at several impoundments along its length. As of July-August 2012, there was an estimated 681m^3

of submerged oil present in depositional areas along the entire 38-mile-long reach of the Kalamazoo River impacted by the spill (Graan & Zelt 2013). Extensive dredging of the river and impoundments was completed in 2012-13, and sediment traps were used to collect submerged oil that was migrating downstream. In 2015, the estimate of residual submerged oil in the Kalamazoo River was between 185 and 325 m^3 (FOSC 2016). While sediment traps remained in place, it was decided that some of this residual oil would be left in place, as the potential ecological damage from recovery by dredging outweighed the requirement to recover the oil (FOSC 2016). Sediment quality as measured by Enbridge in the affected area of the Kalamazoo River and its impoundments varied, but measures of PAH concentrations taken in 2010 and 2011 indicate concentrations that exceeded CCME interim sediment quality guidelines, and in some cases probable effects levels, for benzo(a)pyrene, benzo(a)anthracene, phenanthrene and pyrene (enbridge_sediment_data.csv file, accessed in October 2019 from https://archive.epa.gov/region5/enbridgespill/data/web/html/index.html). However, it was noted that the Kalamazoo River and its impoundments have been previously impacted by releases of such constituents, as well as other potential pollutants, so that assigning cause for these exceedances is difficult. This highlights the importance of establishing baseline conditions through comprehensive monitoring to allow for accurate impact assessment, and the importance of continuing to monitor over time.

In terms of the recovery of spilled oil products, including diluted bitumen, from river systems, there are several helpful case studies that can inform predictions about oil behaviour and recovery success. Many of these were outlined in the DFO status report (2018b). One case study is of value in considering spills during winter where an ice cover is present. Recovery crews attempted to access spilled Bakken crude oil, which penetrated the ice cover and entered the Yellowstone River in Montana in 2015, by drilling holes through the ice and vacuuming or sopping up the oil. However, under-ice recovery of the spilled oil was estimated at less than 10% (State and Federal Trustees, State of Montana and U.S. Department of Interior, 2017). Concentrations of benzene and PAHs were also elevated in the river for several kilometres downstream, and oil sheens were observed in the river over 90 km downstream. These impacts were observed both in the days immediately after the January spill, but also in March during river ice breakup (State and Federal Trustees, State of Montana and U.S. Department of Interior, 2017). The poor recovery rate and extended period of impact highlights the challenges of oil recovery from rivers during winter when an ice cover is present.

2.7 Current State of Knowledge on Toxicity of Diluted Bitumen to Fish

2.7.1 Studying diluted bitumen toxicity in the laboratory

Most studies that investigate the biological effects of crude oil exposure in fish use water-accommodated or water-soluble fractions (WAF). WAF solutions are generated by mixing defined volumes of crude oil in water, allowing the mixture to settle so that undissolved oil droplets collect on the surface and the soluble contaminants can be removed from the lower phase of the mixture. Therefore, only soluble components of the crude oil (and potentially oil micro-droplets, depending on preparation method) are present in the exposure water. Fish take up these contaminants primarily at the gill (i.e. fry to adult stages) or the skin (i.e. eggs), and potentially also via the gut (e.g. consumption of contaminated prey). WAF prepared from diluted bitumen tends to contain lower concentrations of MAH and PAH relative to conventional crude oils (Barron et al., 2018; Philibert et al., 2016).

Many factors will contribute to the toxicity of diluted bitumen, most notably its concentration and the exposure duration, as well as environmental co-factors that drive weathering. Weathering refers to the deterioration of crude oil in the environment. Evaporation of volatile organic compounds (e.g. BTEX) occurs rapidly (minutes to days) and alters the physical properties of the oil and the relative proportions of other constituents in the oil. Sunlight (ultraviolet radiation) alters the chemical structure of PAH and makes them more toxic to fish (i.e. phototoxicity). The use of chemical surfactants and dispersants during clean-up efforts may also influence diluted bitumen toxicity, as these work to disturb surface slicks by generating smaller oil droplets that become more broadly distributed in the water column (i.e. dilution effect) and may be more readily degraded. In general, dispersants can exert their own toxic effects and also increase the toxicity of crude oil to fish (by increasing the uptake and bioavailability of certain contaminants in the oil). Of note, dispersants were not applied as part of the spill response tactics in either the Kalamazoo River or Red Deer River spills.

There are currently 12 peer-reviewed papers presenting data on diluted bitumen toxicity to fish. The majority of studies have assessed toxicity in fish eggs, and the results are summarized below by lethal and non-lethal endpoints. In general, younger life stages are considered *more sensitive* to environmental contaminants, including crude oil (Kennedy, 2015). In addition, younger life stages are *more at risk* of exposure since they cannot escape a contaminated site until they have hatched and are able to swim freely. Salmonids develop slowly during the winter months and emerge in the spring, therefore, the window for exposure risk is longer than for other species, like yellow perch, that hatch in less than one month. In addition, during the weathering process, the density of spilled diluted bitumen increases, and it may sink (e.g. Kalamazoo), which would complicate/limit any clean-up efforts in river systems containing salmon eggs and prolong exposure times.

2.7.2 Lethality of diluted bitumen exposure

Death occurs rapidly upon exposure to crude oil, and is influenced by concentration, duration of exposure, and life stage of fish. For example, 150 mature fish and 1000 juvenile fish died within 48 h of 30,000 liters of gasoline and 24,000 liters of diesel fuel being released into the Pine River, BC in August 1994 (Hodson et al., 2011). Six years later, a pipeline rupture in this same river released 475,000 liters of a light crude oil that spread as a surface oil slick for 20 km downstream. A total of 1600 dead fish were collected downstream from the spill site; however, total fish kill estimates ranged from 25,000 to 250,000 (Hodson et al., 2011). Unfortunately, there are no fish kill estimates for the 2010 Kalamazoo River spill, but fish community and habitat surveys were conducted annually as part of a post-spill monitoring program. During the 5 years of monitoring, no differences were reported for overall species diversity between impacted and reference sites. Certain species, like small-mouth bass, experienced a temporary drop in numbers that was likely linked to poor habitat quality in impacted areas (USFWS 2017).

A standardized test to define a chemical's acute toxicity is the LC50, which refers to the lethal concentration at which 50% of the cohort (group) dies in a defined time period. Acute tests last 24 h to 96 h, and chronic LC50 tests are typically 7 days (d). For example, the 96h LC50 for BTEX ranges from 10 µg/L to 72 mg/L depending on life stage and species of fish. During these tests, the exposure solution is replaced and/or replenished daily to maintain a relatively constant concentration of volatile components. Table 1 provides details from studies that report fish mortalities resulting from diluted bitumen exposure. For context, we note that single PAH species were measured at concentrations as high as 86 µg/L (e.g. fluoranthene) in the Kalamazoo River during the summer months after the Enbridge pipeline failure. For the North Thompson study system, our estimated maximal concentrations of BTEX (279-12,892 ug/L) and PAH (292-13,480 ug/L sum total of 16 EPA priority PAHs) exceed all exposure concentrations used in published laboratory studies (see Section 3.0 for methods used to derive these estimates). However, these high concentrations in real-world spill scenarios are restricted to discrete locations and times, and therefore the maximal observed effects from published studies are likely outcomes in our hypothetical spill scenarios for the North Thompson.

Table 1. Summary of published studies reporting lethal effects of diluted bitumen exposure in fish. Dilbit refers to diluted bitumen.

Species & life stage	Exposure	Test	Results
Rainbow trout: Fry (75-125 d old; 0.3-0.8 g)[1]	Cold Lake Blend (CLB), unweathered and weathered WAF, with renewal	96h LC50	LC50 = 5.66 g oil/L* unweathered CLB, most mortalities occurred in 24 h; 100% mortality at 10 g oil/L (= 35 ug/L PAH); no mortalities for weathered CLB at 18 g oil/L
Fathead minnow: Hatched eggs[1]	Access Winter Blend (AWB), unweathered and weathered WAF, with renewal	Acute (96h LC50), Chronic (24h exposure, mortality up to 7d)	Acute LC50 = 0.63 g oil/L and 2.1 g oil/L, unweathered and weathered AWB; Chronic = 0.6 g oil/L and 1.3 g oil/L unweathered and weathered AWB
Fathead minnow: Fry (7-10 d old)[2]	CLB and Western Canadian Select (WCS), unweathered and weathered WAF, loading rate = 25 and 50 g oil/L, with renewal	96h LC50	Lowest LC50 = 20.5 ug/L PAH* (CLB unweathered) Highest LC50 = >40 ug/L PAH (WCS unweathered) i.e. CLB is more toxic than WCS LC50 are only slightly lower for weathered than unweathered oil
Zebrafish: Eggs to fry (fert. to 7 d larvae)[3]	Dilbit WAF (unspecified blend), loading rate = 1:10 v/v oil:water, with renewal	7d LC50	LC50 = 88% dilbit WAF (there is 46 ug/L PAH in 100% WAF) Ran similar tests on 2 conventional crudes, and overall 100% dilbit WAF was less toxic than 100% WAFs prepared from other oils, but dilbit WAF contained 3-4 fold lower total polycyclic aromatic hydrocarbons (TPAH)

Sockeye salmon: Egg (fert. to hatch, ~72 d, then reared 8 months in clean water)[4]	CLB WAF, unweathered, renewed every 2 wk	Cumulative and delayed mortality	Cumulative mortality (0-72d exposure, including failed hatching) was 10.5% higher than controls for fish exposed to 100 ug/L TPAH; mortality was 3.5% higher than controls during the first 7 d. Delayed mortality (0-150 d post-exposure) was 43% higher than controls for fish exposed to 100 ug/L TPAH (mortality was 36% higher than controls during the first 60 d post exposure)
Sockeye salmon: Smolt (~1.5y)[5]	CLB WAF, unweathered, 24h or 42d (no renewal, TPAH reported are initial)	challenged with a marine bacterial pathogen (vibriosis)	Fish exposed for 42 d to 124.5 ug/L TPAH were more susceptible to disease than unexposed control fish: cumulative mortality was 29.5% higher than controls

* Exposure concentrations are inconsistently reported in the literature, and may reflect a loading value (grams of oil per liter of water or substrate), or a sum total of a subset of 16 to 75 individual PAH measured in the exposure water.
[1]Robidoux et al., 2018; [2]Barron et al., 2018; [3]Philibert et al., 2016; [4]Alderman et al., 2018; [5]Lin et al., 2019
LC50 = lethal concentration for 50% mortality; TPAH = total polycyclic aromatic hydrocarbons; WAF = water-accommodated fraction

Laboratory experiments present mixed results regarding the acute lethality of diluted bitumen exposures. Zebrafish exposed from fertilization for 7 d did not reach 50% mortality using a 100% WAF exposure (>46 µg/L PAH, sum total of 16 EPA priority PAHs; Philibert et al. 2015). Similarly, sockeye exposed continuously to a diluted bitumen WAF with total PAH ~100 µg/L (sum of 75 PAH) from fertilization to young fry reached cumulative mortality of only ~8% during the exposure period; however, delayed mortality surpassed 50% in these sockeye during the 6 months post-exposure (Alderman et al. 2018). In contrast, all rainbow trout fry exposed to a diluted bitumen WAF prepared at 10 g/L oil load (maximum PAH = 15.4 ug/L) died within 96 h, with an estimated LC50 of 5.66 g/L oil load (Robidoux et al. 2018). This latter study exposed a second subset of rainbow trout fry to a WAF prepared from weathered diluted bitumen, and here LC50 was not reached in 96 h even at oil loadings of 18 g/L, indicating a considerable reduction in toxicity as the diluted bitumen weathers.

Based on the available data, a 4,000 m^3 diluted bitumen spill into the Thompson river system or Kamloops Lake could result in anywhere from 10% to 100% mortality of salmon present in rivers and in lakes during the first 24 – 96 h after the spill (i.e. prior to significant weathering of spilled product, and while spill response procedures are focused more on containment than clean-up). It is reasonable to assume mortality on the high end of this range, based on mortality estimates from other crude oil spills into river systems (e.g. Pine River, BC (Hodson et al., 2011)). Delayed mortality may occur in fish surviving the first days post-spill (e.g. Alderman et al. 2017), as a result of developmental malformations or other sub-lethal effects.

2.7.3 Sublethal effects of diluted bitumen exposure

Sublethal effects of crude oil exposure refer to those biological responses that do not result directly in mortality, but are likely to impact individual health and performance, including physiology and behaviour, which in turn could impact population recruitment (new individuals added to a population). Sublethal effects are expected to occur at lower diluted bitumen concentrations and/or longer exposure times. A standardized test to define a chemical's chronic sublethal toxicity is the EC50 – the effective concentration at which 50% of the population displays a sublethal endpoint of interest (e.g. malformation); however, EC50 is not always calculated or reported. Table 2 provides details from studies that report various sublethal effects in fish following diluted bitumen exposure.

Table 2. Summary of published studies reporting sublethal effects of diluted bitumen in fish. Dilbit refers to diluted bitumen.

Species & Life stage	Exposure	Endpoint	Results
Fathead minnow: Egg (fertilization to hatch)[1]	CLB and AWB (unweathered) WAF, loading rate 1:9 v/v oil:water (=0.92 g oil/L), with renewal	Malformation, hatching success	Malformation: EC50 = 0.6 – 0.9 ug/L PAC (= 0.83-1.1 mg/L TPH-F). Hatching: 74-84% success (at 10-32% v/v WAF dilutions), compared to >90% in unexposed controls.
Yellow perch: Egg (fertilization to hatch, 16d)[2]	CLB and AWB as in[1]	Malformation, hatching success	Malformations: 100% of embryos have malformations at 32% WAF (vs 3.8% in controls), but incidence is not significant at more dilute concentrations; EC50 = 3.3-3.8 mg/L TPH-F. Hatching: 2.5% (at 32% v/v AWB WAF), 60% (at 32% v/v CLB WAF), >80% with more dilute exposures and in unexposed controls.
Zebrafish: Egg to fry (fert. to 7 d larvae)[3]	Dilbit WAF (unspecified blend), loading rate = 1:10 v/v oil:water, with renewal	Malformations, hatching success, behavior	Malformations: larvae exposed to 100% WAF (~47 ug/L PAH) had ~20% higher occurrence of pericardial and/or yolk sac edema relative to unexposed controls. Hatching: 20% fewer hatched at 2 d post-fertilization (dpf) (onset of hatching in zebrafish) but caught up by 3 dpf Behaviour: avoidance behaviour in larvae exposed to 100% WAF
Japanese medaka: Egg (fert. to hatch, 17d)[4]	CLB, as in[1]	Malformations	Malformation: EC50 = 2.83 ug/L TPAH
Japanese medaka: Egg (fert. to hatch, 17d)[5]	AWB, as in[1]	Blue sac disease	EC50 = 20.5 ug/L TPAH
Sockeye salmon: Egg (fert. to swim-up, 72 d)[6]	CLB WSF, unweathered, renewed every 2 wk	Malformation, Hatching success, growth	Deformity: 17-20% of embryos with at least 1 deformity at 35 and 100 ug/L TPAH (occurrence in control fish is 2%).

			Hatching: onset of hatching delayed 1-3 d relative to control; time to 50% hatch delayed 3-4 d relative to control fish; effects on hatching observed at concentrations as low as 4 ug/L TPAH. Hatching success was 98% in unexposed control fish, and 92% in sockeye exposed to 100 ug/L TPAH. Body composition: more lipids and less protein in fry exposed to 35 and 100 ug/L TPAH (reduced yolk consumption for growth)
Sockeye salmon: Smolts (1 yr juveniles, pre-smolt exposed 1 and 4 wk)[7,8]	CLB WSF 4 wk; unweathered, unreplenished; initial TPAH given, but decreases exponentially with time	Swimming performance, histopathology, EROD; serum proteome	Reduced swim performance (10% lower relative to control) and cardiac fibrosis after 4 wk exposure to 67 ug/L TPAH; liver EROD increased at 1 wk with 3.5 ug/L TPAH (=lowest concentration) Serum proteome: increases in non-specific immune proteins; other changes suggest fish are more susceptible to exercise-induced tissue damage (after 4 wk exposure to 67 ug/L TPAH)
Atlantic salmon: Smolts (1 yr juveniles, smolts, exposed 24 d)[9,10]	CLB WSF, unweathered, unreplenished over 24 d	Swimming, muscle physiology, histopathology, EROD	No effect on swimming, gill or kidney histology (max conc. 67 ug/L TPAH); Liver EROD takes 2 wk to return to baseline after 67ug/L TPAH exposure; Seawater acclimation response not affected by dilbit
Sockeye salmon: Parr (~1.5y)[11]	CLB WAF, unweathered, 24h or 21d (no renewal, TPAH reported are initial); 13.7 – 124.5 ug/L TPAH	blood parameters, stress indices, EROD	Time and concentration-specific increase in liver EROD activity Concentration-dependent changes in stress indicators within 24 h of exposure and maintained through 21 d at higher WAF concentrations (increased plasma cortisol, glucose, and lactate; decrease liver glycogen) Ionoregulatory disturbances at higher WAF concentrations and/or longer exposures (plasma osmolality, Na+, Cl-)

[1]Alsaadi et al., 2018; [2]McDonnell et al., 2019; [3]Philibert et al., 2016; [4]Madison et al., 2017; [5]Madison et al., 2015; [6]Alderman et al., 2018; [7]Alderman et al., 2017b; [8]Alderman et al., 2017a; [9]Alderman et al., 2020; [10]Avey et al. 2020; [11]Lin et al., 2019
EC50 = effective concentration for 50% occurrence in population; EROD = Ethoxyresorufin-O-deethylase; PAC = polycyclic aromatic compounds; TPAH = total polycyclic aromatic hydrocarbons; TPH-F = total petroleum hydrocarbons quantified using fluorescence

For the study system considered in this report, sublethal exposures may occur kilometers from the spill site as contaminants are carried downstream, even when a containment barrier is in place (e.g. dissolved contaminants moved underneath the boom, detailed in Plains Midstream Canada Spill Interim Water Quality Report June 2012). In addition, flooding of oiled shorelines or snowmelt can redistribute contaminants into the water column many months after the spill (e.g. Kalamazoo River case study). For eggs and other young life stages, sublethal concentrations are likely to induce hatching delay (Philibert et al. 2016; Alderman et al. 2018; Alsaadi et al. 2018; McDonnell et al. 2019) and changes in growth and energy metabolism (Alderman et al. 2018). For example, pink salmon fry (starting fork length ~30 mm) fed Alaska North Slope Crude Oil (ANSCO, from the *Exxon Valdez* disaster in the Prince William Sound, Alaska, 1988) contaminated food for six weeks experienced 45% and 95% growth reductions at 2.8 mg oil per g food (mg/g) and 34.8 mg/g, respectively (Wang et al., 1993). In addition to growth effects, developmental abnormalities such as yolk sac and/or pericardial edema (fluid around the heart) can occur in as much as 40% of the population. Malformations may lead to post-exposure mortalities (Alderman et al. 2018), and pericardial edema during egg development may be a contributing factor to reduced swimming performance in later life stages (e.g. Incardona et al. 2015, but see also Alderman et al. 2018). Sockeye smolts exposed to sublethal concentrations of diluted bitumen WAF for 4 wk experienced a 10% reduction in aerobic swimming performance (Alderman et al. 2018), which could limit success of outmigration; however, Atlantic salmon smolts exposed similarly did not experience any decline in swimming performance (Avey et al 2020).

2.7.4 Diluted bitumen toxicity in relation to Pacific salmon

2.7.4.1 *Species and life stage sensitivities to diluted bitumen*

There are not enough studies published to assess life stage- and species-specific sensitivities to diluted bitumen; however, earlier work on ANSCO suggests similar sensitivities among six species of salmonids, with emergent fry showing the greatest sensitivity across life stages (Moles et al., 1979). Older fish experience adverse effects when exposed to conventional crude oil, including reduced aerobic swimming capacity, altered behaviours, and changes in growth and energy metabolism (e.g. reduced body condition; altered lipid metabolism). Whether or not this suite of adverse effects is consistent with diluted bitumen exposure in older fish is not known. The majority of studies to date on diluted bitumen toxicity exposed fish as eggs, with limited effort on post-hatch life stages and no studies on adult fish. Aerobic swimming capacity was reduced in sockeye salmon smolts (Alderman et al., 2017b) but not Atlantic salmon smolts (Avey et al. 2020) exposed to diluted bitumen at similar concentrations and durations. Atlantic salmon smolts exposed to diluted bitumen were able to repeat swimming performance after 24 h rest but showed a shift from aerobic to anaerobic metabolism in the heart and red muscle after exercise, which could set limits on endurance exercise capacity (Avey et al. 2020). More research needs to be conducted on post-hatch fish from species at risk of exposure to fully understand the potential impacts of a diluted bitumen spill in the aquatic environment.

2.7.4.2 *Anadromous life history*

The potential for sublethal effects of diluted bitumen exposure to impact the unique ecology of Pacific salmon, specifically their migrations and transitions between freshwater and seawater environments (anadromous), represents a major knowledge gap. For example, reduced swimming performance and/or shifts in metabolic strategy within swimming muscles could decrease a smolt's ability to complete sustained exercise necessary for outmigration to seawater or challenge its capacity to escape larger and faster predatory marine fish (Alderman et al., 2017; Avey et al. 2020). Smoltification (adaptation from living in freshwater to living in seawater) could be impacted by diluted bitumen exposure as a result of stress, disruption in hormone pathways, and/or an inability to regulate the body's salt and water composition. All of these processes have been shown to be disrupted in fish exposed to conventional crude oil (Kennedy and Farrell, 2006, 2005), and that are critical for successful seawater transition of smolts. In fact, out-migrant smolts from six salmonid species tested in seawater were twice as sensitive as those tested in freshwater to ANSCO (Moles et al., 1979). Results from a recent study in Atlantic salmon smolts suggests that osmoregulatory capacity is not greatly affected by diluted bitumen exposure (Alderman et al. 2020); however, similar experiments are needed in other salmonids to verify this result as the Atlantic salmon in this study were generally less sensitive to diluted bitumen than sockeye salmon from a similar study (Alderman et al., 2017; Avey et al. 2020).

Whether diluted bitumen exposure affects olfactory imprinting (early-life bond to a location) during early life stages is unknown, but such an effect would carry significant long-term costs to salmon populations by reducing navigation success during the spawning migration. Olfactory (i.e. smell) imprinting occurs during transitional periods, such as emergence and smoltification, and ultimately enhances the fish's sensitivity to olfactory cues from its early rearing environments. The process of imprinting is regulated by thyroid hormones (Specker 1988; Lema and Nevitt 2004), an endocrine system that is also important for development, metabolism, and growth. It is not known if crude oil exposure alters thyroid hormone signaling, but other endocrine systems are affected by crude oil (Lin et al. 2019). Crude oil exposure also induces morphological (Solangi and Overstreet, 1982) and functional (Cave and Kajiura, 2018) changes to the olfactory epithelium, which could further impair the ability of fish to imprint to olfactory cues and/or use these cues during spawning migrations.

2.7.4.3 *Behavioural responses to crude oil exposure*

Many behavioural responses have been observed in fish exposed to crude oil, including lethargy (lack of energy), increased respiration (breathing) rates, altered activity patterns, and impaired feeding and predatory behaviour. Behavioural effects after diluted bitumen exposure in salmon are unknown, but young zebrafish exposed to diluted bitumen for 7 d showed an increased tendency to swim at aquarium edges, suggesting an anxiety-like behavioural response (Philibert et al. 2016). Sub-adult and adult Coho salmon avoided water containing conventional crude oil (230-530 ug/L) and MAH mixtures (2-5 mg/L). While this behavioural response can be beneficial by helping to limit exposure times, this avoidance response could prevent mature adults from reaching their spawning grounds.

2.7.4.4 *Contaminant uptake and clearance*

Water-soluble contaminants in crude oil can enter the fish via thin, high surface area epithelial surfaces such as the gills and gut. The liver processes these contaminants by altering their chemical structure through a series of enzymatic steps (detoxification pathway) that facilitate their excretion via urine. The detoxification response can be quantified by measuring the activity and expression of a key enzyme involved in this process, cytochrome P450 type 1a (cyp1a), which is activated by PAH and crude oil exposure. Thus, quantification of cyp1a gene expression or activity can serve as a biomarker of crude oil exposure. In Sockeye smolts exposed to diluted bitumen, the cyp1a response is evident after 1 wk exposure to concentrations as low as 35 ug/L initial TPAH, and after 4 wk exposure to 3.5 ug/L initial TPAH, which highlights the sensitivity of this biomarker to diluted bitumen exposure (Alderman et al. 2017a). After 4 wk exposure to 67 ug/L initial TPAH, a cyp1a response was also detected in certain tissues (e.g. kidney, muscle), suggesting that (i) PAH were present at high enough concentrations in tissues other than the liver to elicit a cellular response, and (ii) that continued exposure to diluted bitumen causes a bioload of PAH in the body that exceeds the liver's capacity for detoxification. Cyp1a activation was also evident in muscle tissue from Atlantic salmon smolts exposed to diluted bitumen concentrations as high as 67 ug/L initial TPAH for 3 wk, and cyp1a levels did not return to baseline levels until 2 wk recovery in clean water (Avey et al., 2020). Combined, these studies suggest that the body burden of PAH will vary depending on the nature of the exposure (concentration and duration) as well as tissue type.

How quickly contaminants are cleared from the body will depend on their rate of uptake from the environment and the maximal rate at which the liver can process these contaminants, both of which are likely influenced by species, life stage, and environmental factors (e.g. temperature). If uptake surpasses the body's capacity for clearance, PAH and other contaminants in crude oil can accumulate in fish tissues. For example, sea bream (*Sparus aurata*) exposed to benzo(a)-pyrene, a model carcinogenic PAH, can accumulate sufficient amounts in muscle tissue to pose a health risk for human consumption (Zena et al. 2015). This has relevance not just to human health, but broader ecosystem health as well given the importance of salmon in both aquatic and terrestrial food webs.

2.8 Current State of Knowledge on Impacts to Terrestrial Wildlife that Rely on Salmon

A diluted bitumen spill into the Thompson river system and Kamloops Lake could result in high mortality salmon. Although current knowledge is limited for life stage and species-specific sensitivities to diluted bitumen, some research indicates that adult fish experience adverse behavioral, growth and metabolic effects when exposed to conventional crude oil (Section 2.7.3). Each of these effects can impact salmon population recruitment and have consequences for species that rely on salmon. There is also concern associated with the exposure of wildlife to harmful compounds via the ingestion of contaminated prey, which could lead to bioaccumulation or biomagnification of these compounds in other wildlife species. Bioaccumulation refers to the accumulation of a toxic chemical in the tissue of an animal that is caused by the presence of that chemical in its food. Biomagnification is a related process that occurs when the concentrations of chemicals increases in the tissues of animals along with their position in the food web. Depending on how quickly these contaminants can be cleared from the body, PAH and other contaminants in crude oil can accumulate in fish tissues (Section 2.7.4) which could have ramifications for other terrestrial wildlife.

Although not a focus for this research report, we have briefly discussed the potential consequences of reduced food availability and quality to the broader terrestrial ecosystem.

2.8.1 Changes in Food Availability

Consequences of a decline in prey availability can lead to corresponding population declines in higher-order predators. Researchers have noted that declines in salmon abundance from other stressors can lead to reduced densities in eagle, grizzly bear and other wildlife populations (e.g. kokanee salmon collapse, Spencer et al. 1991; eagles, salmon and climate change; Rubenstein et al. 2018). Therefore, depending on the temporal and spatial extent of an oil spill, it could potentially have far reaching effects to the broader ecosystem.

When food resources are scarce, the overall fitness in individuals can decline. For example, a decline in a preferred fish species of cormorant, (European shag, *Phalacrocorax aristotelis*), following an oil spill off the coast of Spain was thought to contribute to lower cormorant reproductive success (Valendo et al 2005 in Henkel et al 2012). If birth rates decline, this can have population level effects, which is of particular concern for those species that may be of special management concern or for those species requiring these resources to prepare for key seasonal cycles (e.g. migration, hibernation).

During the late summer and fall, grizzly bears will focus their energy on obtaining food to increase their body mass prior to hibernation. The availability of high-quality foods, such as salmon, is essential for accumulating those fat reserves for hibernation and in supporting successful reproductive outcomes (during hibernation, embryos will implant on the uterine wall). Higher salmon consumption by coastal bears has been shown improve their body condition, reproductive success and population densities compared to areas without access to salmon (Hilderbrand et al. 1999, Service et al. 2019). Although grizzly bears on coastal BC consume more salmon than their counterparts in the interior of BC (Mowat and Heard 2006), hotspots of salmon consumption inland have been identified (Adams et al. 2017). Further research is needed to understand the role of salmon consumption for interior grizzly bear populations and whether differences in salmon abundance would have any effects on their fitness.

Bald eagles are also a species that regularly feed on salmon, generally carcasses left behind from other predators, and are opportunistic feeders whose diet includes fish, avian species and carrion. Generally, eagles migrate from Alaska southward following the progression of salmon spawning activity. Although several studies have shown bald eagle abundance linked with salmon density (e.g. Hunt et al 1992, Hansen et al 1984 in Elliott et al 2011), other studies have highlighted the complexity of this relationship and perhaps regional differences. For example, Elliott et al (2011) found that in the south-coastal area of BC, the number of chum salmon carcasses peaked well before the peak in eagle numbers. It is clear that these relationships are quite complex and that there is still much more information needed to understand the interactions in these food web systems, as well as, how the system would respond and recover from various natural and anthropogenic disturbances.

2.8.2 Changes in Food Quality

As described in Section 2.6.2, there are several chemical compounds that are found within different types of oil such as monocyclic aromatic hydrocarbons (e.g. benzenes, toluenes, and xylenes), PAHs, and various heavy metals (e.g. mercury). Species within the same taxa may show different sensitivities to pollutants because of life history or physiology differences (Bergeon Burns et al. 2014) making it difficult to generalize impacts even across a single species. However, research suggests that vertebrates may have the capacity to metabolize and eliminate PAH residues which would suggest that there is limited potential for bioaccumulation or biomagnification effects further up in the food chain (Neff 1979, Henkel et al 2012) related to that compound. Although there has been research on heavy metal toxicity following oil spills, the exposure route of these organisms to heavy metals is not well understood. For example, chromium and nickel can bioaccumulate in organisms, and were measured in the tissue of whales within the Deepwater Horizon spill site at higher concentrations compared to tissue samples of whales outside of this area (Wise Jr, JP et al 2014). However, it is not clear whether the uptake of these metals was via exposure through inhalation, dermal absorption, via ingestion of contaminated food, or a combination of all of these processes. Furthermore, while it is likely that the Horizon oil spill contributed to the higher concentrations of metals in these whales, there are additional sources in the Gulf of Mexico, such as the release of industrial waste and exposure to boat paint that contain metals as antifouling agents (Wise Jr JP et al 2014). Thus, pre-existing stressors can confound the ability to ascribe these effects specifically to oil spills which can lead to dismissal of concerns surrounding impacts to the health of wildlife, unless there is adequate baseline data prior to the spill that would capture existing levels of contaminants in the system.

2.8.3 Reduced Habitat Quality

The role of salmon in the ecosystem is not solely via a food source for predators but also as a source of nutrients to the surrounding environment that supports plant growth and health, and in turn, wildlife. For many of the terrestrial species, the consumption of salmon is only one part of their diet, and the continued health of plants and invertebrates in the surrounding landscape is essential. If fewer salmon return, there will be fewer salmon carcasses left by terrestrial scavengers that will contribute to the nutrient cycling process. Bears also consume fruits and serve as seed dispersal agents via their scat. If salmon were limited, bear densities may be lower, which could alter seed dispersal patterns and vegetation growth (Gende et al 2002). Changes in plant diversity and density could then affect densities of omnivorous species, leading to broadscale reductions in biodiversity in the area.

2.8.4 Monitoring Impacts to Wildlife Following Oil Spills

In 2010, a pipeline operated by Enbridge ruptured in a wetland which flowed into surrounding wetlands, the Talmadge Creek and the Kalamazoo River (see Section 2.6.4 of this report). The follow up monitoring after the release of diluted bitumen into the environment, included surveys in the floodplain habitats of the Talmadge Creek and Kalamazoo River in order to characterize the extent and degree of oiling to inform clean up techniques. A fish health assessment and fish community assessment were conducted to evaluate impacts from the spill on fish health and abundance (US Fish and Wildlife Service et al 2015). Enbridge also established a wildlife response center that cared for and released almost 4,000 animals, including 3,650 reptiles and 196 birds (NTSB 2012). Long term effects to wildlife are unclear.

Plains Midstream's 2012 pipeline incident spilled over 460 m^3 litres of oil into the Red Deer River and Glennifer Lake near the town of Sundre, Alberta (see Section 2.6.4 of this report). Although the deployment of booms helped to stop the migration of visible oil on the surface, dissolved components continued to move downstream into Glennifer Lake. Impacts to wildlife and vegetation included upstream soiling/smothering of aquatic organisms and wildlife which the company responded to by employing deterrent systems in areas with the greatest possibility for wildlife coming into contact with contaminated soil, plants and water, as well as rescuing any reported oiled wildlife. However, it remains unclear how regulators and the company addressed potential long-term impacts to wildlife associated with the transport of dissolved components downstream, other than through water quality monitoring. Few details are publicly available as to the type and length of wildlife monitoring that was conducted but one news release indicated that Alberta Environment determined that impacts to wildlife from the spill had been minimal
(http://www.calgaryherald.com/technology/meet+oily+animals+rescued+from+deer+river+spill/6786070/story.html).

Follow up efforts for both the Enbridge and Plains Midstream spills appeared to focus on the short-term effects from a spill, including employing deterrents to minimize continued or future exposure and the rescue and rehabilitation of any oiled wildlife. Open access to information and transparency is important to our understanding of how regulators and proponents are monitoring long-term effects of oil spills on wildlife health, changes to resource availability and quantity, changes to habitat use and the overall cumulative effects from a spill, combined with other stressors to wildlife.

Quantifying impacts on terrestrial vertebrates can be challenging because for some species, there is a lack of baseline data on population sizes, habitat use, or dispersal. Any impact assessment would need to establish recovery endpoints that would represent a return of a population or habitat to some pre-spill condition. Without baseline data, these endpoints will be difficult to characterize and establish. Trying to track impacts from oil exposure to individuals, to populations and community structures are further complicated by the cumulative effect of other stressors on the ecosystem. For example, changes to the abundance and breeding success of seaside sparrows in the Louisiana marshes following the Deepwater Horizon oil spill were compounded by effects from Hurricane Isaac (Bergeon Burns et al 2014). Long term and integrated approaches to monitoring are needed to fully understand impacts from oil spills, regardless of their size and extent.

2.9 Summary of Knowledge Gaps

As a first step in determining the potential impacts of a diluted bitumen spill on Pacific salmon populations in the Area of Interest, this report compiled data relevant to TMX pipeline spill scenarios, as well as data on how the North Thompson River and Shuswap complex are used by freshwater life stages of Sockeye and Chinook salmon. This dataset, along with the current state of knowledge for diluted bitumen toxicity to fish, underlies the modeling and power analysis presented in Section 3.0. However, the comprehensive literature review revealed critical knowledge gaps relevant to the objectives of this report. As summarized in Table 3, these knowledge gaps apply to almost every aspect of predicting how a spill of diluted bitumen from the TMX pipeline will affect salmon. For example, defining the location and spatial extent of a worst-case spill scenario is hindered by a limited understanding of how diluted bitumen will behave in a freshwater system with considerable seasonal variability. Furthermore, the spatial resolution describing how juvenile salmon utilize the area of interest during their freshwater residency is poor, and research into the nature and outcomes of diluted bitumen exposure in fish is only in early stages. Filling these knowledge gaps may improve the capacity to predict, calculate, or mitigate the potential effects of the TMX project on salmon.

Table 3. Summary of Knowledge Gaps identified during Literature Review.

Knowledge Category	Sub-category	Knowledge Gap
When and where will a spill occur?	Pipeline and location conditions	How will pipeline- and location-specific conditions influence when and where a spill might occur?
	Environmental conditions	How will future changes in streamflow resulting from climate and land use change affect the likelihood of a spill from the pipeline?
What will the spatial extent of a spill be?	Diluted bitumen properties	What will the spatial extent be of physical oil product and dissolved constituents?
	Diluted bitumen properties and Environmental conditions	What are the dominant processes determining diluted bitumen fate and behaviour in an aquatic ecosystem (degradation, transformation)?

	Environmental conditions	What is the behaviour of diluted bitumen in low temperatures, or under an ice cover?
	Environmental conditions	How exactly will turbulence, suspended sediments and other conditions in rivers and lakes influence when and where diluted bitumen will become submerged or sink?
Where will fish be at the time of a spill (life-stage specific)?	Fish ecology	What size-cohorts of juvenile salmon typically use the vulnerable area of the watershed?
	Fish ecology	What are the natal origins of juvenile salmon (e.g., from tributaries or other populations) inhabiting the vulnerable area of the watershed?
What will be the nature of diluted bitumen exposure (concentration and duration)?	Diluted bitumen properties	How will weathering of diluted bitumen affect its availability and toxicity to fish?
	Diluted bitumen properties	What are the specific hydrocarbon compositions across various types of diluted bitumen?
	Environmental conditions	How will conditions in water bodies (e.g. turbulence, sunlight, temperature) at the time of a spill specifically translate into concentrations of contaminants of potential concern (e.g., hydrocarbons)?
	Response effort	How will the spill mitigation response influence the volume spilled, spatial extent of impact, and environmental persistence of contaminants?
What are the direct effects of diluted bitumen exposure on salmon?	Diluted bitumen toxicity	What is the comprehensive and detailed scope of diluted bitumen toxic effects?
	Diluted bitumen toxicity	What are the relative salmon life stage and species-specific sensitivities?
	Diluted bitumen toxicity	How long do adverse effects persist in salmon?
	Diluted bitumen toxicity	Do sublethal toxic effects ultimately contribute to population declines?
What are the indirect effects of a pipeline spill and diluted bitumen exposure on fish?	Diluted bitumen toxicity	Will toxic effects in salmon prey items decrease food availability?
	Environmental conditions	How will a spill and the mitigation response impact salmon habitat quality?

How are adverse effects in salmon transferred to other wildlife?	Food Web Impacts	Food web interactions and relationships are complex - how will each trophic (food web) relationship respond to perturbations?
	Contaminant Exposure in Higher Order Predators	What are the exposure routes via the food web and what are species-specific sensitivities to oil?

3.0 Part B: Quantifying and Detecting Impacts to Salmon

The TMX project poses several plausible risks to salmon in the Area of Interest (North Thompson River, Thompson River and Kamloops Lake) that may vary in spatial extent and timing across the salmon life cycle. As outlined in our introduction, this report addresses three key research questions (listed below). The first research question (greyed out in the list) was addressed under Section 2.0. In Section 3.0, we now assess the remaining two research questions related to quantifying these potential risks to the number of returning adult salmon, which is an important metric of fishery resources for the Adams Lake Indian Band.

1) What is the state of knowledge about impacts of oil and/or diluted bitumen spills on Chinook and Sockeye salmon in freshwater systems, and specifically in the Thompson River complex?
2) Given specific hypothetical spill conditions, what are the potential impacts of a spill of a diluted bitumen product in the North Thompson River on Chinook and Sockeye salmon?
3) Using the available DFO data on numbers of returning adults, how precisely would we be able to quantify such an impact on the number of returning Chinook and Sockeye salmon adults?

We address the second research question by calculating the impacts under a worst-case scenario spill based on our current knowledge. We address the third research question by estimating the uncertainty in the recruitment variation for the North Thompson versus the rest of the Fraser basin for individual years. We also calculate the power (probability of simply detecting an effect) for a worst-case scenario spill. It is important to note that the considered spill is worst-case in terms of timing, location and spatial extent of the spill but due to the knowledge gaps identified in the previous section, this scenario may impact the salmon more or less severely than calculated below. We note that the current impact assessment framework assumes that if an impact cannot be detected then there is no impact even though the data may also be consistent with a substantial negative impact. This is a flawed framework for assessing impacts but has unfortunately been used for several large crude oil spills (e.g., Ward et al. 2017, 2018; Shelton et al. 2018).

3.1 Defining Hypothetical Spill Scenarios and Impacts to Salmon

Understanding the potential impacts to North Thompson salmon required us to identify how oil spills might translate into impacts on adult salmon. We began by identifying:

1) the timing, location, and magnitude of potential spills,
2) the fate of diluted bitumen and water in the watershed,
3) the timing, location, and abundance of salmon,
4) the vulnerability and impacts to those salmon from exposure, and

5) how those impacts span the salmon life cycle.

To do this, we first reviewed case studies of oil spills and the downstream consequences to fishes (described in Section 2.6.4). We then constructed a life cycle model of Chinook and Sockeye Salmon within the North Thompson accounting for spatial variability in productivity (i.e. quantity of fish produced), habitat usage, and survival within the mainstem and tributaries of the watershed. Next, we reviewed likely direct impacts to survival (i.e. ability to persist/live) and fecundity (i.e. ability to produce offspring) of salmon directly exposed to a worst-case diluted bitumen spill scenario. Last, we calculated the loss of returning adults given their likely reduced survival and fecundity.

3.1.1 Hypothetical Spill Considerations

3.1.1.1 *Example of the TMX pipeline project spill risk assessment*

The TMX Project involves a twinning of the existing TMP with the addition of Line 2, including new construction of pipeline segments, reactivation of some deactivated segments and construction of new pump stations. The current TMP transports conventional crude oil, diluted bitumen and other petroleum products from Alberta to the west coast of Canada at Burnaby, BC (TMP ULC 2013, Volume 2).

As part of the TMX Project EIA, a qualitative ecological risk assessment (QERA) was completed for pipeline spills (TMP ULC 2013, Volume 7). The QERA focused on the environmental effects of hydrocarbons that would be released with diluted bitumen, including BTEX, as well as PAHs and/or PACs, while metals were not thoroughly considered as contaminants of potential concern (COPC). The receptors chosen as part of the QERA were generalized across regions, and in BC, these receptors included fish, fish eggs and larvae of Chinook salmon, Coho salmon, bull trout, Dolly varden, rainbow trout/steelhead, and cutthroat trout, among other fish species, with a focus on a generic salmonid species to represent the group.

The specific amount of released oil that was considered as part of the QERA was determined based on potential outflow volumes expected at specific locations along the pipeline route. Those volumes were projected based on the assumption of a response to a full-bore rupture comprised of mainline block valves and check valves near watercourses being fully closed 15 and 10 minutes after the rupture occurs, respectively. The "shutdown volume" is therefore expected to be constant at all locations considered, at 500 m^3, while the "draindown volume" is dependent on the pipeline elevation and relative location of valves at the location considered. The TMX Project's outflow modeling was completed for the section of pipeline that runs through the North Thompson River watershed from the Albreda River valley to Blackpool, just downstream, of the Clearwater River confluence, and from Black Pines, downstream of McLure, to Kamloops (Figure 7). It is not clear why this modeling was not completed for the entire length of pipeline in the watershed. The cumulative outflow volumes (shutdown plus drain down volume) predicted along this stretch ranged from a minimum of 500 m^3 to about 4,000 m^3 near the Finn Creek Pump Station (TMP ULC 2013, Volume 7, Section 3.1.6 and Appendix B).

The spill scenarios that TMP ULC considered in its QERA included consideration of multiple weathering, and transport mechanisms in aquatic environments (e.g. evaporation, dispersion, dissolution, microbial degradation). Each of these mechanisms and processes were initially discussed in the QERA in relation to the conditions influencing fate and transport of oil spilled into inland waters in case studies from the northern United States and Canada (TMP ULC 2013, Volume 7, QERA, Section 6.2.2). In aquatic ecosystems, the presence of oil slicks and the dissolution of BTEX substances in water often leads to acutely toxic conditions for fish and other aquatic organisms.

These processes and patterns were considered in the discussion of specific hypothetical spill scenarios as part of the QERA. The spill scenario considered along the North Thompson River involved the release of 1,400 m^3 of Cold Lake Winter Blend (CLWB) from a full-bore rupture at pipeline route kilometer 766.0 near Darfield. In each case, it was assumed that oil in the ruptured section of pipe, as defined by control valve locations, would completely drain through the pipe rupture, and that most of this oil would reach a watercourse. Three different timing scenarios were considered: summer condition (June – August), river in freshet, flow >1,250 m^3/s; and spring or fall condition (April – June or September-November), flow is moderate at about 500 m^3/s; winter condition (December – March) with ice cover on the river and snow on land, flow at 100 m^3/s or less.

For the high-flow summer scenario, oil was expected to travel up to 60 km downstream of the Darfield spill location, with trace amounts reaching upper Kamloops Lake. Due to turbulence, oil was expected to be entrained in the water column. The QERA assumes that suspended sediment loads would be low, but this is unlikely during the freshet. Some oil was expected to adhere to shorelines and some was expected to sink. Fish mortality was expected to occur within 10 km of the spill site, but as concentrations decline further downstream, lethal exposures were considered less likely. The QERA indicates that recovery of fish habitat was expected within 12 months (TMP ULC 2013, Volume 7, Table 6. 22).

For the spring/fall scenario, oil was expected to travel about 25 km downstream. Low turbulence was expected, so entrainment of oil was expected to be limited. Oil was expected to adhere to shorelines, especially cobble and gravel. Oil was not expected to reach the confluence of the South and North Thompson Rivers (TMP ULC 2013, Volume 7, Table 6. 23).

The probable longitudinal extent of oil travel was not provided for the winter scenario – the oil was expected to be absorbed by snow on land, and then to spread out on the ice. Some oil was expected to enter the River through open water patches and to move downstream. Effects on fish and fish eggs were expected to be low because very little oil was expected to contact the water. These effects were also expected to be limited spatially because most of the spilled oil was assumed to be recovered, and recovery of fish habitat was assumed to occur within 6 months (TMP ULC 2013, Volume 7, Table 6. 21).

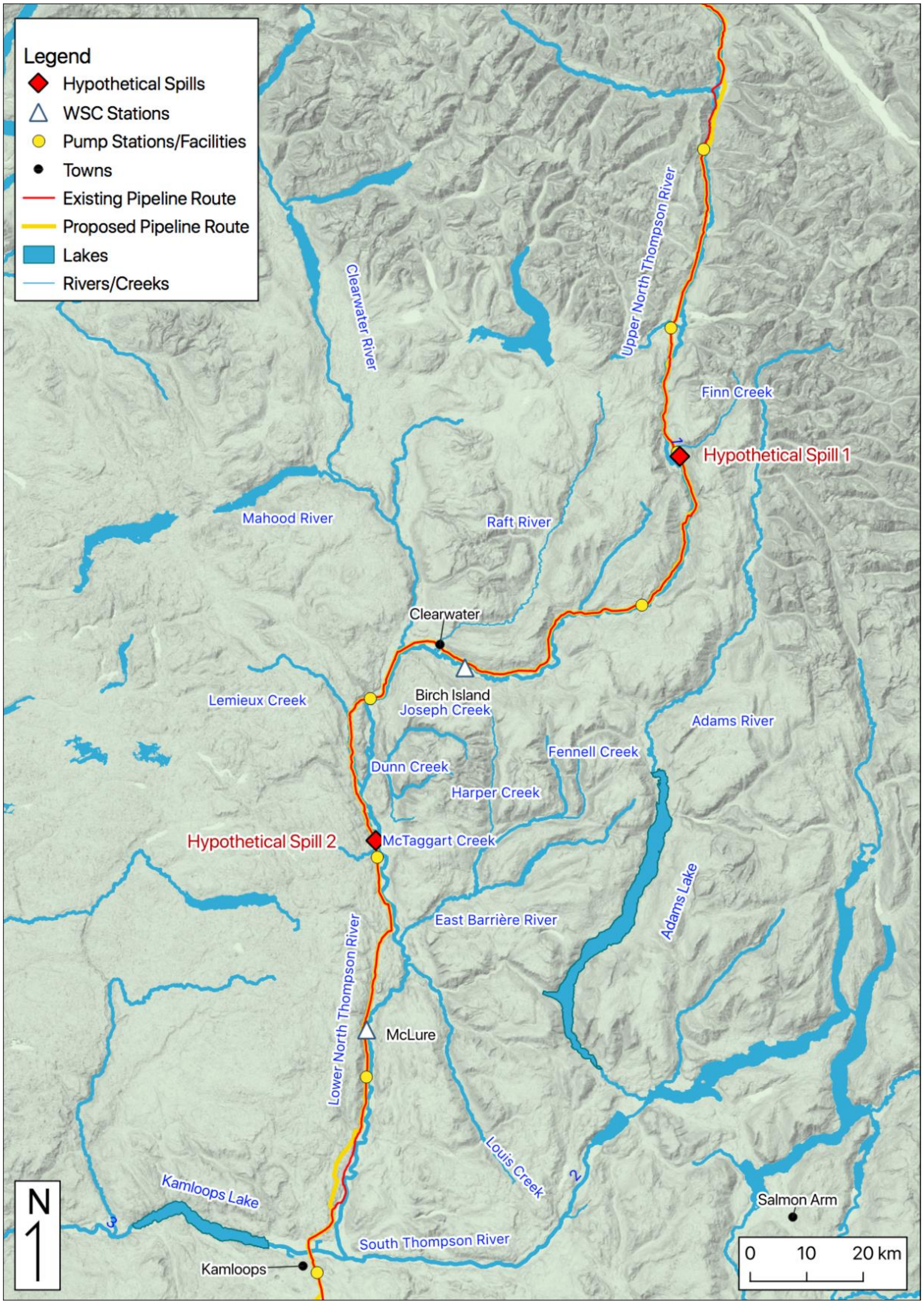

Figure 7. Location of hypothetical spills from the proposed TMX pipeline initially considered for the assessment of impacts to Chinook and Sockeye salmon. Hypothetical spill location 1 represented the worst-case scenario of a release of 4,000 m3 of diluted bitumen. Hypothetical spill location 2 represents the spill location assessed in the TMX qualitative ecological risk assessment (QERA) (TMP ULC 2013, Volume 7), which involved a release of 1,400 m3 of diluted bitumen.

3.1.1.2 *Spill Conditions Used for this Analysis*

The North Thompson River does not have particularly high sediment load (measured as TSS); however, it is a glacial-fed River which means that, especially during freshet, it is likely to have peak sediment loads made up of fine sediments. More recent and comprehensive water quality data are needed to determine this for certain. The presence of such sediment would increase the potential for diluted bitumen to sink.

Flows in the North Thompson are highly variable seasonally, and compared to the Kalamazoo River (see discussion of this case study in Section 2.6.4), are many times higher during the freshet. It should be noted that pipeline ruptures near watercourses have occurred during high flow or freshet conditions due to erosive forces, especially where depth of cover at watercourse crossings is shallow (Teichreb 2013). The stream gradient in the North Thompson is also higher than in the Kalamazoo River. Both of these conditions are likely to contribute positively to turbulence, which is associated with an enhanced potential for diluted bitumen to sink as it weathers.

The increased turbulence may lead to relatively low initial concentrations of dissolved constituents in the water column of the River, by inhibiting dissolution. However, over time and if the oil is not recovered, the concentrations of these constituents will peak. It is also possible that in winter the presence of an ice cover may reduce the role of volatilization (i.e. evaporation) in removing light hydrocarbons from the River immediately after a spill.

Aquatic oil spills are dynamic. The concentrations of the toxic constituents of crude oil vary over time and space, as demonstrated in the case studies described in Section 2.6.4. Based on the water chemistry data collected during and after these reference spills, this report assumes that a worst-case scenario spill from the TMX into the North Thompson would generate sufficient concentrations of toxic constituents to result in the maximal adverse outcomes reported in laboratory studies.

The location of the hypothetical spill will greatly influence the geographic extent and relative severity of impacts to fish and fish habitat. A spill further upstream in the North Thompson River (e.g., Birch Island) would enter the River at a location with lower discharge, and therefore less dilution capacity, than at a location further downstream (e.g., McLure). A spill nearer to the mouth of the North Thompson River or along the section of the Thompson River would be more likely to reach Kamloops Lake, all else being equal.

While TMP ULC used a hypothetical spill volume of 1,400 m^3 with a spill location near Darfield for its QERA (TMP ULC 2013, Volume 7) (see Figure 7, Hypothetical Spill Scenario 2), the maximum modeled cumulative outflow volumes for the section of pipeline along the North Thompson River and at the Thompson River was about 4,000 m^3 (TMP ULC 2013, Volume 7, Section 3.1.6 and Appendix B). This estimate of outflow volume applies to a location just south of the Project's Finn Creek Pump Station, around pipeline kilometre 640, near Finn Creek Provincial Park and just north of a planned watercourse crossing (approximate location 51°36'06.0"N, 119°54'51.0"W; 51.601667 N, -119.914167 W)(see Figure 7, Hypothetical Spill Scenario 1). This volume was determined under the assumption that detection of a pipeline rupture would be immediate and that mainline valves would be fully closed within 15 minutes of the rupture occurring (TMP ULC 2013, Volume 7).

The time required for 4,000 m^3 of diluted bitumen to drain from the pipeline depends on the type of pipeline failure that leads to the spill. In the case of the Plains Midstream spill of 462.75 m^3 of crude oil into the Red Deer River, the pipeline operator initiated closure of block valves 15 minutes after the first indication of a problem, and the pipeline was "offline" at the time (AER 2014), although the meaning of offline was not provided. The pipeline had a diameter of about 30cm, and failure analysis after the spill indicated that a "circumferential" (girth) pipeline weld had failed, likely due to instream exposure of the pipeline and vibration caused by river flows (AER 2014). In contrast, the Enbridge spill of 3,190 m^3 diluted bitumen into wetlands and a tributary of the Kalamazoo River occurred over about 17 hours, during which the operator attempted to make changes to the pressure in the pipeline (NTSB 2012). The failure investigation found that the pipeline was ruptured along a longitudinal weld, with an opening of about 2 m long and 15 cm wide, and that the probable cause of the rupture was corrosion fatigue cracks (NTSB 2012). For this analysis, the period of time required for the hypothetical spill volume to enter the North Thompson River was estimated to be one hour. Again, this represents a rather extreme worst-case scenario, since the release duration of such a large volume of diluted bitumen would depend on the size of the rupture and would slow as pressure in the pipeline is reduced.

We considered three flow scenarios for our assessment of impacts, similar to those considered for various case studies in the TMX QERA (TMP ULC 2013, Volume 7). These include the following:

A. Under **freshet conditions** (high flow, early summer), recovery may be difficult/delayed due to flood conditions. There is a greater potential for diluted bitumen to sink if allowed to weather for several days. A spill into high flows would maximize the extent of floodplain oiling – this can become a long-term source of oil as it is mobilized in subsequent flood/high flow events.
B. Under **winter conditions**, the ratio of spilled diluted bitumen to river flow (discharge) will be much higher, and the difficulties of oil recovery from an ice-covered river will reduce oil recovery immediately after a spill. In this case, submerged oil or sinking oil may not be a major concern as much as the large relative volume of product spilled and delayed or ineffective recovery.
C. Under **open water conditions** (spring, late summer and autumn) a spill will likely result in a more moderate risk, with more favourable recovery conditions (i.e., not high flow, not under ice) and a moderate diluted bitumen:discharge ratio.

Conditions in these scenarios are summarised in Table 4 below.

Table 4. Spill scenarios considered for a spill of diluted bitumen into the North Thompson River near Finn Creek Provincial Park (note: this location is upstream of WSC station at Birch Island). Dilbit refers to diluted bitumen.

Scenario name	Timing	Flow condition (measured at Birch Island)[1]	TSS concentration[2]	Turbulence? Oil sinking potential?	4000 m3 oil: one-hour discharge ratio	Product recovery rate over time
Spring/early summer freshet	May-June (may occur periodically during July and August resulting from storms)	high, possibly flood flows (median max discharge 485 m3/s)	~41 mg/L or higher	high, high	0.0023	~90% over three years (estimated 49,000 - 86,000 gallons dilbit residual in the aquatic environment from Marshall spill)[3]
Early spring or fall	April-May, Sept-Nov	moderate-low (discharge 90 m3/s)	~16.4 mg/L	moderate, low	0.0123	~85% over six weeks (Husky dilbit spill into North Saskatchewan)[4]
Winter, under ice	Dec-Mar	low (median min discharge 30 m3/s)	~2.3 mg/L	low, low	0.0370	<10% over months, remaining permanently in system (Yellowstone spill in winter)[5]

[1]Obtained from https://wateroffice.ec.gc.ca/search/historical_e.html
[2] Obtained from https://governmentofbc.maps.arcgis.com/apps/webappviewer/index.html?id=0ecd608e27ec45cd923bdcfeefba00a7
[3] Federal On Scene Coordinator (FOSC), 2016, FOSC desk report for the Enbridge oil spill in Marshall, Michigan, U.S. Environmental Protection Agency, 241 pp., url: https://www.epa.gov/enbridge-spill-michigan/fosc-desk-report-enbridge-oil-spill, accessed September 2019.
[4] Reported in Derowiz, C. 2019. 'We're deeply sorry:'Husky Energy fined $3.8M for leak into North Saskatchewan River. Toronto Star June 12, 2019.
[5] State and Federal Trustees State of Montana and U.S. Department of Interior. 2017. Partial Claim for Past and Future Assessment Costs January 2015 Yellowstone River Oil Spill.

3.1.2 Calculation of contaminant concentrations

Detailed water quality data available from oil spills that have occurred in the past are scarce, especially for light hydrocarbons including BTEX and PAHs/PACs, and especially in the hours and days immediately following a spill. We used the following data sources to obtain water quality data for two oil spill incidents: The Marshall, Michigan spill of diluted bitumen from an Enbridge pipeline into the Kalamazoo River in 2010 (Michigan Department of Community Health 2013) and the spill of crude oil from a Plains Midstream pipeline into the Red Deer River in 2012 (AER 2012). This information is summarized in Table 5. After consideration of the two spills, it was clear that maximum concentrations of BTEX and PAH constituents in water was highest for the Kalamazoo River spill of diluted bitumen. For this reason, and with the goal of highlighting a worst-case scenario, our focus was on the Kalamazoo River concentrations.

To estimate the maximum potential BTEX and PAH concentrations in water, we used the spilled oil to river discharge ratio determined for the Kalamazoo River spill, compared this to the worst-case spill volume considered of 4,000 m^3, and assumed one hour of river discharge in the North Thompson River at Birch Island under each of the spill scenario flow conditions considered (freshet, under ice, spring/autumn open water) (summarized in Table 6). In all cases, these maximum estimates for BTEX and PAH meet or exceed lethal concentrations. It is important to note that these concentrations are unlikely to occur instantaneously throughout the entire system. Concentrations will fluctuate spatially and temporally during and after the spill, and so there will be an opportunity for some fish to escape these lethal doses. Again, with the goal of highlighting a worst-case scenario, we considered the impacts that would occur if these maximum potential concentrations occurred at all locations within the Area of Interest located downstream of the hypothetical spill location (i.e., mainstem North Thompson River, Thompson River, and Kamloops Lake) for a period of three months coincident with and following each of the spill scenarios (freshet, open water, under ice). These conditions represent extreme worst-case scenarios.

Table 5. Summary of available water quality data for case study spills of crude oil and diluted bitumen from pipelines into freshwaters, focusing on hydrocarbon constituents (BTEX and PAHs)

Incident and References	BTEX concentration (water)	Total PAH (water)	Oil or diluted bitumen:water volume ratios	Notes
Crude oil spill into Red Deer River, 2012 (AER 2012, 2014; Teichreb 2013)	maximum recorded in river >0.025 mg/L toluene and xylenes, >0.01 mg/L benzene, < 0.005 mg/L ethylbenzene (day 1); max recorded in lake >0.014 mg/L toluene, ~ 0.01 mg/L xylene, ~0.005 mg/L benzene (day 2), no detectable concentrations after 9 days - downstream pulse	2-Methylnaphthalene, Fluorene, Naphthalene, Phenanthrene were measured, maximum measured in river day after spill was 0.0065 mg/L (2-methylnaphthalene), 0.0047 mg/L (naphthalene), and 0.0004 mg/L (phenanthrene) - the latter exceeded provincial protection of aquatic life guidelines, and naphthalene exceeded at times during the following 9 days	462.75 m^3 spilled into Red Deer River at flows of about 990 m^3/s, ratio for 87 minutes of spill time is 462.75/5167800 = **0.0000895**	extent of visible product spill was about 40 km on the Red Deer River, ending at Glennifer reservoir where booms contained the surface spill - dissolved constituents continued to move as a pulse downstream and into the reservoir, at times exceeding guidelines, and detectable in the monitored area for about 9 days.
Dilbit spill into Kalamazoo River, 2010 (Michigan Department of Community Health 2013, Fitzpatrick et al. 2015, FOSC 2016)	maximum recorded in river 0.046 mg/L toluene, 0.0043mg/L xylenes, 0.049 mg/L benzene, 0.043 mg/L ethylbenzene (measured July through September 2010).	many PAHs were measured, maximum measured July through September 2010 was 0.00022 mg/L (anthracene), 0.025 mg/L (benzo(a)anthracene), and 0.038 mg/L (benzo(a)pyrene), 0.0028 mg/L (fluoranthene), 0.0011 mg/L (fluorene), 0.057 mg/L (naphthalene), 0.0024 mg/L (phenanthrene), 0.027 mg/L (pyrene)	3190 m^3 spilled into Talmadge Creek/Kalamazoo River at flows of about 100 m^3/s for 17 hours of spill time is 3190/6120000= **0.00052**	traveled 65 km downstream over two days, through several impoundments on the Kalamazoo River

Table 6. Estimates of hydrocarbon constituent concentrations (BTEX and PAHs) derived from reported concentrations following the spill of diluted bitumen into the Kalamazoo River in 2010.

Scenario name	Parameter	Unit (water)	Maximum reported (Kalamazoo River)[1]	Case study oil:water ratio (Enbridge) (unitless)	4000 m3 oil: one-hour discharge ratio (unitless)	Maximum estimated concentration
Spring/early summer freshet	benzene	mg/L	0.049	0.00052	0.0023	0.216
	ethylbenzene	mg/L	0.043			0.189
	toluene	mg/L	0.046			0.203
	xylene	mg/L	0.043			0.189
	acenaphthene	mg/L	0.0004			0.002
	acenaphthylene	mg/L	0.00013			0.001
	anthracene	mg/L	0.00022			0.001
	benzo(a)anthracene	mg/L	0.025			0.110
	benzo(a)pyrene	mg/L	0.038			0.167
	benzo(b)fluoranthene	mg/L	0.0025			0.011
	benzo(g,h,i)perylene	mg/L	0.0022			0.010
	benzo(k)fluoranthene	mg/L	0.00054			0.002
	chrysene	mg/L	0.028			0.123
	dibenzo(a,h)anthracene	mg/L	0.001			0.004
	fluoranthene	mg/L	0.0028			0.012
	fluorene	mg/L	0.0011			0.005
	indeno(1,2,3-cd)pyrene	mg/L	0.00097			0.004
	naphthalene	mg/L	0.057			0.251
	phenanthrene	mg/L	0.0024			0.011
	pyrene	mg/L	0.027			0.119
Early spring or fall	benzene	mg/L	0.049	0.00052	0.0123	1.163
	ethylbenzene	mg/L	0.043			1.021
	toluene	mg/L	0.046			1.092
	xylene	mg/L	0.043			1.021
	acenaphthene	mg/L	0.0004			0.009
	acenaphthylene	mg/L	0.00013			0.003
	anthracene	mg/L	0.00022			0.005
	benzo(a)anthracene	mg/L	0.025			0.594
	benzo(a)pyrene	mg/L	0.038			0.902
	benzo(b)fluoranthene	mg/L	0.0025			0.059
	benzo(g,h,i)perylene	mg/L	0.0022			0.052
	benzo(k)fluoranthene	mg/L	0.00054			0.013
	chrysene	mg/L	0.028			0.665

	dibenzo(a,h)anthracene	mg/L	0.001			0.024
	fluoranthene	mg/L	0.0028			0.066
	fluorene	mg/L	0.0011			0.026
	indeno(1,2,3-cd)pyrene	mg/L	0.00097			0.023
	naphthalene	mg/L	0.057			1.353
	phenanthrene	mg/L	0.0024			0.057
	pyrene	mg/L	0.027			0.641
Winter, under ice	benzene	mg/L	0.049	0.00052	0.0370	3.490
	ethylbenzene	mg/L	0.043			3.063
	toluene	mg/L	0.046			3.276
	xylene	mg/L	0.043			3.063
	acenaphthene	mg/L	0.0004			0.028
	acenaphthylene	mg/L	0.00013			0.009
	anthracene	mg/L	0.00022			0.016
	benzo(a)anthracene	mg/L	0.025			1.781
	benzo(a)pyrene	mg/L	0.038			2.707
	benzo(b)fluoranthene	mg/L	0.0025			0.178
	benzo(g,h,i)perylene	mg/L	0.0022			0.157
	benzo(k)fluoranthene	mg/L	0.00054			0.038
	chrysene	mg/L	0.028			1.994
	dibenzo(a,h)anthracene	mg/L	0.001			0.071
	fluoranthene	mg/L	0.0028			0.199
	fluorene	mg/L	0.0011			0.078
	indeno(1,2,3-cd)pyrene	mg/L	0.00097			0.069
	naphthalene	mg/L	0.057			4.060
	phenanthrene	mg/L	0.0024			0.171
	pyrene	mg/L	0.027			1.923

[1] Data taken from Michigan Department of Community Health. 2013. Public Health Assessment: Kalamazoo River/Enbridge Spill: Evaluation of Kalamazoo River surface water and fish after a crude oil release

3.2 Estimating Impacts on Salmon in the North Thompson Watershed

Research Objective: *Given specific hypothetical spill conditions, what are the potential impacts of a spill of a diluted bitumen product in the North Thompson River on Chinook and Sockeye salmon?*

Below, we describe the details and parameters for Sockeye and Chinook population dynamics that we compiled for our analysis. The data on the fecundity (i.e. production of offspring) and survival of each life stage in the watershed were used to understand how many adults could possibly return each year to the Area of Interest to spawn. Within the salmon lifecycle, each life stage will use a variety of habitats between marine and freshwater environments. Life stages can also vary in which habitats they use within these environments. For example, some salmon populations may spawn in a tributary (outside the vulnerable Area of Interest) but emerging fry may migrate downstream into the North Thompson River six months later (into the vulnerable Area of Interest). Other populations may be inside or outside the Area of Interest the whole time. To address some of these complex components of the salmon life cycle, we categorized the spatial extent of each life stage into areas of the watershed. For example, for each of our key species, we grouped life stages that would be found in the mainstem of the watershed compared to tributaries. We then estimated how much and how long each of the population within those life stages use that habitat. We used these estimates to create a baseline for returning Sockeye and Chinook adults under an unimpacted scenario. We then used the literature review on diluted bitumen impacts from Section 2.7 to estimate how hypothetical oil spills could impact the baseline life cycle for each species and local population given the spatial extent and timing of that spill compared to where and how many salmon would be affected. This then allowed us to compare changes in the returning adults under each oil spill scenario relative to baseline.

We present our process in the sections that follow but further details on life history parameters used in the analysis can be found within Appendix A and further the detailed technical report in Appendix B or at http://www.poissonconsulting.ca/f/1714378447.

3.2.1 Estimating Baseline Salmon Survival in the Area of Interest

3.2.1.1 Life Cycles

The life cycles of Chinook and Sockeye salmon can both be broken into six life stages (eggs, fry, smolt, sub-adult, pre-spawning adult, and spawning adult) which vary in their use of freshwater or marine habitats (Quinn 2018). As noted in Section 2.3, spawning adults deposit eggs in stream gravels which incubate over winter before emerging as fry in the spring. In their first spring, emerging fry migrate downstream to their rearing habitats (streams in the case of Chinook and lakes in the case of Sockeye) to grow and develop into smolts. Smolts subsequently migrate downstream to the sea in the following spring. After three years at sea in the case of Chinook and two years in the case of Sockeye, sub-adults begin returning to the BC coast as pre-spawning adults and begin the spawning migration as spawning adults upstream to their natal freshwater streams to deposit their eggs in the stream gravels. Given the number of eggs each female deposits and the carrying capacity of the streams, the abundance of the remaining life stages is defined by the survival rates from one stage to the next. These lifecycle parameters are defined in Table A1and a discussion of the density dependent relationships for the life cycles can be found in Appendix A.

North Thompson Chinook

Chinook in the North Thompson typically express a stream-type life cycle. Adult Chinook in the Blue, Finn, and Raft Rivers migrate upstream in the spring, while the remaining populations in the North Thompson migrate upstream in the summer. Adult female Chinook average 6,184 eggs in the North Thompson but not all females expend their eggs before senescence (i.e. deterioration) and mortality (Scott et al. 1982c). Female spawning success (i.e., percent eggs retained per female) is ~2.2% in the mainstem North Thompson and ~15% in tributaries (e.g., Raft River and Finn Creek). While Joseph and Lemieux Creeks had juvenile sampling done in early studies (Scott et al. 1982c), they were not included in our quantitative analyses because we lacked adult monitoring for these tributaries to contrast findings.

Adult Chinook spawn throughout the North Thompson with the largest habitat in the mainstem North Thompson; however, there are also productive and high-density tributaries such as Finn Creek (Table 7 below, as well as Table A2 in Appendix A). Eggs incubate over the winter and develop into fry that emerge in the spring. Egg-fry survival is highest in Finn Creek, Raft River, and Clearwater River (14-69%) with reduced survival in the North Thompson, Barriere River, Lemieux Creek, and Joseph Creek (Table 7).

Table 7 Chinook Salmon adult abundance (N), fecundity, egg deposition, fry population estimates, and egg-to-fry survival in the North Thompson watershed.

Site	Adult N	Fecundity	Eggs (Million)	Fry estimate	% Survival
Finn Creek	550-1025	6225	1.8-2.2	810,000	37-69
Raft River	200-405	5837	.5-1.2	150,000	14-28
Clearwater River	3000	6184	9.3	2,900,000	32
Joseph Creek	-	6184	-	20,000	-
Lemieux Creek	15	6184	0.05	1,600	3
Barriere River	100	6184	0.3	7,100	2
North Thompson	2250-4000	6490	7.3-13	1,200,000	9-18

Chinook fry emerge from their natal streams in the late spring and migrate into rearing streams and rivers (Table A3 and A4 in Appendix A). Some fry migrate downstream of the Area of Interest while others will rear in the mainstem North Thompson (Table A5 in Appendix A). Peak fry migration tends to occur later in the season, further downstream in the North Thompson watershed, likely tracking water temperatures (Scott et al. 1982a). Key tributaries like Finn Creek, Raft Rivers, and Clearwater Rivers tend to produce relatively large fry cohorts (0.15-2.9 Million) owing to high incubation, survival, or growth in early life (Scott et al. 1982b; Stewart et al. 1983). Joseph and Lemieux Creeks and Barriere River tend to produce small fry cohorts due to poor incubation, survival or growing conditions.

Most fry and smolts produced within the North Thompson watershed rear downstream of the Kamloops Lake area (Stewart et al. 1983). Sampling from the early 1980s estimated ~18% of fry cohorts and ~1% of smolt cohorts were rearing within the mainstem North Thompson suggesting large downstream migration from the portion of the watershed likely to be directly impacted by TMX (Scott et al. 1982a; Stewart et al. 1983). However, this data is from some highly variable sampling in high-flow conditions suggesting the estimate of ~18% is on the lower range. Most fry rearing within the North Thompson watershed rear within the mainstem North Thompson and not tributaries (Table A5 in Appendix A).

Fry rear for one year in their rearing stream or rivers before developing into smolts and outmigrating towards the Pacific Ocean. The average fry-smolt survival is ~37% (Bradford 1995). Chinook smolts migrate from their rearing streams and rivers into the Fraser estuary and reside for 30 days. Smolt outmigration takes 10 days. In tributaries, smolt outmigration begins in mid-April and ends in early May; smolts in the mainstem North Thompson begin outmigrating in late April and end in mid July (Table A6 in Appendix A).

Variation in smolt outmigration timing may be linked to body sizes (Table A7 in Appendix A). For example, smolts in Lemieux Creek appear to leave earliest at the smallest body sizes suggesting poor fry-smolt rearing and better foraging conditions in the mainstem North Thompson or Fraser estuary.

Juvenile/sub-adult Chinook spend three years at sea before beginning migrations to their natal stream. Marine survival for Chinook Salmon, i.e., survival from smolts to pre-spawning adults, can vary from year-to-year with an average coefficient of variation of ~12.5% (Bradford 1995). Together with on-route mortality, this suggests that smolt-to-spawning adult survival for Chinook typically ranges 0.6–2.1% consistent with observations in Duffy and Beauchamp (2011). Spawning adults begin arriving in their natal streams from July to August, depending on the population (Table A8 in Appendix A). Spawning occurs a few days after peak arrival beginning in early August and ends by early October and post-spawn die-off occurs ~7-14 days later.

North Thompson Sockeye

Sockeye Salmon in the North Thompson watershed have a simpler life history and spatial structure than Chinook. Spawning habitat is predominately the mainstem North Thompson, Finn Creek, and Raft River (rearing in Kamloops Lake) and Fennell and Harper Creeks (rearing in Barriere Lake). As such, Sockeye in the North Thompson watershed are composed of two Early Summer (ES) CUs: (1) North Barriere-ES (*de novo*) and (2) Kamloops-ES (composed of Raft River and miscellaneous North Thompson) (Grant et al. 2011, 2018). Of the Kamloops-ES CU, Sockeye from the Raft River composes ~35-60% of the total escapement, miscellaneous tributaries ~5%, and the rest coming from the mainstem North Thompson. The total spawner abundance for miscellaneous tributaries of the North Thompson approximated 7,000 returning adults in 2018 (DFO 2018a). The majority of North Thompson sockeye exhibit a four-year life cycle (termed a 4_2 life cycle where lake-rearing Sockeye outmigrate to the sea in their second year). Age structure of returning adults in the Kamloops-ES are 71% four year olds and 29% five year olds (DFO 2018a). Age structure of returning adults in the North Barriere-ES are 80% four year olds and 20% five year olds (DFO 2018a). Marine survival for Sockeye salmon, i.e., survival from smolts to pre-spawning adults, can vary exhibit more year-to-year variability than Chinook an average coefficient of variation of ~78% (Bradford 1995). Together with on-route mortality, this suggests Sockeye smolt-adult survival can range 1.5-24%. Sockeye adults return to the North Thompson watershed beginning in mid-August and early-September (Table A9 in Appendix A).

Fry emergence begins in early April with migration to Kamloops Lake (Table A10 in Appendix A). Sockeye fry from the Fennell and Harper Creek populations rear in Barriere Lake. Sockeye fry rear in Kamloops Lake for approximately one year before migrating to the Fraser estuary as smolts. Smolt migration begins ~April 10th, peaks ~April 28th and ends by May 28th (Welch et al. 2009). The outmigration lasts 5 days and sockeye spend ~30 days in the estuary (DFO 2016). Sockeye juveniles and subadults spend ~2 years at sea before migrating to their natal streams for spawning in early summer. On route mortality is ~35-40% for returning adults (Bradford 1995; Martins et al. 2011).

These baseline vital rates for Chinook and Sockeye were included in the next step of our analysis, where we examined how these survival rates might change under hypothetical spill scenarios (Sockeye vital rates are in Table A11 in Appendix A).

3.2.2 Estimating Salmon Survival Under Hypothetical Spill Scenarios

Impacts from the spill scenarios were translated into changes in fish survival across the Chinook and Sockeye life cycle for the mainstem North Thompson and tributary populations. The following impacts to survival are based on a literature review (Table 1 in Section 2.7.2) under scenarios of the maximum concentration of a spill releasing 4,000 m^3 in a short time period (1 hr) and the spatial variation in demography and habitat usage between the mainstem and tributaries. All impacts to fry survival were assumed to occur after density dependent egg-to-fry survival. Below we describe mortality rates for the life stages present during these three spill scenario timings based on the current knowledge of toxicity effects to salmon:

- Spills during the **Freshet scenario** would occur when young salmon are smallest and the most vulnerable in their development. Freshet spills could affect fry-to-smolt survival for those fry rearing in the mainstem North Thompson River and Kamloops Lake. Based on our synthesis of research (Table 1 in Section 2.7.2), assumptions on impacts were that Freshet spills would increase mortality by 10.5% for the egg-to-fry stage (a lower range of mortality caused by the short duration) and 29.5% for the fry-to-smolt stage (Alderman et al. 2018; Lin et al. 2019). Sublethal effects of cohorts exposed to diluted bitumen was included as a 6.5% reduction to adult fecundity (Heintz et al. 2000).
- Spills during the **Fall scenario** would occur during moderate flow and would impact returning adults, eggs from that brood year, and rearing fry or smolts from previous brood years for populations in the mainstem North Thompson River. Fall spills would not affect fry or smolts that reared outside of this area (~82% of fry cohorts may rear outside the impacted area; Table A5 in Appendix A) or eggs spawned in the tributaries. Based on our synthesis of research (Table 1 in Section 2.7.2), assumptions, on impacts were that Fall spills would increase mortality by 36% for the egg-to-fry stage (a moderate mortality impact from longer duration), 29.5% for the fry-to-smolt stage (Alderman et al. 2018; Lin et al. 2019), and 15% for returning adults (Heintz et al. 2000). sublethal effects of cohorts exposed to diluted bitumen was included as a 6.5% reduction to adult fecundity (Heintz et al. 2000).
- Spills during the **Winter scenario** would occur during lowest flow and under ice. Winter spills would affect all eggs from that brood year and any rearing fry in the mainstem North Thompson from previous brood years. Winter spills would particularly affect sockeye cohorts rearing in Kamloops Lake. Based on our synthesis of research (Table 1 in Section 2.7.2), assumptions, on impacts were that Winter spills would increase mortality by 43% for the egg-to-fry stage (the highest impact) and 29.5% for the fry-to-smolt stage (Alderman et al. 2018; Lin et al. 2019). Sublethal effects of cohorts exposed to Winter diluted bitumen spills was included as a 33% reduction to adult fecundity – a higher non-lethal impact than the other two scenarios (Heintz et al. 2000).

The above described mortality estimates from toxicity effects due to exposure to oil on different salmon life stages (based on literature review outlined in Table 1 in Section 2.7.2), were used to estimate changes on the average survival and fecundity of Chinook and Sockeye salmon life stages for each hypothetical spill scenario (Table 8).

Table 8. Average survival and fecundity (number of eggs) of North Thompson Chinook and Sockeye salmon across life stages (egg, fry, smolt, pre-spawning adult, spawning adult) and plausible effects of diluted bitumen spills at highest concentration to survival and fecundity of exposed cohorts. Note - specific Conservation Units can vary in their own vital rates, and the sub-adult life stage is merged with pre-spawning adults. On-route survival between pre-spawning and spawning adult assumes water temperatures ≤16°C.

Stage	Chinook				Sockeye			
	Baseline survival (%)	Survival after spill (%)			Baseline survival (%)	Survival after spill (%)		
		Freshet	Fall	Winter		Freshet	Fall	Winter
Eggs-Smolt[1,2]	7.7	-	-	-	2.1	-	-	-
Eggs-Fry[1-4]	21.0	18.8	13.4	11.2	9.3	8.3	5.9	5.3
Fry-Smolt[1-4]	36.7	25.8	25.8	25.8	21.9	15.4	15.4	15.4
Smolt-Adult[1,2]	1.4	-	-	-	6.2	-	-	-
Smolt-Pre-spawning Adult[1,2]	2.7	-	-	-	9.5	-	-	-
Pre-spawning Adult-Adult[1,5-7]	52.2	-	46.5	-	65.1	-	58.3	-
Stage	**Baseline fecundity (eggs)**	**Fecundity after spill (eggs)**			**Baseline fecundity (eggs)**	**Fecundity after spill (eggs)**		
		Freshet	**Fall**	**Winter**		**Freshet**	**Fall**	**Winter**
Fecundity[1,2,5]	6490	6068	6068	4348	3500	3272	3272	2345

[1]Bradford (1995);[2]Bradford et al. (2009);[3]Alderman et al. (2018);[4]Lin et al. (2019);[5]Heintz et al. (2000);[6]Keefer et al. (2010);[7]Martins et al. (2011)

Table 8 represents the percent survival of each life stage under current or baseline conditions, compared to after a spill for each of the different spill timings. For example, for the Chinook fry to smolt stage, generally 37% of individuals would survive during a non-spill year. If a spill were to occur during the winter, this would lead to a 29.5% reduction in fry-to-smolt survival such that only ~26% of fry survive and develop into smolts.

3.2.3 Risks of Hypothetical Spills to Salmon in the Shuswap Complex

Sockeye and Chinook in the North Thompson are mostly unconnected from the Adams Lake and Shuswap complexes. North Thompson Chinook have similar genetic structure to Upper Fraser River Chinook whereas the Adams Lake run is genetically similar to the Columbia River run. With very few exceptions, North Thompson Sockeye adults run in the ES CUs and rear in Kamloops Lake whereas the Adams Lake and Shuswap CUs have the Fall run timing and rear in Adams or Shuswap Lakes. This suggests that movement and migration between the watersheds and potential vulnerable areas if an oil spill occurs is low.

We considered that the spill scenarios evaluated here would not present a large risk to the Shuswap complex. Given the Fraser watershed and TMX infrastructure, a cohort of Shuswap Sockeye could be directly vulnerable to a diluted bitumen spill in the following scenarios:

1. as smolts when they outmigrate through Kamloops Lake via the South Thompson river.
2. as smolts during their outmigration when the TMX pipeline follows the Fraser River again near Hope, BC
3. as smolts at the conclusion of their outmigration when they reach the Fraser estuary
4. as returning adults when they reach the estuary
5. as returning adults in the Fraser River from river mouth to Hope, BC
6. as returning adults as they pass through Kamloops Lake on the way to Shuswap via the South Thompson river

The worst-case scenario spill proposed was the 4,000 m^3 spill during the low-flow winter period that reaches Kamloops Lake. Shuswap Sockeye would pass through this impact zone 3-5 months later during their outmigration in the spring and summer as larger-bodied smolts or their upstream migration as spawning adults in the Fall. We speculate that larger smolts swimming through the vulnerable areas of Kamloops Lake would pass through the area in ~24-48 hours, given the smolt outmigration lasts ~10 days from rearing lake to estuary. With such a low residence time in Kamloops Lake, and the delay from our spill scenario, the risk to Shuswap Sockeye appears low. Some osmoregulatory disturbances could occur in a 24-48h exposure scenario but only at higher concentrations (~100 ug/L TPAH), which appears unlikely 3-5 months after a spill (Lin et al. 2019). We suspect that fish impaired by passing through Kamloops Lake would quickly recover osmoregulation once they reach uncontaminated water. Shuswap Sockeye might be indirectly exposed to a North Thompson spill if there is broad-scale groundwater contamination or ecosystem-wide effects like a reduced aquatic invertebrate community, but we did not consider these broader impacts.

Shuswap Sockeye could be exposed during the Freshet spill scenario, as this would correspond to smolts outmigrating. Direct mortality impacts from high-concentration and short-term exposure varies from ~3-100%, but larger bodied fish tend to be more robust so that lower concentrations have reduced impacts to survival. As Freshet spills occur during high river flows and have relatively low concentrations, the short-term exposure of Shuswap Sockeye migrating through the area from short-term exposure is unlikely to lead to large impacts to their survival.

3.2.4 Estimating the Spatial Coverage of Impacts to Salmon

The North Thompson watershed is a U-shaped glacial valley that meanders from above the Blue River to Kamloops Lake. The mainstem river expresses the total flow of water through the valley, which includes groundwater. Diluted bitumen spills in the mainstem North Thompson may contaminate surface and groundwaters critical to egg incubation for Chinook, Sockeye, and Coho populations in the North Thompson except for tributaries like Barriere, Clearwater, Lemieux, and Raft Rivers and the mainstem North Thompson upstream of the Albreda confluence. Diluted bitumen spills that reach Kamloops Lake may impact lake-rearing fry for all Sockeye populations except for populations from Fennell and Harper Creeks, which rear in Barriere Lake. Currently, there is uncertainty on whether Chinook fry or smolts use Kamloops Lake other than as a migration corridor. For these reasons, the spill scenarios were hypothesized to directly affect salmon in the mainstem North Thompson River and only indirectly affect the salmon from the tributaries depending on the timing of the spill, timing of their migrations, and habitat use of the mainstem and Kamloops Lake

Sockeye and Chinook salmon populations could use the vulnerable areas of the North Thompson watershed in different ways (Figure 8 and 9). Sockeye salmon populations were represented, for our purposes, in three groupings:

1) Tributary populations were defined as Sockeye populations where adults spawn in tributaries to the North Thompson River, but fry rear in Kamloops Lake (as part of the North Thompson Conservation Unit). These populations spend some of their life cycle in the vulnerable portions of the watershed.
2) Mainstem populations were defined as sockeye populations that spawn in the mainstem North Thompson River and fry rear in Kamloops Lake (as part of the North Thompson Conservation Unit). These populations spend much of their life cycle in the vulnerable portions of the watershed.
3) The last grouping were populations of the Barriere Conservation Unit where adults still pass through the mainstem North Thompson River on their way to spawning in the Barriere River, and fry rear in Barriere Lake. Only migrating spawning adults or downstream migrating smolts from these populations spend any time in the vulnerable portions of the watershed.

Chinook salmon populations were grouped in two ways:

1) the mainstem North Thompson River population where adult Chinook spawn in the mainstem river and fry also rear in the mainstem. These populations spend much of their life cycle in the vulnerable portions of the watershed.
2) Six tributary populations (Louis Creek, Finn Creek, Barriere River, Clearwater River, Mahood River, and Raft River) where adults pass through the North Thompson River on their way to spawn in their natal tributaries. These populations spend some of their life cycle in the vulnerable portions of the watershed.

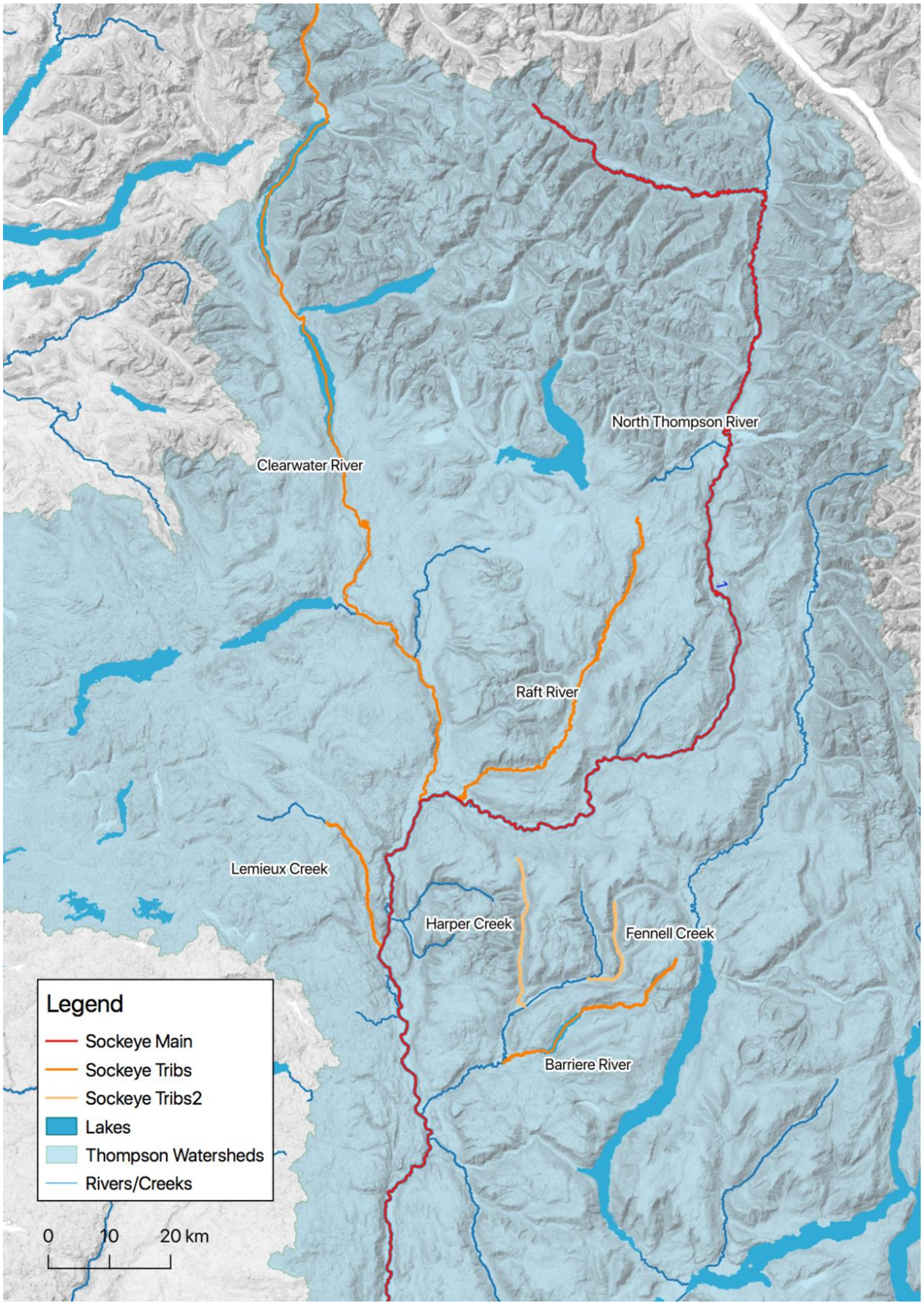

Figure 8. Sockeye salmon populations could use the vulnerable areas of the North Thompson watershed in different ways. To address this complexity in their lifecycle, we grouped Sockeye salmon based on their use of the watershed (mainstem of the river compared to two grouping types for tributaries.

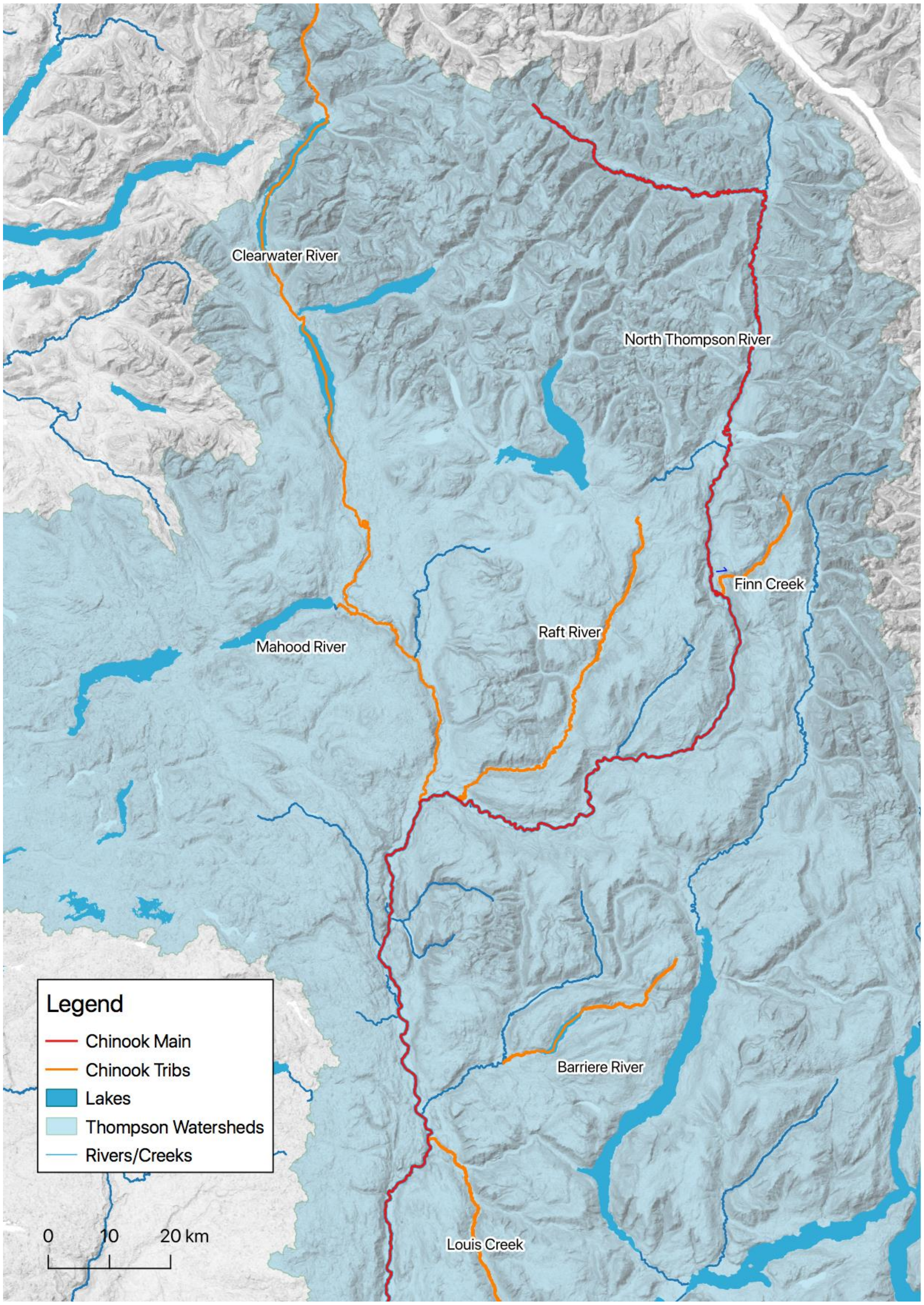

Figure 9. Chinook salmon populations could use the vulnerable areas of the North Thompson watershed in different ways. To address this complexity in their lifecycle, we grouped Chinook salmon based on their use of the watershed (mainstem of the river compared to two grouping types for tributaries.

3.2.5 Site-level impacts within the North Thompson Watershed

In Table 8 (section 3.2.2), we present how each of the seasonal scenarios were likely to impact baseline survival for any salmon directly exposed to the contaminants from a 4,000 m^3 spill. We now need to understand, how much of the population from each of the above spatial groupings (e.g., populations of the tributary, mainstem, and Barriere CU groupings (Figures 8 and 9) might be exposed to that impact because each of the spill scenarios were presumed to impact the life cycle of these groupings in different ways (Figures 10 and 11, Table A12 in Appendix A). We compiled this initial assessment of the likely spatial coverage of impacts across the Chinook and Sockeye life cycle using the timing of fry, smolt, and spawning migrations and usage of the North Thompson watershed.

Lethal impacts in fry-to-smolt survival varied by season and species. Sockeye fry-to-smolt survival was reduced for 100% of fry that reared in Kamloops Lake across all scenarios ('Main' and 'Tribs' groupings in Figures 8 and 11). However, fry-to-smolt survival for the Barriere CU were presumed to experience 20% of this impact in the Freshet spill scenario due to limited direct exposure passing through Kamloops Lake during their outmigration – this impact would be 0% for all other scenarios as they would be outside of the vulnerable area of the watershed ('Tribs2' groups in Figures 8 and 11). Chinook fry-to-smolt survival was reduced for only 20% for the tributary populations to the North Thompson as most smolts appear to rear downstream of the vulnerable area, and 80% for the mainstem population as many fry were presumed to already be settled into their rearing habitat within the mainstem (Figures 9 and 10).

Impacts to on-route adults only occurred in the Fall spill scenario as sub-adult and adult life stages were otherwise in the Pacific Ocean. The spatial coverage of impacts to Sockeye onroute spawning mortality covered 100% of the adults spawning in the mainstem North Thompson, and 50% for any tributary populations (including the Barriere CU) due to limited direct exposure of a Fall spill for adults onroute during spawning migrations. Impacts to Chinook onroute spawning mortality covered 100% of adults spawning in the mainstem North Thompson and 50% of adults spawning in the tributary due to limited exposure as returning adults still pass through the mainstem on their way to the tributary (Figures 9 and 10).

Spatial coverage of impacts to egg-to-fry survival varied by species, season, and between the mainstem and tributary populations. For Fall and Winter spill scenarios, we assumed that 100% of the impact to egg-to-fry survival for Chinook (Figures 9 and 10) and Sockeye (Figures 8 and 11) spawned in from the mainstem North Thompson River. This impact is reduced to 0% for the Freshet scenario as fry have already emerged to begin their migration into their rearing habitats (this emerging cohort could be vulnerable to a fry-to-smolt impact). For all scenarios, there is 0% impact to egg-to-fry survival from the tributary populations for both species as they would be rearing in their natal streams outside the impacted area prior to fry migration (Figures 10 and 11).

The sublethal impact of reduced fecundity as a result of diluted bitumen exposure was presumed to affect 100% of returning adult Sockeye that reared in Kamloops Lake as fry and 0% of adults from Barriere CU (Figures 8 and 11). For Chinook, sublethal impacts were presumed to affect 100% of returning adults from the mainstem but only 20% of returning adults from the tributaries as exposure would be more limited as developing fry from the tributaries reared outside the affected area and only migrated through the area during a limited period of time (Figures 9 and 10).

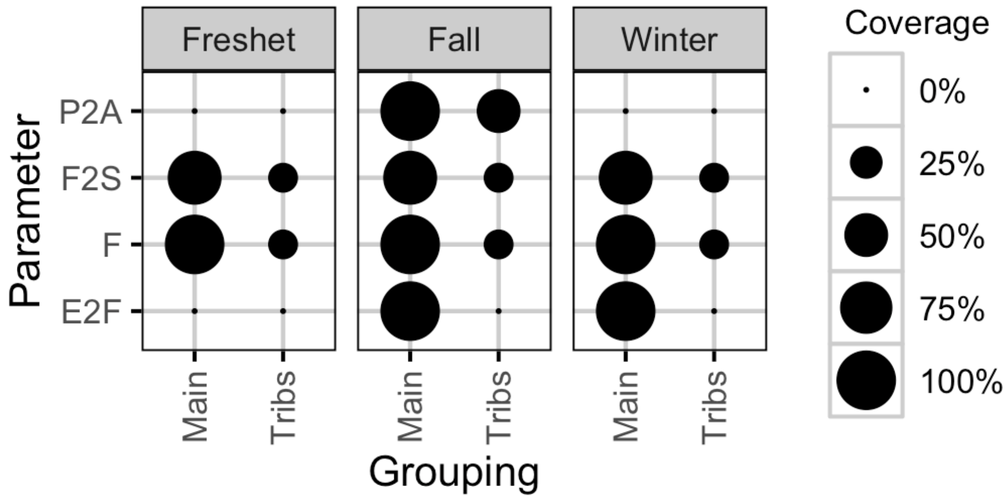

Figure 10. The assumed spill coverage for Chinook by scenario, life history parameter and grouping by watershed origin. Life cycle parameters on the x axis represent transitions between life stages which includes pre-spawning adult to spawning adult (P2A), fry to smolt (F2S), sublethal impacts to future fecundity for exposed cohorts (F, number of eggs a female will lay) and egg to fry (E2F) (Table A1 in Appendix A).

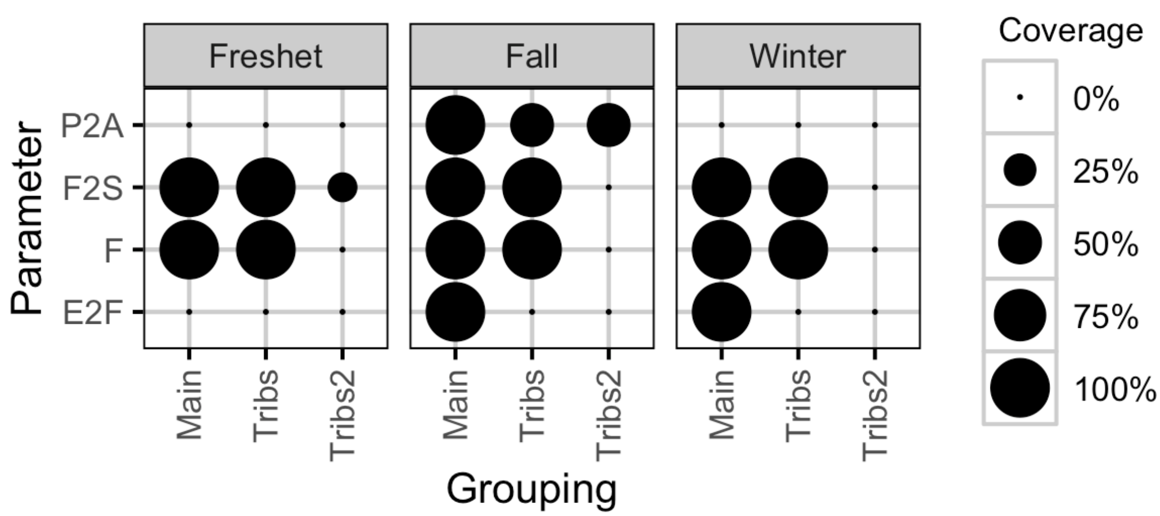

Figure 11. The assumed spill coverage for Sockeye by scenario, life history parameter and grouping by watershed origin. Life cycle parameters on the x axis represent transitions between life stages which includes pre-spawning adult to spawning adult (P2A), fry to smolt (F2S), sublethal impacts to future fecundity for exposed cohorts (F, number of eggs a female will lay) and egg to fry (E2F) (Table A1 in Appendix A).

3.2.6 Results: What are the Impacts on Adult Salmon Returns?

In general, a large spill from TMX could lead to as much as 71% and 73% fewer returning adult Chinook and Sockeye, respectively, to the North Thompson (based on assumptions and knowledge from the literature review) (Figures 12 and 13). Impacts to freshwater survival were modelled to lead to fewer adult salmon to support both population resilience and fishery resources. The extent of these impacts varied spatially as tributaries tended to have much lower declines than salmon in the mainstem North Thompson where impacts were strongest. Sockeye may experience a larger decline than Chinook owing to their usage of Kamloops Lake, an area that may absorb much of the contaminants from a TMX spill. Conversely, our literature review suggested that Chinook Salmon were identified to use much less of the vulnerable area of the North Thompson watershed. Winter spills were identified as likely having the strongest impacts to salmon as both egg and fry cohorts were still using the watershed, and Sockeye would be concentrated within Kamloops Lake (having migrated into the lake during the late Spring from their natal streams and rivers).

Given our hypothetical scenarios, Tables 9 and 10 represent the degree of mortality of returning adults we would see following a spill either during freshet, fall or winter in either of the main stem of the North Thompson or its tributaries. For Indigenous, commercial, and recreational fisheries that rely upon the returning adult salmon from these areas, this may mean they see 71% fewer Chinook salmon (from 1,921 adults currently to 557 adults after the worst impact; Figure 12) and 73% fewer Sockeye salmon available for harvest (from 8,992 Sockeye adults currently to 2,427 after the worst impact; Figure 13). There would likely be spatial variation in these declines across the watershed, and fishing communities that rely upon tributary or other Conservation Units may not see as large of an impact to their returning salmon as those fishing on the mainstem North Thompson River.

Table 9. The Chinook fry carrying capacity (K), number of returning adults at currently fished equilibrium (Eq) and total impact as the additional mortality (M) by scenario and grouping (given the assumed life-history parameters, impacts and coverage).

Species	Scenario	Grouping	K	Eq	M
Chinook	Fall	Main	520475.0	1921.740	0.6113990
Chinook	Fall	Tribs	662442.9	2567.351	0.1408905
Chinook	Freshet	Main	520475.0	1921.740	0.2856600
Chinook	Freshet	Tribs	662442.9	2567.351	0.0712330
Chinook	Winter	Main	520475.0	1921.740	0.7082284
Chinook	Winter	Tribs	662442.9	2567.351	0.1211060

Table 10. The Sockeye fry carrying capacity (K) number of returning adults at currently fished equilibrium (Eq) and total impact as the mortality (M) by system and scenario (given the assumed life-history parameters, impacts and coverage).

Species	Scenario	Grouping	K	Eq	M
Sockeye	Fall	Main	1108127.7	8991.669	0.6414088
Sockeye	Fall	Tribs	1038896.2	8429.904	0.3902631
Sockeye	Fall	Tribs2	641775.4	5207.551	0.0750000
Sockeye	Freshet	Main	1108127.7	8991.669	0.3408250
Sockeye	Freshet	Tribs	1038896.2	8429.904	0.3408250
Sockeye	Freshet	Tribs2	641775.4	5207.551	0.0590000
Sockeye	Winter	Main	1108127.7	8991.669	0.7307605
Sockeye	Winter	Tribs	1038896.2	8429.904	0.5276500
Sockeye	Winter	Tribs2	641775.4	5207.551	0.0000000

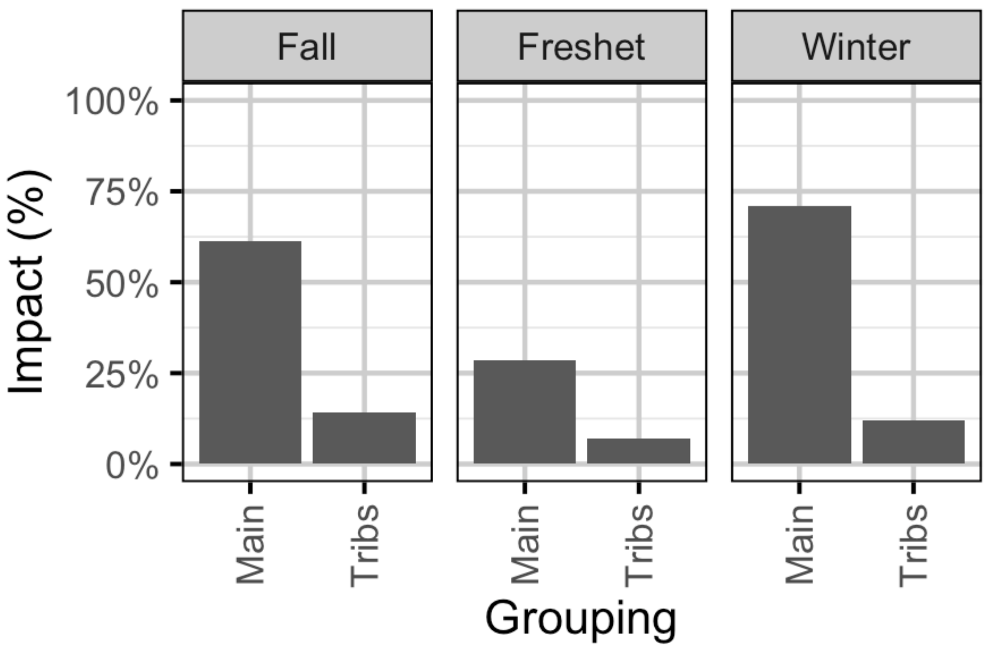

Figure 12. The total impact as the % reduction in returning adult abundance for Chinook by scenario and grouping (given the assumed life-history parameters, impacts and coverage).

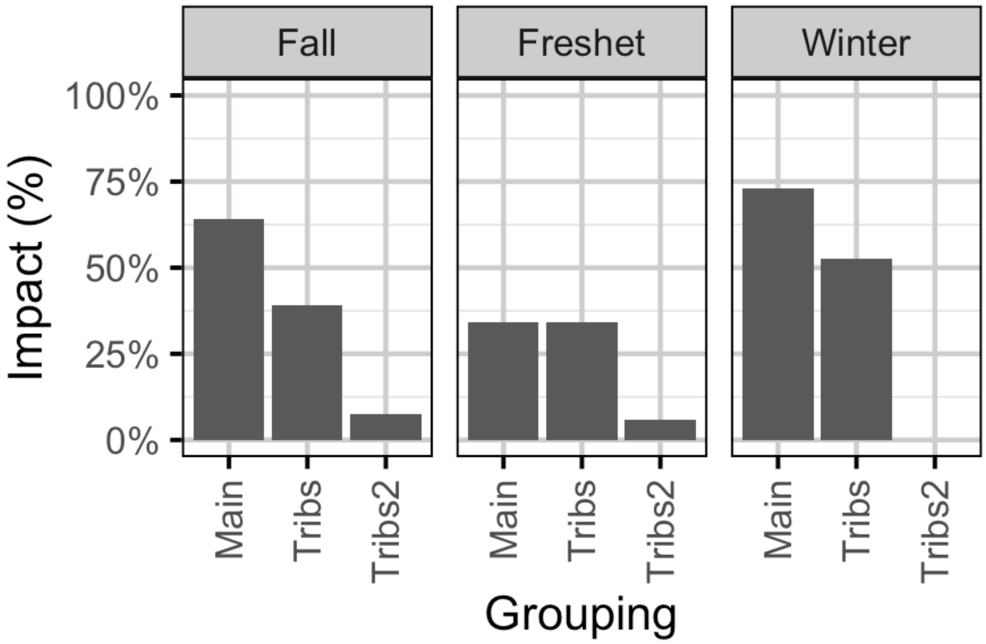

Figure 13. The total impact as the % reduction in returning adult abundance for Sockeye by scenario and grouping (given the assumed life-history parameters, impacts and coverage).

The calculation of total reduced percentage in returning adults was used in the power analysis. The worst-case scenario represented as the highest percentages in Figures 12 and 13 were used to determine whether the existing DFO data would be scientifically rigorous to detect these same changes in returning adults.

3.3 Power Analysis Estimating Impacts on North Thompson Salmon

Research Objective: *Using the available DFO data on numbers of returning adults, how precisely would we be able to quantify such an impact on the number of returning Chinook and Sockeye salmon adults?*

3.3.1 Power Analysis Model

In order to estimate the reliability with which we could quantify the impact of an actual spill on North Thompson salmon, we analysed a DFO dataset of annual returning adult numbers at specific sites using a statistical model. The model estimates the change in the subsequent recruitment (of spawning adults) from the number of spawning adults in a given year. It takes into account long-term Fraser Basin wide trends in the recruitment rate, as well as, Basin wide and conservation unit specific annual variation. In other words, our model accounted for the spatial complexity of salmon within the North Thompson by controlling for long and short-term broad-scale effects across the entire Fraser Basin (e.g., ocean productivity or commercial fisheries harvest that could be expected to affect all salmon in the Fraser Basin) before quantifying regional effects common to species' Conservation Units, and then localized effects at the spawning site within those CUs.

The DFO data represent counts of salmon escapement at specific sites. During data preparation, sites with less than 10 counts, more than 50% zero counts or an average of less than 100 returning adults were excluded. To avoid numerical problems, individual counts of less than 10 returning adults or less than 1 recruit (returning adult) were excluded from the analysis. The site-level returning adult counts are plotted by year and conservation unit below for Chinook and Sockeye in the Fraser Basin. As a reminder, we considered all data from the Fraser Basin in order to control for long and short-term broad-scale effects across all CUs. In the power analysis, we are trying to detect trends in a specific river in a watershed so we need to account for the natural variability at each of these spatial scales. Figures 14 and 15 below show just how much variability exists in returning adult numbers at different locations in the watershed from one year to the next.

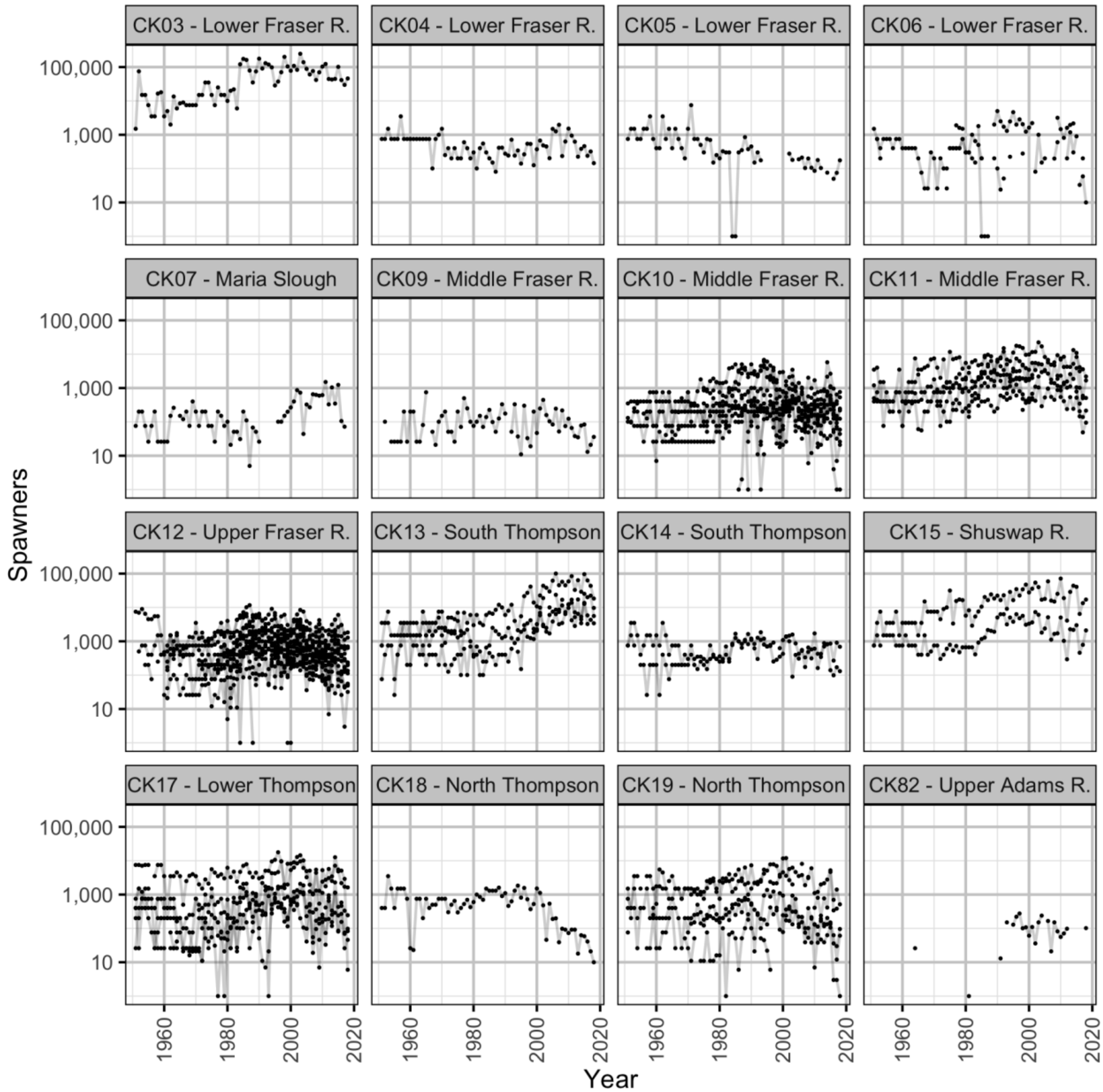

Figure 14. The site-level spawner counts (plotted on a logarithmic scale) by spawner year and conservation unit for Chinook salmon.

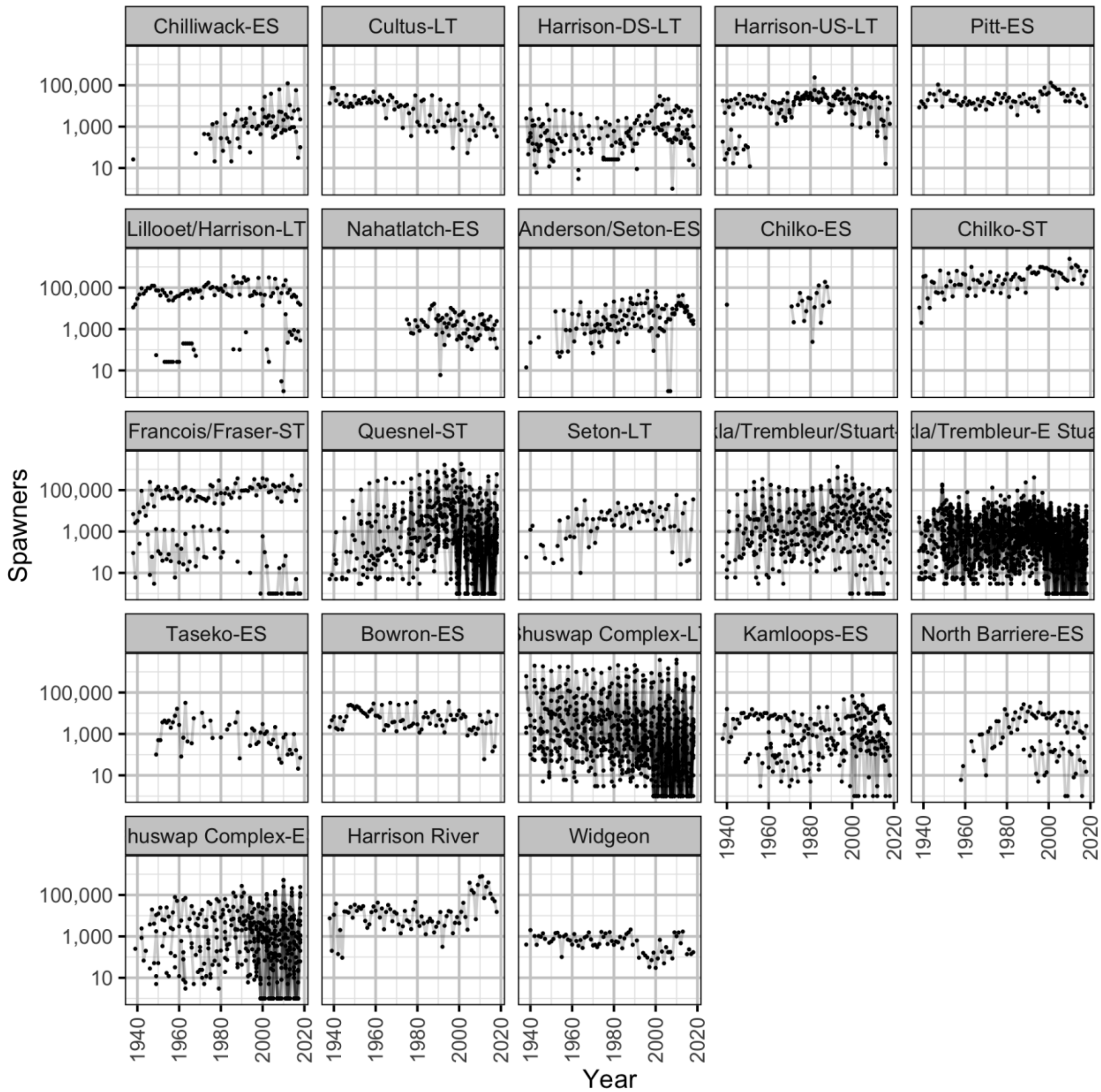

Figure 15. The site-level spawner counts (plotted on a logarithmic scale) by spawn year and conservation unit for Sockeye salmon.

3.3.2 Long-term Trends in the Fraser Basin

The empirical model estimated that across the Fraser Basin, Chinook salmon declined in the 1950s, increased from 1960 to around 2000 and have been declining at an accelerating rate for the past 20 years (Figure 16). The same model estimated that Sockeye salmon have been in decline in the Fraser Basin for the past 30 years (Figure 17). The model accounted for these trends so that they would not affect the ability of the empirical model to detect an impact from our oil spill scenarios.

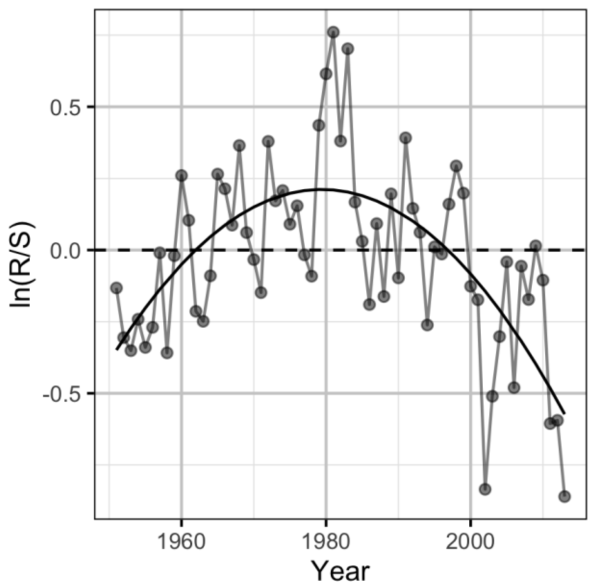

Figure 16. The estimated Chinook returning adults per recruit by year with annual variation in the Fraser Basin.

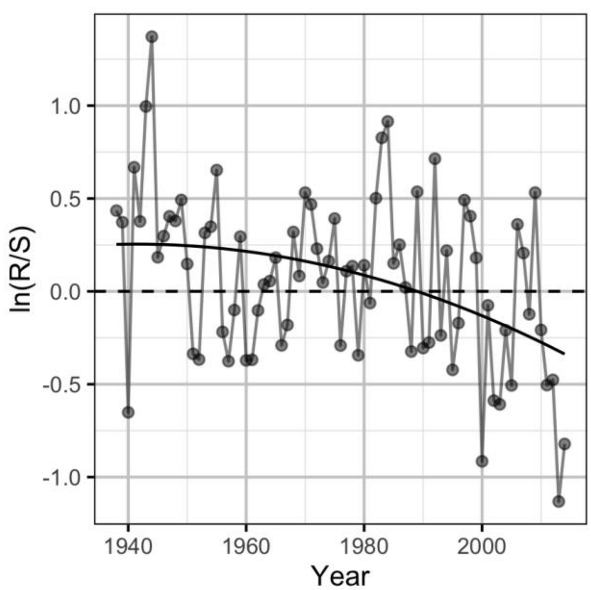

Figure 17. The estimated Sockeye returning adults per recruit by year with annual variation in the Fraser Basin.

3.3.3 Precision of Estimates

To determine the ability of the power analysis to quantify the impacts of a future oil spill, the model was refitted to the original data (Hoenig and Heisey 2001; Colegrave and Ruxton 2003) while estimating the size of the "impact" (in the absence of an actual impact) for each spawning year from 2000 onwards. Technically speaking, the model is attempting to determine how much of a divergence from the expected number of returning adults can be attributed to the natural variability in the data. For simplicity, the analysis assumed that the impact was as severe in the tributaries as the main stem of the North Thompson; affected a single cohort and that the effect on fecundity was not delayed. The 95% confidence interval for each year represents the range of impacts that can be attributed to the natural variability. The expectation was that the annual estimates of the "impact" in the absence of a known impact from 2000 onwards would all be close to zero.

Power measures the probability of detecting an actual impact. The impact (effect size) required to achieve 80% power ($\beta = 0.8$) with a significance level of 5% (α = 0.05) was calculated (Hoenig and Heisey 2001) from the average standard error ($\sigma_{\underline{x}}$) according to the equation $exp(\sigma_{\underline{x}} \cdot \Phi_{\alpha/2}^{-1} - \Phi_{\beta}^{-1}) - 1$ where Φ^{-1} is the normal quantile function. The lower 95% confidence limit indicates the effect size required to achieve 50% power with $\alpha = 0.05$.

3.3.4 Results: With the available data, how precisely can we detect oil spill impacts to salmon returns?

The results indicate that the adult return data is too variable within and between conservation units from one year to the next to reliably quantify the impacts of a large spill (Figure 18). The results also indicate that despite allowing for annual and intra-annual within unit random effects the model fails to adequately account for all of the sources of variation in the North Thompson. This additional variation further reduces the ability to quantify/detect the effects of an impact. Additional analyses should be undertaken in order to identify the source of this variation.

In the case of Chinook, based on the assumed impacts and coverage the largest impact would result in the number of returning adults to the mainstem North Thompson being reduced by 71%. The mortality under the same scenario would be 12% for the tributaries. However, even in the absence of an impact a reduction of 63% of Chinook adults cannot be excluded and 80% power would only be achieved with an impact of 84%. For Sockeye, based on the assumed impacts and coverage the largest impact would reduce the number of returning adults to the mainstem North Thompson by 73%. The mortality under the same scenario would be 53% for the immediate tributaries of the North Thompson and 6% for the tributaries of the North Barriere. However, even in the absence of an impact a reduction of 77% of Sockeye adults cannot be excluded, and 80% power is only achieved with an impact of 90%.

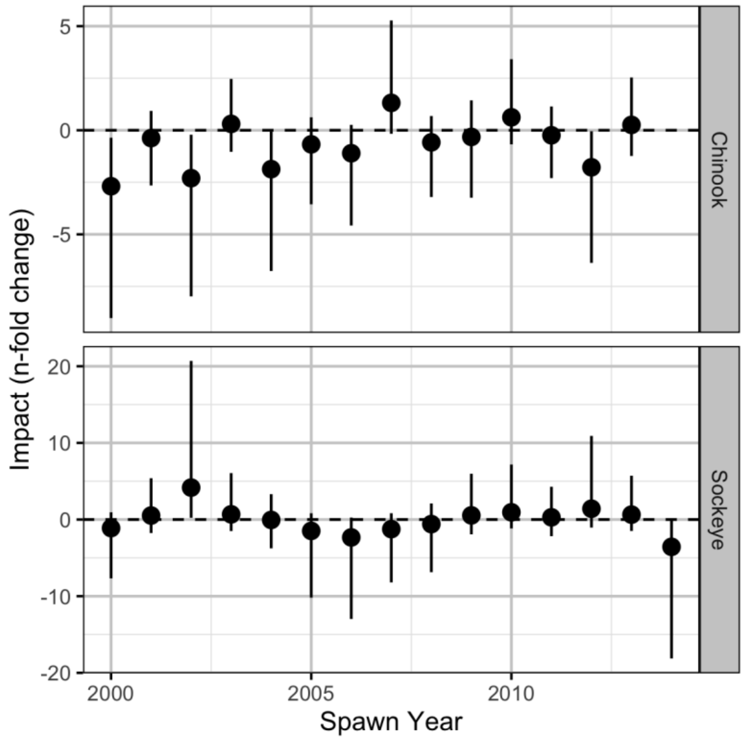

Figure 18. The estimated impact of a diluted bitumen spill by year (with 95% confidence intervals).

Our findings suggest that, in general, a worst-case (in terms of timing, location and spatial extent) spill from TMX could lead to 71% and 73% fewer adult Chinook and Sockeye, respectively, returning to the main stem North Thompson (based on assumptions and knowledge from the above literature review). However, due to inherent variability in the adult return data, the magnitude of the impact of even large spills cannot be reliably quantified and may not even be detectable.

4.0 Discussion and Conclusions

Our literature review, calculations and statistical analysis indicate that 1) there is uncertainty about the likely impact of a large oil spill on the number of returning adults; 2) the impact of an actual spill on the number of returning adults cannot be reliably estimated; and 3) the impact of a large spill cannot be reliably detected. To state in simpler terms: it is not possible to reliably estimate, measure or even detect the impact of a large oil spill on the numbers of North Thompson salmon. This is concerning from both a regulatory and compensatory perspective. It is concerning from a regulatory perspective because it is difficult to approve a project when the possible impacts are uncertain; and it is concerning from a compensatory perspective because the current environmental impact assessment framework assumes that if an impact cannot be detected then there is no impact. Yet as we demonstrate here, even a reduction in the number of returning salmon by over 80% after a large oil spill cannot be reliably detected and thus sizeable impacts to salmon and the environment could be easily dismissed

In order to ensure appropriate compensation for any spill, if a spill were to occur, it is recommended that adequate monitoring of diluted bitumen distribution, duration and concentrations be undertaken until the concentrations are below detection limits. This would provide an indication of the proportion of the salmon in the North Thompson that are likely to have been exposed. It is also recommended that the assumed mortality for given concentrations of constituents be pre-specified so that the impact can be quantified. The approach to calculating the likely impact of a specific scenario provides a general framework; however, the following uncertainties require full consideration in any compensatory and monitoring decisions (Table 3 Knowledge gaps in Section 2.9):

- There are infinite possible spill scenarios that include not only temporal and spatial variation, but a considerable range of environmental factors (e.g. flow, temperature, ice cover) that will ultimately drive the fate and behaviour of spilled diluted bitumen.
- The spill nature and volume, coupled with the fate and behaviour of diluted bitumen in the aquatic environment, determine the exposure dynamics that are relevant to fish toxicity (concentration and duration).
- The impacted zone may include any/all of the following: area covered by visible oil on the water surface, downstream of the limits of visible oil where dissolved contaminants may be present, regions of the watershed where bitumen sinks, and oiled shorelines that may reinject contaminants into the water system during high flows.
- Fish present in the impacted zone at the time of the spill can be exposed to contaminants from the spill. In addition, fish that will utilize habitat in the impacted zone in the future may also experience adverse effects related to contaminant exposure and habitat deterioration.
- The concentration and length of exposure, in addition to the species and life stages of fish exposed, will influence the suite of direct effects observed in the aftermath of a spill.
- There are innumerable indirect effects of a spill that could contribute to salmon population declines and broader ecological impacts.
- Discrete knowledge and baseline data for specific life cycle dynamics of the salmon sub-populations in the impacted zone may improve attempts to estimate/detect reduced salmon returns following a spill.

4.1 Monitoring and Future Research Recommendations

The following monitoring recommendations may help address the inadequacy of baseline data and some of the knowledge gaps previously identified (Table 11). These monitoring activities may be implemented by ALIB independently or in partnership with other Indigenous communities, by government agencies and/or the Project proponent

Table 11. Summary of monitoring and future research recommendations.

Monitoring Timeline	Monitoring compartment	Monitoring detail
Baseline	Water quality	More extensive and comprehensive monitoring of suspended sediments, water temperature, and existing contaminants of potential concern
	Hydrodynamics	Measure turbulence in river flows
	Benthic invertebrates	Establish a standardized benthic invertebrate monitoring program, for example the Canadian Aquatic Biomonitoring Network (CABIN) program which uses a reference model approach that can account for existing impacts
	Salmon	Measure spatial variation in juvenile productivity of mainstem and tributary populations in the watershed
	Salmon	Determine temporal distribution and natal origins of juvenile habitat usage within the watershed
	Salmon	Establish reference values for biomarkers of diluted bitumen exposure (e.g. cyp1a) for different species and life stages of salmon
	Impacts to other wildlife	Produce a more comprehensive synthesis of literature to characterize a food web of a freshwater ecosystem that is representative of an area meaningful to ALIB traditional use. Identify those species that are both highly connected or central to the food web and those that are unique to identify the relative trophic importance (e.g. McCann et al 2017).
	Impacts to other wildlife	Complete a literature synthesis to determine exposure pathways and oil sensitivities of each species in the food web.
	Impacts to other wildlife	Support research into identifying existing contaminant loads in the ecosystem. Some steps could be undertaken as part of a community-led monitoring program examining tissues, etc. from key wildlife and plant species to characterize baseline conditions of heavy metals and other constituents.
Post-spill	Water quality	Implement comprehensive and extensive monitoring as soon as possible following a spill of BTEX, PAHs
	Product spatial	Characterize location of floating and sunken oil in detail

	extent	and over time after the spill
	Benthic invertebrates	Continue previously established standardized benthic invertebrate monitoring program as soon as possible after a spill and over time
	Salmon	Determine spatial-temporal distribution, origin, and abundance of juvenile salmon within watershed, particularly of smallest life history stages most vulnerable to spill impacts
	Salmon	Monitor biomarker levels and compare to reference values in order to gauge spatial and temporal extent of spill impact
	Impacts to terrestrial wildlife	Monitor survival, fitness and health of rehabilitated wildlife following exposure to an oil spill. This can provide information as to oil spill impacts to these taxa and evaluate the effectiveness of recovery efforts for wildlife.
	Impacts to terrestrial wildlife	Establish long term monitoring of wildlife abundance, fitness and health following a spill for species from key taxa would inform how the food web responds and recovers from disturbances. Data should be transparent and made publicly available.

5.0 Literature Cited

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Appendix A: Salmon in the North Thompson Watershed

Life cycles

Table A1. Defining acronyms of lifecycle parameters used in the analysis.

Parameter	Description
F	Fecundity (eggs deposited by a female)
E2F	Egg to fry survival (at low density)
B	Density-dependence
F2S	Fry to smolt survival
S2P	Smolt to pre-spawning adult survival
P2A	Pre-spawning adult to spawning adult survival

Density Dependence Relationships for Life Cycles

The density-dependence was assumed to be described by an asymptotic Beverton-Holt relationship, where egg to fry survival decreases at higher densities due to increased competition for resources. Under the assumption of an equal sex ratio the relationship between the number of spawners (A) and the number of fry (F) can be described algebraically as follows:

$$F = \frac{G/2 \cdot EF2 \cdot A}{B \cdot A + 1}$$

It follows that the fry carrying capacity (K) is

$$K = \frac{EF2}{B}$$

the spawners at current equilibrium is

$$Eq = \frac{E2F \cdot \phi - 1}{B \cdot \phi} \cdot SpR$$

where SpR (spawners per recruit) is

$$SpR = F2S \cdot S2P \cdot P2A$$

and ϕ (the eggs per recruit) is

$$\phi = SpR \cdot G/2.$$

For the purposes of calculating the impact straying between streams was assumed to be zero.

North Thompson Chinook

Table A2 represents the assumed lifecycle parameters for Chinook life stages by system. The assumed parameters were used to calculate the number of returning adults without a spill scenario. The values were then then updated based on the coverages and mortality rates and used to recalculate the number of returning adults in the worse-case spill scenario.

Table A2. The assumed Chinook life-history parameter values in the absence of an oil spill by system. The parameters are defined in Table A1.

System	Parameter	Value
All	F	6.4900e+03
Louis Creek	E2F	2.0819e-01
Finn Creek	E2F	2.3954e-01
Barriere River	E2F	2.3954e-01
Clearwater River	E2F	2.3954e-01
Mahood River	E2F	2.3954e-01
North Thompson River	E2F	2.0819e-01
Raft River	E2F	2.3954e-01
Louis Creek	B	5.8000e-06
Finn Creek	B	2.0000e-06
Barriere River	B	5.0000e-06
Clearwater River	B	8.0000e-07
Mahood River	B	6.0000e-06
North Thompson River	B	4.0000e-07
Raft River	B	2.0000e-06
All	F2S	3.6700e-01
All	S2P	2.7000e-02
All	P2A	5.2200e-01

Table A3. Chinook spawner habitat area (100 m²) and adult densities (fish per 100 m²) in the North Thompson.

Site	Habitat area	Densities
Finn Creek	17.3	45
Raft River	23.7	11
North Thompson	2688.2	1.19

Table A4. Migration timing of Chinook Salmon fry in the North Thompson watershed.

Site	Year	Samples	Start	Peak	End
Finn Creek	1982	2426	22-Apr	01-May	14-May
Finn Creek	1981	19843	03-Apr	18-Apr	07-May
Raft River	1982	2066	07-Apr	16-May	02-Jun
Raft River	1981	1950	03-Apr	20-Apr	11-Jun
Clearwater River	1982	1490	08-Apr	22-May	02-Jun
Joseph Creek	1982	138	10-Apr	-	01-Jun
Lemieux Creek	1982	95	10-Apr	-	01-Jun
Barriere River	1982	75	10-Apr	-	01-Jun
North Thompson (at Barriere)	1982	651	17-Apr	12-Jul	-
North Thompson (at Little Fort)	1981	4287	03-Apr	02-May	21-May

Table A5. Chinook rearing habitat area (m²) and rearing fry densities (fish per m²) after downstream fry migration in the North Thompson (Stewart et al. 1983).

Site	Area	Fry Density	Rearing Cohort	Total Cohort	% Rearing
North Thompson	2,800,000	0.311	870,800	1,200,000	0.73
Raft River	250,000	0.005	1,250	150,000	0.01
Finn Creek	20,000	0.025	500	810,000	0.00
East Barriere River	25,000	0.000	0	7,100	0.00
North Barriere River	480,000	0.000	0	7,100	0.00
Lemieux Creek	100,000	0.000	0	1,600	0.00
McTaggert Creek	12,000	0.000	0	-	-
Dunn Creek	7,200	0.000	0	-	-
Joseph Creek	38,000	0.000	0	20,000	0.00
Clearwater River	1,200,000	0.044	52,800	2,900,000	0.02
Total	4,932,200	0.39	925,350	5095800	0.18

Table A6. Migration timing of Chinook salmon smolts age 1+ in the North Thompson.

Site	Year	Samples	Start	Peak	End
Finn Creek	1982	15	22-Apr	27-Apr	01-May
Finn Creek	1981	12	10-Apr	-	30-Aug
Raft River	1982	2	13-Apr	-	04-May
Raft River	1981	0	NA	-	NA
Clearwater River	1982	11	14-Apr	-	24-Jul
Joseph Creek	1982	1	20-Apr	-	-
Lemieux Creek	1982	82	NA	10-Apr	28-Apr
Barriere River	1982	3	22-Apr	-	-
North Thompson (at Barriere)	1982	57	27-Apr	15-May	22-Jul
North Thompson (at Little Fort)	1981	206	12-Apr	-	-

Table A7. Mean length of Chinook salmon smolts age 1+ in the North Thompson.

Site	Year	Samples	Length (mm)
Finn Creek	1982	9	93.3
Finn Creek	1981	12	84.2
Raft River	1982	3	71.3
Raft River	1981	0	-
Clearwater River	1982	9	77.7
Joseph Creek	1982	0	-
Lemieux Creek	1982	43	68.4
Barriere River	1982	3	79.3
North Thompson (at Barriere)	1982	99	77.6
North Thompson (at Little Fort)	1981	206	89.9

Table A8. Timing of spawning migration for North Thompson Chinook spawner in 1982.

Site	Phase	Start	Peak	End
Finn Creek	Migration	21-Jul	04-Aug	20-Aug
Raft River	Migration	13-Aug	02-Sep	13-Sep
North Thompson	Migration	22-Aug	09-Sep	24-Sep
Finn Creek	Spawning	24-Jul	08-Aug	24-Aug
Raft River	Spawning	23-Aug	05-Sep	19-Sep
North Thompson	Spawning	28-Aug	15-Sep	02-Oct
Finn Creek	Die-off	04-Aug	19-Aug	01-Sep
Raft River	Die-off	29-Aug	12-Sep	24-Sep
North Thompson	Die-off	02-Sep	24-Sep	10-Oct

North Thompson Sockeye

Table A9. Arrival of adult Sockeye in 1982.

Site	Start	End
Finn Creek	15-Aug	30-Aug
Raft River	25-Aug	10-Sep
North Thompson	15-Sep	15-Oct

Table A10. Migration timing of sockeye salmon fry age 0 in North Thompson.

Site	Year	Start	Peak	End
Raft River	1981	05-Apr	06-May	04-Jun
North Thompson (at Little Fort)	1981	05-Apr	03-May	03-Jun

Table A11 represents the assumed lifecycle parameters for Sockeye life stages by system. The assumed parameters were used to calculate the number of returning adults without a spill scenario. The values were then then updated based on the coverages and mortality rates and used to recalculate the number of returning adults in the worse-case spill scenario.

Table A11. The assumed Sockeye life-history parameter values in the absence of an oil spill by system. The parameters are defined in Table A1.

System	Parameter	Value
All	F	3.5000e+03
All	E2F	1.0524e-01
Barriere River	B	2.3000e-06
Clearwater River	B	1.5000e-06
Lemieux Creek	B	2.3000e-06
North Thompson River	B	1.0000e-07
Raft River	B	1.0000e-07
Fennell Creek	B	2.0000e-07
Harper Creek	B	7.6000e-06
All	F2S	2.1900e-01
All	S2P	9.5000e-02
All	P2A	6.5100e-01

Site-level impacts within the North Thompson Watershed

The various systems were grouped as follows in Table A12 and is represented in Figures 10 and 11 in the main report.

Table A12. The system groupings by species, conservation unit and system.

Species	Unit	System	Grouping
Sockeye	Kamloops_Early Summer Timing	Barriere River	Tribs
Sockeye	Kamloops_Early Summer Timing	Clearwater River	Tribs
Sockeye	Kamloops_Early Summer Timing	Lemieux Creek	Tribs
Sockeye	Kamloops_Early Summer Timing	North Thompson River	Main
Sockeye	Kamloops_Early Summer Timing	Raft River	Tribs
Sockeye	North Barriere_Early Summer Timing	Fennell Creek	Tribs2
Sockeye	North Barriere_Early Summer Timing	Harper Creek	Tribs2
Chinook	CK017-Lower Thompson_SP_1.2	Louis Creek	Tribs
Chinook	CK018-North Thompson_SP_1.3	Finn Creek	Tribs
Chinook	CK019-North Thompson_SU_1.3	Barriere River	Tribs
Chinook	CK019-North Thompson_SU_1.3	Clearwater River	Tribs
Chinook	CK019-North Thompson_SU_1.3	Mahood River	Tribs
Chinook	CK019-North Thompson_SU_1.3	North Thompson River	Main
Chinook	CK019-North Thompson_SU_1.3	Raft River	Tribs