IMPERIAL OIL RESOURCES LIMITED

Aquatic Effects Monitoring Program

Imperial Oil - Norman Wells Operations

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Synopsis

This report outlines Imperial's Aquatic Effects Monitoring Program for Norman Wells Operations, developed to meet Water Licence requirements and assess aquatic conditions. It asks whether routine or historic activities are altering accumulated environmental state, using upstream, near-field, and downstream comparisons across key waterbodies. The program integrates seasonal water quality monitoring with small-bodied and large-bodied fish studies to evaluate environmental change and biological responses. It details study design, field methods, laboratory analyses, statistics, thresholds, and reporting needed to detect, interpret, and respond to aquatic effects.

Disclaimer

PROJECT 417085-59897-CA-REP-00002 : Aquatic Effects Monitoring Program - Imperial Oil - Norman Wells Operations

Rev	Description	Originator	Reviewer	TRSA Approver	Revision Date
0	Issued as Final	G. Young	S Gibb/ A. Haigh/ R. Tanna	S. Gibb	31 July 2026

Plain Language Summary

Summary

Imperial Norman Wells Operations (NWO) is an oil and gas site owned and operated by Imperial Oil Resources N.W.T. Limited (Imperial). It is in Norman Wells, Northwest Territories, in the Sahtu Settlement Area, about 700 km northwest of Yellowknife and about 140 km south of the Arctic Circle.

In 2015, the Sahtu Land and Water Board (SLWB) approved Imperial's 10-year Water Licence. This licence allows Imperial to take water from the Mackenzie River. It also sets rules for how much water can be used, what quality of water can be released back into the environment, and how Imperial must monitor the area to check for possible effects on surface water and groundwater. One part of this work is the Aquatic Effects Monitoring Program, or AEMP.

What is an Aquatic Effects Monitoring Program?

The Mackenzie Valley Land and Water Board says that AEMPs are meant to monitor project-related effects on the aquatic ecosystem. This can include changes to water quality, water quantity, aquatic habitat, and aquatic life. Imperial's AEMP is one of the programs used to meet the requirements of the Water Licence. It is designed to answer this question:

> **Are routine or past activities at Imperial's Norman Wells site adding substances to the environment that could harm the aquatic environment by changing its Accumulated Environmental State?**

Accumulated Environmental State (AES) monitoring looks at the overall condition of the environment. It is meant to show whether the whole operation, over time, is affecting overall water quality or fish health. In this AEMP, AES monitoring focuses on water quality and fish health linked to how NWO uses and interacts with the water. Other parts of a full AES program, such as air quality or land animals, are outside the scope of this plan.

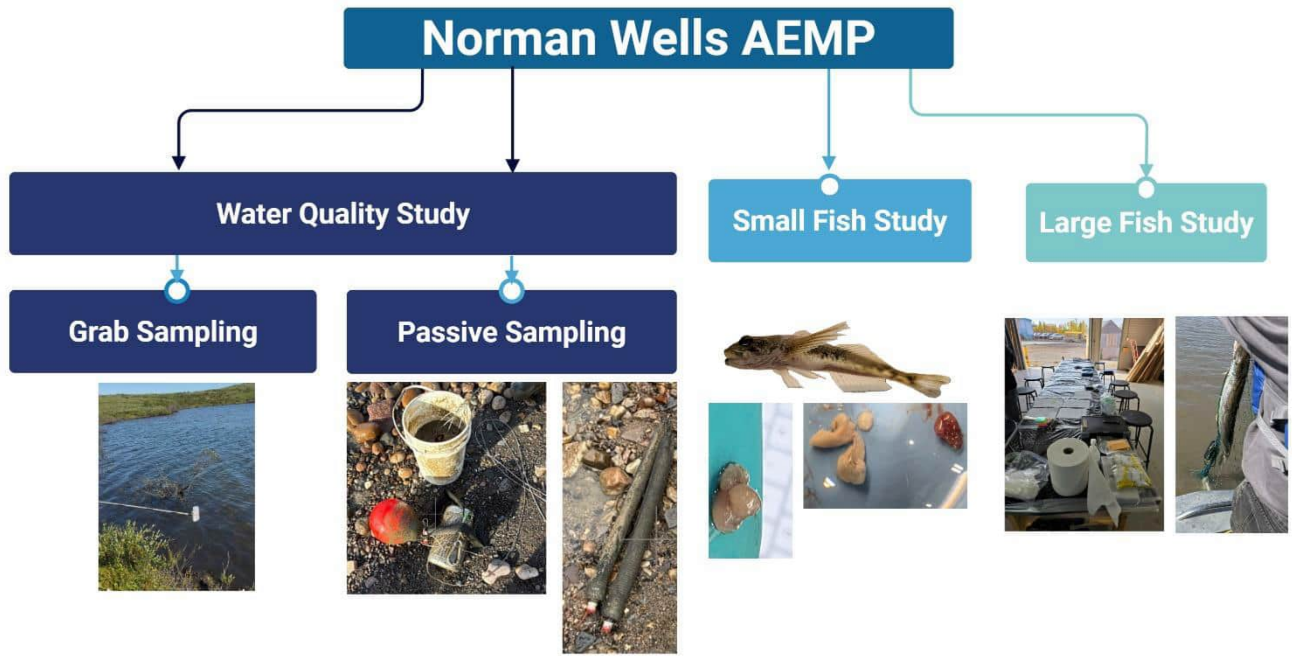
This program is meant to:

- Check for possible influence from Imperial's operation.
- Identify whether those influences may be immediate or long-term.
- Suggest whether more action is needed to protect the aquatic environment.

A strong AEMP depends on two main things:

- Working with communities and including Traditional Knowledge (TK).
- Using a sound scientific design that can be clearly supported and explained.

Main Parts of the AEMP



This AEMP has three main parts:

1. **Water Quality Sampling:**

Water samples are collected at several places upstream, near the site, and downstream of NWO in the Mackenzie River and Bosworth Creek.

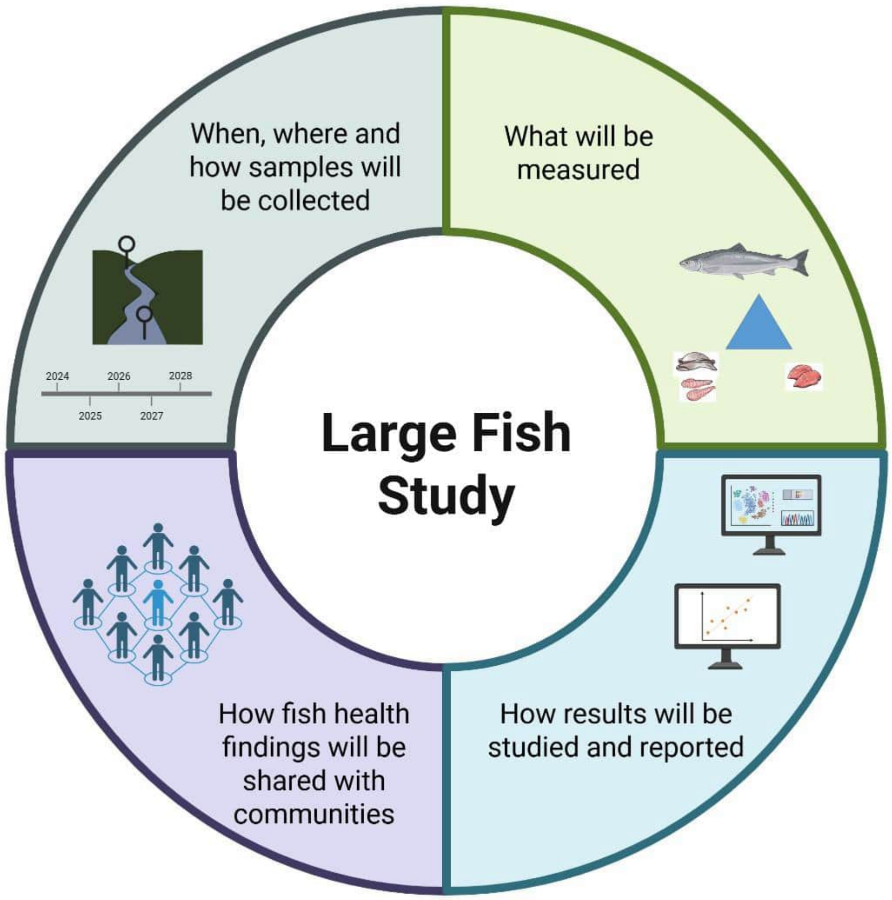
2. **Small-bodied Fish Study (SFS):**

This study focuses on a small fish species in Bosworth Creek, which runs through the site. Bosworth Creek may be more likely than the Mackenzie River to show site-related effects because it is closer to the site and has much less flow. This watercourse is used as a spawning ground and nursery for some large-bodied species (including loche, whitefish, bluefish, jackfish, and pickerel) in the Mackenzie River that are used by communities.

The sentinel species selected for this work is slimy sculpin (*Cottus cognatus*). Slimy sculpin is selected as a sentinel or "representative species" to detect environmental effects early, before other living organisms within the river are affected. For this reason, slimy sculpin are a good choice as they stay in a small area, so their condition reflects the water where they were caught.

3. **Large-bodied Fish Study (LFS):**

This study focuses on larger fish species that are important to local communities as food. Accordingly, the program measures edible-tissue chemistry and fish-health indicators but does not perform a human-health risk assessment. Ongoing help and support from community members will be important for carrying out these programs. The parts of this study that are outlined in this plan are provided below.



Water Quality Sampling

Water quality monitoring will take place in both the Mackenzie River and Bosworth Creek, at locations upstream and downstream of Imperial's Norman Wells Operations.

Different sampling methods will be used to measure different kinds of substances in the water:

- Grab samples are single water samples collected at a specific place and time. These will be used to test general water chemistry, physical water quality, nutrients, organics, and metals. Winter sampling will use grab samples for all parameters.
- Passive diffusion bags are bags filled with clean laboratory water and placed in the water for a period of time. They will be used to test for petroleum hydrocarbon compounds.
- Semi-permeable membrane devices are thin films that act like fish tissue and collect polycyclic aromatic hydrocarbons (PAHs).

Water Sampling Locations

Water will be sampled at upstream and downstream locations around the facility. A map of the 15 locations is shown in *Figure PS-1.*

Samples will be collected four times each year:

- Spring/early summer.
- Mid-summer.
- Fall.
- Winter under the ice.

Bosworth Creek will not be sampled in winter because it freezes to the bottom.

Results from upstream sites will be compared with results from downstream sites to see if water quality changes as it passes the site.

Water will be tested for many things that are specifically listed in the plan, including:

- General water chemistry.
- Nutrients.
- Metals.
- PAHs.
- Hydrocarbons.

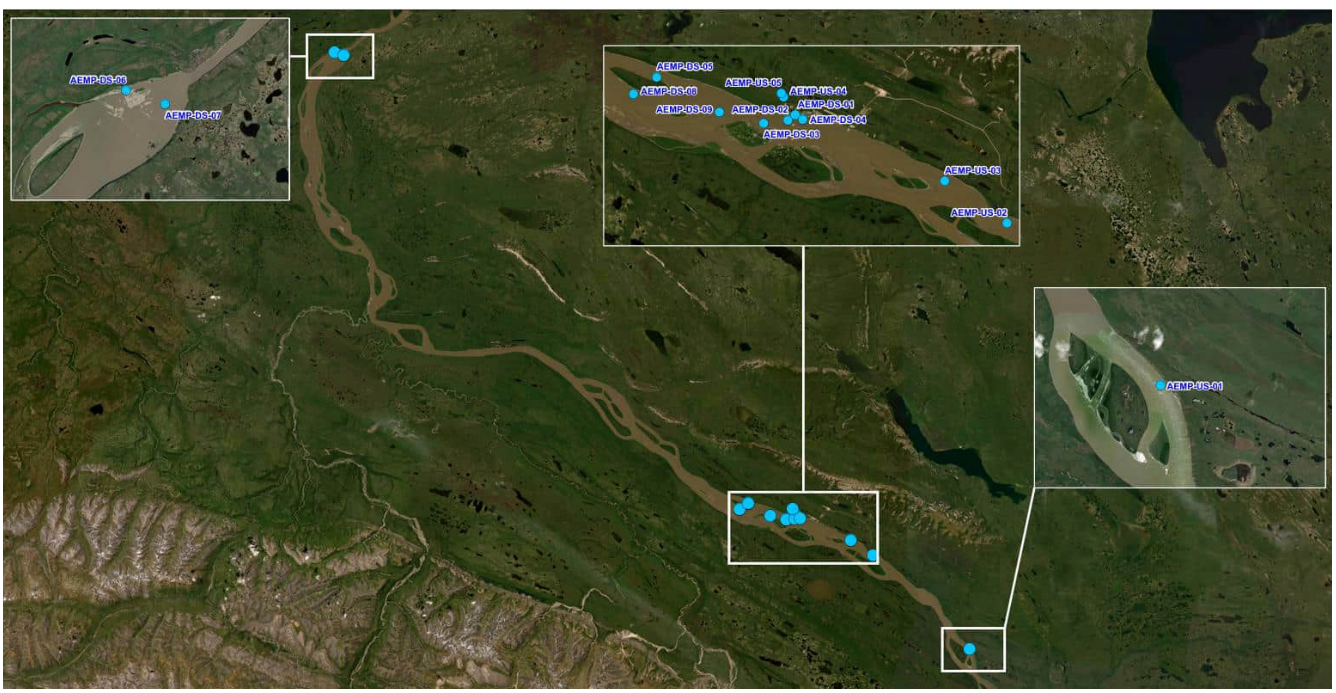


Figure PS-1: Water Sampling Locations

Response Framework

The results from each year will be reviewed in relation to thresholds defined in the response framework of this plan. This will assist with addressing aquatic environment concerns related to Imperial's Norman Wells Operations as they are identified. The plan outlines an adaptive monitoring framework as well. This outlines a clear process for identifying and verifying potential concerns, and how additional focused studies may be triggered where necessary based on monitoring results.

Who Does this Work?

Imperial will hire a professional consulting company to collect data and report the results. This helps make sure the work is done properly, and the results can be trusted. Local companies will also be hired to help with fieldwork, such as boat transportation on the river.

The Large-bodied Fish Study (LFS) will be carried out by local people in each community. Traditional knowledge will help guide where fish are caught, how they are caught, and what local harvesters observe about fish health. The consultant will support this work by braiding TK with Western science methods to provide a more complete understanding of the environmental state.

How is the Information Used and Shared?

The consultant hired by Imperial will prepare a report each year. This report will summarize the work done in the previous year and explain the results.

The results will be reviewed to look for patterns or differences in water quality and fish health between sites upstream and downstream of the facility. Any signs that site activities may be affecting the environment will be looked at carefully.

All data and analysis will be included in one report. This report will be submitted to the Sahtu Land and Water Board (SLWB) every year by April 30, as required under Part I, Section 3 of Water Licence S13L1-007.

Imperial is also committed to sharing the results with local communities in ways that are clear and easy to understand through sharing all data, findings, reports, community engagement, and in other ways as requested by the communities.

Revision History

This document represents Version 5 of the AEMP. Previous versions were submitted to the SLWB as follows:

Version	Revision	Author	Changes	Submission Date
1	0	Imperial	-	March 2016
1	1	Imperial	Water Scope	March 2018
3	1	Imperial	Water Scope	October 2019
4	0	TRSA	Water & Small Fish Scope	December 2022
5	0	TRSA	Large Fish Scope Addition	April 2026

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Glossary

Acronym	Definitions
AEMP	Aquatic Effects Monitoring Program
AES	Accumulated Environmental State
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
ATS	Akritas-Theil-Sen
BLM	Biotic Ligand Model
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CALA	Canadian Association for Laboratory Accreditation
CBM	Community-Based Monitoring
CCEA	Canadian Council on Ecological Areas
CCME	Canadian Council of Ministers of the Environment
CER	Canada Energy Regulator
CES	Critical Effect Size
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
COPC	Contaminants of Potential Concern
CPF	Central Processing Facility
CSM	Conceptual Site Model
DFO	Department of Fisheries and Oceans
DO	Dissolved Oxygen
EC	Electrical Conductivity
ECCC	Environment and Climate Change Canada
EEM	Environmental Effects Monitoring
ELISA	Enzyme-Linked Immunosorbent Assay
EROD	Ethoxyresorufin-O-deethylase
ESRF	Environmental Studies Research Funds
FEQG	Federal Environmental Quality Guidelines
FWAL	Freshwater Aquatic Life
GAM	Generalized Additive Modelling
GNWT	Government of the Northwest Territories
GSI	Gonadosomatic Index
GWMP	Groundwater Monitoring Program
HESL	Hutchinson Environmental Solutions Limited
IOL	Imperial Oil Limited
IORL	Imperial Oil Resources Limited
KIP	Key Indicator Parameter
KIPs	Key Indicator Parameters
LCL	Lower Control Limit

Acronym	Definitions
LDPE	Low-Density Polyethylene
LFS	Large-bodied Fish Study
LFSP	Licence to Fish for Scientific Purposes
LSI	Liversomatic Index
MFO	Mixed-Function Oxygenase
MMER	Metal Mining and Effluent Regulations
MRBB	Mackenzie River Basin Board
MVLWB	Mackenzie Valley Land and Water Board
NMDS	Non-metric Dimensional Scaling
NOEC	No Observable Effect Concentration
NT	Northwest Territories
NWT	Northwest Territories
NWO	Norman Wells Operations
OA	Operating Approval
PAH	Polycyclic Aromatic Hydrocarbon
PAHs	Polycyclic Aromatic Hydrocarbons
PCA	Principal Component Analysis
PDB	Passive Diffusion Bag
PHC	Petroleum Hydrocarbon
PI	Pyrogenic Index
POCIS	Polar Organic Chemical Integrative Sampler
PRC	Performance Reference Compound
PSD	Passive Sampling Device
RCA	Reference Condition Approach
RDL	Reportable Detection Limit
RPD	Relative Percent Difference
SETAC	Society of Environmental Toxicology and Chemistry
SFS	Small-bodied Fish Study
SLWB	Sahtu Land and Water Board
SNP	Surveillance Network Program
SPMD	Semipermeable Membrane Device
SSA	Sahtu Settlement Area
SSD	Species Sensitivity Distribution
TDS	Total Dissolved Solids
TK	Traditional Knowledge
TKN	Total Kjeldahl Nitrogen
TMF	Toxicity Modifying Factor
TPH	Total Petroleum Hydrocarbon
TRSA	Tłegǫ́hłı̨ Reclamation Services Advisian
TSS	Total Suspended Solids

Acronym	Definitions
UCL	Upper Control Limit
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	Volatile Organic Compound
WSC	Water Survey of Canada
YOY	Young of the Year

1. Introduction

Imperial Oil Resources N.W.T. Limited (Imperial) has retained Tłegǫ́hłı̨ Reclamation Services Advisian (TRSA), a partnership between the Tłegǫ́hłı̨ Got'ı̨nę Government and Worley Consulting, to develop an Aquatic Effects Monitoring Program (AEMP) to meet the requirements of their Water Licence (S13L1-007) issued by the Sahtu Land and Water Board (SLWB) for their Norman Wells Operations (NWO).

Norman Wells Operations is owned by Imperial Oil and the Government of Canada and operated by Imperial. It is an upstream oil and gas facility located approximately 700 km northwest of Yellowknife, Northwest Territories (NT). Operations include a central processing facility (CPF), which receives production from the mainland, along the north-eastern shore of the Mackenzie River, natural islands (Goose Island, Bear Island, and Frenchy's Island), and six artificial islands (Figure 1-1).

Figure 1-1: Site Location Map

Imperial currently holds a Type A 10-year Water Licence, S13L1-007 (renewal of Licence S03L1-001), which was approved by the SLWB on March 5, 2015, and granted a temporary extension. On March 11, 2025, Imperial was granted a three-year extension, effective May 4, 2025 to May 3, 2028 (S13L1-007). The Licence is used to regulate the use of water resources and the deposits of waste as they pertain to Imperial's site.

The NWO AEMP has been created to satisfy Imperial's Water Licence S13L1-007, Part I, Condition 1 and developed in accordance with Guidelines for Designing and Implementing Aquatic Effects Monitoring Program for Development Projects in the Northwest Territories (Indian and Northern Affairs Canada, 2009). This document (AEMP Version 5 [V5]) represents the most recent revision of the AEMP document, and supersedes the previous versions submitted in 2016, 2018, 2019 and 2022 (Imperial 2016, 2018, 2019, TRSA 2022). Accordingly, the scope of the proposed monitoring activities reflects the revised Mackenzie Valley Land and Water Board's (MVLWB) and Government of the Northwest Territories (GNWT) Guidelines for Aquatic Effects Monitoring Programs (the *Guidelines;* MVLWB and GNWT, 2019) as well as direction from the SLWB (HSEL 2021) and findings from Working Group session (Section 1.4.1).

1.1 Purpose and Scope

The AEMP will detect spatial and temporal changes in water chemistry and fish tissue chemistry and will use indicators of fish health (condition, liversomatic index, specific liver activity, and gonadosomatic index) as the primary measures of fish health to determine Accumulated Environmental State (AES) and to determine whether detected chemical changes are accompanied by a biological response. Chemistry results are supporting lines of evidence and do not independently establish fish-health effects or human consumption safety. The purpose is to answer the question: Are operations at Imperial's Norman Wells altering "Accumulated Environment State (AES)"?. This question is addressed by measuring water quality and fish health upstream, adjacent to and downstream from the facility and analyzing that data to identify changes.

To achieve this, the scope of the AEMP is to annually:

- Measure Water Quality in the Mackenzie River:
  - Water quality is to be measured during all four seasons.
  - Water quality is measured upstream, near and downstream of NWO.
  - Water quality is measured for several potential contaminants and health metrics.
- Measure Water Quality in Bosworth Creek:
  - Water quality is to be measured during Spring, Summer and Fall (the creek freezes to the bottom during winter).
  - Water quality is measured upstream, near and downstream of NWO.
  - Water quality is measured for several potential contaminants and health metrics.
- Monitor Small Fish Health in Bosworth Creek using Slimy Sculpin (*Cottus cognatus)* as a Sentinel (Target) Species:

- Small fish are assessed in Autumn close to freeze-up and spawning season.
- Small fish are assessed upstream and near NWO.

- Monitor Large Fish Health in the Mackenzie River Using Crookedback (Lake Whitefish; *Coregonus clupeaformis*) and Loche (burbot; *Lota lota*) as Target Species:
  - Large fish are assessed close to their respective spawning periods.
  - Large fish are assessed upstream (near Tulit'a), near (Norman Wells) and downstream (Fort Good Hope) of NWO.
- To analyze and report on all data.

The three components of the AEMP (water quality, small fish, and large fish) are intended to enable assessment of both environmental conditions and responses across biological levels of response. The use of established sensitive cellular response indicators and organ response indicators is meant to serve as biological verification and validation where the relevance and/or importance of changes in water chemistry are unclear (Figure 1-2).

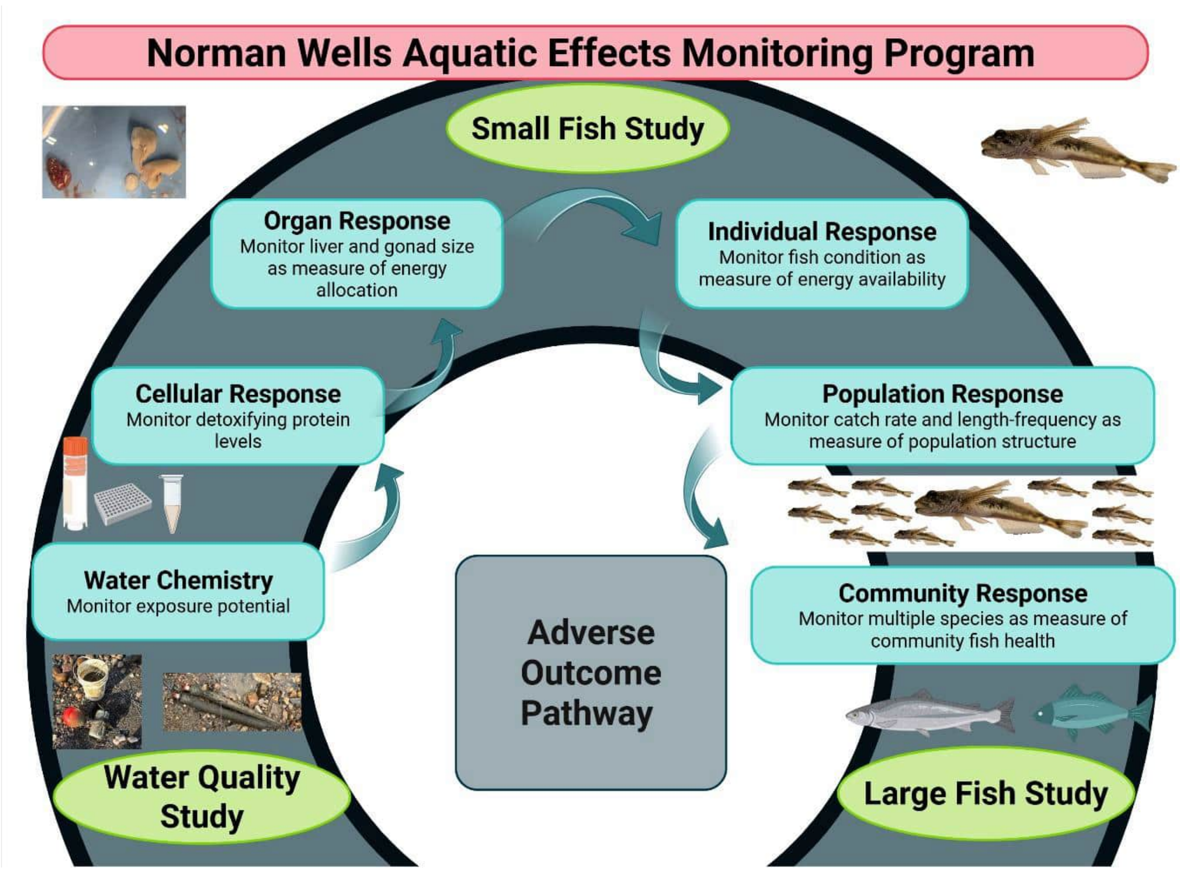

Figure 1-2: Linkages Between Components of the AEMP to Enable Evaluation of the Accumulated Environmental State (AES) of Aquatic Environments at and Around NWO at Different But Related Response Levels Along an Adverse Outcome Pathway

1.2 Objectives

The main objective of the AEMP is to understand if NWO is influencing conditions in surrounding aquatic environments and if fish indicators are being altered in response to any detected changes in conditions. If there are no statistical differences among sites upstream, downstream or near the NOW over time, then no biological effects are expected. If site differences or trends over time are observed, they will become the focus of subsequent tiers of adaptive monitoring (Section 6). These frameworks provide a data-driven approach to investigate whether significant results are driven by the NWO or other environmental processes. Specific predictions are discussed further in Section 4 of this plan, and these results will be used to inform Imperial NWO closure planning.

Additional objectives of this plan are to:

- Ensure the program as proposed is acceptable to the SLWB and local stakeholders and achieves regulatory approval under Water Licence S13L1-007.
- Assess the quality of the water by incorporating time-integrated methods of quantification and grab sample methods.
- Assess aquatic health via fish endpoints and uptake of contaminants of potential concern through fish tissue analysis.
- Use the monitoring results to develop an understanding of the natural variability locally and regionally in the water and fish tissue quality as context for the areas of potential concern.
- Work together with stakeholders to understand and ensure confidence in results through collaboration on monitoring activities and dissemination of results in public forums.
- Test predictions from the regulatory process regarding the effects of a project on the receiving environment. Note that this objective may need to be reviewed following completion of ongoing Environmental Assessments.
- Assess the effectiveness of existing environmental controls and mitigation measures and, if necessary, identify cumulative environmental effects that may inform management of controls and mitigation measures.
- Serve as an early warning system to detect environmentally relevant changes.

1.2.1 Limitations

The AEMP is a monitoring program, and findings will be reported in accordance with AEMP guidance. Data interpretation will be limited to determining if changes have occurred, the extent and magnitude of changes, and any correlation between water chemistry, cellular/biochemical response and biological responses that may infer potential causation. The AEMP is not an environmental risk assessment and therefore does not include management or mitigation recommendations, but the information contained herein may inform closure and clean-up planning.

1.3 Team and Accountability

Imperial is the responsible proponent for the AEMP, and all accountability pertaining to the execution of the program and any follow-up actions or responses from AEMP results remain with Imperial.

Consultants and subcontractors have been engaged by Imperial to support development and execution of the AEMP. At the time of developing this document, TRSA is the primary consultant engaged with the responsibility to execute the program. A summary of the core competencies and responsibilities within the project team is provided in Table 1-1.

Table 1-1: Team and Responsibilities

Component	Responsible Party	Team Members	Comments
Accountability for Execution and Compliance	Imperial	Environment and Regulatory Advisor, NWO field leads.	This responsibility is given to TRSA to execute on Imperial's behalf.
Scheduling, Resourcing and Logistics	TRSA	Project management.	---
Field Execution – Water Sampling and Fish Catch and Processing	TRSA	Environmental professionals and aquatic biologists.	Assisted by local companies and individuals for guides, boats, snowmobiles and Traditional Knowledge.
Sample Analysis	TRSA	Subcontracted laboratories. Environmental professionals and aquatic biologists.	All water and fish tissue analysis to be completed by independent laboratories.
Reporting	TRSA	Environmental professionals and aquatic biologists.	---
Data Sharing	Imperial	Environment and Regulatory Advisor, NWO field leads and Imperial Advocacy specialists.	TRSA to provide technical support.

1.4 Engagement

1.4.1 Healthy Water Healthy Fish Working Group

The Healthy Water Healthy Fish Working Group (the Working Group) has been established by the SLWB to support the development of a new AEMP for Imperial's NWO. The Working Group was established to promote collaboration with communities and stakeholders within the Sahtu, regulators and Imperial to build a robust program for monitoring water quality and the health of small fish and large fish. Group membership includes the SLWB, Sahtu Renewable Resources Board (SRRB) and the Government of Northwest Territories.

The intent of the Working Group is to promote:

- Participation from applicable regulatory bodies, local stakeholder groups, Imperial and various consultants to ensure sufficient engagement and knowledge sharing such that the outcome of the group can be considered a mandate to proceed with an acceptable study.
- Establish how data will be shared and communicated to stakeholders.
- Engage with local people and organizations interested in participating in fish and water quality field programs and to gather traditional knowledge (TK) to inform sampling locations and methods.

- Establish how TK will be managed and integrated.
- Gain expressed support to proceed from all Study Group members that can be carried forward into future permitting and licensing requirements.
- Construct an AEMP that will be viewed as sufficiently robust from both Western Science and TK perspectives to investigate community concerns related to fish and water health and satisfy Imperial's regulatory requirements under the Water Licence.

1.4.2 Community Engagement

As part of the development and implementation of the AEMP, there are four main components of community engagement:

- The Working Group:
  - Leading the design and implementation of the large fish health program.
  - Establishing community support and a regulatory mandate to execute these programs.
- Integration and use of TK to structure and guide Western Science activities, as agreed upon by the communities.
- Program development and execution.
- Ongoing engagement.

1.5 Regulatory Drivers and Requirements

The requirement for the AEMP is stated within Imperial's Type A Water Licence (S13L1-007) issued by the SLWB. The objectives and specific requirements for the AEMP design were provided to Imperial in a letter from the SLWB (2021) accompanied by a technical review from Hutchinson Environmental Solutions Limited (HESL; 2021). Requirements for AEMPs in general within the jurisdictions of the Mackenzie Valley are provided in MVLWB and GNWT 2019.

As the Water Licence is the regulatory mechanism that establishes the requirement for an AEMP, the environmental driver of focus is NWO's water use requirements, specifically, an annual use of water from the environment exceeding 100 m^3/d, LWBMV (2023).

Imperial is required to execute the AEMP annually and report on its findings each subsequent year by April 30th.

The Department of Fisheries and Oceans (DFO) Canada maintains regulatory approval over studies that require fish catch and sacrifice for scientific purposes within federally regulated waters. Accordingly, a license to fish for scientific purposes (LFSP) approved by DFO is required annually to complete the program. Data collected as part of the AEMP are reported back to DFO within 30 days of the licence expiry date under the conditions of the LFSP.

No other approvals or permits are required to complete the work.

Imperial maintains an Operating Approval (OA) from the Canada Energy Regulator (CER); however, no requirements related to the AEMP are included in the OA.

2. Site Description

Norman Wells is located at Latitude 65° 17’ N, Longitude 126° 51’ W, and lies along the northern shore of the Mackenzie River (Figure 1-1), approximately 140 kilometres (km) south of the Arctic Circle (WorleyParsons Komex 2008). The Norman Wells oil field was first drilled by IOL in 1919-1920, with the first well on the banks of the Mackenzie River east of the Bosworth Creek delta.

The discovery well was drilled to test a series of oil seeps occurring on the banks and shore of the Mackenzie River. A significant producing horizon was found at a depth of approximately 150 metres (m). More extensive drilling in the 1920s and 1930s led to the discovery of the main reservoir – a carbonate reef lying largely under the Mackenzie River at depths ranging from 320 meters to 625 metres below ground surface.

The field was further developed in response to the need to supply petroleum to Alaska during, and subsequent to, the Second World War. In the early 1980s, the field underwent a major expansion including the construction of six artificial islands in the Mackenzie River and the construction of the Central Processing Facility (CPF). Currently, petroleum produced from the Norman Wells field is shipped to Alberta via the Mackenzie Valley pipeline.

The IOL lease currently consists of the Former Refinery site, three former battery sites (Bear Island Battery, Battery #1 and Battery #3), a CPF constructed in the mid-1980s, related infrastructure on both the mainland and natural islands in the Mackenzie River and artificial islands constructed to support production pads. The vintage of the Former Refinery and Battery #3 is circa 1940s. A decision to cease petroleum-processing activities at Battery #3 was made in the mid-1980s, at which time a new CPF was constructed. The Former Refinery was shut down in 1996 and dismantled in 1997. All hydrocarbon production is now routed to the CPF prior to shipment to Alberta for refining. The Bear Island Battery and Battery #1 were operational from 1950 to 1983.

Most process-related infrastructure is situated on the northern shore of the Mackenzie River. Although a number of production wells are situated on the Mainland, extension of the field to the south necessitated the construction of artificial islands in the Mackenzie River. These islands were to serve as platforms for drilling and production of crude from the reservoir below. In addition, several production wells have been drilled on three of the natural islands in the river channel (i.e., Bear, Frenchy’s and Goose Islands).

Producing wells are on the Mainland, the Natural Islands (Goose, Bear, and Frenchy’s), and the Artificial Islands (1-Rayuka, 2-Rampart, 3-Dehcho, 4-Ekwe, 5-Iteh K’ee and 6-Little Bear). Crude oil production is received at the CPF, where it is processed for shipment via the Enbridge pipeline to Alberta. No refining is conducted on-site (Imperial 2019).

3. Site Environmental Context

3.1 Environmental Setting

The NWO is situated on the Mackenzie River within the Sahtu Settlement Area (SSA) of the NT. The area is adjacent to the community of Norman Wells and is downstream of the community of Tulit'a and upstream of the community of Fort Good Hope. The operation's location on the Mackenzie River positions it strategically for transport and pipeline access, while also placing it in proximity to sensitive sub-Arctic ecosystems and traditional lands used by Sahtu Dene and Métis peoples for hunting, fishing, and cultural activities.

The SSA is in the Canadian Taiga Plains Ecozone (CCEA 2014) within the Mackenzie River Plain Ecoregion. The Ecoregion is a narrow northern extension of the boreal forest along the east side of the Mackenzie River. The ecoregion is marked by cool summers and very cold winters. The mean annual temperature is approximately -6.5°C. The mean summer temperature is 11.5°C and the mean winter temperature is -24.5°C. The mean annual precipitation ranges from 300 mm to 400 mm. The ecoregion is classified as having a subhumid high boreal ecoclimate.

The ecoregion is a broad, rolling, drift-covered plain lying between Mackenzie and Franklin Mountains, into which the Mackenzie River is entrenched for part of its course. Native vegetation consists predominantly of medium to tall, closed stands of black spruce and jack pine with an understory of feathermoss, bog cranberry, blueberry, Labrador tea, and lichens. White spruce, balsam fir, and trembling aspen occur in the warmer, more moist sites in the southern section of the region. Drier sites have more open stands of black spruce and jack pine. Low, closed and open stands of black spruce, ericaceous shrubs, and sphagnum mosses dominate poorly drained, peat-filled depressions.

Wetlands cover 25-50% of the ecoregion, and are characteristically peat plateau bogs and ribbed and horizontal fens. Permafrost is extensive and discontinuous with medium ice content and is characterized by sparse ice wedges. Dominant soils in the ecoregion are Organic and Turbic Cryosols and Eutric and Dystric Brunisols with some Regosols that have developed on terraced to rolling morainal, alluvial, lacustrine, and organic deposits. Characteristic wildlife includes moose, black bear, beaver, fox, wolf, hare, raven, grouse, and waterfowl.

Limited forestry, oil production near Norman Wells, hunting, and trapping are the principal land use activities.

By November, precipitation primarily falls as snow. Mean monthly snowfall rises sharply in the autumn and then diminishes through the winter months as the Arctic high stabilizes and prevents humid air from the Pacific from moving in. Even as snowfall decreases, snow accumulation steadily increases throughout the winter due to lack of any significant thaws. Maximum snowpack depth is reached in March, then a more rapid decrease in the snowpack occurs as summer approaches (Kershaw 2005).

Daylight reaches a maximum of approximately 22 hours on the summer solstice and diminishes to a minimum of 3.5 hours on the winter solstice (Kershaw 2005).

3.2 Topography

The NWO is predominantly on the north shore of the Mackenzie River. Elevations range from approximately 50 to 70 metres above sea level (masl). The river flows in a west-northwesterly direction past the Town of Norman Wells. The valley within which this major river flows is bounded on the south by the Mackenzie Mountains and on the north by the Franklin Mountains (NWT Centre for Geomatics 2026).

3.3 Permafrost

The Norman Wells area lies in a zone of discontinuous permafrost, where typical maximum permafrost thickness ranges from 50 to 65 m. Permafrost in the Norman Wells area is not uncommon and is regularly encountered at the site beneath roads and other locations (Imperial 2019).

Long-term processes caused by increasing air temperatures in the Arctic have been related to permafrost melting, leading to thaw-induced land cover changes resulting in the development of thermokarst lakes/wetlands, land subsidence, hydrological changes, and landscape instability in the Mackenzie Valley (Chartrand et al 2023). Landscape changes related to permafrost thaw have also been linked to increased suspended solids from slumping banks along the Mackenzie River and its tributaries. These changes have been measured by monitoring programs since the 1980s and have been observed by local communities throughout the Mackenzie River watershed (MRBB 2021).

The presence of discontinuous permafrost in the area influences local groundwater flow patterns. Ice lenses and the low conductivity associated with frozen soil in the subsurface act as barriers to groundwater movement. Two groundwater-bearing intervals have been identified in the NWO area: a shallow discontinuous interval and a deeper unconfined interval.

3.4 Natural Seepage

The presence of natural seeps in the SSA, especially around the Town of Norman Wells, is known to predate Imperial's operation. Many natural oil and gas seeps have been documented in the lower Mackenzie River Valley.

Natural oil and gas seepage continues to occur along the shoreline and below the riverbed in several locations. The surficial on-shore seeps are most visible at these specific locations:

- Along the Mackenzie shoreline upstream and downstream of the former Refinery area.
- Within the Bosworth Creek delta area.
- Along the Mackenzie shoreline below the F-28X well.
- At Seepage Lake (between the Former Refinery area and Bosworth Creek).

- In Bosworth Creek several hundred meters downstream of where the winter road crosses the Creek.

The presence of seeps has led to a natural source of hydrocarbons in the groundwater and surface water at the site (Imperial 2019).

3.5 Mackenzie River

The Mackenzie River drainage basin is the largest river basin in Canada and the tenth largest river basin in the world. The Mackenzie River system flows roughly 4,200 km from the headwaters of the Athabasca River in the Columbia ice-field in Jasper National Park, Alberta, the snowfields of the upper Peace River headlands in northeastern British Columbia and the Liard River system in the Northwest Territories and Yukon to its final destination at the Beaufort Sea of the NWT (MRBB 2004).

Flow of the Mackenzie River at Norman Wells (Station number 10KA001) has been measured by the Water Survey of Canada (WSC) from 1943 to the present. The variability of flows that can be encountered during a month can be extreme, especially during the spring melt (May and July). For example, flows ranged from 2,660 m^3/s on 1 May 1982 to 33,300 m^3/s on 4 July 1988. Based on the available flow data from WSC, the average spring flow of the Mackenzie River is 15,500 m^3/s. The average flow during winter (November to April) is 3,884 m^3/s and ranges from 1,680 m^3/s to 11,600 m^3/s. Seasonal flow based on measurements collected from 2018 to 2025 is illustrated in Figure 3-1. Notably, average flows in the Mackenzie River have been relatively low following 2022, with lower peak flow observed in spring and lower-than-average fall flows (Figure 3-1). The AEMP will continue to use flow data from the WSC station as part of assessing the AES and to assist with interpreting water chemistry results.

The Mackenzie River discharges into the Beaufort Sea of the Arctic Ocean at the Mackenzie River delta, accounting for 60% of the freshwater that flows into the Arctic Ocean from Canada and about 9% of the freshwater discharged to all oceans (Atlantic, Arctic, Pacific) by all Canadian watersheds (MRBB 2004).

The water levels in the Mackenzie River are quite variable throughout the year. Typical levels are approximately 41 masl during the winter, with short-term peaks of up to 51 masl (Komex 1980). Breakup of the Mackenzie River ice at Norman Wells usually occurs over a two-week period in May, and freeze-up typically occurs during a three-week period in October and November. The ice thickness of the Mackenzie River usually ranges from 1 to 2 m.

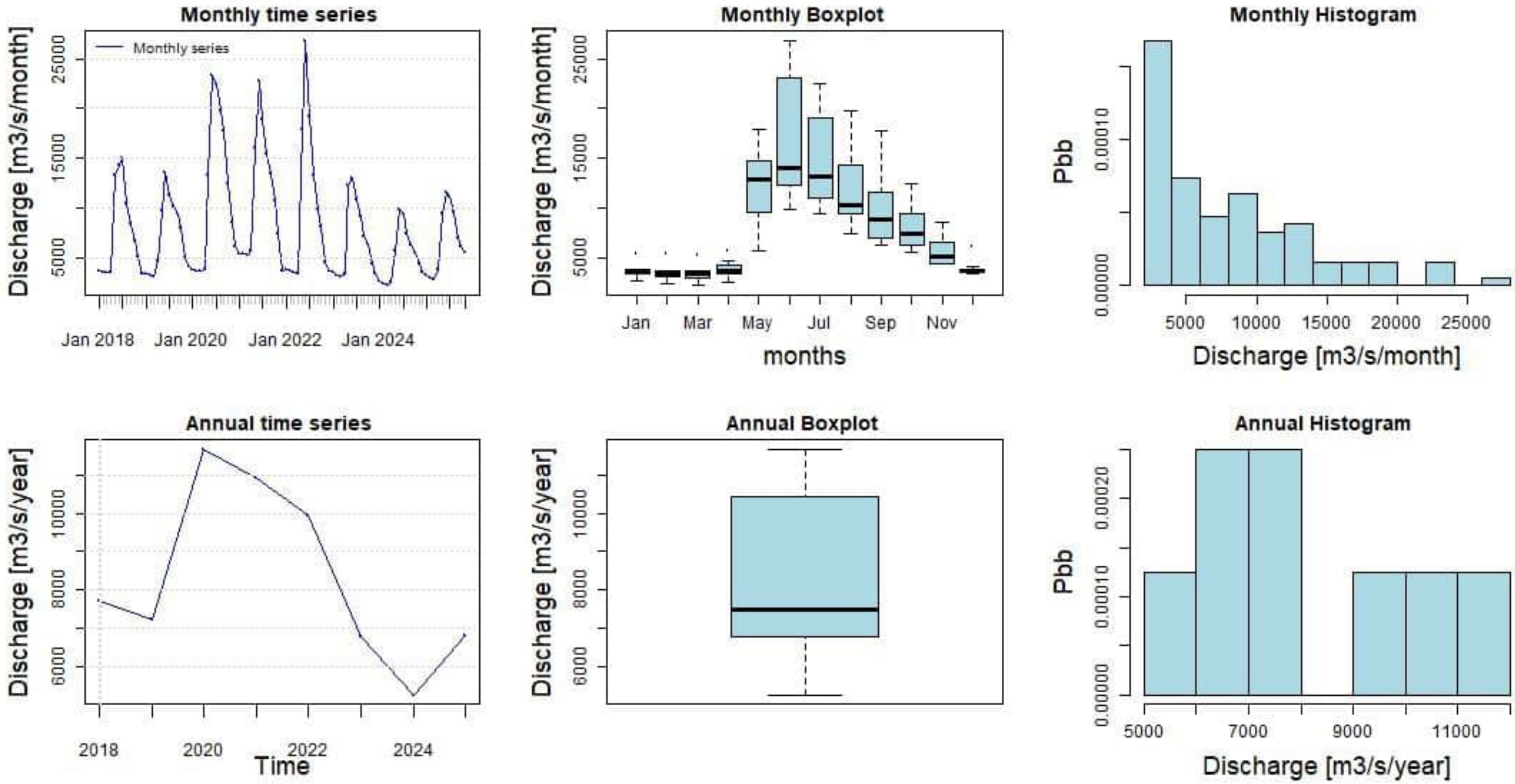

Figure 3-1: Mackenzie River at Norman Wells Hydrological Data – Average Monthly and Annual Discharge (2018 to 2025)

Several fish habitat and community studies have been completed on the Mackenzie River, including surveys in the early 1970s (Stein et al. 1973), which sampled the fish community at the mouths of major tributaries and supported environmental assessments for projects such as the Mackenzie Gas Project (Imperial 2004a). In 2023, Imperial commissioned a fish habitat and community assessment on the Mackenzie River at Norman Wells with a focus on the habitats provided by the six artificial islands (TRSA 2024).

This study included habitat mapping of the Mackenzie River around each of the islands, fish community sampling to infer habitat utilization by fish, review of TK and scientific literature, and assessment of water chemistry. Based on this study, thirty-four fish species have been recorded in the Mackenzie River. Fish catch rates are low around the islands and along the shore near Norman Wells; however, juvenile whitefish, juvenile doré (a.k.a. walleye, pickerel [*Sander vitreus*]), juvenile longnose sucker (*Catostomus catostomus*), trout-perch (*Percopsis omiscomaycus*), and lake chub (*Couesius plumbeus*) were documented in low numbers.

Sand is the dominant substrate in the Mackenzie River near Norman Wells and occurs in most run habitats. Large gravels and cobbles occur along the margins of the river and in areas next to erosional banks, while rubble and boulder substrates occur around the upstream side of each of the artificial islands (TRSA 2024).

3.6 Bosworth Creek

Bosworth Creek drains a small watershed near the town of Norman Wells, in the SSA of the NT. Bosworth Creek is a small watershed, approximately 125 km^2, which originates at the outlet of Hodgson (Jackfish) Lake and travels northwest approximately 8 km and then southwest towards the Town of Norman Wells to eventually drain into the Mackenzie River (Collins et al., 2011). Bosworth Creek is an important part of the local landscape and is used frequently by local residents for recreation.

Seasonal habitat surveys were completed for Bosworth Creek as part of the Mackenzie Gas Project in 2002. Wetted channel widths along the stream varied from 3.5 to 16 m. Fish habitat was primarily riffles, with the remainder composed of shallow run and some moderate-depth run habitat. Coarse gravel and cobble substrate predominated in most habitat types. Unstable or slumping banks were common, with both banks showing signs of erosion at high flow (Imperial 2019).

Flow in Bosworth Creek has been measured by WSC at Norman Wells (Station number 10KA007) from 1980 to the present. Over that timeframe, the average flow is 0.64 m^3/s and has ranged from 0.05 m^3/s to 19.7 m^3/s. The watercourse is frozen to the bottom through winter, and average peak flow (2.96 m^3/s) occurs in May. Seasonal flow patterns for Bosworth Creek from 2018 to 2025 are provided in Figure 3-2. Unlike the Mackenzie River, peak flows in Bosworth Creek typically occur in May before decreasing in June and July. Notably, there is typically a second smaller peak in flow in August and September.

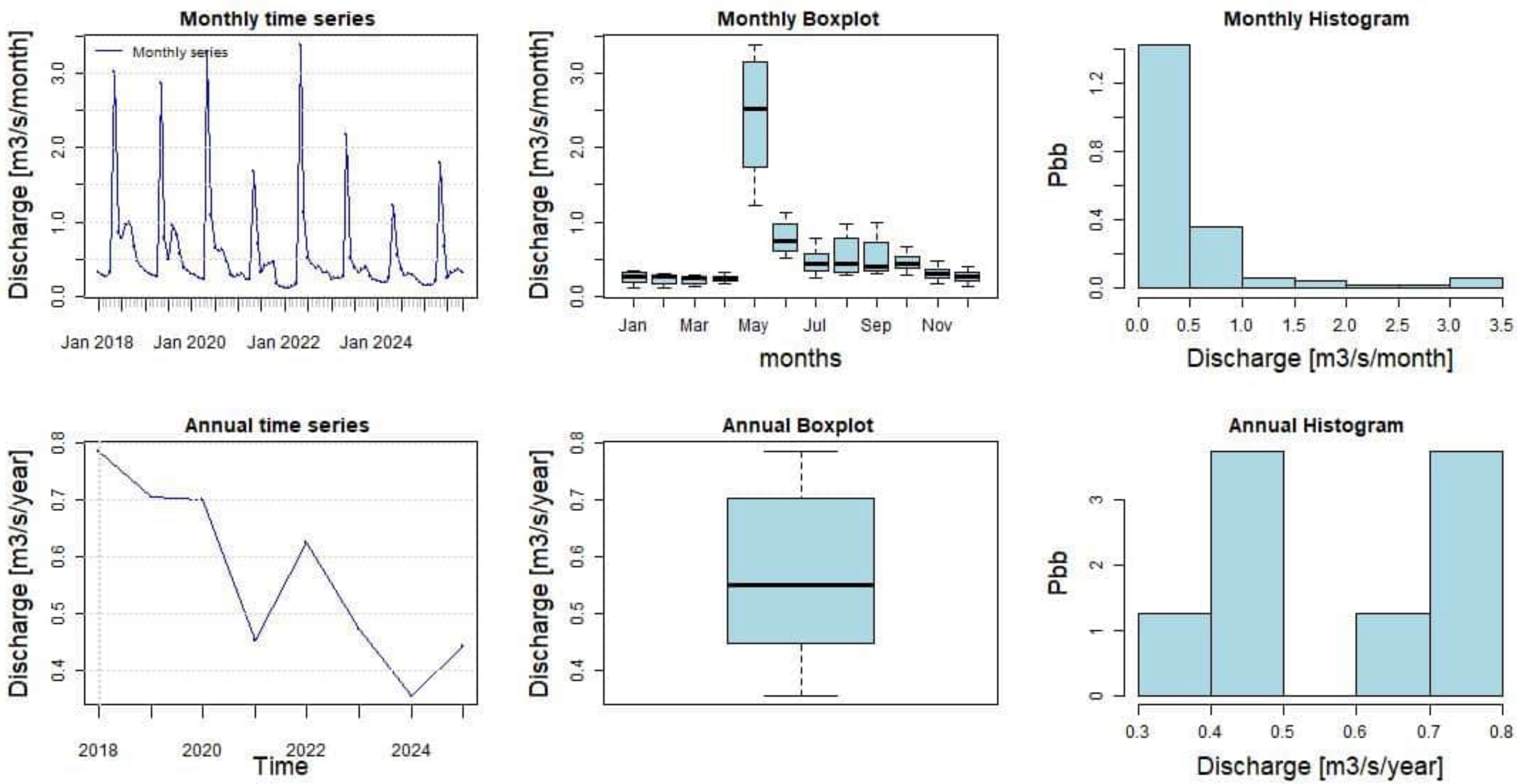

Figure 3-2: Bosworth Creek at Norman Wells Hydrometric Data – Average Monthly and Annual Discharge (2018 to 2024)

4. Overall Program Design

A key adaptation of the AEMP design based on results to date is driven by the lack of a detectable stressor (hydrocarbons and other parameters) in the water at or around Norman Wells.

A review from HESL provided to the SLWB resulted in the following direction to Imperial: *Revise the AEMP from a "stressor based" to an "effects based" design* (SWLB 2021). Direction more specifically included requests to:

- Focus on "accumulated environmental state" as determined through integrated, passive, and continuous small fish sampling will establish if there are changes in fish health between upstream, adjacent to and downstream of the site.
- Revise the AEMP from a "stressor based" to an "effects based" design and include natural stressors (hydrocarbon seeps above and adjacent to the site, seepage of groundwater from the site) to assess cumulative effects.

The resulting design moves away from a stressor-only approach to an effects-based approach that continues to surveil data of potential stressors as relevant context. This plan is regional in scale, incorporating changes in environmental condition and biological responses across the Sahtu Region (upstream of NWO, near Tulit'a and downstream of NWO, near Fort Good Hope). This regional focus enables characterization of relevant reference conditions and provides an assessment basis for downstream areas of potential concern.

4.1 Overview

The goal of the AEMP is to monitor potential effects from Imperial's operation and evaluate the immediate or long-term significance of potential aquatic effects. To achieve this goal, the design of the AEMP is based on understanding the upstream (of NWO) aquatic environment and comparing it to the downstream (of NWO) aquatic environment to determine if the facility is influencing water quality and/or fish health. Additionally, temporal changes in water quality and fish health within locations will be evaluated with various methodologies (Figure 4-1). The combination of spatial and temporal sampling design is recognized as being statistically powerful enough to detect subtle biological changes in aquatic ecosystems in response to disturbance (Martin et al. 2012; Stewart-Oaten 1996).

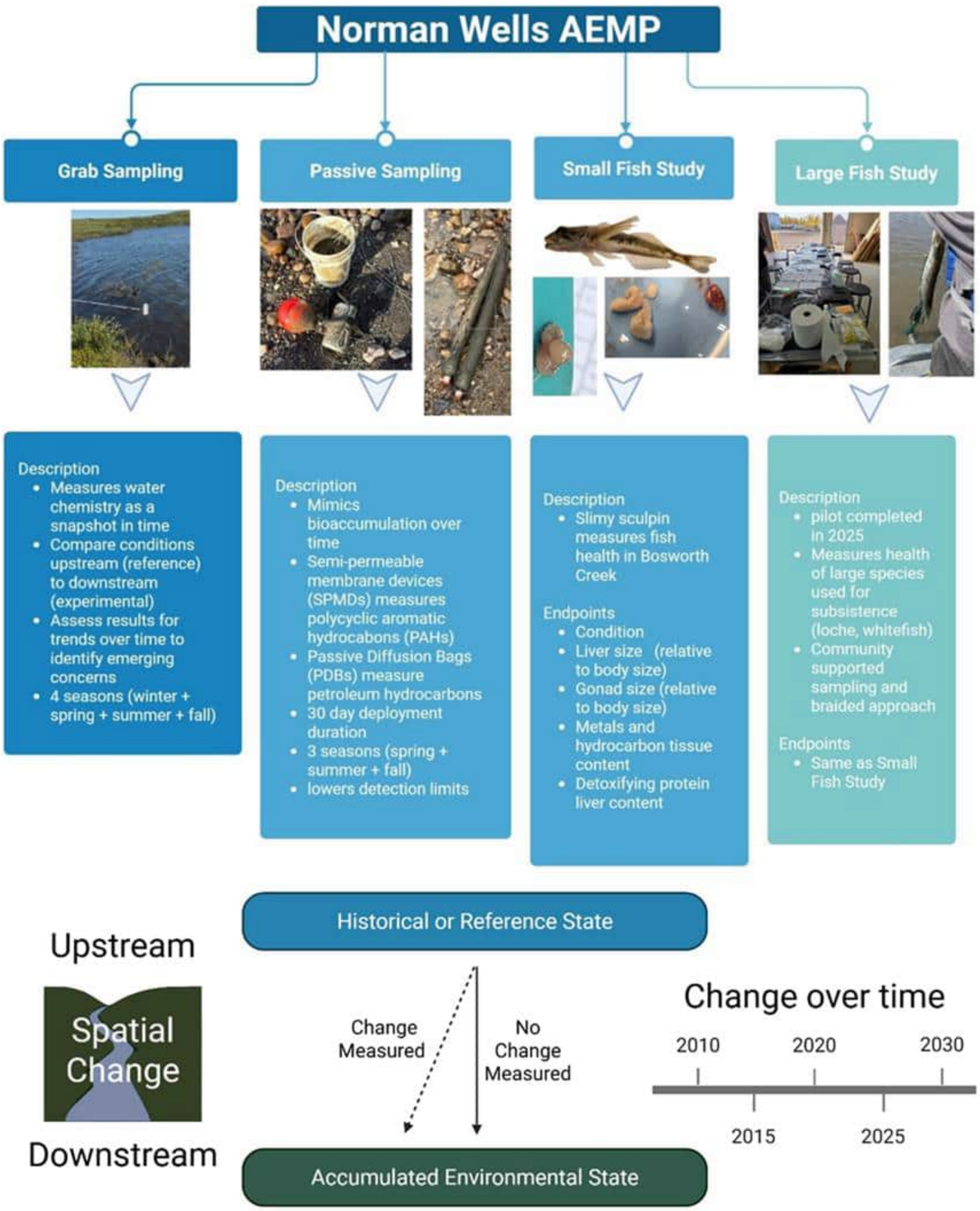

Figure 4-1: Evaluation Approach for Evaluating Spatiotemporal Changes Across AEMP Component Areas to Identify Potential Cumulative Effects Across the Sahtu Region

The program relies upon an adaptive data-driven approach to identifying any indications of facility-related change, establishing the extent and magnitude of any such changes, and using indicators across biological response levels to infer potential causation in alignment with federal Environmental Effects Monitoring Guidance (Environment Canada, 2012).

The AEMP Guidance (MVLWB/GNWT 2019) suggests a Design, Implement, Adapt process. It is within the "adapt" phase that the opportunity exists to ensure that program design and level of investigation follow this data-driven approach. The steps that form the AEMP process are shown below in Figure 4-2 and have been followed to progress through the progressive versions of this program.

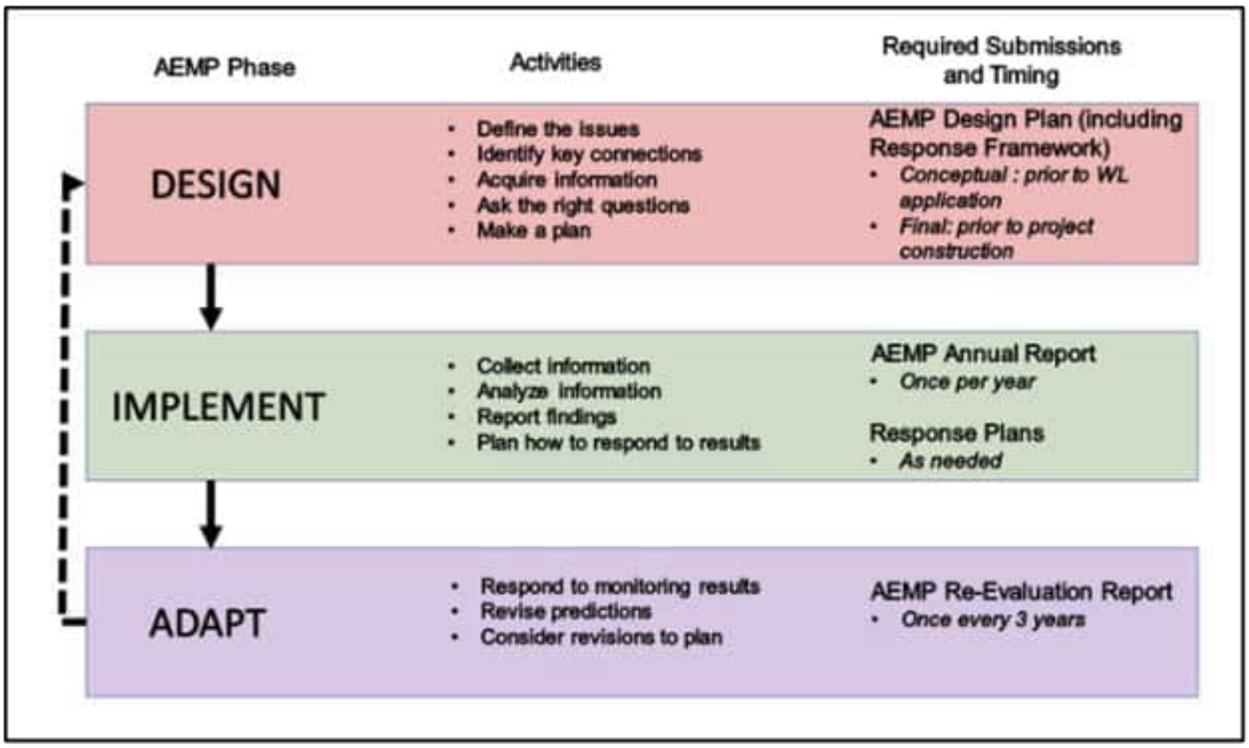

Figure 4-2: GNWT AEMP Guidance Steps (MVLWB/GNWT 2019)

There are three main interrelated components of the AEMP:

- Water quality monitoring in the Mackenzie River and Bosworth Creek (Section 5.1).
- Small fish monitoring in Bosworth Creek (Section 5.2).
- Large fish monitoring in the Mackenzie River (Section 5.3).

4.2 General Issues and Concerns

As per the MVLWB/GNWT (2019) Guidelines, the first step in the development of an AEMP is to identify the issues and concerns associated with a development.

Typically, this step would occur before development took place and would include descriptions of the type of proposed developments, proposed changes to the landscape, and the subsequent proposed environmental management programs. However, as NWO has been in operation since the 1920s, the issues and concerns were based on the existing operations and historical observations rather than on how a proposed development would change the aquatic environment.

Direct engagement between Elders and community leaders with TRSA in Tulit'a on 14 September 2022 and in Fort Good Hope on 19 September 2022 identified concerns around fish populations, changes in the time of year of fish spawning (which influences taste) and the concern that Imperial's NWO could be influencing fish and water quality. A more detailed discussion of community consultations and review comments that were incorporated into the design of this plan is provided in Appendix B.

Community concerns are important in understanding context in how the data needs to be used and how site information can be applied to understand what potential inputs there are to the environment. These communications also help outline potential effects to be monitored. Effects-based monitoring allows for addressing concerns of end users and monitoring for facility inputs.

4.3 Infrastructure and Areas of Potential Concern

A detailed site-wide conceptual site model (CSM) is beyond the scope of the AEMP development as a site-wide CSM is under development through other programs. Although a CSM is not included in this design, information from the completed CSM will be used to confirm potential stressors that have the potential to influence environmental receptors once completed. In lieu of the completed CSM, potential inputs to the aquatic environment from NWO via relevant infrastructure and associated areas of potential concern are described in this section (and summarized in Table 4-1) as a design basis for monitoring and data interpretation. This list of infrastructure and areas has been defined via expression of concern by community members to Imperial in discussions. These infrastructure and areas represent potential sources, where water chemistry monitoring is focused on monitoring exposure pathways, and biological response indicators monitor receptors (Figure 4-3).

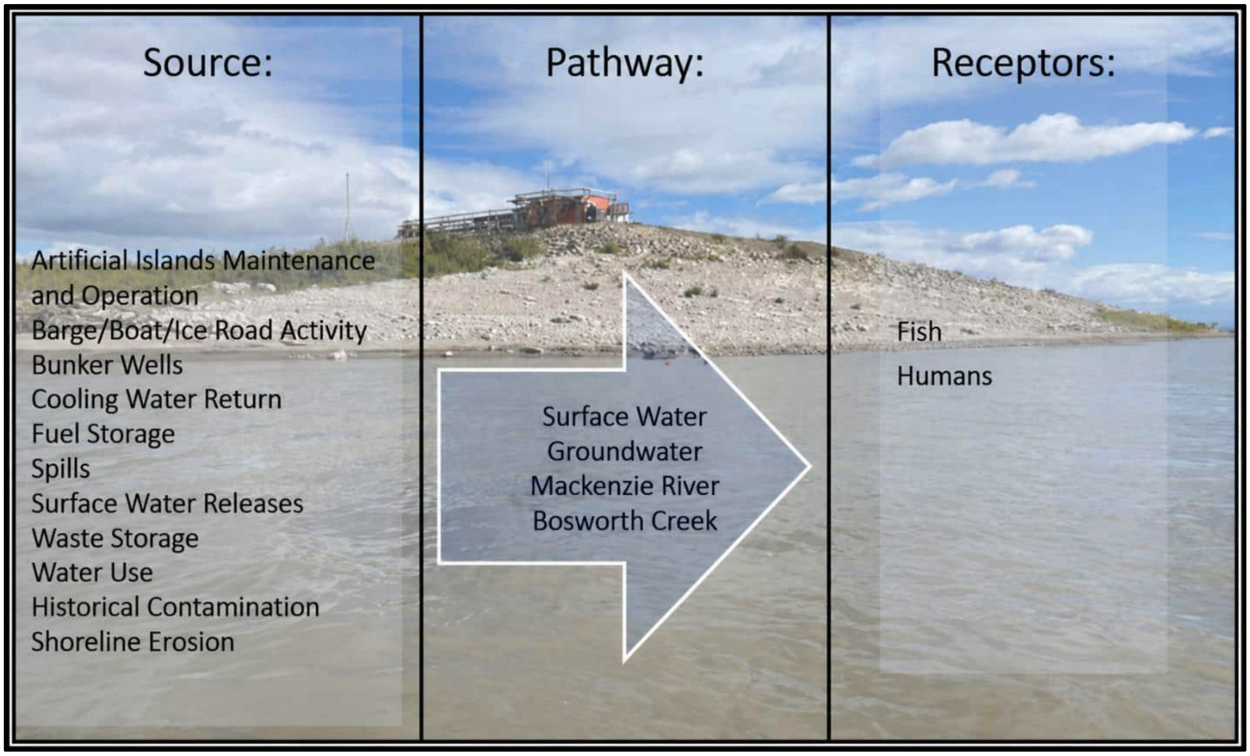

Figure 4-3: Aquatics Source – Pathway – Receptor Diagram

- Artificial Islands:
  - Imperial's main operational areas include six artificial islands (1 (Rayuka), 2 (Rampart), 3 (Dehcho), 4 (Ekwe), 5 (Iteh K'ee), and 6 (Little Bear)). Annually, these islands are inspected to ensure structural integrity. Depending on the inspection results, maintenance may be required to repair armouring and berms.
  - The artificial islands and their maintenance may increase sediment loading to the river through erosion.
- Barge/Boat/Ice Road Activity:
  - In order to access cross river island facilities, Imperial maintains marine operations during open water season (June – October) and an ice bridge during winter (December to April). The marine operations include a crew (passenger) boat for transporting workers, a barge for moving vehicles and equipment, as well as several emergency response boats on standby in the event of an emergency.
  - Potential inputs include fuel spills from boats or other transported equipment or chemical spills from materials during transport.
- Bunker Wells:
  - Bunker wells are production and water injection wells that are below ground in engineered structures. This means that all of the well components and piping are below ground and contained within the structure ("bunker"). Bunkers are equipped with lids that are bolted down before break-up, and emergency shutdown systems that are activated automatically.
  - The bunker wells can be subject to annual flooding.

- Cooling Water Return:
    - Fresh water from the Mackenzie River is used in the CPF through cooling (cooling equipment) and freshwater injection. Water used for cooling is carried through pipes which prevent it from contacting other substances within the CPF (i.e., not process affected). Similar to municipal drinking water systems, water is treated with chlorine to prevent bacterial growth. As water enters the CPF, it is tested at a location known as the "inlet" (SNP Station S13L1-007-1). After the water is tested and has completed its loop through the process, it will end up in the settling pond. The settling pond allows for natural settling of any sand/silt in the water before being returned to the Mackenzie River. Water is tested again at a location known as the "outlet" (SNP Station S13L1-007-2) to ensure it meets the facility's discharge criteria outlined in Water Licence S13L1-007 Part E, Item15 before discharge to the river.
    - As this water is used in a closed system, changes in water quality from the source water in the river are expected to be minimal and may include increased temperature, reduced dissolved oxygen or increased dissolved metals from interaction with the piping system.
- Fuel Storage:
    - Several fuel storage locations (gasoline and diesel) exist across the site for the purpose of operational activities. Typical uses of fuel are marine activities, emergency generators, vehicles and equipment. Designated fuel storage locations are documented, under controlled access, and located in berm-enclosed areas. More information on fuel storage can be found in the Fuel Management Plan, a subset of the Spill Contingency and Response Plan filed with the SLWB.
- Oil and Produced Water Storage:
    - Crude oil is stored in tanks at the CPF and the Refinery Tank Farm prior to shipment through pipeline to Alberta.
    - Lubricating oils are stored in tanks in the CPF area for use in the operation.
    - Produced water is stored in tanks in the CPF area before recycling or down-hole injection disposal.
- Flowline Network:
    - Networks of flowlines are used at the Norman Wells site to connect the field operations (production areas) with the CPF. These lines transport production fluids (oil and produced water) to the CPF. Depending on risk and age of the flowline, etc., maintenance schedules are put in place and may include maintenance pigging, chemical inhibition, and biocide applications. All of these maintenance-type activities (e.g. chemical inhibition) are internal flowline applications. Inline inspection and defect assessments may also be completed to assess flowline condition, remaining life, and operating risk. In addition, flowlines that are buried under the Mackenzie River are subject to an annual bathymetric survey in which the depth of cover over the buried flowline is verified. On occasion Imperial has undertaken work to increase depth of cover on specific flowlines to maintain protective cover. A Flowline Integrity Management Plan is filed with the SLWB and provides more detail on the various flowline programs used on site.
- Spills:
    - Several fluids are either stored in tanks or transported via pipelines, or both, at NWO. These include pipelines carrying, or tanks containing, crude oil or produced water, tanks containing refined hydrocarbons (gasoline, diesel), natural gas, propane, methanol and various salts and solvents.

- A failure of a pipeline or tank could release its contents either directly to the aquatic environment or to the ground where it could reach the aquatic environment through runoff or infiltration to groundwater that discharges to Bosworth Creek or the Mackenzie River.

- Surface Water Release:
  - During the spring/summer seasons, snowmelt and rainwater collect in ditches and impound basins. Often these collection areas are overcome by water and need to be managed to prevent overflow situations. As a result, Imperial undertakes surface water management activities. Activities include the collection of representative samples for field testing and/or laboratory analysis and controlled water releases to surrounding environments. Tested water that meets the requirements in the outlined in Annex A, Part E of the Water Licence is released back into the environment. Data associated with surface water management activities is reported in the Monthly Water Use Report to the SWLB.
  - Surface water release may also include direct runoff of precipitation from roads or pads to the environment. Inputs to the environment from runoff may include mobilization of spilled substances such as oils or other chemicals used on site or elements occurring in soil and rock that dissolve and mobilize from exposed surface material (such as metals in certain soil and rock fill).
- Waste Storage:
  - Hazardous, non-hazardous, and industrial waste is generated and managed on site. Depending on the waste stream, it may be treated on site or transported to facilities outside of the NT for disposal. Domestic garbage is managed by services provided by the Town of Norman Wells and is disposed of at the local landfill.
- Water Use:
  - Water is withdrawn from the Mackenzie River for cooling and for some maintenance and operations uses. Mackenzie River water is also used to construct a seasonal ice road between the mainland and islands. The majority of water used is used within the cooling system and the ice road construction; in both cases, that water is returned to the river. All water withdrawn is measured and reported in the Monthly Water Use Report to the SLWB.
- Historical Activities and Legacy Contamination:
  - Imperial has been operating in Norman Wells since the 1920's. Historical activities include but are not limited to refinery operation, waste disposal, fire training grounds, etc. Imperial has a separate program to assess, monitor, and mitigate historical impacts.
  - Legacy contaminated areas in NWO include former well sites, flare pits, historic spills, the former refinery area and drilling fluid sumps. These areas are generally managed through ongoing progressive reclamation of the site. Migration through groundwater to the aquatic environment could include hydrocarbons, PAHs, metals and salts from historical operations. Information gathered from legacy area environmental assessments has been used to determine KIPs.
- Shoreline Erosion:
  - Increased sedimentation rates to the Mackenzie River could exist around NWO as there is increased use of the shoreline in that area compared to undisturbed areas. Furthermore, there is some reduction in vegetation in certain areas. The artificial islands would also represent areas of increased erosion rates but also increased deposition rates.
  - Erosion can increase suspended solids in the water and could mobilize both naturally occurring and anthropogenic parameters held in the soil.

Table 4-1: Areas of Concern Representing Potential Sources, with Relevant Pathways and Receptors identified.

Areas of Concern (Potential Sources)	**Relevant Pathways and Receptors**			
	Humans Health	**Fish**	**Water Quality**	**Water Quantity**
Artificial Islands Maintenance		☑	☑	
Barge/Boat Activity	☑	☑	☑	
Bunker Wells			☑	
Cooling Water Return		☑	☑	
Fuel Storage	☑		☑	
Oil and Produced Water Storage	☑		☑	
Flowline Maintenance			☑	
Historical Activities	☑	☑	☑	
Shoreline Erosion			☑	
Spills	☑	☑	☑	
Surface Water Release	☑		☑	
Waste Storage	☑		☑	
Water Use			☑	☑

4.4 Incorporation of Traditional Knowledge (TK)

The *Guidelines* (MVLWB/GNWT 2019) outline the importance and role of TK in designing an AEMP. Insights that TK provide as a result of the connection the Sahtu people have to the Mackenzie River and land are vital for the success of the AEMP.

The Working Group has been convened to develop and review key components of the AEMP and provide a means for TK incorporation. Future iterations of the AEMP will continue to rely on the community to gather and incorporate TK.

Engagement with Elders regarding species relied upon for subsistence activities, catchability, monitoring locations and execution safety was conducted via in-person interviews and accompaniment on boats on 14 September 2022 in Tulit'a and 19 September 2022 in Fort Good Hope.

Specifically, TK and community input have been used in the following ways:

- Water Sample Location Selection:
    - New locations that represent a concern or interest.
    - Accessibility and informational relevance of locations.
- Large Fish Target Species:
    - Species have been selected based on community input to ensure fish of high value to the communities (i.e., fish that people eat) are targeted in the study.
    - TK is incorporated in annual planning to ensure target fish are harvested as close to spawning for their species in the region as possible.
- Large Fish Analytical Methods:
    - Large fish will be dissected in the communities in collaboration with local fisher people, with consultant biologists and locals assessing fish with their own perspective. TK provides contextual observational scientific data related to condition (e.g., colour and texture of tissue, eye condition, colour and texture of organs, signs of illness). These observational data will be used to provide context to analytical data produced from chemical analysis of tissues.

The importance and sacredness of TK is meant to be incorporated and respected herein. Imperial and their consultants will work with the communities to ensure that the TK that is shared will be used in accordance with the community's wishes to enable "two-eyed" seeing (braiding Western Science with Traditional Knowledge to evaluate concerns). This collaborative learning approach will be crucial in the successful execution of these programs. Further information on TK data management is provided in Appendix C.

It is anticipated that the Working Group will continue to operate throughout execution of the programs to facilitate the incorporation of TK, evolving concerns, study design input, and to improve the overall relevance and value of results.

5. Methods and Analysis

5.1 Water Quality Monitoring

The Water Quality component of an AEMP is both effects- and stressor-representative. Water is a receptor in its own right but is also the pathway for exposure to aquatic species; therefore, the water monitoring program is able to serve two purposes:

- Effects-based monitoring of water quality through understanding upstream and downstream water quality over time and comparison of those two states, i.e., the effect of degraded water quality.
- Stressor-based information to inform potential variations observed in the effect-based small and large fish programs, i.e., the cause of degraded fish health.

5.1.1 Sampling Approach

The objective is to develop an aquatic monitoring program with a scope that is appropriate for the risks from day-to-day operations at NWO, is achievable within the challenging environment and is planned to be executable within the seasons typical for safe access (open water and fully frozen).

The water quality monitoring program has been built using the following:

- Incorporation of previous sampling locations suitable for maintaining historical dataset.
- Target locations that consider representativeness of the aquatic environment while also being safely accessible.
- Target locations that represent conditions at and around the NWO facility.
- Target locations near Fort Good Hope to address concerns expressed by that community.
- Target locations releasing natural seep oil in the Mackenzie River.
- Target sampling dates that represent spring, summer, autumn and winter conditions.
    - *Note that sampling is not evenly spread through a year due to safety limitations.*
- Maintaining consistency in sample timing year to year.
- Keeping Mackenzie River and Bosworth Creek data separate.
- Defined Key Indicator Parameters (KIPs) that relate to potential influences.
- Defined data evaluation methods.
- Defined data quality assurance and quality control (QA/QC) methods.
- Defined data reporting methods.

5.1.2 Sampling Design

Monitoring is designed to ensure that:

- Samples are collected both upstream and downstream from potential points of influence or known stressors.
- there is sufficient spatial resolution to enable isolation or attribution of changes to specific reaches of the aquatic environment.
- there is sufficient temporal resolution to enable characterization of seasonal patterns and allow for associated variability to be accounted for.

Method and sample location trials conducted in summer 2022 tested the viability and access considerations for proposed sampling. Program development field test activities and results are provided in Appendix B.

5.1.3 Site Selection

Consideration of existing water quality programs and community input were used to define where sampling should continue, be enhanced, or scaled back to achieve the goal of being able to detect and quantify changes and trends in water quality.

The watercourses of interest for surface water quality near NWO are Bosworth Creek and the Mackenzie River. Conditions at upstream reference locations and sampling locations downstream will be compared to detect potential influence of the Imperial Site (Section 4.3). Sites will be selected based on physical characteristics to ensure water chemistry is representative of the receiving environment.

The upstream sampling locations on the Mackenzie River and Bosworth Creek will continue to document background conditions where there is no potential influence from NWO, whereas downstream locations on these respective rivers will be placed at areas of potential concern to detect any influence.

5.1.4 Sampling Frequency

Sampling will occur three times annually in open water conditions through the river's flow regime, which includes high (spring), moderate (mid-summer), and lower (autumn) flows. Under-ice sampling initiated based on direction by the SLWB (2021) commenced in 2022 and will continue to provide a fourth sampling event annually. Note that under-ice sampling is limited to the Mackenzie River, as Bosworth is generally frozen to ground in winter and passive sampling is not conducted under ice due to challenges in retrieval of the devices once they have frozen in (Section 5.1.5). Table 5-1 summarizes the sampling annual schedule and methodology.

Table 5-1: Sampling Frequency and Methods

Sampling Event	Typical Time of Year	Sample Number of Times per Year	Number of Locations Sampled	Sample Method
Under Ice Sampling	February - March	1	12 (Bosworth not included)	Grab sample. No field parameters
High Flow	June	1	15	Grab sample. Deploy passive samplers.
Moderate Flow	August	1	15	Grab sample and passive sample.
Low Flow	September/October	1	15	Grab sample and passive sample.

5.1.5 Method Development – Passive Sampling

Advocacy for the use of Passive Sampling Devices (PSDs), particularly semi-permeable membrane devices (SPMDs), was reiterated via third-party review of Version 3 of the AEMP as a method for quantifying low concentrations of hydrocarbon exposure in aquatic environments at NWO (HESL 2021). The rationale for suggesting the use of such devices is that grab samples are insufficient for quantifying time-integrated or environmentally relevant conditions. However, the Mackenzie River is a system with a high level of suspended solids, which can interfere with detection of organic contaminants with SPMDs by virtue of the tendency of hydrophobic organic compounds to adsorb to particles in the water column. Though SPMDs are intended to provide insight into the bioavailability of compounds, the same confounding properties that a silty (high suspended solids) river has the adsorption of F3-F4 hydrocarbons limit the availability of these compounds to SPMDs.

Trial activities in summer 2022 (Appendix B) tested the feasibility of deployment and effectiveness of PSDs in quantifying petroleum hydrocarbons and PAHs via a pilot study. Three PSD technologies, including passive diffusion bags (PDBs), low-density polyethylene (LDPE)-thin film devices and triolein film SPMDs, were deployed for varying lengths of time at Tulit'a and Norman Wells in the Mackenzie River and in Bosworth Creek. Shallow zones at Norman Wells and Tulit'a were targeted to ensure the PSDs were submerged and could successfully be retrieved.

The results of the pilot study are included in Appendix B and summarized as follows:

- Deployment and retrieval of PSDs in the Mackenzie River and Bosworth Creek is viable.
- Deployment systems and locations must consider:
    - Feasible locations that meet the intent of the sample location.
    - Sufficient water depth to ensure continued exposure through changes in water levels over the deployment period.
    - Accessibility throughout the season.
    - Safety of the people deploying and retrieving devices.

    - Damage from floating debris.
    - Vandalism.
- SPMDs are a viable and preferred option for PAH passive sampling and analysis.
- PDBs are a viable and preferred option for light-end (soluble) PHC passive sampling and analysis.
- PHC F3 and F4 can be analyzed from water collected in PDBs.

The results suggested that film-based passive samplers can detect PAH concentrations in water (LDPE thin-film devices and triolein film SPMDs). A limitation identified during the pilot study and supported by findings obtained by ECCC in the oil sands region is that under-ice deployment of SPMDs results in low PAH concentrations, is labour intensive, and exposes workers to hazardous conditions working on ice (ECCC 2018; Appendix D). Based on these results, winter deployment of passive samplers is not included in the AEMP, and winter sampling includes grab samples only.

SPMD analysis for PAHs has been able to achieve the desired lower detection limits (parts per million vs. parts per ten thousandth for grab sample methods), allowing for quantification of water concentrations via PAH mass on the triolein film. Without addition of this sampling technology, results remained below detection limits in grab samples.

PHC analysis from PDBs is run using standard laboratory analytical methods but is meant to achieve greater sensitivity and biologically relevant concentrations via the partitioning of hydrocarbon samples to the environment within the PDB over time (USGS 2000). PDBs are generally used and designed for groundwater sampling in groundwater monitoring wells and have been adapted for use in this scenario, though their value over grab sampling has not been established due to results being below detection limits – matching previous grab sampling results.

The limitation in using LDPE thin-film devices and triolein film SPMDs for PHC sampling is the absence of available commercial analysis (pers. comm. Bureau Veritas Labs, ALS Global, SGS Axys Environmental) or successful use in detection or surveillance of PHC concentrations within available research. Bureau Veritas previously offered PHC analysis for SPMDs but has now ceased to offer that analysis. SGS Axys Environmental was chosen to analyze SPMDs for PAHs based on their familiarity with SPMD extraction methodology and analysis and their being the only commercial laboratory that offers SPMD analysis. Note that the University of Alberta offers SPMD analysis but indicated they do not have capacity to support the program. Environment and Climate Change Canada (ECCC) has also been using SGS Axys for similar work in and around the Alberta oil sands area. Imperial and their consultants will continue to assess commercially available options.

Specialized non-commercial, non-accredited lab services were secured in order to enable chemical analysis of the SPMDs deployed over August and September of 2022. Results are included in Appendix B.

5.1.6 Water Sample Locations

Water sampling locations are presented on Figures 1 to 3 and are summarized in Table 5-2.

Table 5-2: AEMP Water Sampling Locations (Figures 1 to 3)

Name	Target Environment	Monitoring Block	Potential Facility-Related Stressors	Number of Samples per year	Latitude (Northing)	Longitude (Easting)	Comments
Upstream Sample Locations							
AEMP-US-01 (Tulita/Midway Island)	Mackenzie; near shore river flow	Upstream background	None	4	64.97904	-126.09987	After mixing from Bear River; approx. 30 km upstream of NWO.
AEMP-US-02 (10 Mile Island)	Mackenzie; near shore river flow	Upstream background	None	4	65.23335	-126.73602	Approx. 16 km upstream of NWO.
AEMP-US-03 (6 Mile Island)	Mackenzie; near shore river flow	Upstream background	None	4	65.27085	-126.77791	Approx. 10 km upstream of NWO.
AEMP-US-04 (Bosworth Creek)	Bosworth; main creek flow in a deep cutbank	Bosworth Creek	None	3	65.29494	-126.88292	Upstream of facility and Enbridge line 21.
AEMP-US-05 (Bosworth Creek)	Bosworth: upstream from winter road	Bosworth Creek	None	3	65.29791	-126.88653	Upstream of facility, Enbridge line 21 and winter road.
AEMP-US-06 (Town Dock)	Mackenzie; near shore river	Upstream background	None	4	65.27810	-126.84299	In an area of natural seeps, immediately upstream of NWO,
Downstream Sample Locations							
AEMP-DS-01 (Bosworth Creek)	Main creek flow in a deep cutbank	Bosworth Creek	Imperial site	3	65.28184	-126.86905	Near the Lower Bosworth Bridge within NWO.
AEMP-DS-02 (Marine Dock)	Near shore flow, near facility	Imperial site	Boat Activity and Water Release	4	65.27932	-126.87707	Within the facility footprint. Near areas of natural oil seeps.
AEMP-DS-03 (Island 3)	Mid-channel flow	Imperial site	Flowline; Island Maintenance	4	65.27790	-126.91692	Off an artificial island at the downstream end of the facility footprint.
AEMP-DS-04 (Refinery)	Mid-channel flow	Imperial site	Imperial site	4	65.27954	-126.84972	Within the facility footprint. Near areas of natural oil seeps and a potential contamination source.
AEMP-DS-05 (Radar North)	Mid-channel flow as it splits around an island	Near-field downstream	Imperial site	4	65.30947	-127.09514	Approximately 10 km downstream of the facility of the north side of a natural island.
AEMP-DS-06 (Fort Good Hope-Blue Fish)	Deep pool area near natural islands – identified by locals as a high value fishing area	Far-field downstream	Imperial site	4	66.18755	-128.97973	Upstream of the Ramparts on the west side of the River Approximately 17 km upstream of Fort Good Hope and 190 km downstream of Norman Wells.
AEMP-DS-07 (Fort Good Hope – Ramparts)	Mid-channel flow	Far-field downstream	Imperial site	4	66.17896	-128.92648	Directly upstream of the Ramparts on the east side of the River Approximately 17 km upstream of Fort Good Hope and 190 km downstream of Norman Wells.
AEMP-DS-08 (Radar South)	Mid-channel flow as it splits around an island	Near-field downstream	Imperial site	4	65.29882	-127.10331	10 km downstream of the facility of the south side of a natural island.
AEMP-DS-09 (Goose Island)	Downstream of the facility	Near-field downstream	Imperial site	4	65.28158	-126.96288	At the end of the facility footprint downstream of Goose Island.

5.1.7 Sampling Methods

All samples are to be collected and handled using approved Standard Operating Procedures, the Protocols Manual for Water Quality Sampling in Canada (CCME 2011) and the Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment, Volume 4 – Analytical Methods (CCME 2016), where available, that minimize uncertainty and cross-contamination.

5.1.7.1 Grab Samples

Open water grab samples are to be collected by wading into the stream and using an extendable pole with a sample cup to extend the reach. Samples are to be collected upstream of where the sampler is standing to minimize influence from sediment disturbance.

A sample will be collected by lowering the sample cup to a depth of approximately 30 cm (or mid-column if depth is less than 30 cm) and bringing the full sample cup to the surface. Samples will be collected by placing the mouth of the cup facing into the flow. Water will be poured into laboratory-supplied sample containers specific to the analysis required and following the laboratory instruction for each bottle type. Where applicable, sample preservatives are pre-charged in the sample container by the laboratory. Water for analyses requiring filtration will be collected in a clean sample bottle and then filtered on-site using a 45 µm inline filter and placed into the appropriate containers.

In winter, a borehole through ice will be drilled, and samples will be collected by lowering an extendable pole into the open hole. Samples will be collected from approximately 30 cm below the bottom of the water surface. Sample bottles will then be filled in accordance with the above.

Prior to sample collection, the sampling cup will be triple rinsed using water from the waterbody at the sample location. Rinse water is to be discarded downstream of the sampling location or on the ice away from the borehole.

Samples will be stored in coolers, on ice, for shipment to an accredited laboratory. Chains of custody will be completed for each laboratory submission.

5.1.7.2 Passive Samples

Passive samplers will be deployed at all sample locations in the spring, summer and autumn events. Passive samplers will not be deployed under ice in the winter due to challenges of deployment and retrieval. All PSDs will be deployed for a period of approximately 30 days, with actual deployment times and durations recorded. Results for SPMDs will be time-integrated to account for any deployment time discrepancies.

Passive sampler deployment and retrieval are challenged by deep, fast-moving water, changing water levels and the possibility of damage by people, boats, wildlife or drifting debris.

Passive samplers in the Bosworth Creek will be secured to an articulating arm system with a buoy to allow the PSDs to be suspended in the water column and adjust vertically with changes in water level (Figure 5-1).

Figure 5-1: From Top Left to Bottom Right Photographs Show Examples of PDBs Being Filled with Organic Free Water; Triolein SPMD on Bracket; PSD Anchoring System for the Mackenzie River; SPMD Carrier Being Deployed Into the Mackenzie River; PSDs Deployed in Bosworth Creek; and PSDs After Being Retrieved from the Mackenzie River

Due to seasonal drops in water level in the Mackenzie River, a shore-based deployment system will not be effective as devices may not remain submerged during the required deployment time. PSDs will be secured to a heavy anchor to keep them in place and a buoy to keep the devices near surface (Figure 5-1). The target minimum depth for PSDs will be approximately 30 cm (12") below water surface (Alvarez 2010). Cables will be used to create additional anchor points on shore to aid in device retrieval. All devices will be secured using high strength stainless steel cable and fasteners.

5.1.7.2.1 Passive Diffusion Bags

A minimum of two PDBs will be deployed at each sample location. Additional bags may be deployed to collect field duplicates or to ensure against potential loss. PDBs will be filled with laboratory-supplied organic free water prior to deployment (Figure 5-1).

Following approximately 30 days of deployment, water in PDBs will be transferred to laboratory-supplied sample bottles for standard BTEX,PHC F1 through F4 and total petroleum hydrocarbon (TPH) analysis. Once collected, samples will be handled in accordance with methods described in Section 5.1.7.1.

5.1.7.2.2 Semi-Permeable Membrane Devices

There is limited guidance or standards for SPMD deployment, however, there are two procedural documents that have been reviewed and incorporated for sampling procedure: the Guidelines for the Use of the Semipermeable Membrane Device (SPMD) and the Polar Organic Chemical Integrative Sampler (POCIS) in Environmental Monitoring Studies developed by the United States Geological Survey (USGS, 2010) have been reviewed in developing this methodology and ECCC (2018) Standard Operating Procedures for Field Water Quality Sampling using Semi-permeable Membrane Devices (SPMDs). ECCC 2018 is prescriptive in detail and will be followed for field sample methods; it is included as Appendix D.

Triolein film SPMDs will be stored frozen prior to and after deployment and during shipping to an accredited laboratory. Triolein film will be deployed within specially designed brackets (Figure 5-1) and placed in a carrier (Figure 5-1). Three SPMD strips will be deployed for each sample to allow for field duplicate analysis and to ensure against loss.

Factors such as water temperature, water flow rate and buildup of a biofilm on SPMD surface can affect the rate at which chemicals adsorb to the film. These factors can reduce water concentration accuracy. In order to reduce these effects, a performance reference compound (PRC) will be pre-charged into each SPMD film to quantify potential degradation of analytes during sample collection as a positive control. Dibenz[*a,h*]anthracene-d_{14} will be used as a PRC. The PRC method was developed by Huckins and colleagues (2002).

5.1.7.3 Field-Measured Parameter Sampling

At all sampling locations, in situ measurements will be taken as water samples are being collected for laboratory analysis, except during winter under-ice sampling due to technical challenges. In situ measurements will consist of dissolved oxygen concentration (DO), pH, temperature, and electrical conductivity (EC) using a multi-probe water meter.

In-situ measurement will be collected by suspending the probe in laminar flow within the water column at approximately 30 cm below the water surface. Results will be recorded once the meter has stabilized.

5.1.7.4 Laboratory Analysis

All samples collected for laboratory analysis will be shipped to Canadian Association of Laboratory Accreditation (CALA) accredited commercial laboratories within Canada. Laboratory analytical methods will be summarized in the laboratory certificates of analysis (CoAs) provided in annual reports. Note that SPMD analysis methods are proprietary and are deemed confidential by SGS Axys.

5.1.7.5 Safety

The Mackenzie River is a dangerous environment and travel on the river could be fatal if strict safety protocols are not met. Sample crews will not sample under unreasonable conditions which may result in periodic missed samples. Such conditions may include unpredictable ice cover, high stream flows, adverse weather events or dangerous wildlife near sample locations.

5.1.8 Quality Assurance and Quality Control

A quality assurance/quality control (QA/QC) program is incorporated into the field and laboratory methods utilized to ensure accuracy during sampling and to quantify any uncertainty introduced during the field execution or laboratory analysis. QA/QC methods are described in Appendix E.

5.1.9 Water Sample Analytical Suite

Laboratory analysis of water samples will include the parameters listed in Table 5-3.

Imperial has identified several KIPs of concern based on potential site inputs and findings from a Special Effects Study (Imperial 2022). All parameters will be analyzed, but data evaluation will focus on KIPs and data from PSDs. KIPs are prioritized indicators that are linked to biological domains in terms of providing energy to living organisms (e.g., nutrients) or having the ability to disturb biological processes that consume energy – both being relevant to establishing and maintaining health. Additional KIPs were added through the Working Group

The KIPs are shown in bold text in Table 5-3.

Table 5-3: Water Quality Variables for Laboratory Analysis

Category	Parameters	Ecological Significance	Sample Method
General	Electrical conductivity (measured and calculated), Dissolved Oxygen (DO), pH, Temperature, Total hardness as $CaCO_3$, Total alkalinity as $CaCO_3$	Extreme pH values can have direct toxic effects on aquatic organisms and alter toxicity and mobility of many pollutants. Toxicity of many metals is inversely related to hardness	Grab sample Field analysis for: DO, pH, EC, temperature
Indicators	**Chloride**, **Sulphate**, **Iron**, Manganese, **Total dissolved solids (TDS), Total suspended solids (TSS)**	High TDS levels can have a negative effect on aquatic life. High TSS may hinder photosynthetic activity and hinder the exchange of gases over the gills of fish and other aquatic organisms.	Grab sample
Cations, Anions, and Ion Balance	**Calcium**, **Magnesium**, Potassium, Sodium, Bicarbonate, Carbonate, Hydroxide, Anion sum, Cation sum, Ion balance	May affect toxicity of other constituents.	Grab sample
Organics	Total organic carbon, Dissolved organic carbon,	Elevated levels of organic compounds may be harmful to aquatic organisms.	Grab sample
Nutrients	Nitrite as N, Nitrate as N, Nitrate plus nitrite as N, Total Kjeldahl nitrogen (TKN), Ammonia as N, Sulphide, Sulphur (total and dissolved), Orthophosphate	Un-ionized ammonia is toxic to aquatic organisms, and toxicity increases with both temperature and pH. Nitrite can be toxic to fish. Elevated nitrate and orthophosphate can lead to increased primary production and increase the risk of eutrophication.	Grab sample
BTEX compounds	**Benzene, Toluene, Ethylbenzene,** m&p-xylene, o-xylene**, Total xylenes**	Varying degrees of toxicity	Grab sample (winter) PSD - Passive Diffusion Bag
Select Hydrocarbons	Oil and grease, PHC F1 (C6-C10), PHC F1 (C6-C10) – BTEX, PHC F2 (>C10-C16), F3 (>C16-C34) and F4 (>C34-C50)	Varying degrees of toxicity	Grab sample (winter) PSD - Passive Diffusion Bag
Polycyclic Aromatic Hydrocarbons (PAHs)	Acenaphthene, Acenaphthylene, Acridine, Anthracene, Benzo(a)Anthracene, Benzo(a)Pyrene, Benzo(b,j)Fluoranthene, Benzo(c)Phenanthrene, Benzo(e)Pyrene, Benzo(g,h,i)Perylene, Benzo(k)Fluoranthene, Chrysene, Dibenzo(a,h)Anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-c,d)Pyrene, Naphthalene, Perylene, Phenanthrene, Pyrene, Quinoline	Varying degrees of toxicity	Grab sample PSD - SPMD
Alkylated PAHs	C1-Naphthalene, C2-Naphthalene, C3-Naphthalene, C4-Naphthalene, Biphenyl, C1-Biphenyl, C2-Biphenyl, C1-Fluorene, C2-Fluorene, C3-Fluorene, Dibenzothiophene, C1-Dibenzothiophene, C2-Dibenzothiophene, C3-Dibenzothiophene, C4-Dibenzothiophene, C1 Phenanthrene/Anthracene, C2 Phenanthrene/Anthracene, C3 Phenanthrene/Anthracene, C4 Phenanthrene/Anthracene, C1 Fluoranthene/Pyrene, C2 Fluoranthene/Pyrene, C3 Fluoranthene/Pyrene, C4 Fluoranthene/Pyrene, C1 Benzo(a)anthracene/Chrysene, C2 Benzo(a)anthracene/Chrysene, C3 Benzo(a)anthracene/Chrysene, C4 Benzo(a)anthracene/Chrysene, C1 Benzo(b,j,k)Fluoranthene, C2 Benzo(b,j,k)Fluoranthene, C1-Acenaphthene, 1-Methlynaphthalene	Varying degrees of toxicity	Grab sample PSD - SPMD
Metals and Trace Elements (total and dissolved)	**Aluminum**, Antimony, **Arsenic**, **Barium**, Beryllium, **Boron**, **Cadmium**, **Chromium**, Cobalt, Copper, **Iron**, Lead, Lithium, Mercury, **Molybdenum**, **Nickel**, Phosphorus, **Selenium**, Silicon, Silver, Strontium, Thallium, Tin, Titanium, **Uranium**, Vanadium, **Zinc**	Elevated levels of metals can be harmful to aquatic organisms.	Grab sample

5.2 Small-Bodied Fish Monitoring

Prior to November 2019, the AEMP has taken the form of community engagement, water quality monitoring, and an adaptive monitoring approach. Previous work in the Mackenzie River and Bosworth Creek showed no significant differences in endpoints relating to fish health that were evaluated (Hrudey and Associates 1988, Lockhart et al. 1989, Golder 2007, WorleyParsons 2012). Despite this historical assurance, concerns have been raised regarding the potential effects of NWO on local fish populations. In response to these concerns, Imperial has been leading the development of a small-bodied fish monitoring program to be incorporated into the AEMP.

5.2.1 Approach

Small-bodied target species have smaller home ranges and provide a more site-specific understanding of conditions. Therefore, the intent of the small-bodied fish study (SFS) is to further develop the site-specific understanding of fish health near NWO using a control-impact approach (Environment Canada 2012).

5.2.2 Program Development

The SFS has been completed during annual monitoring since 2023, and results from previous monitoring activities have been used to develop the following methodology. As few fish monitoring studies have taken place in areas upstream of Norman Wells and near Bosworth Creek, a desktop analysis was devised, followed by field verification and community engagement to establish sampling locations for small-bodied fish. The desktop analysis looked at constraints (accessible sites, similar environmental conditions, past capture success) and the field verification included electrofishing activities from 2022 to 2025 (Appendix B).

Analyses incorporated into the SFS are intended to answer the following questions:

- Is fish health in Bosworth Creek adversely influenced by NWO?
    - Compare fish health metrics (e.g., fish length, liver size, and gonad size relative to body weight) between potentially influenced sites and non-influenced upstream sites.
- Do NWO increase the body burdens of contaminants of potential concern in fish within Bosworth Creek?
    - Compare tissue residue concentrations of metals and PAHs between potentially influenced sites and non-influenced sites upstream using summary statistics, statistical comparisons among upstream and downstream sites, and control limit comparisons.

Although small-bodied fish are not typically used by communities, the target species is a year-round resident of Bosworth Creek and is benthic (meaning it spends most of its life living near or within the substrate, resulting in increased exposure to potential contaminants). Bosworth Creek supports the juvenile stages of many species used by the community (e.g., loche, jackfish, whitefish, and bluefish). Therefore, the SFS identifies potential concerns directly from the NWO, and monitors for adverse conditions that could affect large-bodied fish species found in the Mackenzie River during life history stages that require smaller, tributary habitats.

The development of the SFS is based on previous pilot-level sampling and community engagement detailed in Appendix B. Given low catch rates of potential target species and safety considerations for sampling on the mainstem of the Mackenzie River, the SFS focuses on monitoring conditions in Bosworth Creek. The large-bodied fish study (LFS) is better suited to characterizing fish health in the mainstem of the Mackenzie River and targets species utilized by communities (Section 5.3).

5.2.3 Program Design

5.2.3.1 Target Species Selection

An appropriate sentinel species is one with the following characteristics (adapted from Arciszewski et al. 2010 and Gray et al. 2018):

- Abundant.
- Sedentary.
- High site fidelity.
- Has measurable life history characteristics relevant for the assessment.

These characteristics give a high likelihood that any contaminant present in the water and the food chain will be taken in by a given fish and be detectable. As they do not change sites and are non-migratory, small-bodied fish caught near any potential source of contaminants should show a reaction.

Slimy sculpin have a small home range and high site fidelity. Several tagging, mark-recapture, and stable isotope studies have assessed the home range and site fidelity of slimy sculpin (Gray et al. 2004; Cunjak et al. 2005; Keeler and Cunjak 2007). Gray et al. (2018) summarized the median movements of slimy sculpin from these studies (range from 1 m to 30 m), and the maximum lateral movement documented in the literature was 209 m in Montana (Schmetterling and Adams 2004). The riffle-run composition and habitat quality of Bosworth Creek support a thriving population of sculpin based on previous sampling activities (Figure 5-2). Mochnacz and Reist (2007) surveyed several sites just upstream of the NWO and found abundant (>100 individuals) slimy sculpin as well. In addition, slimy sculpin are benthic and have been used in similar studies to show changes in fish health indicators (Gray et al. 2018). Consequently, slimy sculpin are the proposed target (sentinel) species for the SFS.

Sampling on Bosworth Creek from 2022 to 2025 has shown that slimy sculpin can be captured in sufficient numbers to meet the requirements of the MMER (i.e. 20 mature males and 20 mature females from each site). In addition, catch rates over this sampling period have not decreased, suggesting that sampling for the AEMP has not caused a population reduction within Bosworth Creek. Consequently, slimy sculpin is the only target species proposed for the SFS.

Figure 5-2: Example of a Slimy Sculpin Captured from Bosworth Creek

5.2.3.2 Fish Health Endpoints

Endpoints to test during the SFS have been based on third-party reviewer inputs, community engagement, and standards established in the MMER (Environment Canada 2012). The specific endpoints chosen for the SFS based on these inputs and analytical constraints are provided in Table 5-4.

Table 5-4: Parameters to Measure in Fish Monitoring Activities

Component	Parameters
Body Burden (PAHs)*	Total PAHs
Body Burden (Metals)*	Arsenic (As), Cadmium (Cd), Copper (Cu), Iron (Fe), Mercury (Hg), Nickel (Ni), Lead (Pb), Manganese (Mn) and Zinc (Zn).
Fish Health	Condition Factor: $$\text{Condition Factor} = \frac{length(mm)}{\text{weight(g)}^3} * 10^5$$ Relative liver size; Liversomatic Index (LSI). Relative gonad size; Gonadosomatic Index (GSI). General visual assessment and sex identification.
Mixed-Function Oxygenase*	Detoxifying Enzyme Content – CYP1A1 protein/mRNA content, and/or ethoxyresorfin-O-deethylase (EROD) enzyme activity assay.
*Note that due to the size of sculpin, a number of separate liver samples will be used to establish a composite sample achieving minimum sample size for lab analysis where required.	

Body burden of PAHs in composite samples and liver mixed-function oxygenase (MFO) detoxification enzymes are both indicators of hydrocarbon exposure (Headley et al. 2001, Tetreault et al. 2003) and have been shown to be effective in monitoring industrial activities (Spencer et al. 2008). Total PAH concentrations can be compared with other regional and site-specific monitoring program results.

The CYP1A protein is a member of the cytochrome P-450 superfamily of enzymes and is the most important MFO enzyme responsible for detoxification of xenobiotics (Hodson et al. 1991, Brooks et al. 2015). The activity and/or quantity of CYP1A has been established as a reliable biomarker for quantifying PAH exposure based on the biological process presented in Figure 5-3. The ethoxyresorufin-*o*-deethylase (EROD) assay is a well-established method for characterizing induction of this enzyme through its relationship with the aryl hydrocarbon receptor (AhR). However, the EROD assay is prone to interference from other AhR ligands, and no commercial laboratories are known to offer this bioassay. Hodson and colleagues (1991) developed the EROD assay and recognized at the time that future assays measuring protein or mRNA could be used to refine the quantification methods for CYP1A. Enzyme-linked immunosorbent assay (ELISA) methods for protein quantification are now also well-established, and commercial kits are available for the CYP1A protein. During the design phase of the AEMP, Imperial has worked with Innotech Alberta to develop an ELISA protocol for measuring CYP1A enzyme content in the liver of slimy sculpin collected. However, positive control results in 2025 did not provide results supporting the validation of this method. The ELISA method will continue to be implemented during the AEMP; however, alternative methods with improved validation (e.g. targeted mRNA quantification and EROD through academic institutions) will continue to be investigated as options for quantifying MFO activity in slimy sculpin. Therefore, CYP1A quantity in slimy sculpin liver will be characterized by EROD, mRNA or ELISA assays to compare PAH exposure between sampling locations on Bosworth Creek.

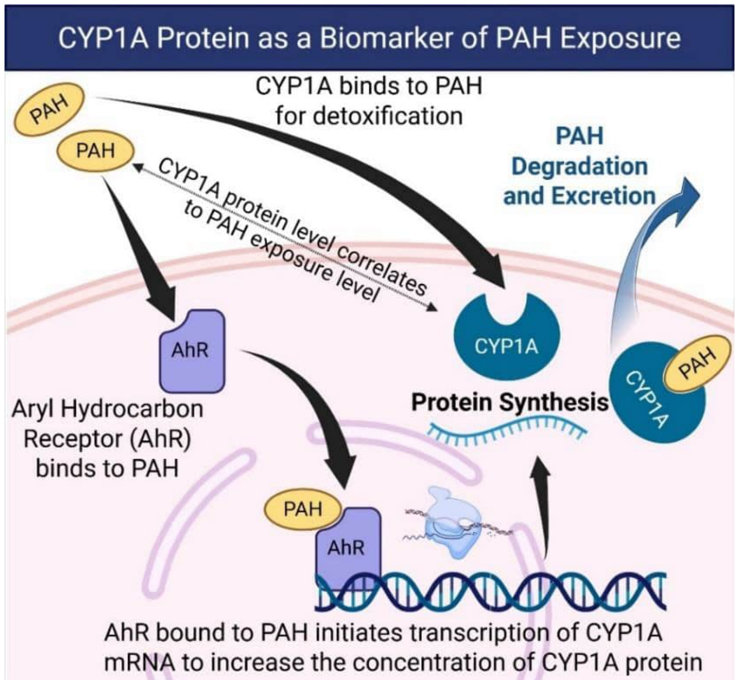

Figure 5-3: Summary of the Role of Aryl Hydrocarbon Receptor (AhR) Biological Pathway in the Degradation of Polycyclic Aromatic Hydrocarbons (PAHs) and the Rationale for CYP1A Protein Acting as a Biomarker for PAH Exposure

Due to the high suspended solids of the system and the tendency for metals to be introduced and distributed at a regional scale, these analytes have also been included as indicators for evaluation in fish tissue. The presence and levels of iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) are of particular importance as these metals are required for maintaining healthy cellular function and are integral to enzyme-mediated physiological processes critical to normal development and reproduction of fish. Whereas body burdens of PAHs can be influenced by rapid biotransformation in the liver (Fragoso et al. 2006), metals are sequestered and eliminated through a separate system of biological pathways (Wang and Rainbow 2010). Consequently, metal body burdens more closely reflect concentrations in the water, allowing them to act as potential tracers for overall contaminant exposure.

Energy availability and allocation in individual fish will be characterized as outlined in Figure 5-4, in addition to quantification of contaminant levels and liver response (i.e., MFO analysis). Overall fish condition (calculated using condition factor) will provide an estimate of energy storage. Gonad weight relative to body weight will be used as a proxy for measuring energy allocated to reproductive processes, while liver weight relative to body weight is a suitable proxy for determining energy allocated to processes required for survival and daily activities. These endpoints can be measured in the field and summarized using the gonadosomatic index (GSI) and liversomatic index (LSI) to make interpretation easily understood. These indices enable assessment of potentially disproportionate energy allocation to one process over another (Gibbons and Munkittrick 1994). The patterns associated with changes to energy allocation, with specific examples previously observed, are summarized in Table 5-5.

5.2.3.3 Supporting Water Quality

Integrated assessment of fish health will be achieved via water quality characterization in areas co-located with fish sampling activities. This quantification of stressors where fish develop and reproduce will provide context into effect-based results generated via health and reproduction endpoints. In the program as proposed, supporting water quality analyses in the fish health component will remain consistent with the core water quality monitoring program. Water and tissue chemistry provide exposure context, while condition, liversomatic index and gonadosomatic index are primary fish-health validation endpoints.

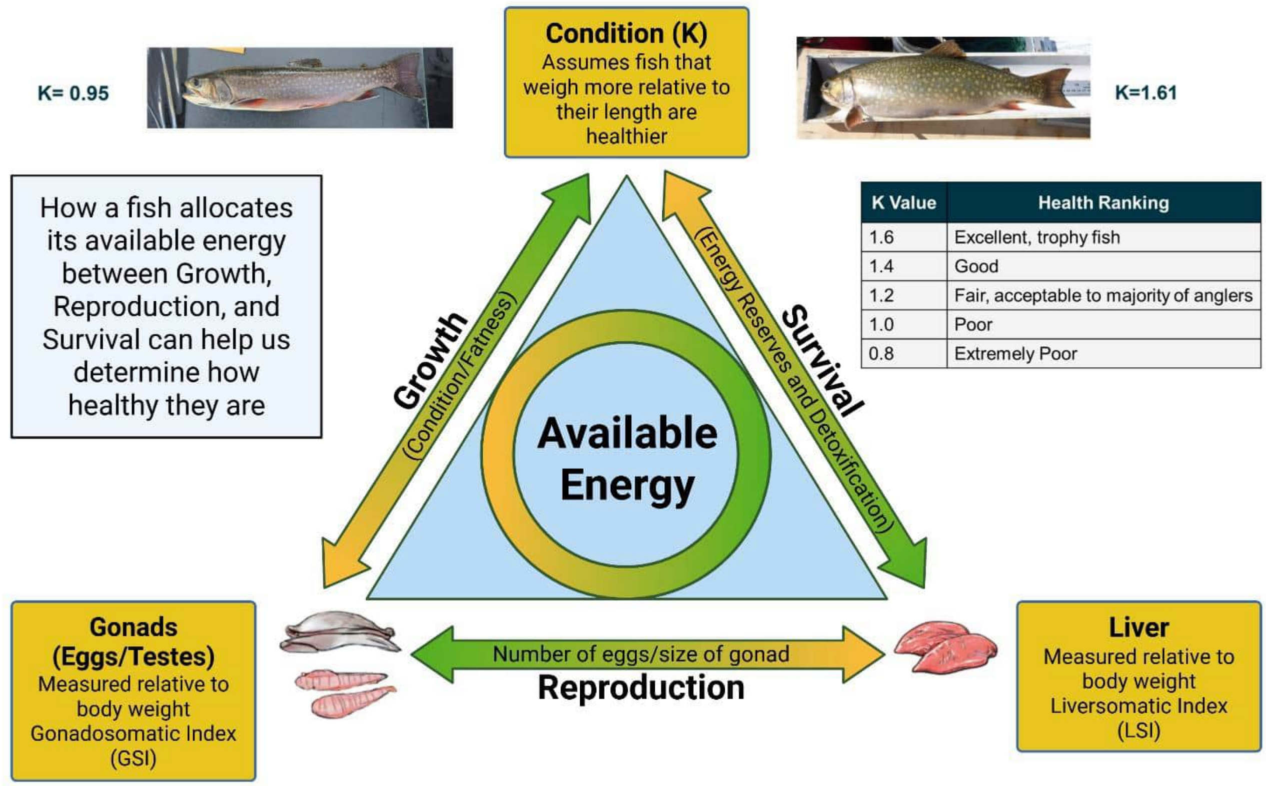

Figure 5-4: Condition Factor (K), Gonad, and Liver Energy Allocation Schematic, Where the Disproportionate Shift of Energy Allocation Away or to Any Direction as a Result of the Accumulated Environmental State Can be Used to Infer the Presence of Potential Effects

Table 5-5: Example Patterns of Response in Condition Factor, Relative Liver Size, Relative Gonad Size, that Represent a Change in Fish Health as Observed in Specific Examples

	Condition Factor	Relative Liver Size	Relative Gonad Size	Example
Abundance of Food/ Eutrophication (Excessive Richness/Nutrients)	+	+	+	Nutrients, forest fires, increased surface water, runoff/drainage
Potential Disruption of Reproduction Related Pathway	+	+	-	Some pulp and paper mills
Potential Stimulation of Reproduction Related Pathway	-	-	+	Some metal mines
Organic Pollutants, Including Polycyclic Aromatic Hydrocarbons (PAHs)	-	+	-	Municipal wastewater effluent, oil and gas activity, forest fires
Limitation of Food	-	-	-	Toxicity. Climate change

5.2.4 Sample Periods and Frequency

As per federal EEM Guidance (Environment Canada, 2012), the SFS will be sampled once annually at each location in Bosworth Creek. The AEMP proposes that sculpin are sampled once annually in the fall (September to October) based on life history characteristics, sculpin physiology, and federal recommendations for sampling sculpin in northern Canada (Arciszewski et al. 2010).

Fish undergo seasonal changes throughout their lives that influence the relative size of the liver and gonads. It is standard to sample before spawning begins and as close to the spawning period as possible to reduce variability in fish health studies and maximize environmental sensitivity. Slimy sculpin in northern Canada are likely to spawn in May-June (Arciszewski et al. 2010). Spawning is preceded by males establishing nests in rocky substrates, and males display nest-guarding behavior during this period (Brasfield et al 2013; Keeler and Cunjack 2007). Sampling conditions are typically poor at this time because of high flow rates and reduced water clarity. Therefore, sampling is scheduled for fall each year before the watercourse begins freezing and sampling conditions are optimal. This timing avoids impacting the target species during a highly sensitive life stage (i.e., mature fish spawning and/or incubating eggs) and aligns with the recommendations from Arciszewski et al. (2010) that suggest the following:

> *"The best sampling time for slimy sculpin in northern lakes would be late August or even into September, as close to ice-up as is reasonable to ensure enough time to sample. This permits an increased chance of capturing YOY [young of the year] sculpin, and more meaningful data on mature fish gonad sizes."*

Where successive years show an absence of trends and congruence in health indices at areas of concern with respective reference areas, the provision to default to minimal monitoring cycles less than annually is considered. Accordingly, the Adaptive Monitoring response framework (Section 6) will be applied to manage changes in frequency in a defensible manner.

5.2.5 Sampling Locations

There are three sampling reaches within the proposed SFS, two of which have been sampled since 2023 (AEMP-FS-01 and AEMP-FS-02) and a second upstream sampling reach that was added in 2024 (AEMP-FS-03; Table 5-6). The second upstream location was added to provide additional background data for comparison with the downstream sampling reach and thus improve the robustness of the monitoring program. Selected sampling reaches for the SFS and integrated water sampling sites are shown on Figure 5-5.

The proximity of sampling locations to each other was compared with slimy sculpin home range information in available literature to ensure there was no potential overlap in the fish population being sampled. The minimum distance between proposed sampling reaches in Bosworth Creek is approximately 550 m to ensure that populations sampled at these locations are distinct.

Table 5-6: Areas for Integrated Small-Bodied Fish Health and Water Quality Monitoring

Name	Description	Potential Facility-related Stressors	Latitude	Longitude
AEMP-FS-01 (Bosworth Creek Upstream)	• Downstream from natural seep. • Easily accessible. • Used as part of water quality monitoring program to date. • Sculpin Monitoring Location.	None	65.29246° to 65.29600°	-126.88119° to -126.88525°
AEMP-FS-02 (Bosworth Creek Downstream)	• Near known seeps and discharge sources. • Easily accessible. • Used as part of water monitoring program to date. • Sculpin monitoring location.	Imperial site	65.283467° to 65.285386°	-126.86497° to -126.87632°
AEMP-FS-03 (Bosworth Creek Upstream of Winter Road)	• Upstream of known seeps and discharge sources. • Sculpin monitoring Location.	None	65.29945° to 65.30208°	-126.88826° to -126.88867°

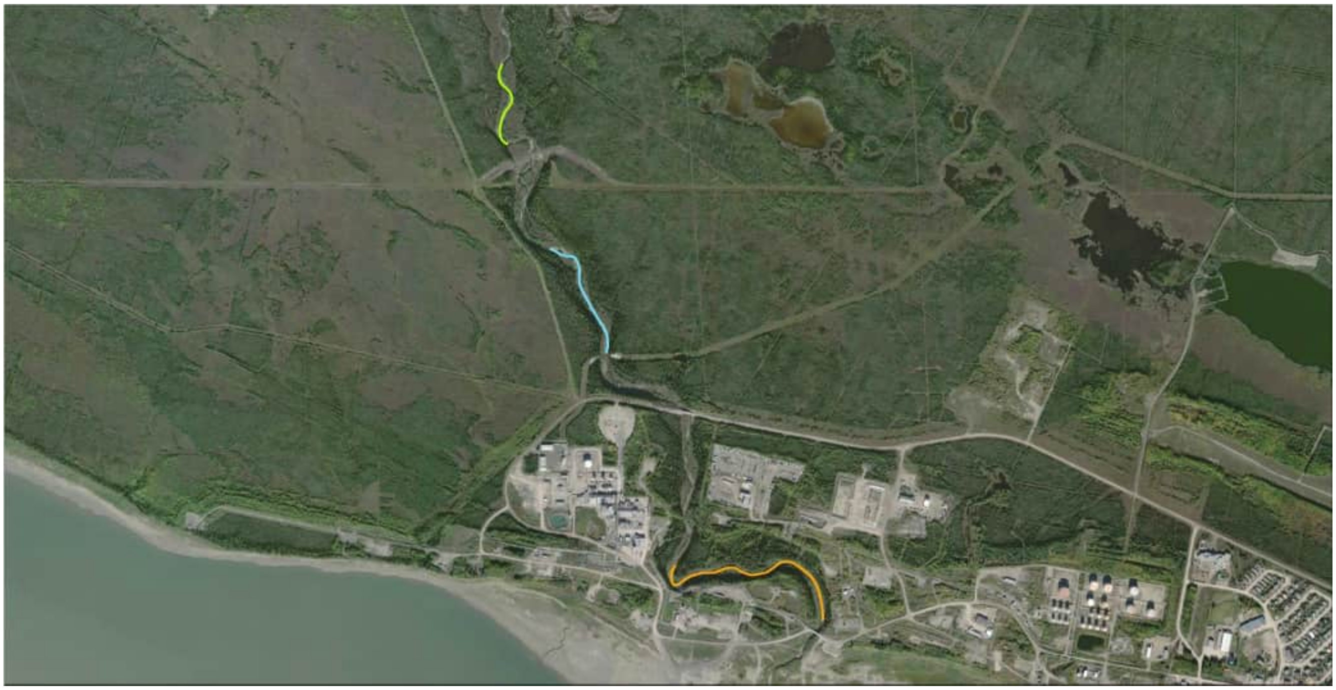

Figure 5-5: Small Bodied Fish Sample Locations – AEMP-FS-01 identified in green, AEMP-FS-02 identified in blue, and AEMP-FS-03 identified in orange.

5.2.6 Sample Methodology

The SFS will be driven by Imperial with the assistance of local community members when possible. Continued consultation with local Government of Northwest Territories Environment and Natural Resources, local renewable resource boards, and educational programs will include promoting direct involvement of local community members in fish collection and processing for the SFS.

The methods employed during the SFS sampling program includes collection of slimy sculpin from Bosworth Creek, transporting fish to a clean dissection work area, measuring fish morphometrics, and processing tissue samples while conducting a visual assessment of fish health. These steps are detailed in the following sections and represented in photographs shown in Figure 5-6.

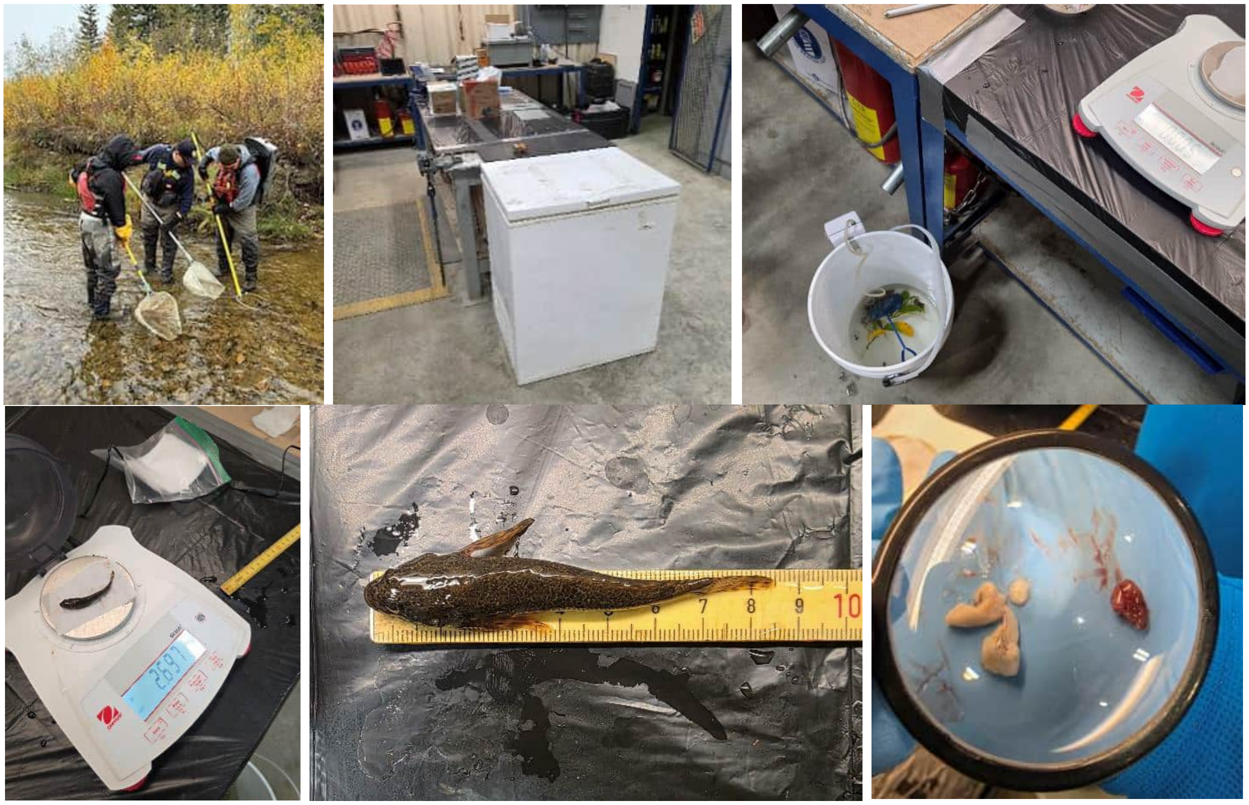

Figure 5-6: From Top Left to Bottom Right Photographs Show Examples of Backpack Electrofishing on Bosworth Creek; Clean Dissection Work Area for SFS; Aerated Bucket Used for Fish Transport to Dissection Area; Measuring Slimy Sculpin Body Weight; Measuring Slimy Sculpin Length; and Mature Testes (Male Gonads) and Liver from Slimy Sculpin (September 2025)

5.2.6.1 Fish Collection

A minimum of 40 sexually mature slimy sculpin (20 male, 20 female) are required per location to afford sufficient statistical power and meet analytical sample volume requirements. Sampling during the 2023 AEMP determined that most immature individuals were <50 mm long; therefore, sampling activities will target individuals with lengths exceeding 50 mm (TRSA 2024).

Slimy sculpin will be collected from Bosworth Creek using a backpack electrofishing unit and dip nets. Captured fish will be taken in aerated buckets to a clean area where fish dissections can occur (Figure 5-6). A LFSP will be obtained from the DFO for the collection and euthanasia of slimy sculpin before field activities commence. The application for the LFSP must meet DFO's requirements, including expressed support from local communities at or near locations of the proposed activities.

5.2.6.2 Fish Dissection

Fish will be euthanized by anesthetization in tricaine methane sulfonate (MS-222) followed by severing the spinal cord at the brain stem.

Length (to the nearest mm) and weight (to the nearest 0.01 g) of euthanized fish will be measured prior to inspection and dissection activities. Length data are specifically valuable in estimating age in cold regions due to constrained summer temperatures. Pictures and visual inspection (internal and external) of individual fish will be conducted by an expert Aquatic Biologist with support from local community members when possible. External and internal assessment parameters will identify abnormalities and condition of:

- External Parameters:
  - Gill and operculum condition.
  - Fin condition.
  - Presence of any injuries, bumps or lesions.
  - Eye condition.
- Internal Parameters:
  - Liver colour.
  - Bile colour.
  - Presence and number of parasites.
  - Stage of development of gonads.
  - Mesenteric fat.
  - Presence of tumours and other visible abnormalities.

Liver samples will be eviscerated from individual fish to form a composite sample (where required for small-bodied fish), or individual liver samples will be flash-frozen or retained in RNA Later buffer for subsequent characterization of MFO induction. It is important to minimize the time between fish mortality and tissue collected for MFO and protein bioassays given that physiological processes that take place after death alter enzyme activity significantly (Hodson et al. 1991). Consequently, the time between mortality and liver collection during fish collection must be minimized and standardized between sampling locations.

As small-bodied fish cannot be filleted to produce muscle tissue in the same manner as large fish, achieving minimum sample sizes for PAH analysis of 5 g from fish with an average weight of 1.27 ± 1.15 g (Mochnacz and Reist 2007) will require compositing of tissue samples. Notably, the 5 g limit suggested provides the minimum tissue quantity required and does not account for tissue loss during homogenization or tissue required should re-analysis be required. The preferred tissue quantity requested by the analytical laboratory is 20 g to 50 g (Grace 2023, pers. comm.).

5.2.6.3 Laboratory Analyses

Tissue samples from sexually mature individuals will be sent to commercial analytical labs for PAHs and metals analysis. In addition, sculpin lengths measured each year will be combined into a length-frequency distribution to determine if specific size classes exist that can be used to estimate fish age.

If compositing is required, these analyses will be used to organize individual samples according to size to minimize the increased variability caused by potentially compositing fish from different age classes. Analyses for a suite of PAHs and metals will be undertaken using gas chromatography–mass spectrometry (GC-MS) and laser ablation methods currently available (requiring smaller tissue samples).

Liver samples will be flash frozen or retained in RNA Later buffer following dissection and will remain frozen during transport or frozen once received by the lab. Once samples are received by the analytical laboratory, samples will be stored frozen at a nominal temperature of -80 °C until testing commences. Samples will be prepared and analyzed for CYP1A1 content using a commercially available ELISA kit and/or EROD activity assay (Hodson et al. 1991). The CYP1A protein content and activity measurements will be normalized to total protein in tissue lysates, which will be determined using a commercially available kit.

5.2.6.4 Quality Assurance and Quality Control

A sampling plan will be prepared and distributed to all field staff prior to commencing the SFS. Standard operating procedures outlining methods for sample collection and handling will be included in the sampling plan. All sample containers will be pre-labelled prior to sampling. All pertinent information and sample specimen identification will be recorded on standard forms. Information such as length, weight, sex, biological specimen sample labels, and by-catch records will be included in the forms. Storage temperatures will be monitored daily.

Quality assurance of analytical results will be provided through review of quality controls implemented by the respective laboratories used for tissue residue and MFO characterization. For tissue residue analysis, this will include analyses of internally and externally duplicated samples, reference materials, and measurement of percent moisture and lipid content. For MFO characterization, samples will be analyzed in triplicate, and the correlation coefficient for the standard curve used for protein quantification will be reported. MFO analysis will include a method blank and splitting of one sample per year to provide a duplicate analysis. The QAQC procedures for assessing the performance of the analytical laboratory will include both the SFS and LFS given that both programs use the same, or similar, chemical analyses. A more detailed discussion of the QAQC procedures for the fish health programs is provided in Appendix E.

5.2.7 Fish Health Analytical Suite

Small-bodied tissue samples will be analyzed annually for the parameters presented in Table 5-7. Analytes identified as KIPs for the Norman Wells field align with the metal KIPs for the water quality monitoring program with the addition of metals that have been shown to be useful tracers of exposure and are indicated by **bold** text. A summary of the tissues analyzed during the SFS is provided in Table 5-8.

Table 5-7: Small-Bodied Fish Tissue Analytical Suite in 2024

Category	Parameters
Polycyclic Aromatic Hydrocarbons (PAHs)	Acenaphthene [AN], Acenaphthylene [AC], Anthracene [A], Benzo(a)Anthracene [BA], Benzo(a)Pyrene [BaP], Benzo(b)Fluoranthene [BbFl], Benzo(e)Pyrene [BeP], Benzo(g,h,i)Perylene [BG], Benzo(j,k)Fluoranthene [BjkFl], Chrysene [C], Dibenzo(a,h)Anthracene [DA], Dibenzothiophene [D], Fluoranthene [FL], Fluorene [F], Indeno(1,2,3-c,d)Pyrene [IP], Naphthalene [N], Perylene [PR], Phenanthrene [P], Pyrene [PY].
Alkylated PAHs (aPAHs)	C1-Naphthalene [N1], C2-Naphthalene [N2], C3-Naphthalene [N3], C4-Naphthalene [N4], C1-Fluorene [F1], C2-Fluorene [F2], C3-Fluorene [F3], Dibenzothiophene [D], C1-Dibenzothiophene [D1], C2-Dibenzothiophene [D2], C3-Dibenzothiophene [D3], C4-Dibenzothiophene [D4], C1-Phenanthrene/Anthracene [PA1], C2-Phenanthrene/Anthracene [PA2], C3-Phenanthrene/Anthracene [PA3], C4-Phenanthrene/Anthracene [PA4], C1-Fluoranthene/Pyrene [FlPy1], C2-Fluoranthene/Pyrene [FlPy2], C3-Fluoranthene/Pyrene [FlPy3], C4-Fluoranthene/Pyrene [FlPy4], C1-Benzo(a)anthracene/Chrysene [BaAC1], C2-Benzo(a)anthracene/Chrysene [BaAC2], C3-Benzo(a)anthracene/Chrysene [BaAC3], C4-Benzo(a)anthracene/Chrysene [BaAC4], C1-Benzofluoranthenes/Benzopyrenes [BFlBPy1], C2-BenzoFluoranthenes/Benzopyrenes [BFlBPy2], C1-Acenaphthene [AN1], 1-Methlynaphthalene.
Metals and Trace Elements	**Aluminum**, Antimony, **Arsenic**, **Barium**, Beryllium, **Boron**, **Cadmium**, **Chromium**, Cobalt, Copper, **Iron**, Lead, Lithium, Manganese, Mercury, **Molybdenum**, **Nickel**, Phosphorus, **Selenium**, Silicon, Silver, Strontium, Thallium, Tin, Titanium, **Uranium**, Vanadium, **Zinc.**
Mixed-function Oxygenase Protein	Total protein, CYP1A protein content.

Table 5-8: Summary of Tissues Harvested and Analyzed During the Small Fish Study

Tissue	Measurements	Preservation	Analysis
Liver tissue	Total weight in grams	Frozen in tubules and/or retained in RNA Later buffer, kept on ice for shipping if flash frozen	Liver CYP1A protein content
Gonad tissue	Total weight in grams	*N/A – Discarded*	*N/A - Discarded*
Small-Body Composite	Total body weight in grams	Kept frozen in glass jars or in sealed plastic bags, kept on ice for shipping	Metals
Whole body	Total body and sample weight in grams	Wrapped in clean foil and kept frozen in glass jars or in sealed plastic bags, kept on ice for shipping	PAHs

5.3 Large-Bodied Fish Program

In the mainstem Mackenzie River throughout the Sahtu Region, fish are relied upon as a source of food and livelihood. Gill nets are set by fisher people in Tulit’a, Norman Wells and Fort Good Hope to catch fish throughout most of the open water season following spring freshet. In late fall and winter, hooks are used to catch fish as well. Species that are caught vary throughout the summer and fall based on their respective spawning periods and life stages.

Sustained concern around the health of fish and fish consumption has led to efforts to establish the design basis (target species, locations, timing) for a large-bodied fish monitoring program that addresses fish health, and the revision of the Problem Formulation for the AEMP. Accordingly, the large-bodied fish monitoring program will be focused on fish species that are relied upon by local communities as a food source, and that enable the assessment of AES in the Sahtu Region. Fish have been used successfully in characterizing aquatic ecosystem health by virtue of both direct (water chemistry) and indirect (food web) pathways of exposure to environmental conditions and thus enable the quantification and comparison of AES within and across monitoring locations.

5.3.1 Approach

The LFS will use a community-based monitoring (CBM) approach that braids TK with western science to maximize the benefits of the program for the local community. This approach aligns with other CBM programs on the Mackenzie River downstream (near Tuktoyaktuk) and upstream (near Yellowknife) from NWO (Mercer et al. 2023). Collaboration between community members and expert aquatic biologists using CBM has been shown to improve community confidence and ensure that research findings are communicated back to the community in a relevant and understandable way. The braiding of TK and western science is therefore continuous throughout the design and execution of the program.

5.3.1.1 Community Reporting Program

During the 2025 LFS pilot study, community members in Fort Good Hope expressed their desire to provide fish health information for the fish they capture during the year as part of the AEMP. Subsistence and recreational fishers that use the Mackenzie River throughout the year could provide useful information, particularly outside of distinct sampling periods. Consequently, a dedicated email address has been established along with a field form for public use (Appendix F). Citizen-science approaches are becoming more widely used and can be powerful tools for environmental monitoring (e.g., mercury monitoring in Northern British Columbia). The community reporting program will be advertised at consultation events, and results will be compiled into annual reports. The main goal of the community reporting program will be to provide an improved understanding of the health of fish captured from the Mackenzie River. Fish assessed as part of the community reporting program will not be retained for chemical analysis.

5.3.2 Program Development

Development of the LFS has been in progress since 2022 and has included three working group meetings between the SLWB, Imperial, TRSA, and representatives from community organizations such as Yamoga Land Corp, K'asho Got'ine Dene Band, K'asho Got'ine Foundation, Sahtu Renewable Resources Board, Tulit'a Dene Band, Norman Wells Renewable Resources Council, and Fort Good Hope Renewable Resource Council, along with discussions with community members and elders in Fort Good Hope, Tulit'a and Norman Wells. These interactions and follow-up discussions with elders at Tulit'a and Fort Good Hope involved exchanges of western science information and TK starting a path to ensure proposed monitoring activities are both feasible and relevant to their respective locations. A summary of the consultations related to the development of the LFS is detailed in Appendix B.

In engaging with community members to gain knowledge of fish species which were of importance and/or the basis of concern, and the methods by which fish are collected, invaluable information and connections were made. Accompanying subsistence fisher people while gill netting allowed for conversations around the effort required to catch specific species of interest at different times of year (minimum number of fish required being 20 male, 20 female for monitoring). These interactions and the subsequent discussions with elders at Tulit'a and Fort Good Hope involved exchanges of western science information and TK that ensure monitoring activities are both feasible and relevant to their respective locations. These same relationships between elders, community members and expert Aquatic Biologists are the basis for collaboration in the execution of planned field activities.

The pilot LFS program completed in 2025 provided many insights for refining how the LFS is designed and executed to meet the program goals. The following design and methods for the LFS integrate learnings from the pilot program with the goal of improving communication processes to get results back to the community and allow them to have a role in the execution of the monitoring program to promote trust. The dissection area for the LFS was at the Fort Good Hope school, allowing youth from the community to observe the dissection process and learn how elders and aquatic biologists determine the health of fish. This was a well-received approach by the community and fostered the transfer of knowledge between young and old, as well as between TK and western science. The pilot program identified that providing areas adjacent to the fish processing station to relax and communicate around a fire and enjoy tea would be beneficial, particularly for elders. Such socialization areas would promote knowledge sharing and would separate fish processing areas that are typically highly controlled, highly congested, and provide little comfort. The intent of the LFS is to build on the relationships and learnings from the 2025 pilot program to expand the LFS into a full-scale CBM program that follows a similar execution plan in Tulit'a, Norman Wells, and Fort Good Hope.

5.3.3 Program Design

From a western science perspective, there are special considerations, steps, and criteria that must be met in a study design. These program needs include:

- Have at least two fish species: a pelagic [open water] dweller such as crookedback (a.k.a. lake whitefish) and a bottom feeder such as loche (a.k.a. burbot) to ensure monitoring across the river habitat.
- To prioritize species that have a well-understood life history so they can be effectively targeted during suitable life stages.
- To prioritize species that are abundant enough to meet the sampling numbers required for the program without influencing the sustainability of the population in the Mackenzie River.
- To prioritize species with a spawning period that allows for safe execution and catch close to that period (i.e., not during freeze-up or break-up of the river).

TRSA understands that an Indigenous perspective is holistic and integrates results from the LFS over longer time periods with other components of the AEMP and other regional programs, as well as integrates a wider dataset into analysis, such as changes in overall environmental seasonal trends (e.g., temperature). This program needs to satisfy several criteria by combining both TK and western science to promote "two-eyed seeing" and improve community confidence. The LFS is to combine viewpoints from both knowledge systems using a braided approach that places equal value on each, avoids using one to validate the other, and presents information in accessible terminology (MRBB 2021). In a braided approach, there are three strands within the braid, with the strands representing TK, Western science, and the combined understanding that develops from bringing these two knowledge systems together. This braiding continues throughout the study design and execution of the program, with an annual technical report and community meetings to share findings.

Previous engagement with community members and the Study group has highlighted the importance of the sharing findings component of the LFS, and overall AEMP. In addition to annual reporting that is to be provided in language that can be understood by the community, annual meetings to present results are required. These meetings can be in coordination with community sampling efforts and should incorporate all community members, including youth and elders.

5.3.3.1 Target Species Selection

The overall goal of the LFS is to establish a program that provides meaningful data to communities related to fish species of high value for consumption. This need is the primary driver for fish species selection. The LFS will target loche and crookedback based on the various consultations described in Section 1.4.2 and Appendix B. Both species provide country food sources for local communities and can be captured annually from the Mackenzie River near each of the communities (i.e., Fort Good Hope, Norman Wells, and Tulit'a). In addition, the Study group recommended targeting both loche and crookedback given their importance to local communities, historical reports of reduced quality for edible tissue (e.g., mushy fillet meat in crookedback and black liver in loche; Lockhart et al. 1987, Cott et al. 2018), and well-understood biological life histories. As these large-bodied fish species are highly mobile and migratory species, the intent of the LFS is to test potential effects at the regional scale.

5.3.3.2 Fish Health Endpoints

The fish health parameters measured as part of the LFS will align with those described for the SFS (Section 5.2.3.2). This includes measuring tissue concentrations of PAHs and metals, CYP1A protein activity/content in liver tissue, and characterizing fish health using:

- Body length relative to body weight (Condition).
- Liver weight relative to body weight (also assessed as LSI).
- Gonad weight relative to body weight (also assessed as GSI).
- Visual inspection.

Cott and others (2018) compared the fish health of loche determined using visual assessment of livers and TK with fish health as determined using scientific endpoints. Although there were no correlations with contaminant loads in fish, the visual assessment using TK identified fish with higher lipid contents and lower parasite content. This study provides an example of how TK and western science can be utilized together to provide a more complete assessment of fish health. Specific endpoints related to the visual assessment of fish condition are described in more detail in Section 5.3.6.3.

5.3.4 Sampling Period and Frequency

Although there have been some studies using western science to assess the fish community in the mainstem Mackenzie River near the NWO, much of what is known comes from TK passed down within the community. Consequently, the sampling periods for the LFS were determined using TK within the community regarding migration windows of crookedback and the traditional fishing season for loche.

Both loche and crookedback will be sampled annually as part of the LFS which aligns with the EEM guidance (Environment Canada 2012). Loche are commonly captured from the Mackenzie River from Tulit’a to Fort Good Hope, however, sampling methods and season for loche will require a separate sampling program later in the year. While crookedback are typically collected in gill nets in the late summer to fall (July to September), loche are targeted by communities later in the year (November to February) using set lines. These time-periods align with pre-spawning periods for each species and will achieve maximum environmental sensitivity and reduce variability. Exact timing of sampling for large fish will be informed by the local communities to align with subsistence fishing activities given that they will be aware of any potential annual changes in the timing of migrations within the Mackenzie River.

Notably, community fisher people have reported crookedback spawning migrations in the Mackenzie River in July and August near Fort Good Hope, however, crookedback captured during the pilot study in 2025 were ripe with well-developed gonads suggesting they had not yet spawned. This suggests that sampling for this target species can be effectively executed as late as September to align with the SFS if needed.

5.3.5 Sampling Locations

As large-bodied fish can cover very large home ranges, the intent of the LFS is to test for potential effects at the regional scale. The LFS will sample for target fish species at three communities including Tulit'a, Norman Wells, and Fort Good Hope to characterize fish health upstream and downstream from Norman Wells (Table 5-9). At Norman Wells, locations for fish monitoring are intended to be co-located with areas downstream of NWO and at areas of known seeps upstream. The presence of natural seeps at reference sites is important to test if the Norman Wells site differs significantly from areas of natural hydrocarbon exposure.

Table 5-9: Proposed Sampling Locations for the Large Fish Study on the Mackenzie River

Upriver Background	Facility Impact	Downriver Effect
Tulit'a	Norman Wells	Fort Good Hope

Engagement with community members to understand abundance and catchability of specific large-bodied fish species across regions provided critical information for building a program that is harmonized across the region (i.e., focused on the same species). The program will rely on local input to determine specific sampling locations within an established range. The sharing of knowledge between expert aquatic biologists and community members has led to the alignment of LFS sampling locations with locations relied upon by subsistence fisher people in most cases. Engagement from Tulit'a suggests that most fisher people in this community obtain fish from the Bear River rather than the Mackenzie River. Sampling areas for the LFS will be limited to the Mackenzie River mainstem, but capture locations will correspond with subsistence fishing locations when possible.

Specific locations have not been defined at this stage of the AEMP for the following reasons:

- Target locations should be chosen as valuable to community members and suitable for the target species (i.e. catch fish where people catch for personal consumption).
- Fishing location information may be knowledge people want kept confidential.
- Locations may need to be altered based on river flow conditions or season.

The program will annually assess specific locations with community members supporting the field execution. Sampling areas will be reported as a general area/reach unless reporting the specific sampling locations has been approved by the community.

5.3.6 Sample Methodology

The major steps and considerations for executing the LFS from a western science viewpoint include fish collection and transport, external and internal health exams, and tissue harvesting. Each of these steps for sampling crookedback is described in the following sections and outlined in Figure 5-7. Sampling steps for loche will be similar to those described but will employ different fish collection methods such as set lining.

Figure 5-7: Major Steps Required for Completing a Community-Based Fish Health Field Study

5.3.6.1 Fish Collection

Local community members will provide support in the collection of fish by deploying nets and/or set lines, and retrieval of fish. The program will rely on local fishers for accessing locations, boats, nets, and other equipment. People will be compensated for their time and equipment. Aquatic biologists will accompany community members during fish collection when possible to promote knowledge sharing.

Fish nets need to be checked regularly to ensure that fish are alive and have not been stressed. Fish will be handled with respect following Animal Care guidelines and as a requirement of scientific licenses issued to complete this work. Collection time will be recorded, and fish will be taken to a dissection location established in a clean area where capture method and species will also be recorded.

5.3.6.2 Fish Transport

Following euthanasia (putting the fish down), fish are placed directly on ice inside clean coolers. Coolers must have a lid that can be fixed securely. The highly sensitive nature of our analyses means that cross-contamination (contamination from other sources) via contact with surfaces and materials that have been in the presence of dust, open fires, boat motors, all-terrain vehicles, and/or in the bed of pick-up trucks can result in a contamination signal that can interfere with signals detected from the environment. Fish are kept enclosed on ice to cool the fish and prevent degradation.

Fish dissections should take place ideally within a clean enclosed area to protect samples from cross-contamination via dust and other local emissions that may affect chemistry results. Failing this, outdoor areas which are protected from wind, with surfaces covered in plastic sheeting, can serve as a less ideal alternative.

5.3.6.3 Fish Dissection

Dissections will follow a process similar to that described for small-bodied fish in Section 5.2.6.2. These dissections will be completed by an expert aquatic biologist and an experienced subsistence fisher and/or elder from the local community. Fish health will be assessed using field forms that integrate data fields from both TK and western science perspectives. These forms will be based on feedback from the 2025 LFS pilot program (Appendix B).

The identification of fish species and assigning a sample identifier are the first pieces of information to be recorded upon commencement of fish health exam activities. Pictures are taken of the fish on both sides with the sample identification in the frame of the picture. Subsequently, fork length (to the nearest mm) and body weight (to the nearest gram) of the fish are measured and recorded. To ensure consistency, the individual weighing and measuring lengths of fish is to remain in that role throughout the process.

The exterior fish health exam involves recording observations specific to the: Eyes, head, body surface, opercles (tissue plate covering gills), gills and fins (Figure 5-8). Any observations of abnormalities such as discoloration, lesions, tumours, or parasites are documented in this stage. Viewpoints from each assessor will be incorporated into the assessment, and the completed form will be reviewed together. The health exam metrics are to be reviewed with community members to ensure TK observations are incorporated.

Dissection of fish to expose and provide access to internal organs takes place at individual stations, which are cleaned between dissections to prevent mixing of any tissues or fluids that may affect data between fish samples. This will involve cleaning fish boards and dissection tools with 80% ethanol or a combination of hexane and acetone between fish and placing tools in ethanol between dissections of each fish; stations must be kept clean to ensure that samples are representative of actual conditions.

Upon dissection/opening of the body cavity, pictures of the internal organs are taken, followed by the visual assessment of the liver, bile, spleen, gonad, kidney, presence of fat, and presence of parasites (Figure 5-9). Colour, texture, developmental stage and overall condition are included as assessment metrics.

Edible tissue (e.g., filets and loche liver) from fish will be placed into glass jars or sealed plastic bags (e.g., Whirlpak®) and then frozen (-20°C) for later PAH and metals analysis. For PAH analysis, tissue will be wrapped in aluminum foil and placed into sealed plastic bags, whereas filets retained for metals analysis will be placed directly into sealed plastic bags. Tissue quantities required for each analysis and logistics for disposing of additional edible tissues will be determined by the community.

Ensuring that sampling stations and tools are clean from the previously dissected samples, the tissues summarized in Table 5-10 are extracted, weighed, and preserved for subsequent analyses. Minimum sample sizes will be confirmed with the analytical laboratory before fieldwork begins, and sample containers should be prepared ahead of sampling for efficiency and cleanliness. Some tissues may need to be subsampled to meet analytical requirements. For example, loche liver may be treated as edible tissue and submitted for metal and PAH analysis, but liver tissue would also be submitted for CYP1A protein content analysis. In this case, the liver tissue would be separated into three different containers with specific storage conditions to avoid contaminating the analytical results.

Tissue quantities required for analysis are small compared with the overall fish size, and it is anticipated that much of the edible tissue can be kept by the community. Therefore, extra tissue from each fish will be distributed in accordance with the wishes of the community.

Figure 5-8: Example of the Process Used for Completing the External Health Exam for Large Fish Species

Figure 5-9: Example of the Process Used for Completing the Internal Health Exam for Large Fish Species

Table 5-10: Summary of Tissues Harvested and Analyzed During the Large Fish Study

Tissue	Measurements	Preservation	Analysis
Liver tissue	Total weight in grams.	Frozen in tubules and/or sealed plastic bag, kept on ice for shipping.	Liver CYP1A protein content/activity. Metals, PAHs (Loche only).
Gonad tissue	Total weight in grams, fecundity (egg count).	*N/A – Used by community.*	*N/A - Used by community.*
Fillet	Weight in grams.	Kept frozen in glass jars, or sealed plastic bags (metals), or wrapped in clean foil and placed in sealed plastic bags (PAHs), kept on ice for shipping.	Metals, PAHs.
Otolith/Fin clip	Lab assessed age structure.	Dried, placed in envelope.	Age of fish.
Stomach Contents	numerical and volumetric.	*N/A – Discarded.*	*N/A – Discarded.*

5.3.6.4 Laboratory Analysis

Chemical analyses for the LFS will align with those outlined for the SFS (Section 5.2.6.3) to ensure consistency between the two programs. These science-based analyses will be coupled with assessments of fish health based on TK of experienced subsistence fishers so that a combined approach to fish health assessment is possible. The analytical schedule for the LFS is consistent with the SFS, as summarized in Table 5-7. Metal concentrations will be measured in ten female and ten male fish from each target species, while PAHs will be measured in ten fish for each target species. Given that loche liver is a valuable food for many communities, ten loche liver subsamples will be submitted to the analytical lab for PAH analysis.

5.3.6.5 Quality Control and Quality Assurance

The QA/QC approaches for the LFS will follow those outlined for the SFS in Section 5.2.6.4 and Appendix E. This includes:

- Providing a sampling plan to all field staff, including supporting community members, prior to commencing fish collection.
- Following established standard operating procedures and best practices.
- Collecting field information on standardized field forms.
- Reviewing results from internal quality controls implemented by the respective laboratories (e.g., method blanks, duplicate analyses, surrogate recoveries, laboratory control samples, and spiked matrices).
- Reviewing results from external quality controls (e.g., standard/certified reference materials and externally split samples).

For MFO characterization, samples will be analyzed in triplicate, and the correlation coefficient for the standard curve used for protein quantification will be reported. MFO analysis will include a method blank and splitting of one sample per year to provide a duplicate analysis.

5.3.7 Large-Bodied Fish Tissue Residue Evaluation

Large-bodied fish tissue residue chemistry will be retained as a supporting line of evidence. Indicator-metal concentrations may be compared with SETAC (1999) ecological effects thresholds where relevant. This comparison is not a food-safety determination. Detailed evaluation methods are provided in Appendix I.

5.4 Data Evaluation and Interpretation

Annual data evaluation will integrate changes in water chemistry, fish tissue chemistry, and fish health. Detailed statistical methods, censored-data treatment, screening comparisons, critical effect sizes and statistical power evaluation are provided in Appendix I. Interpretation will focus on whether spatial or temporal chemistry changes are accompanied by changes in Condition, LSI (+ liver enzyme activity) and/or GSI. Verification

To verify any anomalous result or measurement to be true and accurate, data collection procedures and laboratory procedures will be reviewed as part of the data quality QA/QC process. Anomalous results will be compared with historical results and discussed in terms of their effect on data interpretation (e.g., do potential biases exist that make guideline comparison less conservative). Such results will be identified as anomalous and logged for future reference.

The QA/QC components of the AEMP will be designed to assess the program's accuracy, reproducibility, and precision. Quality control limits outlined by Imperial (2004b) will be used and will account for differing heterogeneity between sample matrices (i.e., water samples are more homogeneous than tissue samples and are therefore expected to have better precision).

For the field duplicate samples, the QA/QC results will be evaluated by calculating the relative percent difference (RPD) between the parent and duplicate sample results using Equation 4 and comparing the RPDs to designated alert limits.

Equation 4

$$\text{RPD }\% = \left(\frac{|x1-x2|}{{(x1+x2)}/{2}}\right) * 100$$

Where x_1 = original field sample.
x_2 = blind field duplicate sample.

Consistent with laboratory practices and to permit reliable calculations, an RPD is only considered to be statistically relevant when the original and duplicate sample concentrations are at least five times the reportable detection limit (RDL). These limits vary parameter to parameter and sample to sample and are indicated by the laboratory alongside the analytical results in the Certificates of Analysis. For water, the RPD alert limit for hydrocarbons and PAHs is 80%; the alert limit for all other parameters presented herein is 50%. For fish tissue, the RPD alert limit is 30% to 40% depending on recommendations from the CCME (2016).

The designated alert limits for method, field, and trip blanks are five times the RDL for each parameter measured in water and fish tissue.

5.5 Review of Data from Other Environmental Programs at NWO

The AEMP is one of many programs that Imperial undertakes either as part of the Water Licence regulatory requirements or as part of progressive reclamation. Data from water management programs, groundwater monitoring programs, remediation of legacy contamination, ongoing studies and/or response to future environmental incidents may be reviewed to help understand potential sources of water quality changes, if observed. Data from these programs may also be used to inform changes to KIP focus or sampling locations as the AEMP program evolves and responds.

There are several large-scale monitoring programs that are ongoing in the NT, including community-based programs that collect data on the Mackenzie River and Bosworth Creek. Data collected through these programs is available through the Mackenzie River datastream (Mackenzie Datastream 2026) and other publicly available datasets (e.g., NWT Discovery Portal).

Slimy sculpin have been used as a sentinel species for effects-based monitoring activities throughout the NT and Canada (Arciszewski et al. 2010; Arciszewski et al. 2015). Statistical comparisons between tissue concentrations and fish health metrics reported in these previous studies and those measured during the AEMP would not be reliable given the differing regions and experimental designs. However, qualitative comparisons between AEMP results and those previously reported will be incorporated into the summary report annually.

6. Response Framework

The response framework for the NWO AEMP follows the guidance provided in the MVLWB/GNWT guidelines for AEMPs (2018) and will guide the response of monitoring activities in a data-driven way if potential concerns are identified. The overall goal is to provide a systematic approach to responding to the results of the AEMP. Results from one year of sampling would be assessed against a framework of potential future work based on reported results. Some general recommendations have been provided, but it is important that future steps are not overly prescriptive in the plan as future sampling designs must be developed based on results of the initial sampling program.

An effective response framework begins with a robust design that clearly outlines what results represent a concern and what changes to the monitoring program need to be implemented (Figure 6-1). The design component of the response framework involves establishing action levels that represent triggers for various levels of concern (i.e., low, medium, and high) to prevent environmental conditions from reaching an undesirable significance threshold. Annual monitoring activities using the methods outlined in the preceding sections represent the implement phase of the response framework, which includes an annual report identifying any exceeded action levels and summarizing any potential concerns identified through the monitoring program. In the adapt phase, the process for adapting monitoring activities is established and may include the development/approval of response plans. This includes the process for confirming potential concerns and determining what further actions are required to mitigate potential influences on the environment. Given that the NWO is expected to be shut down in 2026, the response framework will integrate its results and any response plans with reclamation and closure planning to assist with prioritizing reclamation activities.

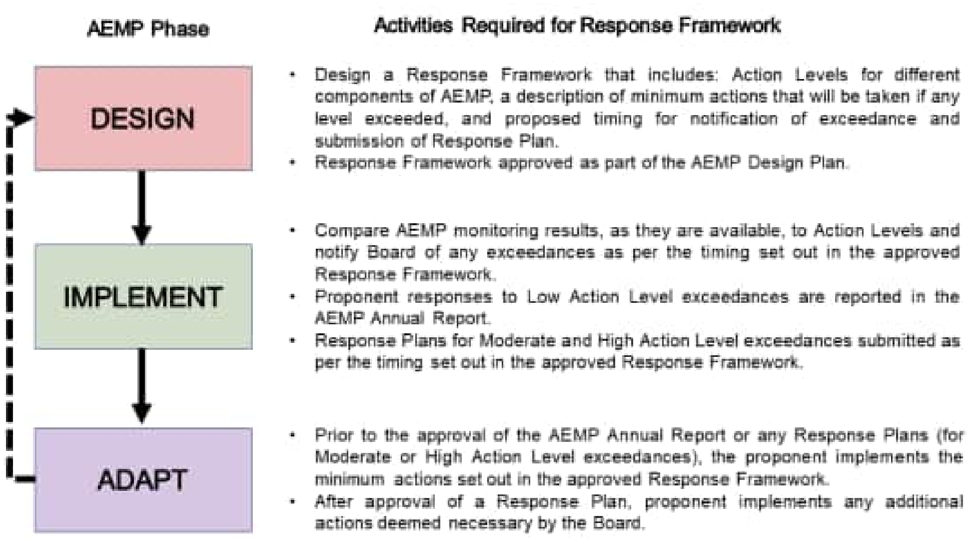

Figure 6-1: Phases of the AEMP Response Framework

6.1 Response Framework Design

6.1.1 Significance Threshold

Differences exist between a detectable difference, an exceedance of an established CES, and organism impacts (Munkittrick 2009). Organism impacts under the AEMP guidelines are those effects above the significance threshold, where the level of change is potentially adverse and therefore unacceptable. This level is context-specific and informed by various measures such as impacts to fisheries. Fish populations in the Mackenzie River have supported subsistence fisheries for local communities for thousands of years and continue to be an important food source in the region.

The intent and design of the NWO AEMP is to prevent potentially irreversible changes from occurring through responses to action-level triggers that are documented during the monitoring program. Typically, projects requiring an AEMP are in the early stages of development and transitioning from baseline data collection into operational monitoring. The NWO has been operating for over 100 years; therefore, there may be a perception that this significance threshold has already been reached in the Mackenzie River. Especially since TK identifies environmental changes over long time frames. In such cases, the concept of shifting baselines becomes an important consideration. For example, the environmental conditions in the Mackenzie River in the 1920s and 1930's would have been very different from the current environmental state. As previously discussed, the NWO AEMP is designed to monitor for current effects on the Mackenzie River from the NWO by comparing potentially influenced areas downstream with reference conditions upstream from Norman Wells over time. Ongoing effects leading towards or contributing to the significance threshold would be captured within this design by identifying concerns at lower biological levels (e.g., individual fish and tissue level responses) that could be lead to concerns at higher biological levels (e.g., population and ecological community) related to the significance threshold.

6.1.2 Action Level Thresholds

A single response framework accounts for observations and actions for water quality, small fish and large fish. The PAH and metal loading in water, and MFO induction, can be used to set detectable CES thresholds, but they do not directly assess organism health. These endpoints can indicate stressors that may affect biological endpoints but aren't considered biological endpoints in themselves (low action level). Alternatively, fish health (condition factor) and indices of energy allocation such as LSI (metabolism and detoxification) and GSI (reproduction) are relied upon as biological endpoints with established CESs. Changes in these biological endpoints are indicative of changes in the ecosystem that have a closer relationship with the significance threshold. Therefore, changes to fish health represent moderate or high action level thresholds since these effects indicate that conditions may be approaching the significance threshold (Table 6-1).

Table 6-1: Applied Action Levels for AEMP Study Results (Adapted from AEMP Guidelines (2019)

Action Level	Study Results	Type of Actions	Relevance to Significance Threshold	Timeline
Low	Applies for the Water Quality Component of the AEMP • **Significant trend**: Trend analysis for identified KIP is observed at experimental sites but not observed at reference sites and could represent degradation of water quality. • **Concentration exceeds CES**: Values outside the tolerance limits based on 95% prediction intervals for an identified KIP. • **Downstream water quality differs from upstream:** Statistically significant differences are identified between reference and experimental sites that suggest a potential influence from NWO. • **Water chemistry exceeds quality criteria:** Water quality guidelines for protection of aquatic life or drinking water are exceeded at experimental locations but not at upstream references, and exceedance is not related to natural processes.	• Confirm action level threshold exceedance as described in the adaptive monitoring framework • Investigate potential temporal and spatial extent of change based on water chemistry • Review fish study results to investigate extent of potential influence on cellular or biological indicators • The need for additional sampling cycles, potentially with additional reference sites and new exposure areas, would be evaluated as part of the adaptive monitoring framework. • Assess the need for further studies to assess potential sources of exposure.	Water chemistry provides an early indicator of potential changes that could lead to deterioration of the AES over time or space. Actions are to verify the potential effect and investigate the cause if needed to prevent changes to the AES.	Reported within annual summary report
Moderate	Applies to the SFS and LFS components of the AEMP. • **Downstream Fish health differs from upstream:** Condition of slimy sculpin downstream exceeds the CES (±10% difference between sites), and/or GSI or LSI downstream exceeds the CES (±25% difference between sites) • **Concentration exceeds CES**: Tissue residue concentrations outside the tolerance limits based on 95% prediction intervals for an identified KIP • **Downstream tissue quality differs from upstream:** Statistically significant differences are identified between reference and experimental sites that suggest a potential influence from NWO operations. • **Tissue concentration exceeds quality criteria:** Tissue concentrations exceed toxicological thresholds at downstream sites but not upstream reference sites.	• Confirm action level threshold exceedance and investigate cause as described in the adaptive monitoring framework • The need for potentially assessing the degree of bioaccumulation in species that eat slimy sculpin will be evaluated. • Closure and reclamation groups will be informed of the need for mitigation and development of a recovery plan should an investigation of cause identify a potential concern within the NWO.	Potential effects on slimy sculpin in Bosworth Creek may be indicative of localized changes within the NWO and could influence large-bodied fish during early life stages. Small-scale changes in large-bodied fish health may or may not indicate potential changes at the population or ecological community level.	Once a threshold is triggered, the potential effect will be reported in the annual summary report and confirmed during the subsequent monitoring year. If confirmed, the SLWB will be informed within 30 days, and a response plan will be prepared within the subsequent monitoring year. The response plan will be integrated into closure and reclamation plans to prioritize remediation needs.
High	Applies to the LFS component of the AEMP • **Downstream fish health differs from upstream:** Condition of crookedback or loche downstream exceeds the CES (±10% difference between sites), and/or GSI or LSI downstream exceeds the CES (±25% difference between sites) • **Tissue concentration exceeds food quality criteria:** Tissue concentrations exceed maximum levels for foods in Canada at downstream sites but not upstream reference sites. • **Declining catch rates and smaller fish:** Crookedback and/or loche catch rates decrease alongside a decrease in fish length at downstream sites but not upstream reference sites.	• Confirm action level threshold exceedance and investigate cause as described in the adaptive monitoring framework. • The need for additional sampling cycles, potentially with additional reference sites and new exposure areas, would be evaluated as part of the adaptive monitoring framework. • Closure and reclamation groups will be informed of the need for mitigation and development of a recovery plan should an investigation of cause identify a potential concern within the NWO.	Potential effects on individual large-bodied fish have the potential to reduce the ability of the fish to reproduce, grow, and deal with stress. Such effects can have a direct influence on recruitment (the number of fish added to the population each breeding season) and lead to population reductions. Such metrics are important for fisheries management and can be directly related to the significance threshold.	Once a threshold is triggered, the potential effect will be reported in the annual summary report and confirmed during the subsequent monitoring year. If confirmed, the SLWB will be informed within 30 days, and a response plan will be prepared within 120 days. The response plan will be integrated into closure and reclamation plans to prioritize remediation needs.

6.2 Adaptive Monitoring Framework

The adapt phase of the response framework will include an adaptive monitoring approach that responds to potential effects by triggering confirmation steps to verify results during the subsequent monitoring year. Once the potential effect is confirmed, the frequency, location, and extent of monitoring may be altered to better describe the extent and magnitude of the potential effect. This may include, for example, increased sampling through an epidemiological approach that seeks to determine the source of an input or include review of data from other monitoring programs to attempt to determine a source of change. The framework for this tiered monitoring approach is based on the recommendations outlined by Munkittrick and Arciszewski (2019). If such steps fail to confirm any effect, the program can revert to its previous monitoring state, and additional data collected will contribute to the database and mitigate against any further false positives (Type I errors). The source of any observed changes in water quality or fish health will need to be theorized and rationalized following the adaptive monitoring framework before any change in monitoring to further investigate that change is determined.

The response framework is developed based on the significance threshold and action levels, and when those thresholds are approached or exceeded, the operationalization of the adaptive monitoring framework. The adaptive monitoring framework provides a systematic response to action level thresholds, including confirming a potential effect, focused monitoring to delineate the magnitude and extent of the potential effect, investigating the cause and integrating corrective measures into closure planning (Figure 6-2).

If no significant differences are detected in any parameter for a period of three consecutive years, the monitoring activities at the monitoring location may revert to a minimal monitoring state to help direct monitoring resources to areas of greater concern. Where successive years show an absence of trends and congruence in health indices at areas of concern with respective reference areas, the provision to default to minimal monitoring cycles less than annually is considered. Accordingly, the adaptive monitoring framework will be applied to manage changes in frequency in a defensible manner. Any changes to sampling frequency will be determined in consultation with and approved by the Working Group and the SLWB. If significant results are found in one or more parameters, the site would return to standard surveillance monitoring and will be evaluated as outlined in Figure 6-2. As per the GWNT AEMP Guidance (2019), a re-evaluation of the AEMP design will occur every three years (Figure 4-2).

Response actions will generally not include additional sampling frequency. Verification of anomalies will be investigated in subsequent sampling activities. Analytical data processing and analysis time requirements, particularly for SPMD analyzed parameters, will generally not support a rapid response type action. Rather, indications of facility inputs will be investigated using a spatial, epidemiological type approach whereby data is used to investigate potential inputs.

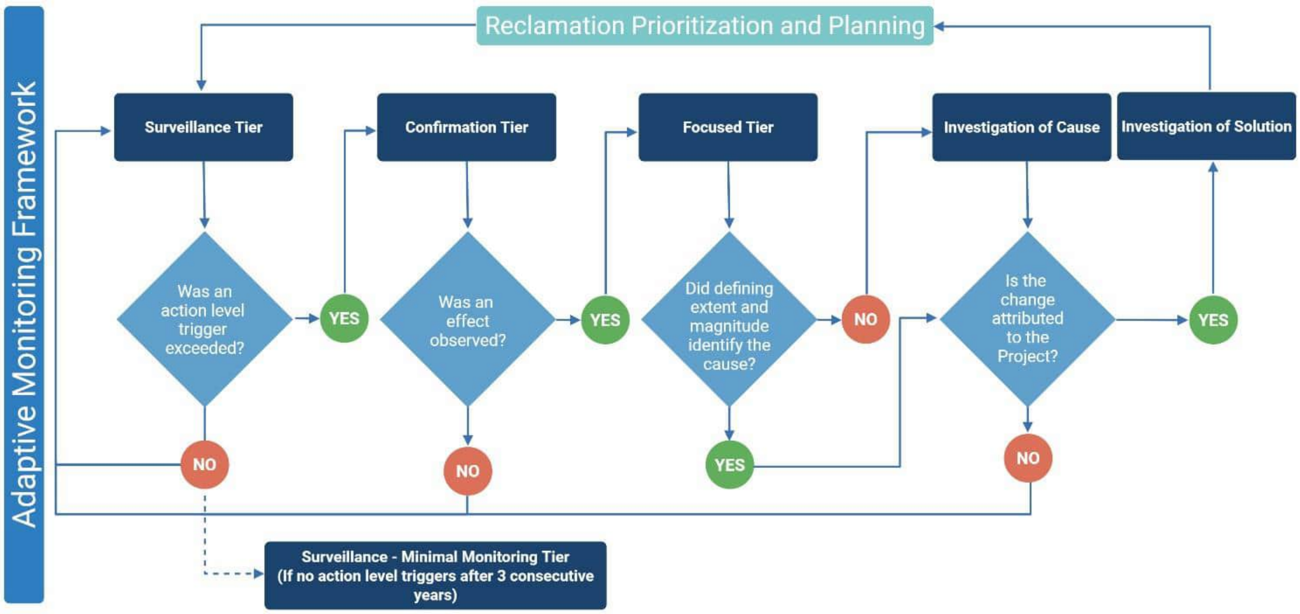

Figure 6-2: A Tiered and Triggered Adaptive Monitoring Structure Used as the Response Framework for the Current AEMP (Adaptation from Arciszewski and Munkittrick, 2015 and Munkittrick et al. 2019)

7. Reporting

All data will be reported annually to the SLWB on or before April 30th annually as per Part I – Section 3 of Imperial's Water Licence (S13L1-007). One AEMP standalone summary report (including both water quality and small- and large-bodied fish study data) will be provided to the SLWB. Reporting will occur on all analyzed parameters with analytical focus on the KIPs, PSD data and fish health metrics (Table 5-3).

The CBM Program shared the importance of bringing the results back in the community in a meaningful way. Imperial will continue to engage with Sahtu communities to ensure that community stakeholders are informed in a meaningful way (i.e., equating water quality and fish health results to how they relate to expressed community concerns) and have the opportunity to provide feedback.

New datasets are being established with AEMP Version 5. As such, trend analysis will be limited in the first years of sampling. For Years 1 and 2 of executing this AEMP Program (Version 5 as proposed), where available, data will be supplemented with the AEMP Version 3 (2017 – 2022) dataset but only where those sample locations are being continued within AEMP Version 5 or where data from upstream sample locations can be incorporated into the background chemistry data set The primary data analysis method (i.e., comparison of upstream and downstream location chemistry) will be possible for all data collected and will form the majority of data analysis included in the report for years three and year four. Trend analysis will commence with the fifth year of data collected.

Annual reports will include:

- Results and analysis of water quality testing.
- Results of the SFS, including:
  - Methods employed and any variations from this design plan.
  - Results from fish biological endpoints, PAHs, metals and MFO.
  - Discussion of results.
- Results of the LFS, including:
  - Methods employed and any variations from this design plan.
  - Results from fish biological endpoints, PAHs, metals and MFO;
  - Discussion of results.
- Review of the results in the context of the AEMP guidelines and the response framework, along with proposed next steps.
- An assessment of what the overall data is indicating related to the key question: Are the routine or historic activities at the Imperial site at Norman Wells introducing substances into the receiving environment that could cause acute or chronic effects by altering the Accumulated Environmental State of the aquatic environment?

Results will be framed in the context of the applied action levels set out in Section 6. As discussed in Section 1.4.2 of this AEMP, Imperial will engage with the Sahtu community to ensure stakeholders are informed and have the opportunity to provide feedback.

8. Conclusion

An Aquatic Effects Monitoring Program has been developed to help answer the question:

Are the routine or historic activities at the Imperial site at Norman Wells introducing substances into the receiving environment that could alter the Accumulated Environmental State of the aquatic environment?

The components developed herein are three aspects of a wider monitoring network system that includes Imperial-led groundwater and surface water monitoring, facility process monitoring, progressive reclamation and monitoring of historical contamination, and emergency response procedures. The key components herein are:

- Water quality monitoring of the Mackenzie River and Bosworth Creek:
  - This incorporates sampling locations and techniques intended to characterize the Environmental State of the water bodies regionally and locally (around Norman Wells Operations) both upstream and downstream of the facility.
- Small-bodied fish monitoring program:
  - Designed to be executable with available fish species in environmentally relevant locations (one site-influenced location and two non-influenced locations) that have small home ranges allowing data to be more reliably attributable to NWO stressors, if indicated.
- Large-bodied fish monitoring program.
  - Designed to be modelled after a CBM approach executed with communities along the Mackenzie River near the NWO to investigate the condition of large-bodied fish important to subsistence fisheries within the Mackenzie River.

While the Mackenzie River and the large fish within it are the primary focus of community concerns, water quality and fish health findings from Bosworth Creek will be applied across the wider aquatic environment, with the creek serving as a sentinel-type environment that would be more sensitive to detectable change.

Aquatic environment concerns in the Mackenzie River will be directly investigated through water quality sampling, the SFS and the LFS. These investigations will be guided by the action level thresholds in the response framework to prevent exceeding the significance threshold. Adaptations to the monitoring design and potential need for future special effects studies will be guided by the adaptive monitoring framework in a data-driven process that progresses from concern identification and validation to detailed investigation. The adaptive monitoring framework also defines how monitoring activities can be reduced where no concerns are identified through successive monitoring.

9. Closure

We trust that this plan satisfies your current requirements and provides suitable documentation for your records. If you have any questions or require further details, please contact the undersigned at any time.

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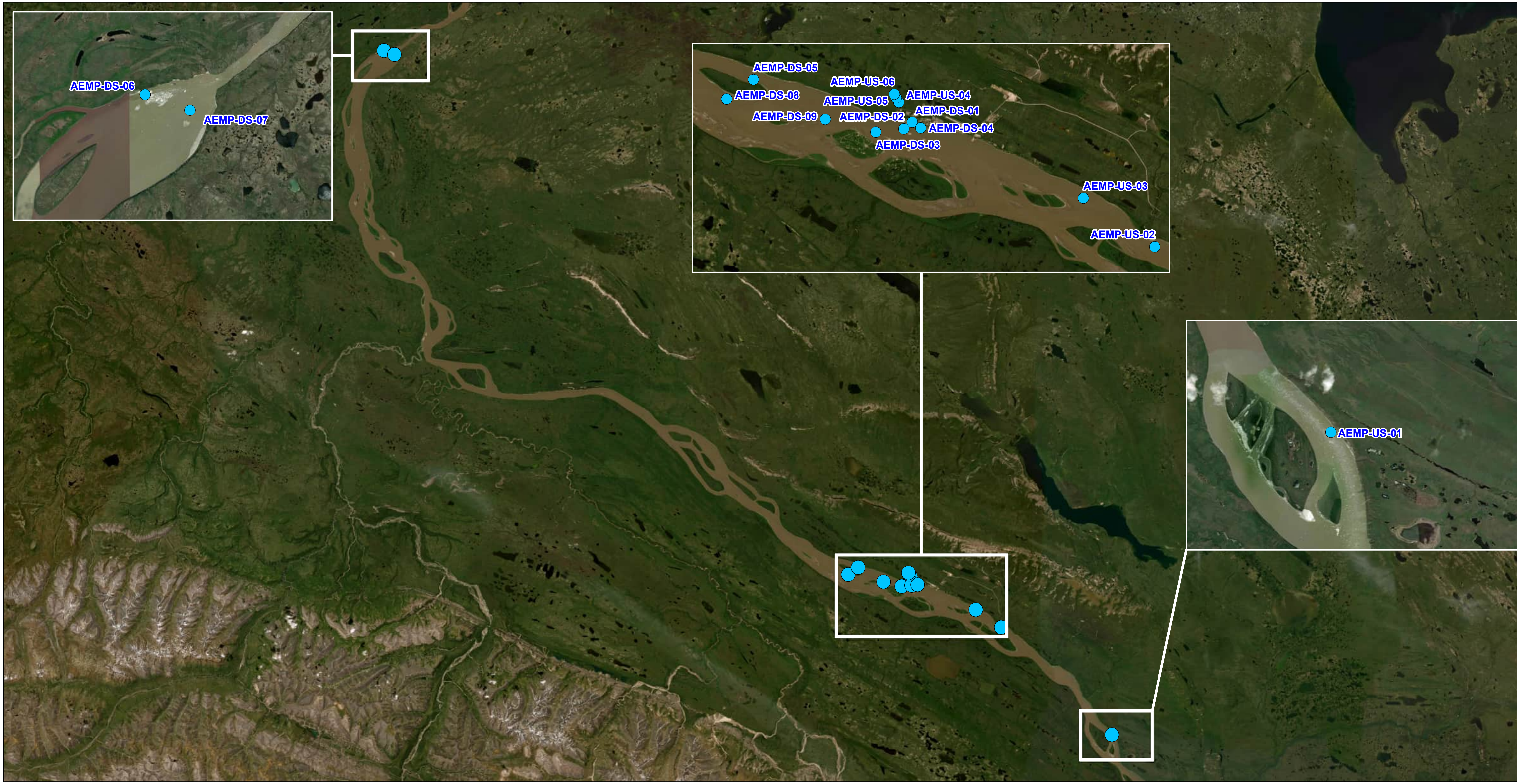
11. Acronyms, Glossary, and Units of Measure

Term	Description
Adaptive Management	An approach that responds to a change that is determined to be an ecological effect as a result of the stressors to develop mitigative strategies or changes to the operation.
Accumulated Environmental State	The existing state of the system as it has integrated all existing stressors, both natural and anthropogenic (human influence). In relation to the AEMP, the AES is focused on the aquatic environment including water quality and fish health.
Adaptive Monitoring	An approach that responds to a potential effect by triggering confirmation steps which may include changing the frequency of monitoring and the extent and magnitude of monitoring. The process and steps that serve as a response framework in this document.
AEMP	Aquatic Effects Monitoring Program
ANOVA	Analysis of Variance
Background Chemistry	The chemical characterization of substances or locations that are not influenced by releases from a site (USEPA 2002). This may represent the natural state of the environment or a state that has been influenced by other factors but not by the site in question.
Baseline Chemistry	Data that serves as a basis for comparison with the subsequently acquired data.
BLM	Biotic Ligand Model
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CBM	Community-Based Monitoring
rROS	Robust Regression on Order Statistics
MLE	Maximum Likelihood Estimation
GAM	Generalized Additive Modelling
CPF	Central Processing Facility – the main facility that processes oil at Norman Wells prior to shipment.
Control-Impact	Control-impact designs compare areas potentially affected with those that cannot be because of geographical location or sequence in time.
Gradient	Gradient designs for monitoring recognize that other physical, chemical, or biological variables may be correlated with the indicators of interest, and that some of the residual variability in the value of the indicator may be removed by incorporating such covariates into statistical analyses.
Groundwater	Water located beneath the surface that exists in the pore spaces of soil and rock formations.
GWMP	Groundwater Monitoring Program; Imperial monitors select groundwater wells across the operating site. The groundwater wells included in this program are located in proximity to operating facilities and near potential receptors.
KIPs	Key Indicator Parameters. Chemical and water quality parameters that have been identified as most applicable to the Site.
Imperial Site	Norman Wells Operations
Large-Bodied Fish Study (LFS)	A monitoring program focused on large-bodied fish species that are of value to local communities as a food source.
Low Density Polyethylene (LDPE) Thin - Film	A type of PSD used to capture organic compounds. Their primary use is in surface water sampling for Polycyclic Aromatic Hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs).

Term	Description
Low Action Level	Conditions that, if exceeded, would trigger the adaptive monitoring approach. The low action level is set at the critical effect size for a specific measurement endpoint to ensure that changes are detected and addressed in a proactive manner.
Modifying Factors	Factors that would make the effect better or worse.
NMDS	Non-Metric Dimensional Scaling
NOEC	No Observable Effect Concentration
Norman Wells Operations (NWO)	The department within Imperial that is responsible for the operation and decision-making associated with all well sites, flowlines, the central processing facility and maintenance activities.
PAHs	Polycyclic Aromatic Hydrocarbons
Passive Diffusion Bag (PDB)	A PSD used to capture volatile organic compounds (VOC) in water. An example of VOCs would be light hydrocarbons (e.g., BTEX).
Passive Sampling Device (PSD)	Technologies that sequester and concentrate bioavailable organic compounds from the environment.
Pathway	How a stressor can reach the environment.
PCA	Principal Component Analysis
Receptor	A living organism, ecosystem or natural resource that is responding to environmental changes.
Reference Condition Approach	The reference condition approach (RCA) uses a pre-established biological and environmental dataset of sites representative of unimpaired conditions (reference sites). This dataset is used to match a set of environmental variables to biological conditions using predictive models.
Semipermeable Membrane Device (SPMD)	A type of PSD used to capture and organic compounds. Their primary use is in surface water sampling for PAHs and PCBs.
SETAC	Society of Environmental Toxicology and Chemistry
Small-Bodied Fish Study (SFS)	A monitoring program focused on small fish that can act as a sensitive sentinel species and be indicative of the health of the wider ecosystem.
SNP	Surveillance Network Program – a groundwater and surface water monitoring program associated with the Water Licence. Surface water monitored within the SNP program includes runoff/storm collection ponds, sumps and potentially process affected waters.
SSD	Species Sensitivity Distribution
TMF	Toxicity Modifying Factors
VOC	Volatile Organic Compounds

Figures



Water Sampling Location

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IMPERIAL
NORMAN WELLS
AQUATIC EFFECTS MONITORING PROGRAM

AEMP WATER SAMPLING LOCATIONS

Date: 04-APR-24	Drawn by: KR	Edited by: KR	App'd by: AH

Project No. 417085-49223-23200

1 | REV 0

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ISSUING OFFICE: VANCOOUVER GIS

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Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

Water Sampling Location

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IMPERIAL
NORMAN WELLS
AQUATIC EFFECTS MONITORING PROGRAM

NEAR FACILITY AEMP
WATER SAMPLING LOCATIONS

Date: 04-APR-24	Drawn by: KR	Edited by: KR	App'd by: AH

Imperial

Project No. 417085-49223-23200

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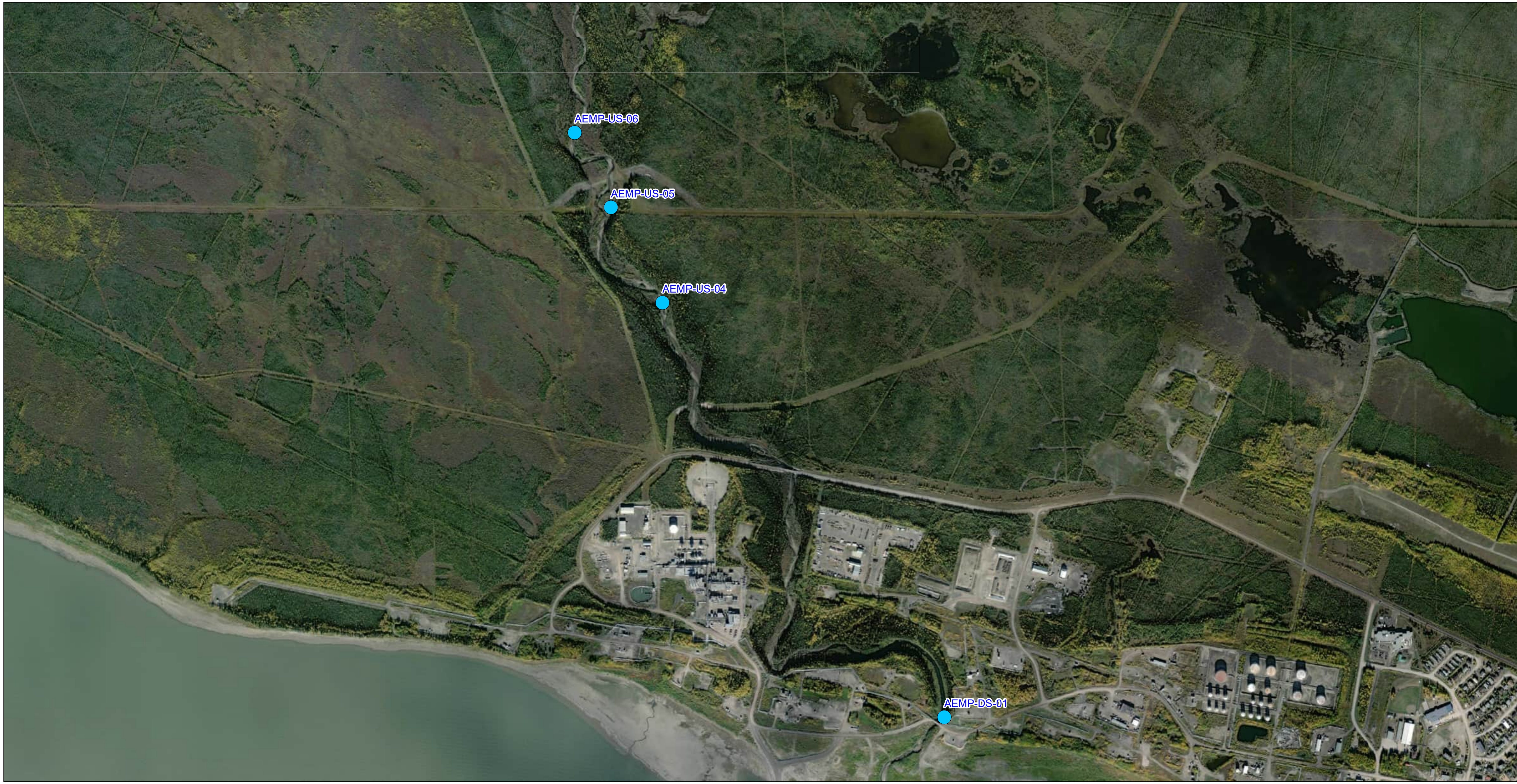

Water Sampling Location

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Meters
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IMPERIAL
NORMAN WELLS
AQUATIC EFFECTS MONITORING PROGRAM

BOSWORTH CREEK AEMP
WATER SAMPLING LOCATIONS

Date: 04-APR-24	Drawn by: KR	Edited by: KR	App'd by: AH
Imperial		Project No. 417085-49223-23200	
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Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

SFS-01
SFS-02
SFS-03

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Meters
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IMPERIAL
NORMAN WELLS
AQUATIC EFFECTS MONITORING PROGRAM

BOSWORTH CREEK FISH SAMPLING RANGE

Date: 04-APR-24	Drawn by: KR	Edited by: KR	App'd by: AH
Imperial		Project No. 417085-49223-23200	
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ISSUING OFFICE: VANCOOUVER GIS

PLOT DATE & TIME: 4/4/2024 9:49:12 AM
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Appendix A. Limitation of Liability, Scope of Report and Third-Party Reliance

Limitation of Liability, Scope of Report and Third-Party Reliance

This report has been prepared and the work referred to in this report has been undertaken by Tłegǫ́hłı̨ Reclamation Services Advisian (TRSA), for Imperial Oil Resources Limited. It is intended for the sole and exclusive use of Imperial Oil Resources Limited, its affiliated companies and partners and their respective insurers, agents, employees, and advisors (collectively, "Imperial Oil"). Any use, reliance on or decision made by any person other than Imperial Oil based on this report is the sole responsibility of such other person. Imperial Oil and TRSA make no representation or warranty to any other person with regard to this report and the work referred to in this report and they accept no duty of care to any other person or any liability or responsibility whatsoever for any losses, expenses, damages, fines, penalties or other harm that may be suffered or incurred by any other person as a result of the use of, reliance on, any decision made or any action taken based on this report or the work referred to in this report.

The investigation undertaken by TRSA with respect to this report and any conclusions or recommendations made in this report reflect TRSA's judgment based on the site conditions observed at the time of the site inspection on the date(s) set out in this report and on information available at the time of preparation of this report. This report has been prepared for the specific application to this site and it is based, in part, upon visual observation of the site, subsurface investigation at discrete locations and depths, and specific analysis of specific chemical parameters and materials during a specific time interval, all as described in this report. Unless otherwise stated, the findings cannot be extended to previous or future site conditions, portions of the site which were unavailable for direct investigation, subsurface locations which were not investigated directly, or chemical parameters, materials or analysis which were not addressed. Substances other than those addressed by the investigation described in this report may exist within the site, substances addressed by the investigation may exist in areas of the site not investigated and concentrations of substances addressed which are different than those reported may exist in areas other than the locations from which samples were taken.

If site conditions or applicable standards change or if any additional information becomes available at a future date, modifications to the findings, conclusions, and recommendations in this report may be necessary.

Other than by Imperial Oil, copying or distribution of this report or use of or reliance on the information contained herein, in whole or in part, is not permitted without the express written permission of TRSA. Nothing in this report is intended to constitute or provide a legal opinion.

Appendix B. Program Engagement and Development

Appendix B - Historical Program Development Summary

B.1 Introduction

The main inputs to the development of the SFS in Version 5 of the Aquatic Effects Monitoring Program (AEMP) are the relevant directions from the Sahtu Land and Water Board (SLWB), recommendations from HESL (2021), MVLWB/GNWT Guidance (MVLWB and GNWT 2019), concerns from local communities, and results of pilot studies carried out in 2022 and 2023. These inputs include recommendations prepared by Dr. Munkittrick (2019) and direction from the SLWB via HESL (2021), and the revised AEMP guidelines (MVLWB 2019).

In his review, Dr. Munkittrick (2019) outlined the positions of Imperial and the SLWB, discussed the objectives of AEMP and Environmental Effects Monitoring (EEM) and provided recommendations. Key aspects of the recommendations provided by Dr. Munkittrick are summarized in Table B-1.

Previous work completed on fish species in the Norman Wells area is summarized in Senes Consultants Limited and Glen Guthrie (2009) and WorleyParsons (2012). The majority of previous work has been either on larger species (e.g., burbot, whitefish) or exploratory programs looking at fish presence, metal loading, or other factors.

Engagement with local community members and Elders in regard to concerns about fish and fish consumption was conducted most recently in November 2022 at Tulita, Fort Good Hope and at Norman Wells and through the Healthy Water/Healthy Fish study group (the Study Group) engagements.

The Study Group is an SLWB-led initiative intended to bring together regulatory agencies, community members, stakeholders and Imperial Oil to develop an AEMP that meets regulatory requirements and incorporates community concerns. Participation in the Study Group fluctuated over time.

The most recent Study Group Sessions, at the time of publication, were:

- September 2025:
  - An in-person session held in Fort Good Hope intended to frame the Large Fish Program and complete a trial run that included catching, dissecting and data sharing. The session included involvement with Fort Good Hope community members, the SLWB, Imperial Oil and TRSA.
  - The outcome of this session was that the group gave Imperial Oil the mandate to submit, for circulation and review, an updated AEMP plan.
- November 2025:
  - A technical session focused on addressing outstanding comments related to the water quality and small fish components.

- March 2026:
  - An in-person session held in Tulit'a intended to inform the community of the AEMP design and current plans for the 2026 sampling program. Single-day meeting provided a chance for community members to be informed of community involvement opportunities and provide feedback on the program design.

To date, community involvement has mainly focused on development of a large-bodied fish study (LFS). The design of the SFS is largely science-based but offers opportunities to incorporate support from local communities during execution. Community support during sampling and processing activities provides a potential opportunity for knowledge sharing and education during the SFS.

B.2 Direction and Development Feedback

More recently, comments received following review of the proposed AEMP Version 4.0 expressed concern that the SFS included only one potentially impacted sampling location, only one target species, and did not include sampling locations on the Mackenzie River mainstem (Table 5-1). Efforts by Imperial and TRSA to address these concerns are summarized in Section 5.1.2.

Table B-1: Inputs into AEMP Design

Reference	Relevant Text
Sahtu Land and Water Board Recommendations Letter to Imperial (May 30, 2018)	Recommendation 7: "The AEMP must document how the proposed sampling program (i.e., sampling frequency, location, number of samples, analytes) will, at a minimum, allow exceedances of the Low Action Levels to be detected. Small-bodied fish, such as Slimy Sculpin, should be added to the aquatic effects monitoring program design (ecological effects) in response to community concerns for more study on aquatic organisms, as they are home range limited and their health and contaminant metrics are more likely to catch changes that will be missed in a water quality program. A Low Action Level for the small-bodied fish metrics should be defined that, if exceeded, would potentially trigger studies on large-bodied fish, such as loche (Burbot)."
Third-Party Review by Kelly Munkittrick (June 23, 2019)	"Aquatic monitoring should be included as part of the AEMP or pre-closure baseline monitoring, with the following considerations: • Aquatic monitoring should be designed to assess whether there are meaningful responses in fish to the cumulative situation. • Fish sampling should focus on smaller-bodied fish species that have smaller home ranges. Exposure sites should be selected as closely as possible to the area of most concern, and reference sites should be located upstream and if possible, within the development area but outside excepted anthropogenic exposure areas. • An important component of the program is defining what comprises a meaningful response, which requires the development of lower action levels (conditions that if exceeded would trigger an adaptive management approach). This definition should be based on comparable reference sites. • If the cumulative effects assessment fails to detect a meaningful response, further work on fish is probably unjustified.

Reference	Relevant Text
	• If cumulative effects assessment detects a meaningful response, it is the responsibility of follow-up studies to isolate the contributions of relevant stressors, based on identified potential sources and pathways.”
Third-Party Review by Kelly Munkittrick (June 23, 2019) *(cont’d)*	“There are a number of issues with previous fish studies. The power or ability to detect an effect is affected by species selection, sample size, timing of sampling, location of reference site(s), location of exposed site, and endpoints utilized. The previous studies provided limited fish monitoring on the mainstem river, but they used exposure sites that were considerable distance downstream (where fish were utilized by the communities). There has not been any recent fish monitoring in the near field downstream location where potential exposures would be highest. The background natural contamination in the area will create challenges for separating natural and anthropogenic contamination, but the absence of meaningful effects to the cumulative exposures would be worthwhile to investigate.”
Path Forward Letter Sent to Sahtu Land and Water Board by IORL (June 26, 2019)	“Imperial has reviewed these recommendations and plans to retain an environmental consultant to assist with development of a cumulative effects aquatic monitoring program (part of AEMP Version 3.0). The program design will focus on answering the key questions described above. [Refer to Third Party Review by Kelly Munkittrick (June 23, 2019) above]. Imperial believes that the proposed updates to the existing AEMP (inclusion of an aquatic component) will address the outstanding concerns identified by the SLWB (contained within the letter from SLWB to Imperial dated May 30, 2018) and enable alignment to be reached in time for the summer 2020 sampling season. Imperial is proposing to submit the updated AEMP (Version 3.0) to the SLWB in fall 2019 and obtain a decision from the SLWB by year-end 2019. Imperial requests feedback from the SLWB if there are concerns with this approach.”
Review of Path Forward Letter by Sahtu Land and Water Board (September 6, 2019)	“The Board accepts the recommendations from the report prepared by Dr. Munkittrick and is in agreement with the approach and timeline proposed by Imperial to revise and resubmit the AEMP (version 3.0) to the Board for public review and approval.”
Board Direction Letter by Sahtu Land and Water Board (September 24, 2021)	It is the opinion of the Board, based on all the evidence presented during this regulatory review process and the Hutchinson Environmental Science Ltd. Technical Review completed for the Board, that the NWO AEMP Version 3.0 is NOT APPROVED. The Board DIRECTS Imperial to submit a response to the recommendations contained in the HESL 2021 TR within 90 days from the date of this letter, outlining a proposed process and timeline for submission of a revised AEMP version 4.0 to the Board, for approval and a response and action for each of the eight identified shortcomings in the current AEMP version 3.0 that has been presented to the Board for approval.
Third-Party Review of AEMP 4.0 by Colin Macdonald	Small fish monitoring – Hydrocarbon analysis might show very few compounds if the hydrocarbons are being metabolized. A search of the literature should be able to provide information to predict tissue levels of hydrocarbons and PAHs in sculpin or similar species.
Third-Party Review of AEMP Version 4.0 by HESL (2021)	The number and location of small-bodied fish sampling locations are insufficient. Only one effects location was identified in Bosworth Creek, and it is influenced by both IORL operations and natural oil seeps, so effects from IORL will be difficult to distinguish from seeps. No locations were selected in the Mackenzie River, and although the fast flows and substrate may not support sculpin in all areas, sculpin could be present in more quiescent areas and be caught by minnow traps (which were not identified as a sampling option by TRSA). HESL (2021) recommended a Special Effects Study to explore the potential for small-bodied fish sampling in the Mackenzie River, which followed up on recommendations by Munkittrick. Although the feasibility of small-bodied fish sampling was evaluated in the pilot work completed by TRSA in 2022, a comprehensive Special Effects Study was not conducted. • A Special Effects Study should be conducted to evaluate the feasibility of catching slimy sculpin in the Mackenzie River and other locations where effects by IOLR occur without inference from seeps or other confounding factors. • Additional sample locations should be added to clearly test for effects related to IOL operations.

Reference	Relevant Text
Third-Party Review of AEMP Version 4.0 by HESL (*cont'd*)	The methods proposed by TRSA are reasonable and in keeping with modern biological monitoring. Per previous comments, HESL recommends that other sampling methods (e.g., minnow traps) be considered in environments not suitable for electrofishing, so that the small-bodied fish program is not limited by capture methods.
Review of AEMP Version 4.0 by GNWT-ENR	No locations within the Mackenzie River, the primary area of concern concerning both exposure and effects, have been proposed. There is no mention of assessing small-bodied fish populations and/or the ability to capture small-bodied fish within the Mackenzie River. IORL has restricted its attention to wadable waters where backpack-based electrofishing is feasible (Advisian 2022a, Section 5.5.1). Slimy sculpin are capturable through other methods, including traps, which could be deployed in the Mackenzie River. See for example, Gray et al. (2018) and references therein. GNWT-ECC recommends that IORL choose an additional small-bodied fish for the small-bodied fish sampling program or provide a rebuttal to the recommendation made for at least two species by Munkittrick (2019). GNWT-ECC recommends that IORL assess small-bodied fish populations in areas of concern such as those presented in Table 1-1 (Advisian 2022b), IORL (2019 Figure 8), and HESL (2021 Table 7).

B.3 Exploratory Programs

B.3.1 Passive Sampling Feasibility

A review of AEMP Version 3 by Hutchinson Environmental Services Limited (HESL) and communicated via the Sahtu Land and Water Board (SLWB) recommended the use of passive sampling devices. The rationale for use of these devices is the time-integrated data that is produced, and as a result, environmentally relevant concentrations are achieved via equilibrium with the surrounding water.

Although these technologies are often valuable in inferring potential exposure (burden concentrations) of contaminants in aquatic biota, their effectiveness can be challenged in systems like the Mackenzie River which contain high turbidity. The turbidity, an artifact of suspended solid particles, can interfere with the substrates relied upon to equilibrate by limiting surface area. Additionally, in the case of organic compounds, many of the compounds of interest are not bioavailable in a highly turbid environment, as these compounds adsorb to particles – precluding adherence and/or detection on passive sampling device surfaces.

Passive sampling devices have been used successfully and reliably for the detection of compounds such as polycyclic aromatic hydrocarbons (PAHs) in aquatic environments; however, the use of these devices for the quantification of petroleum hydrocarbons (PHCs) is unconventional. Activities undertaken in order to test the efficacy of these devices in characterizing organic contaminant exposure in the Mackenzie River and Bosworth Creek and to secure available laboratory analytical services are presented below.

Pilot studies using passive sampling devices (PSDs) and investigating capture success of small-bodied fish in the Mackenzie River mainstem and Bosworth Creek have been done alongside AEMP activities in 2022 and 2023. These activities were initiated to address concerns regarding the proposed design of the SFS as it was outlined in AEMP Version 4, specifically, the lack of small fish study locations within the Mackenzie River. The results of the 2022 pilot study are summarized in a memorandum from TRSA to Imperial on December 19, 2022 (Appendix 4). Findings from the PSD deployment in 2022 indicated that passive sampling techniques are suitable in the Mackenzie River and Bosworth Creek despite concerns associated with high turbidity. Consequently, passive sampling techniques have been incorporated into AEMP Version 5 (Section 4). Passive samplers such as SPMDs provide a measure of bioaccumulation potential of organic contaminants like PAHs (Huckins et al. 2006). Therefore, inclusion of passive sampling in the Mackenzie River and Bosworth Creek allows comparison of organic contaminant exposure between control and potentially impacted sites without the influence of contaminant metabolism in the target species. This addresses concerns regarding the potential to underestimate exposure to PAHs when measuring tissue residue concentrations. Components of the 2022 pilot study related to fish monitoring focused primarily on the collection of large-bodied species and is discussed further in Section 6.

B.3.1.1 Laboratory Engagement

TRSA approached several laboratories to secure commercially available analysis for LDPE thin film and SPMD devices. Results of conversations with the laboratories regarding available analyses are summarized below.

SGS AXYS - Richard Grace

- Trusted contact and advisor to Advisian on fish tissue chemistry analysis and preferred vendor for triolein passive sampling devices procured from EST Solutions in the USA.
- Mr. Grace confirmed that Axys does not analyze hydrocarbons from passive sampling devices, but does provide analysis for PAHs, and does not know of a company providing commercial analysis support in this area.
- Discussion of field blank requirements and trip blank requirements and advantages/disadvantages of using internal standards for PAH analysis, which were deemed not required for this initial reconnaissance work.
- To confirm the effectiveness of these technologies for use in quantifying hydrocarbons in a time-integrated fashion, need to target a minimum 3-week exposure period.

ALS Global Laboratories (ALS)

- In reaching out to Milica and Dana at ALS Global Labs per referral by David Leeder from HESL, confirmation was received from ALS (Kieran Tordoff) on 5 August 2022 that the lab is unable to process passive sampling substrate for either PAHs or PHCs, with PHC success being limited with passive sampling.

Bureau Veritas Laboratories (BV)

- A phone call on 8 August 2022 with Joshua Dias (Business Development Director) confirmed that BV does not have the capability or method development capacity to extract and analyze passive sampling substrates for PAHs or petroleum hydrocarbons.

Meta Analytical Inc. – Selected Laboratory Services

- Since commercially available labs could not complete the analysis of the passive sampling devices for hydrocarbons, Advisian turned to Meta Analytical Inc. for support. In seeking specialized support for extraction and analysis of low-density polyethylene (LDPE) thin film and triolein semi-permeable membrane device (SPMD) substrates, Meta Analytical was secured for the pilot study of passive sampling devices to characterize efficacy in the Mackenzie River and tributaries. Meta Analytical specializes in the development and testing of biomimetic organic chemistry tools.
- Meta was able to extract PHC F2-F4 results from SPMD samples, but results were not reliable due to sample device interference. Further, the findings were limited to PHC F2-F4, which mostly includes non-soluble hydrocarbon fractions.

B.3.1.2 Findings Carried Forward

Results of field testing and laboratory analysis, along with recommendations from Meta Analytical, point to the following:

- Deployment and retrieval of PSDs in the Mackenzie River and Bosworth Creek is viable.
- SPMDs are a viable and preferred option for PAH passive sampling and analysis.
- PDBs are a viable and preferred option for light-end (soluble) PHC passive sampling and analysis.
- Available PSD technologies are not suitable for heavier-end hydrocarbon (F3-F4; insoluble) passive sampling and analysis.

As such, the use of SPMDs for PAH analysis and PDBs for soluble hydrocarbon analysis have been incorporated into the AEMP. A target deployment time of 30 days has been selected based on findings, logistics, and need for a discrete timeframe.

B.4 Small-Bodied Fish Study (SFS)

B.4.1 Mackenzie River

During the execution of the 2023 AEMP, minnow traps were set at various locations on the Mackenzie River mainstem and backpack electrofishing was used to sample the fish community along the shore (Table 5-2). In addition, Imperial has retained TRSA for a study determining the fish habitat and community present in the Mackenzie River adjacent to the artificial islands at the NWO. The scope for this study included sampling the habitat around the artificial islands using backpack electrofishing, minnow trapping, and underwater videography. These activities are collectively referred to as the Mackenzie River Fish Study (MRFS) for conciseness.

Table B-2: Fish Community Sampling Locations During the 2023 Mackenzie River Fish Study

Name	Description	Latitude	Longitude	Fish Caught
MRFS-MT1	• Outlet of Prohibition Creek.	65.135519°	-126.316303°	No fish caught
MRFS-MT2	• on mainland near Department of Transportation Lake.	65.254000°	-126.691442°	No fish caught
MRFS-MT3	• east side of Radar Island.	65.312306°	-127.111992°	**1 whitefish spp**.
MRFS-MT4	• on mainland approximately 6 km downstream from Radar Island.	65.351742°	-127.268108°	No fish caught
MRFS-MT5	• the outlet of Bosworth Creek.	65.280797°	-126.869417°	No fish caught
MRFS-MT6	• upstream from the NWO at McKinnon Territorial Park.	65.262183°	-126.730061°	No fish caught
MRFS-MT7	• approximately 1.0 km downstream from the Imperial Marine Dock.	65.285266°	-126.899294°	**1 whitefish spp.** **1 lake chub**
Island Habitat Study Sampling				
ISL1-MT1	• North side Island 1 in cobble substrate.	65.27684997	-126.869507	No fish caught
ISL1-MT2	• North side Island 1 in cobble substrate.	65.27670999	-126.868375	No fish caught
ISL1-MT3	• North side Island 1 in cobble substrate.	65.276855	-126.871731	No fish caught
ISL2-MT1	• Back eddy on north shore of Island 2 in riprap and cobble.	65.27252398	-126.846956	No fish caught
ISL2-MT2	• Downstream end of north shore in gravel/sand substrate.	65.27296999	-126.851571	No fish caught
ISL2-ROV1	• South shore near the upstream end of point bar on Island 2. • Video survey from shore into main channel with deep run habitat and sand substrate.	65.27186575	-126.8510041	No fish observed
ISL3-MT1	• Small back eddy created by large rubble and riprap substrate at upstream end of Island 3.	65.27700998	-126.910845	No fish caught
ISL3-MT2	• Small back eddy created by large rubble and riprap substrate at upstream end of Island 3.	65.27694929	-126.9103446	No fish caught
ISL3-MT3	• Interstitial area between large riprap and rubble substrates at upstream end of Island 3.	65.27680504	-126.910221	No fish caught
ISL3-MT4	• Back eddy on north shore near upstream end of Island 3. • Boulder substrate with large rubble.	65.27675802	-126.910329	No fish caught
ISL4-MT1	• Small pool in large rubble/riprap armouring on northeast corner of Island 4.	65.27349302	-126.896284	No fish caught

Name	Description	Latitude	Longitude	Fish Caught
ISL4-MT2	• Small pool in large rubble/riprap armoring on northeast corner of Island 4.	65.27335203	-126.896207	No fish caught
ISL4-MT3	• Southeast corner of Island 4. • Shallow run on leading edge of the island with boulder garden in sandy substrate.	65.27252801	-126.897096	**1 juvenile walleye**
ISL4-MT4	• Southeast corner of Island 4. • Shallow run on leading edge of the island with boulder garden in sandy substrate.	65.27249004	-126.89769	No fish caught
ISL4-EF1	• Southeast corner of Island 4. • From pipeline to upstream corner of island through boulder garden.	65.272565° to 65.272474°	-126.898923° to -126.896861°	**1 trout-perch 1 longnose sucker**
ISL4-ROV2	• From southeast corner of Island 4. • Video survey of shallow run with boulder garden in sand substrate.	65.272569	-126.897093	No fish observed
ISL5-MT1	• Southeast corner of Island 5. • Shallow run on leading edge of the island with boulder garden in sandy substrate.	65.26903301	-126.883676	No fish caught
ISL5-MT2	• North shore of Island 5. • Shallow run habitat with sand substrate of sandbar.	65.27084802	-126.887428	No fish caught
ISL5-MT3	• South shore of Island 5. • Backwater habitat with sand substrate.	65.26905002	-126.886015	No fish caught
ISL5-EF1	• South shore of Island 5. • From backwater habitat along shore to upstream end of island with boulder garden in sand substrate.	65.269031° to 65.269075°	-126.885955 to ° -126.883952°	**5 lake chub**
ISL6-MT1	• Northeast corner of Island 6. • Small pool created by large rubble/riprap armouring.	65.26650301	-126.869186	No fish caught
ISL6-MT2	• Southeast corner of Island 6. • Shallow run habitat with boulder and large gravel substrate.	65.26573397	-126.869601	**1 lake chub**
ISL6-MT3	• Eastern shore of Island 6. • Leading edge of island with shallow pool habitat and sand substrate.	65.26603203	-126.86928	No fish caught
ISL6-MT4	• Southeast corner of Island 6. • Shallow run habitat with boulder and large gravel substrate.	65.265567	-126.869937	No fish caught

Gee-type minnow traps baited with dry cat food were set and left overnight at each of these locations. Bread was added to traps as well based on the recommendation of a local fisherman.

Two juvenile whitefish (*Coregonus sp.*) were captured from the shore of the Mackenzie River, one at the location downstream from the Imperial marine dock and the other downstream from the NWO on the east side of Radar Island (MRFS-MT3). One lake chub (*Couesius plumbeus*) was also captured along the shore of the Mackenzie River downstream from the Imperial marine dock.

Baited minnow traps were deployed in the mainstem Mackenzie River from September 26 to October 3, 2023, during the island habitat study. Traps were deployed in areas with suitable habitat over a total of 773.8 trap hours. One juvenile walleye (*Stizostedion vitreum*) and one lake chub were captured in minnow traps at Island 4 and Island 6, respectively. Some habitat adjacent to Islands 4 and 5 were suitable for backpack electrofishing and were fished over 703 seconds and 819 seconds of effort, respectively. This electrofishing on October 3, 2023, resulted in the capture of one trout-perch (*Percopsis omiscomaycus*) and one longnose sucker (*Catostomus catostomus*) from Island 4, and five lake chub from Island 5.

The Mackenzie River is a fast-flowing and highly turbid watercourse (Stein et al. 1973), and few shallow shoal areas were observed during the 2023 AEMP field activities or island habitat assessment. Consequently, habitat suitable for backpack electrofishing the mainstem in 2023 was limited to the area 1 m to 2 m from shore. Wading conditions farther from shore were unsafe and posed an unacceptable risk to workers. Habitats suitable for minnow trapping were also limited adjacent to both the mainland and artificial islands. Pool habitats with limited flow were rare and generally associated with eddies adjacent to the leading edge of the artificial islands and large rubble/boulder substrates. Wave action along the shore also reduced the availability of suitable minnow trapping locations.

B.4.1.1 Trial Findings

Obtaining small-bodied fish from the mainstem Mackenzie River in sufficient numbers to support tissue and fish health assessment is not feasible based on the TRSA fishing efforts to date. While more targeted efforts to collect lake chub could potentially meet abundance requirements, this species is migratory and believed to migrate into shallow areas along lake shorelines and tributary streams for spawning (COSEWIC 2018). Spawning migrations ranging from 0.8 km to 1.6 km have been reported for lake chub, although longer distances of at least a few miles are common (Stasiak 2006; Povolo 2014). These attributes limit site fidelity and sedentary behaviours of lake chub that are required characteristics of a suitable sentinel species for the SFS (Section 5.2).

A suitable small fish study on the Mackenzie River near Norman Wells has been determined to not be viable.

B.4.2 Bosworth Creek

In September of 2022, TRSA confirmed the presence of slimy sculpin in Bosworth Creek through an electrofishing program. As part of the 2023 AEMP, slimy sculpin were collected in sufficient numbers from two sites in Bosworth Creek and submitted for laboratory analyses following the methods outlined in Section 5.7.

During the assessment of the fish community in Bosworth Creek in 2022, no other potential target species had sufficient abundances to act as a second sentinel species within Bosworth Creek. Notably, longnose dace (*Rhinichthys cataractae*) have life history characteristics suitable for use as a sentinel species and have been used in other effects-based studies (Lazaro-Côté et al. 2021; Evans et al. 2012).

Although this species is present in Bosworth Creek near the NWO, it was not captured in sufficient numbers in Bosworth Creek. This is based on observed counts during preliminary sampling in 2022, as well as during sculpin sampling from 2023 to 2025.

It is TRSA's understanding that Dr. Munkittrick's recommendation for at least two sentinel species is to ensure sufficient statistical power is achievable when the abundance of one sentinel species is insufficient.

In Dr. Munkittrick's review (2019), the preferred fish health monitoring scenario is one that assesses cumulative impacts in fish near the exposure area. Suggested endpoints to test in his report were body burden (PAH concentrations in both bile and muscle tissue) and liver detoxification enzyme induction (mixed-function oxygenase, MFO), both of which are indicators of hydrocarbon exposure (Headley et al. 2001, Tetreault et al. 2003) and have been shown to be effective in monitoring of industrial activities (Spencer et al. 2008).

B.4.2.1 Desktop Analysis

Potential sample sites for small-bodied fish were identified in accordance with the AEMP guidelines (Section 3) and based on the following constraints:

- Proximity to the Operation (exposure area).
- Accessibility and sampling efficacy.
- Known populations of slimy sculpin (tributaries).
- Area with known natural seeps.
- Preliminary site scoping.

B.4.2.2 Field Verification

Field verification activities were completed in August and September 2022 for the purposes of ensuring the feasibility of salient aspects of the SFS. A small-bodied sampling component was added to the 2023 AEMP, and slimy sculpin were collected and analyzed from two sites (one control and one exposure site) within Bosworth Creek.

The riffle-run composition and habitat quality of Bosworth Creek support a thriving population of sculpin for the proposed biomonitoring. This was verified at the AEMP-FS-01 and AEMP-FS-02 sites by electrofishing in 2022 and 2023 (Table 5-4). A third site (second reference site), AEMP-FS-03, upstream from the winter road crossing, was added in 2024 and has also provided suitable habitat and abundance. It is notable that Canyon Creek, a tributary of the Mackenzie River upstream from Norman Wells, was previously discussed as a reference location, but the addition of a second reference location within Bosworth Creek was selected. This change was discussed and agreed to in the November 2025 technical Study Group session.

B.4.2.3 Trial Findings

Bosworth Creek was found to have sufficient abundance of slimy sculpin to maintain an annual study using two reference and one impact site. A second sentinel species was not identified in sufficient abundance.

B.5 Large-Fish Study Development

The first Study Group meeting was held in Fort Good Hope on November 29 and 30, 2022, and a key outcome was that communities wanted to be involved in the implementation of a LFS. Therefore, a community-based monitoring approach is best suited for ensuring an effective AEMP that meets the needs of the communities. The study cannot progress without cooperation and input from local resources within each of these communities, because community members will be relied upon to support fish collection, assessing fish health, and sample processing and to provide a Traditional Knowledge perspective on fish health observations. Ideally, local community members are involved in all aspects of the LFS from design to data interpretation, reporting, and decision-making.

The second working group took place in Fort Good Hope in July 2023. This meeting further progressed the discussion of the AEMP program, including a large fish program.

An outcome of that session was that the working group is now referred to as the Healthy Water Healthy Fish or Tu Luge Study Group, to emphasize the essential connection between clean water, healthy fish and community well-being. The most recent meeting of the Study Group took place in Fort Good Hope in September 2025. This meeting included one day of discussions to share and align on the group's vision and agree on an approach for the LFS. The second day included a trial for the fish collection and handling, fish health assessment, and tissue processing at the community school. The third day included a debrief of the trial and discussion of what went well, what could be improved, and key takeaways. The results of the 2025 Large Fish Trial will be presented to the communities in 2026. Outcomes from this meeting, as well as previous community inputs, have been integrated into the proposed plan for the LFS.

Imperial and TRSA engaged with local community members and Elders regarding target species for the large-bodied fish program that may be considered for the Mackenzie River.

TRSA presented the selection criteria that would ensure species provide the ecological representation desired (i.e., one pelagic and one benthic species) and were species with sufficient data available to understand baseline condition.

From this engagement, burbot:loche (*Lota lota*), coney:inconnu (*Stenodus leucichthys*), northern pike:jackfish (*Esox lucius*), lake whitefish:crookedback:humpback whitefish (*Coregonus clupeaformis*), and white sucker (*Catostomus commersonii*) were identified as likely target species due to abundance and catchability, and that most of these fish are relied on for subsistence. Although white sucker are not consumed throughout the Sahtu Region communities, the bottom-dwelling nature of these species enables any changes that are limited to deeper habitats to be evaluated. In addition to being of importance to local communities, these species are also the focus of over 10 years of fish health monitoring activities in the Hay River and the Slave River co-led by the Government of Northwest Territories and local communities (SLR 2017). The ability to review data generated from the AEMP and make cross-regional comparisons can provide context to monitoring results in the absence of a long-standing historical dataset.

Coney and crookedback (whitefish) were the only species captured during the 2025 pilot in Fort Good Hope, suggesting these species occur in sufficient numbers to support environmental monitoring. Loche are commonly captured from the Mackenzie River from Tulit'a to Fort Good Hope; however, sampling methods and season for loche will require a separate sampling program later in the year.

While coney and crookedback can be collected in gill nets in the fall (August to September), loche are targeted by communities later in the year (November to February) using set lines. These time periods align with pre-spawning periods, which will achieve maximum sensitivity and reduce variability in tissue-level changes. The working group recommend targeting both loche and crookedback given their importance to local communities, historical reports of reduced quality for edible tissue (e.g., mushy fillet meat in crookedback and black liver in loche; Lockhart et al. 1987, Cott et al. 2018), and well-understood biological life histories.

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Appendix C. Traditional Knowledge Management

Dear Community Member,

Imperial's Norman Wells Operations is grateful for your participation and valuable contributions to the design of the Aquatic Effects Monitoring Plan (AEMP).

This document outlines how Imperial proposes to respectfully incorporate knowledge shared through the collaborative *Healthy Water, Healthy Fish Study Group – Tu Luge*. We recognize the importance of Indigenous Data Sovereignty and aim to establish a transparent protocol for the ownership, collection, access, and use of Indigenous Knowledge (IK) shared within the Study Group.

With guidance and permission from the Study Group, IK gathered during the study will be included in the AEMP and annual reports submitted to the Sahtu Land and Water Board (SLWB). Imperial understands the need to protect this knowledge and recognize the cultural and ecological significance of fish. IK shared by Elders and other knowledge holders will be protected in accordance with the Study Group's established protocol.

In September 2025, the Study Group will conduct a workshop and field trial focused on sampling large fish, integrating both Conventional Science (CS) and IK. The goal is to produce scientifically robust results that meet SLWB reporting requirements while reflecting community perspectives on aquatic health in the Mackenzie River, in relation to Imperial's operations.

This document outlines proposed methods for incorporating shared IK into the AEMP. Imperial is committed to upholding the principles of Indigenous Data Sovereignty and affirms that ownership of IK remains with the communities who choose to share it.

Looking ahead, Imperial seeks to establish formal knowledge-sharing agreements that reflect community protocols and expectations across Sahtu communities. We anticipate continued collaboration, two-way learning, and integration of IK throughout the aquatic effects monitoring program and future closure planning.

AEMP background

Aquatic effects monitoring is a requirement under the SLWB Type A Water Licence for Norman Wells Operations. The AEMP outlines how monitoring is conducted to assess potential impacts on water and fish health. The program consists of three components:

1. Water sampling to assess long-term water health
2. Small-bodied fish health investigations (local focus)
3. Large fish health investigations (regional focus)

Approaches for water quality and small fish monitoring are established in AEMP Version 4. IK from the Study Group is important to developing the large fish program for Version 5.

This collaborative effort involves the communities of Tulita, Norman Wells, and Fort Good Hope, with TRSA conducting the work on Imperial's behalf to support licence compliance.

3. Types of information

To meet AEMP requirements, both aquatic monitoring scientists and community members have specific objectives. The table below outlines conventional scientific data that includes physical measurements and chemical analyses from accredited labs. Integrating IK with this data is key as the Study Group refines study parameters.

Step	Samples	Measurements	Handling	Indicator	Measurement Endpoint	Relevance/Importance
1. Fish Collection	Whole fish	Fish Species Identification	Immediate euthanasia, place on ice (release if non-target)	-	-	Correct fish are obtained and the required number of males and females (10 males, 10 females)
2. Fish Transport	Whole fish	-	Ensure samples are on ice and enclosed	-	-	Sample is protected from contamination by other sources are controlled
3. Initial Measurements / Exterior fish health exam	Whole fish	Picture (left and right)	Use of gloved hands to conduct exterior fish health assessment	Colour/texture/quality condition as defined in fish exam sheet	Physical anomaly/abnormalities	Ensuring that any Traditional Knowledge-based changes or observations specific to the exterior of the fish are documented
	Whole fish	Weight	Weighing with gloved-hands on scale	Weight	Weight at age relative to background	Change of weight at age indicates a potential change in growing seasons and/or food energy
	Whole fish	Length	Measuring length with gloved-hands on scale	Length, inferred age	Change in length/size at age relative to background	Change in length at age indicates a potential change in growing seasons and/or food energy
	Fin clip and/or otolith	Age (lab)	clip pelvic fin using dissection scissors	Age	Change in population age relative to background	Change in age classes represented over time can indicate a population level change (i.e. changes in recruitment of new fish to population over time)
4. Internal Fish Health Exam	Whole fish	Picture (body cavity/organs)	Use of gloved hands to conduct interior fish health assessment	Colour/texture/quality condition as defined in fish exam sheet	Physical anomaly/abnormalities	Ensuring that any Traditional Knowledge-based changes or observations specific to the exterior of the fish are documented
5. Sample Extraction and Analysis	Liver	Liver weight	Ensure all liver tissue is obtained to get an accurate measurement Weight measurement, sub-sample weight measurement, freeze	LSI, EROD	Critical Effect Size and Liver activity relative to background	Change in liver size relative to overall weight, and relative to gonad size can indicate an effect
	Gonad	Gonad weight Fecundity (egg count)	Ensure whole sample is obtained to get an accurate measurement Weight measurement, egg count sub-sample weight measurement	GSI, Egg count	Critical Effect Size and Number of eggs in 0.1g relative to background	Change in gonad size relative to overall weight, and relative to liver size can indicate an effect
	Filet	Metals via Trich Analytics Inc Polycyclic aromatic hydrocarbons (PAHs) via AXYS Analytical Inc	Sample (wet weight) measurement, Refrigerate	Metals concentration PAH concentration	Metals concentration relative to background PAH concentration relative to background	Change in tissue metals concentration relative to upstream locations Change in tissue PAHs relative to upstream locations?

Incorporating IK into the AEMP

Imperial values IK and seeks guidance on how it should be used. Below are proposed methods for incorporating IK into the AEMP, and we welcome your input:

- Meeting and field notes: SLWB may record sessions, with notes circulated for participant review before posting to the public registry. These notes would inform the updated AEMP.
- TRSA field notes: TRSA staff may document conversations during fieldwork, with notes reviewed by the Study Group before use.
- Community note-taker: A community member could be utilized to document discussions during field trials and teaching sessions. These notes could be shared with TRSA and Imperial for inclusion.
- Community summary: Study Group members may prepare a summary with recommendations, which could be referenced in the AEMP and included as an appendix.

Imperial proposes the next version of the AEMP will be drafted by TRSA, incorporating insights from the Study Group and the 2025 field trial. Any IK components to be included in the next version of the AEMP will be shared with the Study Group for review before submission to SLWB and public posting.

Imperial will present updates and Study Group contributions during community meetings.

Access to collected data
To build transparency and trust, Imperial will share all notes, data, and lab results from the field program with the Study Group. Upon review and endorsement by the Study Group, this information will be made available to Sahtu communities upon request. Raw data, field notes, and lab results can be provided in digital or physical formats, based on community preference.

Definitions
For this discussion, the following definitions are used for clarity:

Data includes, but is not limited to, records, files that comprise research observations, findings, or outcomes, including primary materials and analysed data, transcriptions, photographs, and recordings collected or produced.

Indigenous Knowledge refers to the lived experiences, understandings, and teachings that Indigenous Peoples have developed and sustained over generations through deep relationships with the land, water, animals, and spiritual world. It is rooted in Indigenous worldviews, languages, and cultural practices, and is passed on through oral histories, ceremonies, storytelling, and land-based learning. TK is dynamic and evolving, reflecting both ancestral wisdom and contemporary realities. It is held collectively by communities and guided by Elders and knowledge keepers, who act as stewards of this knowledge. TK is not simply historical—it is current, relevant, and vital to the health, identity, and governance of Indigenous communities.

Please review this letter and provide any additional information that Study Group participants feel is important to clarify the above points.

Appendix D. SPMD Field Methods

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Standard Operating Procedures for Field Water Quality Sampling using Semi-permeable Membrane Devices (SPMDs)

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Version 1.0 (*final draft)*

July 2018

Environment and Climate Change Canada

Freshwater Quality Monitoring and Surveillance – Athabasca Arctic Watershed

Canada

Summary of Revisions		
Version	**Date**	**Summary of Revisions**
1.0	July 2018	• addressed reviewers comments, editorial changes and formatting.
Draft	November 2017	• draft for review

This Standard Operating Procedure may be cited as:

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Acronyms

COC	Chain of custody
ECCC	Environment and Climate Change Canada
EST	Environmental sampling technologies
FWQMS	Freshwater Quality Monitoring and Surveillance
ISO	International Organization for Standardization
POCIS	Polar Organic Chemical Integrative Sampler
PRC	Performance reference compound
QA	Quality assurance
QC	Quality control
SOP	Standard operating procedure
SPMD	Semi-permeable membrane device
USGS	United States Geological Survey

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1.0 Introduction

The following standard operating procedures (SOPs) for the use of semi-permeable membrane devices (SPMDs) in water quality sampling are based on the United States Geological Survey (USGS) Guidelines for the Use of the Semipermeable Membrane Device (SPMD) and the Polar Organic Chemical Integrative Sampler (POCIS) in Environmental Monitoring Studies (USGS 2010). Guidance from the International Organization for Standardization (ISO) guidelines for passive sampling (Technical Committee ISO/TC 147 2010) was taken into consideration. These procedures are limited to the field application of SPMDs. These procedures do not address study design, deployment infrastructure, health and safety, analytical requirements, or data management and quality assurance (QA)/quality control (QC). Consistent use of these procedures will ensure that the data generated are accurate, scientifically robust, and comparable between samplers, sampling events, and sampling sites.

2.0 General Considerations

SPMDs used in water quality monitoring are intended to measure levels of organic compounds within the water column. SPMDs are susceptible to both uptake and loss of compounds at all stages of use; hence, exposure of SPMDs to air or other sources of potential contamination at times other than during in-water deployment may compromise the sample. Minimizing SPMD exposure must be considered when working with these devices during storage, transportation, handling, field exposure, equipment use, and cleaning.

The following must be considered when using SPMDs:

- The tins within which SPMDs are stored must be tightly sealed at all times; damage to the tins may compromise the seal.
- Exposure to contaminants (vapor, liquid, solid) outside of the intended sampling period will compromise the sample.
- SPMDs are inactive at approximately –20°C and should always be kept at a temperature of less than 0°C outside of deployment. This is particularly critical once the SPMDs have been retrieved, as activity associated with the organic matter and biological organisms attached to the SPMDs may alter organic compounds.
- Cleanliness, cleaning standards, and equipment standards are essential for preventing contamination.
- Detailed documentation is critical in supporting the QA/QC of samples, data integrity, and the interpretation of results.

Many events that occur prior to, during, and after sampling may compromise the integrity of the sample and the associated data. A sample may be considered compromised if:

1. the membrane is not intact (i.e., damaged);

2. the membrane has been exposed to contamination;

3. the deployed membrane has not remained submerged throughout the deployment period (e.g., a sample exposed to air or submerged in sediment is not representative of water); and

4. the deployed membrane has shifted location during deployment or has not remained within the same general vicinity of the original sample location (e.g., it was swept downstream of additional sources of water or potential water resource stressors).

3.0 Equipment

3.1 SPMD Membranes

SPMDs are designed to mimic biological organisms in the passive accumulation of compounds. Each membrane is composed of lay-flat, low-density polyethylene tubing that contains a thin layer of a pure, high-molecular-weight lipid (triolein). A single membrane that is to be deployed in the field is loaded onto a stainless steel "spider" or carrier. The carrier is placed in a stainless-steel deployment canister, which may house up to five spiders. One sample consists of a composite of three membranes. Figure 1 depicts a membrane, spider, and canister.

Figure 1. Preparing for the field deployment of a membrane and spider (top right) and canister (bottom right).

SPMDs are manufactured by Environmental Sampling Technologies (EST; http://www.est-lab.com/) and shipped to Environment and Climate Change Canada (ECCC) in clean tins (Figure 2). ECCC receives membranes that are used in the following five ways: as samples, field blanks, travel blanks, dialysis blanks, and spike blanks (Table 1). All membranes, apart from the spike blank, are spiked by EST with 10 µg of fluoranthene-d10, 10 µg of anthracene-d10 and 1 µg of dibenz [a,h] anthracene-d14. These performance reference compounds (PRCs) are used to calibrate for differences in conditions (e.g., temperature, flow, biofouling) between sites and over time; the concentrations of these compounds within the SPMDs are used to calculate the time-averaged concentration of organic compounds in the water column.

Figure 2. Semi-permeable membrane device tins. The large tin is representative of a sample membrane, the medium tin represents a field blank, and the small tin represents travel/dialysis/spike blanks.

Table 1 – Semi-permeable membrane device types and applications
Three membranes are treated as one composite sample or blank.

Membrane Type	Number of Membranes	Handling	Application
Sample	3	Deployed in water	Measuring levels of dissolved compounds in the water column with PRCs. The samples are deployed in canisters that are attached to a deployment array (see the ECCC FWQMS-AA SOP *Deployment Arrays*), which consists of an anchored, suspended float in deep waters or a weighted block in shallow waters.
Field Blank	3	Transported with the sample and opened during field deployment and retrieval	Measuring the exposure of the sample during deployment and retrieval with PRCs. Each sample has a companion field blank (i.e., one field blank for each site and sampling event), which is used to correct sample concentrations for exposure that has occurred outside of the water column.
Travel Blank	3	Transported with sample and field blank – unopened	Measuring the exposure of sample and field blanks during transport – with PRCs. Each QC sampling event (i.e., approximately 10% of sampling events) includes the collection of triplicate samples with one companion field blank and travel blank.
Dialysis Blank	3	Remains in the freezer – unopened	Measuring background levels of compounds upon manufacture with PRCs. Dialysis blanks for each SPMD lot (i.e., a minimum of three for each batch from EST) are retained in storage until the analysis of samples and companion blanks. Concentrations of PRCs in these blanks are used in the calculation of water concentrations.
Spike Blank	3	Remains in the freezer – unopened	Measuring the background levels of compounds upon manufacture – without PRCs. Spike blanks for each SPMD lot (i.e., a minimum of three per batch from EST) are retained in storage until the analysis of samples and companion blanks.

PRC = Performance reference compound; ECCC = Environment and Climate Change Canada; FWQMS = Freshwater Quality Monitoring and Surveillance; SOP

= standard operating procedure; QC = Quality control; SPMD = semi-permeable membrane device; EST = Environmental Sampling Technologies.

Table 2 – Supporting equipment

Supporting Equipment	Equipment Description	Application	Equipment Requirements
Temperature logger (e.g., HOBO®)	A portable data logger used to record "real-time temperature".	Monitoring the temperatures to which SPMDs are exposed during both deployment and sample transit, including prior to deployment and after retrieval. Attached to a stainless-steel SPMD canister during deployment.	HOBO® (http://www.onsetcomp.com/products/software): Connect the unit to a HOBO® Waterproof Shuttle with Coupler (part # COUPLER2-C) prior to operation and enable temperature logging at 10-minute intervals using HOBOware software.
Trackpacks (e.g., NorthStar Science and Technology)	A small removable unit allowing for GPS tracking.	Monitoring field units in remote locations. GeoFences are set up around SPMD deployment arrays to trigger warning emails if the units have moved. They are attached on top of a buoy, facing skyward.	NorthStar Science and Technology (https://www.northstarst.com/): Open an account with a NorthStar representative to activate hardware. Set up airtime requirements for active units. These devices use the Globalstar satellite network.
Multi-probe (e.g., YSI® Sonde)	A multi-probe unit that allows for discrete or unattended sampling of several water quality parameters, including water temperature, specific conductance, pH levels, dissolved oxygen, and turbidity.	Measuring water conditions at the time of SPMD deployment and retrieval.	YSI® (http://www.ysi.com/index.php): Units must be calibrated and maintained in accordance with the YSI user's manual. Calibration of the unit is completed at the beginning of each field trip and on every 5th day of unit use.
Velocity meter (e.g., Sontek® Flowtracker)	A wading velocity measurement device that calculates discharge using two- or three-dimensional currents.	Calculate velocity at 60% depth at the deployment sites. Measurements are taken at the time of deployment and retrieval during flow conditions.	Sontek® Flowtracker (http://www.sontek.com/): Follow the operating procedures detailed in the user's manual. Accompanied by a hand level and wading rod.
Hand-held weather meter (e.g., Kestrel)	A hand-held "pocket weather meter" allowing users to measure a number of environmental conditions, including wind speed and air temperature.	Measure weather conditions on site during the deployment and retrieval of SPMDs.	Kestrel (http://kestrelmeters.com/): Sensors are factory calibrated. Consult the instruction manual for maintenance requirements.

Additional equipment is listed in Appendix A.

SPMD = Semi-permeable membrane device; ECCC = Environment and Climate Change Canada; FWQMS = Freshwater Quality Monitoring and Surveillance; SOP = standard operating procedure.

4.0 Methods

4.1 Storage and Transportation

- SPMDs are more proficient at sampling air than water; the membranes should be kept at temperatures between 0°C and –20°C at all times when not deployed (USGS 2010). Store SPMDs (Figure 2) in a freezer (preferably in temperatures of –20°C) while not in use, as lower temperatures inhibit the uptake and loss of volatile organic compounds, including PRCs, from SPMDs. Freezer storage is particularly critical once the SPMDs have been retrieved, as the activity associated with organic matter and biological organisms attached to the SPMDs may alter the organic compounds. Temperatures below –20°C may cause the membranes to become brittle and prone to breakage.

- Transport the SPMDs in their original sealed tin in a cooler with wet (blue) ice packs and a temperature logger. Do not use dry ice, as it may cause the membranes to become brittle and susceptible to cracking. The ice packs should be placed in plastic bags in case of leakage. As best practice, SPMDs should be frozen at –20°C for a minimum of 24 hours prior to shipping.

- Transport the deployment canisters in clean packaging (e.g., a clean poly bag or garbage bag).

- Denting of the tins may damage the argon seal and expose the membranes. Take adequate measures to prevent damage to the cans (i.e., using packing materials and/or tightly packed ice packs).

4.2 Prior to Deployment/Retrieval

- Clean the deployment canisters following the SOP provided by EST (detailed in Appendix B). Once cleaned, store the canisters in their original packaging, if possible. Wrap the canisters in a clean poly bag. If a float is being used as part of the array, clean the float using the same procedure.

- Activate the HOBO® temperature logger by programming it to record the temperature every 10 minutes (i.e., delayed logging) using the HOBO® Shuttle and Onset software.

- Activate Trackpack.
- Check the array location.
- Select the SPMDs (samples and companion blanks) from the same lot number (assigned by EST upon manufacture) and label all tins with the following: sample number, site name, and sampling (deployment) date.
- Ensure that the sample tins and associated blanks used for the previous deployment are packed for subsequent retrieval.
- Print and populate the field sheets (Appendix C).
- Pack clean deployment canisters.
- Pack coolers immediately before departure. Remove the SPMDs from the freezer and pack them with wet ice packs in coolers, confirming that the SPMD lot numbers match the samples/field blanks/trip blanks for each site. Add a temperature logger to the cooler.
- Calibrate the YSI® Sonde.

4.3 Field Methods

4.3.1 Deployment

Upon arrival at the site, take multi-probe readings of water pH levels, specific conductance, dissolved oxygen, temperature, and hand-held weather readings. Complete the field sheets.

1. Stage for SPMD exposure. Ensure all working surfaces and equipment are clean, such that the SPMDs are not exposed to contaminants other than those in the air and water. Lay out the tins (sample and field blanks) and equipment (canisters, temperature logger, church key, stopwatch, camera, rubber mallet, etc.) in a manner that is conducive to efficient SPMD transfer (i.e., limiting the time of exposure to air and precipitation). Assign roles among the team – designate a crew member to be gloved for SPMD carrier handling, as this individual is not to touch other surfaces ("clean hands"), including the canisters and tins; the other crew members should be responsible for handling the tins, canisters, timing, photography, notetaking, etc.
2. Prior to deployment, slightly pry open the lids on the sample and field blank tins using a church key. Prepare the stopwatch and begin timing upon simultaneously removing the lids from the tins. Minimize sample and field blank exposure to precipitation and direct sunlight, as this will rapidly degrade some polycyclic aromatic hydrocarbons. An umbrella may be used

to shelter the membranes, particularly if deployment is unexpectedly delayed.

3. **DO NOT HANDLE** the membranes. Do not use bug spray, lotion, or other items that may contain organic compounds. The “clean-hands” crew member should wear new nitrile gloves and load the carriers onto the centre spindle of a clean deployment canister as rapidly as possible, without compromising the sample or the health and safety of the field crew. Stainless-steel or Teflon spacers may be used to separate individual carriers within a canister. If a membrane is not properly attached to the carrier, or if the carrier will not fit onto the canister spindle, carefully remove the membrane from the carrier and place it loosely into the deployment canister; try to handle the membrane by the end loops. Note this on the field sheet.

4. Screw the canister lid tightly onto the canister. Matching the mounting ring on the lid with its opposing ring on the canister body, secure and fasten the lid to the canister using a zip tie, stainless-steel carabineer, or other fasteners.

5. Attach the temperature logger to the sampling canister ring.

6. Attach the deployment canister to the sampling array.

7. As the deployment canister enters the water, simultaneously replace the lids of the empty tins and the field blank tins and stop the timer. With care, immediately reseal the tins using a rubber mallet on the edges of each lid. Return the tins to the cooler. These tins will be used to retrieve the sample in the following month.

8. Fill in the field sheet and document the field blank exposure time, as well as any damage or possible membrane contamination.

4.3.2 Retrieval

Upon arrival at the site, take multi-probe readings of water pH, specific conductance, dissolved oxygen, temperature, and hand-held weather readings. Complete the field sheets. After doing so, complete the following steps:

1. Stage for SPMD exposure as in Section 4.3.1, “Deployment”.

2. Ensure that a plan is in place to safely and effectively remove the canisters from the water (e.g., secure the deployment array/float).

3. Prior to sample retrieval, prepare the tins as in Section 4.3.1, “Deployment”. Prepare the stopwatch and begin timing when the lids from the tins are removed and the canisters simultaneously breach the water’s surface. Remove the fasteners from the canister (e.g., cut the zip tie).

4. Handle the membranes as indicated in Section 4.3.1, “Deployment”. The “clean-hands” crew member should wear nitrile gloves and carefully remove the carriers from the canister and place them in their original tins. If the carriers are covered with excessive sediment, gently shake them to dislodge the sediment prior to placing them in the tin. Note this on the field sheet.

5. Take a photo of one of the membranes prior to placing it in the tin. This photo may be used to verify biofouling and sediment exposure.

6. Simultaneously replace the lids of the tins and stop the timer. Carefully and immediately reseal the tins using a rubber mallet on the edges of each lid. Return the tins and the accompanying temperature logger to the cooler.

7. Fill in the field sheet and document the field blank exposure time and any damage to – or possible contamination of – the membranes. Deployment canisters may be stored in a polybag or garbage bag and transported back to the laboratory or warehouse for cleaning. Cleaning is much easier if the debris on the canisters is not allowed to dry.

4.3.3 Field Observations

Upon arrival to the site, take multi-probe readings of water pH levels, specific conductance, dissolved oxygen, temperature, and hand-held weather readings. Complete the field sheets.

Field observations are recorded on the SPMD field sheet (Appendix C). Weather, flow velocities, and site-specific conditions and characteristics (e.g., wind, precipitation, fume exposure, membrane damage, sediment exposure, and change in deployment array location) should be noted, as they may affect the uptake or loss of compounds from the sample and field blank membranes and will be critical to data interpretation. The following should be noted in the field:

- **Weather:**
    - **Cloud cover:** Estimated percent cloud cover; in such conditions, photodegradation of organic compounds can occur.
    - **Wind:** Wind speed and direction; SPMDs are efficient air samplers and exposure to wind and airborne contaminants will affect the uptake and loss of compounds.
    - **Temperature:** Air temperature; temperature affects the rate of uptake and loss of organic compounds (i.e., higher temperatures increase the rate of exchange).
    - **Precipitation:** Rain or snowfall; SPMDs may absorb precipitation.

- **Hydrological observations:**

  - **Flow:** Flow velocity; the rate of flow affects the rate of compound exchange between the water and the SPMD. General observations regarding changes in flow and the location of the deployment array are noted.

  - **Depth:** Water depth; the depth of the canister relative to the water's surface and the bed may be used to interpret water temperature, sediment exposure, and photodegradation.

  - **Ice conditions:** Ice thickness; the thickness of the ice and the depth of the overlying water may be used to interpret water temperature and photodegradation, as well as the exposure of SPMDs to ice-borne contaminants.

- **Membrane condition and contamination:**

  - **Biofouling:** Biofouling class; the accumulation and growth of organic matter/suspended sediment and algae on SPMDs can alter the exchange of compounds between the water and the membranes, and it can also result in the bacterial degradation of organic compounds. Qualitative estimates of biofouling are recorded using five classes, which range from 0 (no apparent biofouling or suspended sediment accumulation) to 4 (a high degree of biofouling or suspended sediment accumulation; i.e., the film's surface is obscured by thick growth/accumulation).

  - **Bed sediment exposure:** Sediment exposure class; in shallow waters, SPMDs may become exposed to or buried by bed sediments, reducing the degree to which the membranes represent water samples. Qualitative estimates of bed sediment exposure are recorded using five classes, which range from 0 (no apparent bed sediment exposure) to 4 (when more than three quarters of the membrane's surface area is exposed to bed sediment).

  - **Membrane integrity:** Damage to the SPMDs or failure of the tin seal; the membranes may tear, the tins may become dented, and the seal may break. Membranes and tins are inspected, and the conditions that may compromise their integrity are noted.

  - **Contamination:** Contamination originating from the air, sediment, equipment, or field practices are noted.

4.3.4 Site-Specific Conditions

Site conditions will affect the nature of the water sampled by the SPMDs and will have implications for the employed deployment and retrieval techniques. SPMDs are typically deployed within the thalweg of the water body to represent the dominant water conditions in the channel, above the bed and in consideration of changing water levels to avoid contamination of the membranes with channel sediments, in shaded areas whenever possible to limit photodegradation of compounds, and away from stagnant waters to limit fouling of the membranes. Site-specific considerations that must be kept in mind to ensure the integrity of a sample during the sampling process thus include:

- **Water depth:** SPMDs may be suspended from the surface by an anchored buoy in deep waters or deployed on the bed in shallow waters.

- **Flow velocity:** Swift-flowing waters versus slow-flowing waters, which affect the rate with which the compounds are exchanged between the water and membranes.

- **Access:** Access may be by floatplane, boat, or wading.

- **Season:** SPMDs may be suspended under ice.

4.3.4.1 Open-Water Rivers

The deployment and retrieval of SPMDs in large, swift-flowing rivers typically require access via motorboat or floatplane and working with an anchored buoy (ECCC 2018a). The deployment location should be approached from a downstream position, whether motoring by boat or taxiing by floatplane. The motor should be turned off a minimum of 20 m away from the buoy and the craft should be allowed to drift toward the deployment array, if the water current allows. If the motor is left running during SPMD deployment or retrieval, this should be noted on the field sheet.

If a grappling device is used to capture the buoy, care should be taken to not breach the water’s surface with the canisters prior to crew preparation for retrieval. A minimum lead time of 10 minutes should be taken to ensure that the fuel residue dissipates before exposing the SPMDs or opening the tins. If the motor must remain running, note this on the field sheet.

Equipment and sample loss occurs rapidly in swift-flowing rivers; take appropriate measures to avoid the loss of equipment and samples. Upon departure, allow the craft to drift downstream of the buoy prior to restarting the motor; maneuver clear of the buoy.

4.3.4.2 Rivers Under Ice

The deployment and retrieval of SPMDs in large rivers in the winter typically require access via snowmobile or helicopter, as well as working with samples that are suspended under ice (ECCC 2018a). The deployment location should be approached from downwind and the motor should be turned off a minimum of 20 minutes prior to SPMD deployment or retrieval.

Snow may need to be cleared from the deployment location. An electric auger, hand auger, or ice chisel should be used to create or clear an opening in the ice. If a gas-powered auger must be used, a minimum lead time of 20 minutes should be taken to allow the fuel residue to dissipate before opening the tins and exposing the SPMDs. If a gas-powered auger is used, note this on the field sheet. Clear the hole of all slush and ice prior to the deployment and retrieval of canisters.

4.3.4.3 Streams

The deployment and retrieval of SPMDs in streams typically requires access by wading and working with samples that have been deployed on or near the bed (ECCC 2018a). Proper scouting of the deployment location will reduce potential delays during deployment and retrieval (i.e., it will limit the amount of time the SPMDs are exposed to air), as well as health and safety mishaps with field crew.

Care must be taken to ensure that the sample is not compromised when wading. Approach the deployment array from downstream and take multi-probe measures upstream of the sampler. In streams with soft sediments and/or slow-moving water, extra care must be taken when approaching the array, as movement of the sampling personnel may disturb/resuspend sediments, exposing the SPMDs to a sediment plume and potentially compromising the sample. If the deployed devices are secured with a cable, caution should be exercised when wading in or out of the stream to avoid the cable. Arm-length gloves may be necessary in cooler waters, especially if water levels have risen since deployment. Changes in water levels may result in exposure of the SPMDs to air, compromising the sample.

4.3.4.4 Wetlands

Deployment and retrieval of SPMDs in wetlands typically require access by a small, non-motorized zodiac, as well as working with samples that have been deployed with an anchored buoy. Extra care should be taken in wetlands where waters are stagnant, as the exposure of SPMDs to disturbed/resuspended sediments may compromise the sample.

4.4 After Deployment/Retrieval

- In the field, following deployment and retrieval, immediately return all blanks and samples to the cooler with ice packs and accompanying HOBOs®. Upon returning to the laboratory or warehouse at the end of the day, the SPMDs should be immediately returned to the freezer (preferably in temperatures of –20°C), along with the appropriate temperature loggers, as per the protocol outlined in Section 2.0, “General Considerations”.

- Ensure the dialysis and spike blanks are kept frozen at all times and submitted for analysis alongside the samples, field blanks, and trip blanks.

- Clean the deployment canisters following the SOP provided by EST Labs (Appendix B). Clean the canister immediately following retrieval for efficient cleaning and place the canister in a clean polybag; then, return the canister to its original – or to an alternative – storage box.

- Organize and backup field sheets and photos as soon as possible.

- Download and backup the temperature logger data once the membranes are returned to a freezer.

- Initiate and populate the tracking files (see Section 4.5).

- If shipping from the site is necessary, find the most direct and efficient route possible. Longer travel times result in higher temperatures, which may affect the membranes. All coolers should be packed with sufficient ice packs and appropriate HOBOs® and blanks. Use packing material, if necessary, to prevent damage to the tins.

- When shipping to the laboratory for analysis, pack the samples and companion (field, travel, dialysis, and spike) blanks in coolers with ice packs. As a best practice, the samples and blanks should be frozen at –20°C for 24 hours prior to shipping. Contact the laboratory for chain of custody (COC) forms, shipping directions, and contacts. Provide the laboratory with the tracking information and confirm receipt.

4.5 Record Keeping

- **Field Sheets:** Retain a hardcopy in a binder organized by year and site. Create an electronic copy and store it in a secure location.

- **Photos:** Store copies of the membrane photos with the associated field sheet.

- **Deployment and retrieval tracking:** Organize a spreadsheet that displays planned, deployed, and retrieved membranes. Populate a separate spreadsheet with sample information and all related field and laboratory notes. This ensures easier access to sample numbers and provides a quick overview of any occurrences that may have compromised a sample, or that may be relevant to data interpretation. Any exceptions, such as why a specific sample may not be usable, should be flagged or noted in this document.

- **Temperature loggers:** Create a readout of the logger using the appropriate software (e.g., HOBOware). Export the data onto a spreadsheet. Calculate the mean, maximum, and minimum temperatures for the time between deployment and retrieval, then enter these data into the sample tracking spreadsheet along with the field multi-probe measures.

- **Laboratory tracking:** Print hard copies of all data and associated COC forms received from the laboratory. Keep the electronic copy in a secure place. Organize and retain communications with the laboratory that pertain to sample processing and tracking.

5.0 Field QA/QC

SPMDs are used to measure concentrations of organic compounds within the water column. SPMDs are susceptible to both compound uptake and loss at all stages of use; thus, exposure of the SPMDs to air or other sources of potential contamination beyond in-water deployment has the potential to compromise the sample. An appropriately quality-assured and quality-controlled program safeguards the integrity of the sample and the information attained from it.

QA/QC of the SPMD field program is captured in the design and delivery of the program. This section addresses those QA/QC measures that are taken with respect to the field program; it does not address data or laboratory QA/QC.

The field QA/QC program aims to ensure that i) exposure of SPMDs to contaminants outside the water column (i.e., outside the period of deployment) is minimized; and ii) contamination/exposure of the SPMDs outside of water sampling is measured. As such, the program includes the application of SOPs by trained personnel, as well as the collection of blanks.

5.1 QA/QC Program Design

The SPMD program includes the following QA/QC measures:

- Each sample has a companion field blank (Table 1).
- At a minimum, all samples and blanks are labelled with their site name, deployment date, retrieval date, sample type, and other specifications, as appropriate (e.g., PRC type).
- A minimum of 10% of sampling events are QC events, which include the collection of a full suite of QC samples (Table 1):
    - triplicate samples;
    - a single field blank; and
    - a single trip blank.
- QC sampling events are cycled through each of the sites on an annual basis:
    - e.g., for a program that includes sampling at nine sites on a monthly basis over a total of 7 months in a given year (excludes shoulder seasons), one QC event will occur at each site over the course of the

year – this is particularly important where multiple teams/agencies are collecting samples across the region being monitored.

- Review of field and trip blank data to determine if the methods need to be modified:
    - e.g., trip blank hits may indicate a need to decrease the potential for contamination during transport; and
    - e.g., field blank hits that exceed expectations may indicate the need to decrease the exposure time or conditions during the deployment/retrieval of samples).
- The retention and analysis of dialysis and spike blanks, which provide measures of background concentrations of organic compounds upon manufacture (Table 1).
- The selection of a laboratory that meets the analytical requirements of the program, such as the application of QA/QC measures, including:
    - analysis of method blanks, method spikes, and laboratory replicates;
    - the use of appropriate calibration standards and methods; and
    - the use of appropriate surrogates and recovery acceptance criteria for organics.

Data management and processing procedures, including QA/QC, are outlined in ECCC 2018b.

5.2 Methods

The quality of SPMD samples and their associated information may be assured through the application of SOPs by trained personnel. These specified procedures are to be applied to both samples and blanks.

These procedures, when adhered to, should ensure that samples (including QC samples) are not exposed to contaminants during (or resulting from) storage, transportation, handling, field exposure, equipment use, and cleaning. If exposure does occur, QC samples should be collected following the SOPs listed in Section 5.1, “QA/QC Program Design”; this will ensure that the level of exposure may be measured, allowing for correction.

In short, SPMDs:

- shall be handled as specified in the SOP;
- must be stored under tight seal and without damage;

- must not be exposed to contaminants (vapor, liquid, or solid) outside of the intended sampling period; and,
- SPMDs should be kept at a temperature between -20°C and 0°C at all times outside of deployment.

5.3 Record Keeping

Detailed documentation is essential when supporting QA/QC. Standard, comprehensive, and secure record keeping is essential for sample tracking, data integrity, and interpretation of the results.

Data records shall include:

- sample number;
- site name;
- sampling date (deployment and retrieval);
- PRC type (10 μg, 2 μg, or photodegradation);
- lot number (of the SPMDs received from the manufacturer);
- sample type (sample, field blank, trip blank, dialysis blank, or spike blank);
- GPS coordinates (latitude and longitude);
- water depth (if possible, at deployment and retrieval);
- flow rate (if possible, at deployment and retrieval);
- physical measures (water temperature, pH level, dissolved oxygen, and turbidity at deployment and retrieval);
- air exposure time;
- water temperature (logged mean, minimum, and maximum);
- analysis date (sent to/received from the laboratory);
- number of films per sample; and
- comments – handling/damage/exposure of films, biofouling (degree/class), sediment exposure, shipping concerns, and laboratory comments (e.g., loss of sample).

This information will be used in data QA/QC and interpretation, and it can also be used to identify samples that have been compromised by such factors as:

- damage;
- contamination;
- changes to sampling conditions (e.g., samples exposed to air or submerged in sediment are not representative of those obtained in water); and,
- changes in location during deployment (e.g., swept downstream of additional sources of water or potential water-resource stressors).

Data records shall be backed up on a regular basis as a best practice.

5.4 Field Audits

Field audits are conducted to ensure that SOPs are followed. Audits should take place at a minimum of twice a year – once during open-water sampling and once during under-ice sampling. If multiple crews are conducting the sampling, an annual field audit should take place with each crew. A checklist (Appendix D) is completed during each audit. Practices that do not adhere to the SOPs are noted, including follow-up actions and outcomes. The results of the audit are shared with the crew members that participated in the audit.

6.0 References

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Appendix A. Equipment List

Primary Equipment List	***Quantity***	✓
SPMDs for Retrieval		
Sample	As needed	
Field Blank	As needed	
Trip Blank	As needed	
SPMDs for Deployment		
Sample	As needed	
Field Blank	As needed	
Trip Blank	As needed	
Icepacks (wet/blue)	As needed	
Cooler(s)	As needed	
Deployment Canisters (cleaned with solvents and bagged)	As needed	
Clean work surface Supplies (to use while handling SPMDs and canisters)	As needed	
Temperature Logger (i.e. HOBO temperature loggers)	1/site	
Nitrile Gloves	Multiple	
Paint Can Opener	2	
Rubber Mallet	1	
Umbrella	1	
Field Sheet	As needed	
Stopwatch	1	
Camera	1	
Depth Sounder	1	
GPS	1	
Program Specific Array Equipment	As needed	
Supporting Equipment List		
Multi-probe meter (e.g., YSI Sonde)	1	
Flow velocity meter (e.g., SonTek Flow Tracker)	1	
Weather meter (e.g., Kestrel Pocket Weather Meters)	1	
GPS tracking (e.g., Trackpacks)	1/site	

Appendix B. Standard Operating Procedure — Cleaning of SPMD Canisters

Objective

The purpose of this SOP is to detain the procedures for cleaning of the SPMD deployment devices before and after field deployment. These procedures are based on Standard Operating Procedure (SOP) E-13 developed by Environmental Sampling Technologies Ltd. (EST), which manufactures the SPMDs and is a supplier of the deployment canisters and film carriers. These procedures are adhered to by Environment Canada, unless otherwise specified.
These procedures apply only to the deployment devices (i.e., stainless steel canisters). The carriers (i.e., stainless steel spiders that carry the films) are cleaned and loaded with films by EST and returned to their sealed tins upon retrieval.
Cleaning is to take place in a clean environment where exposure to contaminants is minimized (e.g., lab, clean space in field/warehouse lab). The use of acetone and hexane must take place in a well-ventilated area (preferably within a fume hood).

Equipment and Supplies

- free-rinsing, non-perfumed laboratory detergent (e.g., Fisher brand Sparkleen I)
- hot water bath (e.g., stainless steel sink)
- drainage rack
- firm, bristled brush, scour pad
- chemical-safe squirt bottles
- PPE
- ACS (American Chemical Society) certified nanograde or pesticide grade acetone (e.g., A19-A Acetone, Fisher Chemical 27 L-5593)
- high-resolution gas chromatography-suitable hexane (e.g., H307-4 n-hexane, Fisher Chemical 126 L-11570)
- bowls/trays (preferably stainless steel if they are to come into contact with the canisters) to capture excess solvent
- clean paper towels upon which to dry solvent-rinsed canisters
- new plastic bags / polybags
- rigid storage container
-

Procedures

Upon Receipt from Manufacturer:

1. Dismantle the deployment devices, if necessary, and soak in a hot water bath using free-rinsing, non-perfumed laboratory detergent (such as Sparkleen 1).

2. After soaking in the detergent solution for several minutes, scrub each piece thoroughly with a firm, bristled brush, then rinse with hot water and set in a drainage rack to dry.
3. Once dry, place the deployment devices in new plastic bags and place in designated, sealed, rigid storage container (i.e. Rubbermaid) until cleaning prior to deployment.

Before Deployment (as close to deployment date as possible; no more than 2 weeks):

1. Remove the deployment devices from the designated storage container they have been stored in. Soak and rinse the pieces in a hot water bath, then set in a drainage rack to dry. Ensure that the bath (e.g., sink) has been cleaned with free-rinsing, non-perfumed laboratory detergent and rinsed with hot water prior to rinsing the deployment devices.
2. Once each piece is dry, rinse each one with ACS (American Chemical Society) certified nanograde or pesticide grade acetone to remove water, and then allow to dry.
3. Rinse each piece thoroughly with hexane (high-resolution gas chromatography-suitable), then allow to dry.
4. Place and seal the deployment devices in new polybags until the time at which they are deployed. Store the bagged devices in a location where the bags will not be damaged and where their exposure to contaminants will be minimized.

After Deployment:

1. The deployment canisters may be covered with deposits (algae, minerals, micro-organisms, etc). Storage of the devices in plastic bags upon retrieval (prior to cleaning) will maintain a high moisture level and, thereby, ease future cleaning effort.
2. When ready for cleaning, disassemble the devices, if necessary, and soak the pieces in a hot water bath using free-rinsing, non-perfumed laboratory detergent for approximately 10 minutes. The devices may need to soak for a longer period of time if deposits have dried or are particularly resistant to cleaning.
3. Using a firm, bristled brush, scouring pad or small wire brush, remove as much of the deposits as possible. If the deposits are still resistant to removal, refer to and follow the EST SOP E-13 for cleaning using an acid bath or muffle furnace. Rinse the pieces with hot water and set in a drainage rack to dry.
4. Place the deployment devices in designated, sealed, rigid storage containers until the time at which they are cleaned before deployment. Store the devices such that their exposure to contaminants will be minimized.

Appendix C. SPMD Field Sheet

SPMD FIELD SHEET
Environment Canada

SITE NAME: ____

GPS COORDINATES: _________________ N ___________________ W   DATUM: ______________

DATE OF: **DEPLOYMENT**______________________   **RETRIEVAL**_________________________

CREW: DEPLOYMENT____

RETRIEVAL____

HOBO # _____________

SPMDs STANDARD Lot #: ____________________ Triplicate ☐ yes ☐ no

EXPERIMENTAL ☐ 2 ug ☐ Photo Lot #:____________ Triplicate ☐ yes ☐ no

SAMPLE No. STND SAMPLE ____

STND FIELD BLANK___________________ STND TRIP BLANK__________________

EXP SAMPLE ____

EXP FIELD BLANK_____________________ EXP TRIP BLANK___________________

SITE DRAWING (Include location of buoy and other samples, landmarks, and **buoy displacement**)

	DEPLOYMENT	**RETRIEVAL**
WEATHER CONDITIONS		
	☐ **See “Retrieval” – Previous Sample**	
AIR TEMP (^{O}C)		
WIND STRENGTH		
PRECIPITATION		
CLOUD COVER (%)		
OTHER SAMPLES		
	☐ **See “Retrieval” – Previous Sample**	
WATER QUALITY	☐ PAH ☐ Metals ☐ Nutrients ☐ Other ________________ Time: Sample #:	☐ PAH ☐ Metals ☐ Nutrients ☐ Other ________________ Time: Sample #:
OTHER (i.e., biosampler)		

	DEPLOYMENT	RETRIEVAL
SITE AND FLOW CONDITIONS		
	☐ **See "Retrieval" – Previous Sample**	
WATER DEPTH (m) (Effective)		
ICE THICKNESS (m)		
FLOW (m/s)		
HAS ARRAY MOVED?	☐ yes ☐ no Details/GPS Coord.:	☐ yes ☐ no Details/GPS Coord.:
AUGER BOAT MOTOR	☐ electric ☐ gas ☐ running ☐ off Approx. time for fumes to dissipate:	☐ electric ☐ gas ☐ running ☐ off Approx. time for fumes to dissipate:
FIELD MEASUREMENTS		
	☐ **See "Retrieval" – Previous Sample**	
TIME (local time zone)		
WATER TEMP (^{O}C)		
pH		
SP. CONDUCTIVITY (us/cm)		
DO (mg/L)		
TURBIDITY (NTU) (degree of clarity if no probe)		
SPMD EXPOSURE		
TOTAL TIME (min/sec)		
NOTABLES (e.g., contamination, damage, tins dented, rain/blowing snow etc.)		
FILM PHOTOS	N/A	☐ yes ☐ no
BIOFOULING CLASS BF = biofilm SS = suspended sediment	N/A	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4

Classes

0- No apparent BF/SS
1 - Slight BF/SS (slight discoloration and/or reduction in transparency).
2- Low BF/SS (visible and patchy growth/accumulation of BF/SS).
3- Moderate (film surface evenly covered by thin growth/accumulation of BF/SS).
4- High BF/SS (film surface obscured by thick growth/accumulation of BF/SS).

BED SEDIMENT EXPOSURE CLASS BS = bed sediment	Dominant Substrate on Deployment: ☐ < 2cm sediment ☐ > 2cm sediment ☐ silt/clay ☐ sand ☐ gravel ☐ cobble ☐ armoured	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 **0-** No BS apparent **1-** <1/4 surface area covered by BS. **2-** 1/4 to 1/2 surface area covered by BS **3-** 1/2 to 3/4 surface area covered by BS **4-** > 3/4 surface area covered by BS

Appendix D. Field Audit Checklist

SPMD FIELD AUDIT

FIELD AUDIT DATE:
AUDITOR NAME:
SITE NAME:
CREW:

FIELD SHEETS					
All fields completed:	Y (Yes) N (No)	If N (No) - Describe	Follow-Up Actions / Responsible authority	Follow-Up By: Date	Outcome / Date
sampling event details					
site drawing					
weather conditions					
other samples					
site and flow conditions					
field measurements					
spmd exposure					
EQUIPMENT					
Equipment Box is complete:	Y (Yes) N (No)	If N (No) - Describe	Follow-Up Actions / Responsible authority	Follow-Up By: Date	Outcome / Date
all tools necessary are available					
SPMDs include appropriate:	Y (Yes) N (No)	If N (No) - Describe	Follow-Up Actions / Responsible authority	Follow-Up By: Date	Outcome / Date

samples (standard and experimental)					
field blanks					
trip blanks (if required)					
same lot numbers					
appropriate labelling (sample type, date, location)					
clean canister					
Coolers contain:					
ice					
hobos					
YSI is:					
calibrated					
PROCEDURES					
SOPs are adhered to:	Y (Yes) N (No)	If N (No) - Describe	Follow-Up Actions / Responsible authority	Follow-Up By: Date	Outcome / Date
sample and blank exposure to potential contaminants minimized (e.g., boat motor) and noted in field sheets					

samples and blanks are handled as per the SOP to minimize damage and contamination					
sample and field blank were exposed as per SOPs (e.g., synchronized exposure)					
sample and field blank exposure time was minimized while taking due care not to compromise the sample or health and safety					
clean canister was used for deployment					
deployment depth was approximately 1m from the surface (except in shallow waters) and SPMDs do not contact the bed					
field sheet and films were photographed upon retrieval					
tins were sealed and seal checked					
temperature logger was retrieved/deployed					

Additional information can be obtained at:

Environment and Climate Change Canada
Public Inquiries Centre
7th Floor, Fontaine Building
200 Sacré-Coeur Boulevard
Gatineau QC K1A 0H3
Telephone: 1-800-668-6767 (in Canada only) or 819-997-2800
Email: ec.enviroinfo.ec@canada.ca

Appendix E. Water Sampling and Fish Health Quality Assurance and Quality Control

Appendix E - Water Quality Assurance/Quality Control

A quality assurance/quality control (QA/QC) program is incorporated into the field and laboratory methods utilized to ensure accuracy during sampling and to quantify any uncertainty introduced during the field execution or laboratory analysis. QA/QC methods are described below.

Best efforts will be made to ensure analytical hold times are met for each analysis; however, logistical constraints and unforeseen delays can occur. If analytical hold times are exceeded, the potential influence on the reported measurement will be reviewed and discussed with the laboratory following an initial review of the certificate of analysis.

E.1 Quality Assurance

TRSA, through Worley Consulting, maintains in-house quality assurance methods that include:

- Training:
  - Field supervisors are vetted through a Site Supervisor Progression Program that assesses technical and safety competency.
- Standard Operating Procedures (SOPs):
  - Worley Consulting maintains a library of SOPs that are built from industry standards and professional expertise. SOPs exist for elements such as field equipment use and calibration, sample collection, sample handling and data management. Adherence to SOPs is required.
- Field Data Collection Method:
  - Data is collected on standardized field forms (either paper or electronic).
- Sample Integrity and Handling:
  - Worley Consulting SOPs cover sample integrity requirements such as clean glove, bottle handling, filtering, storage, temperature for storage and field equipment sanitization.
- Sample Identification and Labelling:
  - All samples are collected into bottles with designated, location-specific sample labels and number of containers per sample is tracked.
- Hold Times:
  - All samples are tracked against analyte-specific hold times to ensure samples are analyzed within established timeframes post-collection to minimize analyte degradation. Exceedances of hold times are common for some parameters due to limited shipping options from Norman Wells. Hold time exceedances are evaluated for their impact on data reliability.
- Storage:
  - All SPMD triolein films are stored below 0°C before and after deployment, including during shipping.

- Chain of Custody:
  - All samples are shipped to accredited laboratories using standard chain of custody methods that record sample name, sample time, number of containers, sampler names, project information and required analysis.
- Laboratory Selection:
  - Canadian Association for Laboratory Accreditation (CALA) laboratories are selected for all water analysis. CALA accredited laboratories must adhere to management and technical requirements of ISO 17025 and must follow accepted analytical procedures. Laboratory credentials and methods used are provided in individual laboratory certificates of analysis.

E.2 Field Sample Quality Control

E.2.1 Grab Sample and PDB Quality Control

Grab sample and PDB QA will include field duplicates, trip blanks and field blanks during each sampling event:

- Field Blanks:
  - Used to detect contamination during sampling, shipping, and laboratory analysis; sample containers are filled in the field with laboratory-verified contaminant-free water. Water sample containers will be filled with certified organic-free and deionized water at a selected sample location. Field blank samples will be transported and analyzed along with field samples.
- Trip Blanks:
  - Used to detect contamination that occurs during transport to and from the area where samples are collected; sample containers filled with laboratory-verified contaminant-free water are transported to the field and back but are not opened.
- Duplicate Field Samples:
  - Assesses the reliability of field and laboratory methods and results. At least 10% of samples collected in the field will be accompanied by a duplicate sample to be analyzed by the laboratory. A field duplicate will include a secondary set of sample containers filled with analyte from the same source as the parent sample. Additional PDBs will be deployed at one location to allow for duplication of hydrocarbon parameters from the PDBs.

E.2.2 SPMD Quality Control

SPMD deployment will include field duplicates, trip blanks and field blanks during each sample event:

- Field Blanks:
  - Used to detect contamination during sampling, shipping, and laboratory analysis. A container with one SPMD strip inside will be transported to each sample location and opened at each location for the same duration as is required to deploy and retrieve the sample.
- Trip Blanks:
  - Used to detect contamination that occurs during transport to and from the area where samples are collected. A container with one SPMD strip inside will be transported to each sample location during deployment and retrieval. The container will not be opened. It will be shipped with samples to the laboratory for analysis.
- Duplicate Field Samples:
  - Assesses the reliability of laboratory methods and results. At least 10% of samples collected in the field will be accompanied by a duplicate sample to be analyzed by the laboratory. A field duplicate will include a secondary SPMD film strip to be deployed and handled in the same manner as the parent sample.
- Fabrication Blank:
  - (Day Zero Blank – Are films that have been manufactured at the same time as films deployed to account for interferences or contamination from film storage, processing and analysis (Alverez 2010). A container with one SPMD film is sent directly from the supplier to the laboratory and stored until samples come from the field for analysis.

E.3 Laboratory Quality Control

All samples will be analyzed by accredited laboratories using their internal laboratory QC programs. Typical laboratory QC will consist of one or more of the following analyses:

1. Instrument and extraction surrogate recoveries for the water samples that were analyzed.
2. The analysis of method blank, laboratory duplicate, matrix spike and/or laboratory control samples for the sample analytical batches that were analyzed. The laboratory QC results will be presented in the certificates of analysis.

E.4 Analysis of Field and Laboratory QA/QC Data

All laboratory and field-based QA/QC data will be analyzed to determine if the data presented is fit for purpose. Laboratory QA/QC results will be compared to the standards developed within CCME 2016.

E.4.1 Field Sample QC Analysis

Uncertainty in field QC analytical results will be qualified by reviewing reported results against historical data and environmental quality guidelines to determine if data is fit for purpose or if data integrity issues present a meaningful impact on data interpretation. QC elements and review considerations are presented in Table E-1.

Table E-1: Field QC Elements and Metrics

QC Element	Metric	Typical Acceptance / Alert Considerations
Field Duplicate	Meets relative percent difference (RPD) alert limits (Section 1.3.1.1).	PAHs = >80%. All other parameters = >50%.
Field Blank	Indicates potential cross-contamination from sampling equipment or ambient field handling practices.	Should be non-detect. Any detection warrants scrutiny of all associated samples. Compare results against >2× MDL for PHC F2–F4 or >5× MDL for other analytes alert limits.
Trip Blank	Checks for transport-related contamination, especially critical for volatile hydrocarbons.	Should be non-detect. Any detection warrants scrutiny of all associated samples. Compare results against >2× MDL for PHC F2–F4 or >5× MDL for other analyte alert limits.
Holding Times and Preservation	Confirms samples were analyzed within required timeframes and preserved properly to maintain integrity.	Must meet method-specified holding times and preservation requirements.

E.4.1.1 Field QC Methods and Alert Limits

Field duplicates will be analyzed using a RPD method:

$$\text{Field Duplicate RPD (\%)} = \left\{\frac{(|C1-C2|)}{\left(\frac{C1+C2}{2}\right)}\right\} x\ 100$$

Where: RPD = relative percent difference.

C1 = one of the observed values from the field duplicate analysis.

C2 = the other observed value from the field duplicate analysis.

Field QC sample alert limits employed are as follows:

- Field Duplicate RPD:
  - Hydrocarbons = >80%.
  - All other parameters = >50%.
- Field and Trip Blanks:
  - PHC F2-F4 = >2 x method detection limit (MDL).
  - All other parameters = >5 x MDL.

If field QC sample results are found to exceed their respective alert limits, then the cause of the exceedance will be investigated, and the implications on overall data quality and reliability will be presented.

E.4.2 Laboratory QC Analysis

Uncertainty in laboratory QA analytical results will be qualified by reviewing reported results against historical data and environmental quality guidelines to determine if data is fit for purpose or if data integrity issues present a meaningful impact on data interpretation. QA elements and review considerations are presented in Table E-2. Method blank concentrations may be similar to concentrations in deployed SPMDs for some PAHs based on historical results. Where detections or observed in method blanks, the reported concentrations will be blank corrected to account for potential contamination during laboratory analysis.

Table E-2: Laboratory QA Methods and Metrics

QC Element	Metric	Typical Acceptance/Alert Considerations
Method Blank (MB)	Identifies contamination introduced by laboratory reagents, glassware, or instrumentation.	Non-detect.
Surrogate Recoveries	Measures method performance for each organic sample—validates extraction and analysis efficiency.	Must fall within lab-specific control limits. Labs provide acceptance windows per method.
Laboratory Control Sample (LCS)/LCSD	Demonstrates overall method accuracy (LCS) and precision (LCSD) using a clean control matrix.	%Recovery and RPD must fall within laboratory control limits.
Matrix Spike/Matrix Spike Duplicate (MS/MSD)	Evaluates analyte recovery and precision in the actual sample matrix, identifying matrix interferences.	%Recovery and RPD must meet method-specific control limits.
Laboratory Duplicates	Assesses analytical precision for a sample/matrix under laboratory conditions.	RPD must meet method or lab precision criteria.
Initial/Continuing Calibration (ICV/CCV) and Continuing Calibration Blank (CCB)	Confirms instrument calibration, accuracy, and absence of carryover throughout the batch.	Calibration checks must meet method calibration windows; CCBs must be clean.

E.5 Fish Health Quality Assurance/Quality Control

The QAQC program assures that fish health and tissue residue results are reliable, reproducible, and verifiable. Where applicable, quality control criteria have been adopted from the Canadian Council of Ministers of the Environment (CCME) Guidance Manual for Environmental Site Characterization in support of Environmental and Human Health Risk Assessment (CCME 2016). Quality criteria in the CCME guidance document are based mainly on water and soil/sediment matrices. Tissue sample matrices are more comparable with soil/sediment, so criteria for these have been used for the QA/QC program (CCME 2016).

Both internal (laboratory-based controls) and external quality controls (field-based controls and Worley quality standards) have been employed to address data accuracy, precision, bias, and to identify sources of potential contamination during analysis.

The fish health programs follow the Worley Consulting standards for quality assurance as outlined in Section 1.1. In addition to the procedures listed in Section 1.1, fish muscle tissue and whole body samples are immediately placed on ice and frozen as soon as feasible. Liver samples are flash frozen in pre-labelled and pre-frozen vials and placed directly into frozen cooling racks to prevent thawing. All samples remain frozen during transportation from sample locations to analytical laboratories.

Analytical methods used to characterize fish health (protein content) and tissue residue concentrations are sensitive; therefore, field sampling procedures must be carefully controlled to prevent contamination from handling during dissection and tissue harvesting. Dissection surfaces and tools must be thoroughly cleaned between individual fish using 80% ethanol or acetone/hexane washes to prevent cross-contamination. Personnel handling fish must wear nitrile gloves that are either cleaned or replaced between each fish, and dissection areas must be established in clean areas that are protected from dust and emission sources.

E.5.1 Internal Laboratory Quality Control

Internal laboratory QA procedures will include analysis of method blanks, matrix spikes, duplicate samples, and calibration standards for each sampling event:

- Method Blanks:
  - Used to identify potential contamination with laboratory equipment and ensure that contaminants from outside sources do not influence results. Analyzed variables should remain below the detection limit since there are no analytes present in the blank material. Method blank materials such as canola oil are housed at the analytical laboratory.
- Matrix Spikes:
  - Used to identify laboratory bias. Concentrations will be measured in spiked samples and compared with concentrations reported in the parent material of the associated spike and a percent recovery can be calculated. Percent recoveries are compared with acceptable ranges to identify measurements that may be biased.
- Duplicate Samples:
  - Used to estimate the precision and reproducibility of results. Duplicates are created by splitting tissues from within a single sample after homogenization so that results can provide an assessment of the homogeneity of the sample.
- Calibration Standards:
  - Calibration standards are employed by laboratories on an ongoing basis to assure that analytical equipment is functioning properly and results are not subject to drift. Results from calibration standards are compared with typical operating ranges to ensure proper function throughout the analysis of each sample batch.

E.5.2 External Quality Controls

Quality control procedures that are outside the control of the analytical laboratory are used to ensure that results are fit for purpose, reproducible, and accurate. For the AEMP external control samples include tissue samples split during tissue harvesting and submitted to the lab independently such that the laboratory does not know the source of the duplicate tissue (external duplicate), as well as reference materials with documented tissue concentrations:

- External Duplicates:
  - Used to assess reproducibility of independent tissue samples while ensuring the laboratory is blind as to which sample represents the parent sample. Fish tissues from a single fish (or single composite sample) will be retained in separate containers that are labelled using standard procedures for the parent sample and using a pre-determined code that allows the consultant to identify the parent sample but ensures the laboratory is unaware of the parent samples identity.
- Reference Materials:
  - Used to identify potential bias and the accuracy of results. Standard and certified reference materials are developed by providing tissue samples to numerous labs that measure the concentrations of target analytes. Results from the various labs are compiled to determine an average concentration and reference range based on the variability of the results. These tissues are obtained by each analytical laboratory, analyzed with each batch of environmental samples, and results are compared with the previously measured reference concentrations.

E.5.3 Analysis of QA/QC Data

Analytical results will be qualified by reviewing reported results against historical data and tissue residue thresholds to determine if it is fit for purpose. Where QAQC results indicate a potential bias or concern, the potential impact on data interpretation will be discussed as part of the annual summary report. The QC elements and review considerations for fish tissue analytical results are presented in Table E-3. In addition, all laboratory quality criteria provided in Table E-2 are required for assuring the accuracy of tissue residue results.

Table E-3: Quality Control Elements and Acceptance Criteria for Fish Tissue Analysis

QC Element	Metric	Typical Acceptance / Alert Considerations
Duplicate	Meets relative percent difference (RPD) alert limits.	Polycyclic Aromatic Hydrocarbons (PAHs) = >50%. Metals (excluding aluminum, barium, lead, mercury, molybdenum, potassium, silver, sodium, strontium, and tin) = >30%. Aluminum, barium, lead, mercury, molybdenum, potassium, silver, sodium, strontium, and tin = >40%.
Method Blank	Indicates potential cross-contamination from analytical equipment.	Should be non-detect. Any detection warrants scrutiny of all associated samples. Compare results against >5× MDL.

QC Element	Metric	Typical Acceptance / Alert Considerations
Matrix Spike	Checks for potential bias and accurate concentration results.	Percent recoveries of the spiked concentration should be within: • 50-140% for PAHs. • 70 to 130% for metals.
Reference Materials	Confirms results are reliable given the accuracy and reproducibility of previously measured reference concentrations.	Must be within reference range while accounting for ±25% variability between laboratories.

Appendix F. Community Fish Observation Feedback Form

FISH HEALTH DATA SHEET

Instructions: *Please fill out the form with as much information as you have. Please complete for both healthy and unhealthy fish. Sheets can be returned by using the following email:* *ImperialNormanWellsAEMP@worley.com*

Site Information

Date: ______________ Time: ____________ Location: __________________________

Coordinates (Lat/Long or UTM): ____

Weather Conditions

☐ Sunny ☐ Cloudy ☐ Rain Air Temp: ___°C Water Temp: ___

Additional Weather Comments: ____

Fish Details

Species: ___________________ Length: _____ cm (____ in) Weight: _____ kg (____ lbs)

Sex: ☐ Male ☐ Female ☐ Unknown Catch Method: ____________________________

Additional Comments or Concerns (Please add comments about things like: stomach contents, meat quality, etc.)

____

____

____

Insert Photo

Appendix G. Upstream Water Quality Dataset

Appendix G - Establishing the Upstream / Background Dataset

Upstream background concentrations of KIPs will be compiled from all upstream locations into one upstream range set on a per waterbody basis (i.e., one set for the Mackenzie River and one set for Bosworth Creek). As the AEMP is intended to detect changes in water quality between upstream and downstream locations, rather than to determine overall environmental health; comparison to a background (i.e., upstream) dataset is better suited to detecting change as opposed to comparison to a fixed water quality objective.

Due to season changes in water quality, particularly concentrations of suspended solids, data will be checked for relationship to flow and, where such a relationship is found, will be flow-corrected to allow for comparison across seasons. Where no relationship to flow is noted, data can be pooled without flow correction.

Background data will be added to and updated every two years (i.e., every eight additional data points per location).

Baseline data will be defined as a minimum of eight data points extending from well installation to a statistically significant change in trend or to the current reporting period (once the minimum eight points is reached; USEPA 2009). Previously collected data will be used for existing sampling locations.

G.1 Calculation of Background Control Limits

The Background dataset will be used to calculate the Background Control Limits for each KIP. Background Control Limits will be calculated using the tolerance interval approach as described in Helsel (2012), provided that the data meets the following conditions:

- The data set includes at least eight data points.
- Greater than or equal to 40 percent of data are detectable.
- The Background source data set does not include:
  - An increasing trend (determined via the Akritas-Theil-Sen [ATS] Slope with Kendall’s tau).
  - A decreasing trend (determined via ATS Slope with Kendall’s tau).
  - Verified outliers (removed prior to defining baseline data sets).

The equations used to determine the UCL and LCL are as follows:

Equation 1: Upper and Lower Control Limit Calculation

$$UCL = \ Upper\ 95\%\ confidence\ limit\ of\ Q(90)$$

$$LCL = \ Lower\ 95\%\ confidence\ limit\ of\ Q(10)$$

Where:

$Q(90) = 90th\ percentile\ of\ measured\ data$

$Q(10) = \ 10th\ percentile\ of\ measured\ data$

$UCL = Upper\ Control\ Limit$

$LCL = Lower\ Control\ Limit$

G.1.1 Managing Data During Background Establishment

During Background data establishment, the following scenarios may occur that will require consideration in how the data is used:

- Data Below the Detection Limits:
  - In cases where less than 40 percent of the baseline data set are detectable, the UCL will be set to five or two times the typical RDL (as applicable) and the LCL will not be calculated (not applicable).
- Outliers:
  - An outlier is defined as a value originating from a different statistical population than the rest of the sample. Outliers will be identified using Tukey's Box Plot Method which is suitable for non-normally distributed data (USEPA 2009).
  - A valid reason for removing an outlier is required before it could be removed from the data set (USEPA 2009). The following are defined as valid reasons for outlier identification and removal from the dataset:
    - Anomalous concentrations recorded due to poor sampling conditions such as limited water below ice or disturbance of substrate during sampling procedure.
    - An error in transcription, dilution or analytical procedure, etc. that could be identified, but the error could not be corrected.
    - The value was part of a group of parameters with one-time detections that were not replicated in subsequent follow-up verification sampling or any other sampling event.
    - Values for multiple parameters in a field duplicate sample were atypical relative to the parent sample and were not confirmed by subsequent monitoring results.
    - The value was a one-time detection that was more than one order of magnitude greater than the reportable detection limit.

- One parameter reported over multiple samples from different sampling locations in one sampling event was high biased or low biased.
- The data quality of anomalous KIP concentrations could not be verified due to historically incomplete files.

- Trends in Data:
    - Data for inclusion in the Baseline dataset will be analyzed for trends using the ATS slope with Kendall's tau. Data showing statistically significant trends may be rejected or removed from the background dataset.

Trends in upstream data will be assessed on a per location basis to determine if they are indicative of wider environmental changes that should be accounted for in the Background data or if they are location specific. As upstream locations are not site-influenced, trends in upstream data would not be attributable to site related activities. Due to the lack of potential site influence, data may be added to the Background dataset before a trend is observable (data added every two years); if trends are identified after further sampling events, then its data may be removed from the dataset.

Appendix H. Use of Third-Party Data Sources

Memorandum

Subject	Imperial Norman Wells Operations – Aquatic Effects Monitoring Program – Third Party Data Sources
Project No.	417085-59897
Project	Imperial Norman Wells Operations – Aquatic Effects Monitoring Program

1. Background

The Sahtu Land and Water Board (SLWB) hosted the *Tu Luge* (Health Water, Health Fish) Working Group session in Fort Good Hope, Northwest Territories, in September 2025 to facilitate development of a large fish monitoring program by Imperial Oil as part of their Aquatic Effects Monitoring Program (AEMP) as is required under their Water Licence (S13L1-007).

During that session, a commitment was made to establish how data from other sources such as publicly available government data, academic studies and community monitoring, can be incorporated into the AEMP reporting and data analysis. Data from sources other than that directly collected by Imperial and their consultants will be used to increase the dataset available with the goal of increasing the reliability of the findings of the AEMP. As a secondary benefit, data may be valuable as a check on the reliability of the data collected for the AEMP.

This memorandum is intended to establish currently available data sources to be used, it will be incorporated as an appendix in the next iteration of the AEMP plan document and changes or additions will be managed within future annual reports.

2. Third-party Data Sources Considered

The AEMP will consider two categories of data to inform and complement the data collected through the dedicated program:

- General environmental monitoring data through government sources; and
- Dedicated studies such as community-based monitoring programs and academic studies.

2.1 General Environmental Monitoring Data

- Water level and flow data in the Mackenzie River and Bosworth Creek through Environment and Climate Change Canada (ECCC):
  - Real-time hydrometric data is reported for the Mackenzie River at Norman Wells (station 10KA001) and Fort Good Hope (station 10LD001) and for Bosworth Creek at Norman Wells (station 10KA007).
  - Watershed data for stations upstream within the Mackenzie watershed will also be reviewed for potential changes to the wider aquatic environment.
  - https://wateroffice.ec.gc.ca/index_e.htmlWeather and climate data.
- Precipitation and air temperature data are available through ECCC for Fort Good Hope, Norman Wells and Tulita:
  - https://climate.weather.gc.ca/
- Wildfire information through Government of Northwest Territories (GNWT):
  - https://www.gov.nt.ca/ecc/services/wildfire-update/en/firedata

2.1.1 Data Usage

General environmental data will be used to understand the overall environmental variables that may affect water quality or fish health. Changes in water and fish metrics will consider these variables as potential factors in that change. Examples of how this data may inform the program are:

- Temperature extremes or trends may stress fish or result in increased sedimentation in water which can alter water chemistry;
- Wildfires may deposit contaminants into the river such as polycyclic aromatic hydrocarbons (PAHs); or
- Runoff changes from seasonal norms (extreme rainfall events, low snowpack, etc.) can alter expected water chemistry.

2.2 Dedicated Environmental Monitoring Programs and Studies

The AEMP will review data collected and available through publicly available studies and datasets. Where relevant studies are found but are not publicly available, Imperial or Tłegéhłı̨ Reclamation Services Advisian (TRSA) will contact the primary author of the report for permission to use that data.

Where data is available for use, such as water quality data, TRSA will assess the applicability to the program and directly incorporate that data into the AEMP dataset. Where studies are available that investigate water quality or fish health in the Mackenzie River or Bosworth Creek, those studies may be used to assess the validity of the AEMP's findings.

Specific data sources identified for use are:

- The Mackenzie Datastream: https://datastream.org/en-ca/
  - A publicly available dataset run by the Gordon Foundation with support from ECCC and the GNWT, among others;
  - This is a community-based open data platform which includes water chemistry data collected at Norman Wells (station NW10KA001). The current dataset includes chemistry data from 2000 to 2025.
  - Data collected for the AEMP will be uploaded to the Mackenzie Datastream; TRSA is currently investigating how to become a contributor to this effort so AEMP data can be uploaded.
- The NWT Cumulative Impact Monitoring Program (CIMP)
  - Data related to the local aquatic environment will be reviewed through the NWT Discovery Portal: https://nwtdiscoveryportal.enr.gov.nt.ca/geoportal/
  - The NWT Community-based Water Monitoring 10-Year Summary Report 2025 provide a summary of methods and findings.
- ECCC Data Catalogue
  - A publicly available data source from ECCC that presents federally supported studies.
- The Polar Data Catalogue: https://www.polardata.ca/
  - A publicly available data repository where research conducted through government bodies or programs, such as the Northern Contaminants Program, is stored.

TRSA will conduct an annual literature review to determine if any studies in the region provide relevant data for use.

2.2.1 Data Usage

When data is available and appropriate, it will be directly incorporated into the monitoring dataset.

Where reports are available but data is not published, the methods and findings from those reports will be reviewed and compared to findings from the AEMP.

3. Acknowledgements and Permissions

Where specific studies are identified and data is not already posted to a publicly available database, TRSA will contact the study lead for permission to access use the data.

All data sources will be cited.

Appendix I. Statistical Analysis and Data Evaluation Methods’

I.1 Overview

Data evaluation will be part of the AEMP Report submitted to the SLWB on or before 30 April annually as per Part I – Section 3 of Imperial's Water Licence (S13L1-007). The statistical approaches that will be applied annually during the AEMP are summarized herein. Environmental data regularly contains analytical results that are below the detection limit of the analytical method and are reported as a non-detection (also referred to as censored values). The statistical methods proposed for the AEMP include the information in non-detections (i.e., detection limit values and the frequency they occur) by utilizing survival analysis methods that are described in more detail in the following sections.

Table I-1: Summary of Statistical Approaches Used for Analysis of AEMP Data

Environmental Media	Sampling Target	Analytes	Statistical Approaches	Censored Data Treatment
Water	Grab sample	Ionic composition Nutrients Metals Hydrocarbons	Summary statistics[1] Piper plots Tolerance intervals Spatial comparisons between upstream and downstream locations Trend analysis Multivariate statistics[2] Guideline comparison	Percentile and survival analysis Akritas-Theil-Sen (ATS) trend analysis with Generalized Additive Model (GAM) smoothing for flow or seasonal Kendall with ATS μ-score/rank transformation[2]
	Passive samplers	Polycyclic aromatic hydrocarbons (PAHs), hydrocarbons	PAH/aPAH congener profiling Pyrogenic Index Total hydrocarbons Total PAHs Guideline comparison Spatial comparisons between upstream and downstream locations	Total PAH as a range based on minimum and maximum potential values Survival analysis
Fish Tissue Residue - Large-bodied fish	Edible tissue (e.g., fillet or loche liver)	Metals	Summary statistics SETAC effects-threshold comparison ANOVA/PERMANOVA hypothesis tests Control charting Trend analysis	Percentile and survival analysis
Fish Tissue Residue - Small-bodied fish	Whole-body composite	PAHs	Total PAHs Regional comparisons PAH/aPAH congener profiling	Total PAH as a range based on minimum and maximum potential values
	Liver	Protein content	ANOVA hypothesis tests	Qualify results below the lowest calibration standard and report measured concentration

Environmental Media	Sampling Target	Analytes	Statistical Approaches	Censored Data Treatment
Fish Health	Energy storage	Body weight relative to length	Condition ANOVA/ANCOVA hypothesis tests	No censoring
		Liver weight (relative to body weight)	Liversomatic index (LSI) ANOVA/ANCOVA hypothesis tests	No censoring
	Reproductive energy use	Gonad weight (relative to body weight)	Gonadosomatic index (GSI) ANOVA/ANCOVA hypothesis tests	No censoring

Notes:

Superscript 1 - Summary statistics include measures describing data distribution for each parameter, including mean, standard deviation, median, quantiles, minimum, maximum and percent detection.

Superscript 2 - Variables included in multivariate analysis will be key indicator parameters (KIP) with up to 60% of results below detection and <10% missing results.

I.2 Water Quality Statistical Approaches

Water quality analyses will focus on assessing changes in water chemistry as it passes through NWO (i.e., changes that may be directly attributable to influence from the Operation). However, changes in the upstream dataset are possible over time that may be attributable to forces such as climate change or significant environmental events (e.g., landslides). Water quality of the upstream dataset will be assessed for such changes to the overall river system and be used to establish background conditions within the Mackenzie River (Appendix G). Community knowledge of environmental conditions during each year will be integrated into the interpretation of analytical results in addition to the following data evaluation methods. This can include but is not limited to observed flow, water temperature, fish quality, fish abundance, and how conditions compare to those historically observed.

The goals of the water quality data analysis will be to answer the following questions:

- Are **temporal changes** occurring year-over-year at one sampling location over time?
  - Present all parameters with historical data graphically and in table format.
  - Statistically test for significant increasing or decreasing trends.
  - Use multivariate analyses and clustering to identify patterns in water chemistry among sampling seasons and years.
- Do chemical concentrations **change spatially** between potentially impacted versus non-impacted locations?
  - Compare upstream to downstream water quality using statistical hypothesis testing.
  - Develop tolerance limits for KIPs with an appropriate dataset established (dataset development is provided in Section I.2.7.

- Use multivariate analyses and clustering to identify patterns in water chemistry among upstream and downstream sampling locations.
- Compare upstream to downstream ionic composition with Piper plots.

- Do chemical concentrations in the Mackenzie River and/or Bosworth Creek pose a risk to aquatic biota?
  - Compare concentrations with published guidelines accounting for conditions of the receiving environment.
- Are observed changes related to NWO activities or natural regional changes along the river?
  - Investigate longitudinal effects as the river naturally changes downstream.
  - Comparison with other available data sources and studies.

I.2.1 Establishing Normal Ranges

Data for KIPs will be plotted so that new monitoring data can be compared with established tolerance limits based on the upstream dataset. Tabulated results will be accompanied by graphics to help visualize and distinguish any changes or trends over time. Upstream water quality data is assumed to be unaffected by NWO and representative of naturally occurring conditions (i.e., normal range). Due to the potential for changing conditions associated with climate change (e.g., increased sediment loading, increased groundwater infiltration related to degrading permafrost), the upstream data will be used to establish normal ranges rather than discrete "background" numbers. This normal range will be established based on the tolerance intervals that set the upper control limit (UCL) and lower control limit (LCL) for each KIP. Control limits will be developed for each KIP based on the 95% confidence on the 90th and 10th percentiles of upstream data pooled across sampling locations as described by Helsel (2012). Survival analysis methods including robust Regression on Order Statistics (rROS; when sample size is less than 50 and data fits a known distribution) or Maximum Likelihood Estimation (MLE; when sample size is larger than 50 and data fits a known distribution) to incorporate measurements below detection into statistical analyses.

Normal ranges established based on upstream data will be used to assess downstream conditions and enable meaningful visual assessment. In addition, this allows for direct comparison of an individual event's data with the normal range and helps determine if exceedances of applied guidelines are naturally occurring. The background chemistry will be an evolving dataset as more data is collected (Appendix G), derivation of the numbers presented will be included in an appendix of the annual report.

Visual representation of data will be accompanied by supplementary summary statistics (i.e., minimum, median, 25th percentile, 75th percentile, 95th percentile, maximum, mean, standard deviation and detection frequency) for various comparisons. Survival analyses (e.g., rROS or MLE) that account for the proportion and level of censored results will be used to compute appropriate summary statistics for parameters with results below detection.

Water quality data from the duration of the AEMP will be compared, along with historical data from other monitoring programs (e.g., SNP), to assess any interannual differences or potential temporal trends; as well as to help separate natural variability from potential effects from the Imperial site.

I.2.2 Assessing Change Over Time (Temporal Trend Analyses)

The Akritas-Theil-Sen (ATS) slope is a version of Sen's slope developed for determining a median slope when censored data is present and will be used to account for censored data during the AEMP. An ATS slope that is positive indicates an increasing trend while a decreasing trend is indicated by a negative slope. Slopes will be presented both in absolute terms (mg/L per year) and normalized relative to the median concentration (% change per year). Kendall's tau will be used as a measure of the strength of the correlation between chemical concentration and time. Significant trends will be those with a p-value of less than 0.05 and a normalized slope of 5%.

Water chemistry is highly dependent on discharge in watercourses. Therefore, the relationship between discharge and chemical concentrations of each KIP will be modelled using generalized additive modelling (GAM) and the ATS slope calculated on the residuals from the GAM to identify trends over time. Where chemical concentrations as a function of discharge do not fit the GAM effectively, the ATS slope will be calculated using chemical concentrations to identify trends over time. As more data becomes available, censored versions of a seasonal Kendall's test or fitting cosine/sine functions can be used to control for seasonal variability. Any KIPs containing censored data will employ statistical methods that incorporate the information provided by the detection limit levels and the proportion of censored data.

I.2.3 Upstream vs Downstream Site Comparison

Water chemistry concentrations reported during the AEMP will be presented graphically in scatterplots in relation to the distance from the NWO. If potential trends exist based on a visual assessment of the data, a trend analysis using the methods described for assessing changes over time will be applied to determine if visual observations represent significant trends that indicate spatial changes downstream from the NWO.

For each KIP, statistical hypothesis testing using Analysis of Variance (ANOVA) to compare group means among sites will be used to compare conditions upstream (background) with those observed downstream (experimental). Where a portion of the data is censored (below detection), a censored regression ANOVA approach will be used so that rROS (sample size less than 50) or MLE (sample size greater than 50) can be used to impute censored values. There are three upstream water quality sampling locations with historical data, and a fourth will be added as part of AEMP Version 5. Meanwhile, there are ten downstream monitoring locations, resulting in an unbalanced study design. To address this limitation, water quality monitoring locations on the Mackenzie River will be grouped together using a blocking approach to reduce the imbalance between upstream and downstream data. Monitoring locations will be grouped into upstream sites, sites within the NWO (Imperial sites), and downstream sites as far downstream as Fort Good Hope (downstream sites).

These analyses will be completed for all KIPs that do not have an identified temporal trend, given that potential trends over time could influence the results of site comparisons using data pooled across years.

I.2.4 Multivariate Statistical Analysis

Multivariate statistical techniques are useful for spatial and temporal comparisons among sites where a large multi-dimensional data set exists. Historical monitoring activities to date have developed such a dataset for the AEMP. Given the availability of historical chemistry data, multivariate statistics will be used to reduce the dimensionality of the dataset such that patterns within the data are more easily identified. These patterns will be used to identify similarities and differences among sites based on the entire dataset, while clustering will allow similar sites to be grouped together based on water chemistry. Principal component analysis (PCA) is the preferred multivariate method to be used for the AEMP; however, non-metric dimension scaling (NMDS) will be applied if data distributions do not fit the requirements of the PCA. Given that the dataset includes censored results, multivariate analyses will be based on ranked μ-scores that incorporate censored data into the analysis rather than raw chemistry data. Data requirements, specific analytical methods, and selection of variables included in the multivariate analysis will be discussed within the annual report.

Piper plots provide a visual tool to describe ionic composition of water to compare among water types and identify mixing between different sources. Seasonal and annual piper plots will be used to determine water type at each site and compare ionic composition between upstream and downstream monitoring sites.

I.2.5 Published Environmental Guideline Comparison

As a primary driver for the AEMP is to address concerns related to fish and water health, risk-based guidelines for aquatic environments (CCME FWAL 2012) and drinking water (Health Canada 2022) will be used for comparison purposes. In addition, the Federal Environmental Quality Guidelines (FEQG; ECCC 2024) will be added for some parameters where more recent data has been used in the guideline derivation compared with existing CCME guidelines.

Tabulated results will include guidelines for ready comparison. All water quality variables will be compared to the following guideline sets with guideline exceedances highlighted:

- Canadian Council of Ministers of the Environment guidelines for the protection of freshwater aquatic life (CCME FWAL; CCME 2012).
- Federal Environmental Quality Guidelines (FEQG; ECCC 2024).
- Health Canada Guidelines for Canadian Drinking Water Quality (Maximum Acceptable Concentrations only; 2022).

It is important to note that concentrations of water quality parameters may naturally exceed applied guidelines and not be indicative of degradation caused by NWO.

These are guidelines against which data can be compared, but they do not always account for the natural conditions (such as the naturally high suspended solids in the water) of some of the northern rivers (GNWT Environment & Natural Resources, 2014a). Guideline exceedances will therefore trigger an investigation of whether the observed results suggest influences from NWO or results are indicative of natural conditions related to surficial geology, surface-groundwater interactions, or seasonal changes (e.g., surface run-off, natural seeps).

The toxicity and bioavailability of many potential contaminants are influenced by toxicity modifying factors (TMF) that are environmental conditions such as water temperature, ionic composition (or hardness), pH, and concentration of organics. In such cases, environmental quality guidelines account for TMFs by establishing equations and/or tables that adjust guideline values accordingly. For the AEMP, the upstream water quality data set will be used to represent the natural conditions of the receiving environment. The 25th percentile of results from upstream sampling locations will be used to represent these upstream conditions to calculate appropriate guideline comparisons.

The FEQG for copper will be calculated using the biotic ligand model (BLM) calculator developed by ECCC, which accounts for the effects of TMFs on copper bioavailability. This tool produces a site-specific species sensitivity distribution (SSD) to calculate a guideline protective of 95% of plants/algae, invertebrates, and fish. Several other FEQG metals such as aluminum, iron, and cobalt use a similar approach to derive guidelines that account for conditions in the receiving waterbody. An example of the SSD for copper using 25th percentile values for TMFs upstream from Norman Wells on the Mackenzie River from 2018 to 2025 is provided in Figure I-1. Temperature for calculated guidelines was 20°C, which is approximately equivalent to the 90th percentile of temperatures measured in the Mackenzie River by the CBM program site upstream from Norman Wells (Mackenzie Datastream 2026). The lower confidence limit of the derived guideline will be used for comparison with downstream water quality. It is notable that temperatures in the Mackenzie River and Bosworth Creek are typically lower than those applied to calculate the copper guideline; this provides a precautionary approach that will be protective of aquatic biota throughout the year. Where guideline values are influenced by TMFs, the precautionary principle will be used to calculate guideline values that are more protective of the aquatic environment. The TMF values used for determining site-specific guideline values for the Mackenzie River and Bosworth Creek based on sampling from 2018 to 2025 are provided in Table I-2. These values will be updated each year based on the additional upstream data collected during the AEMP.

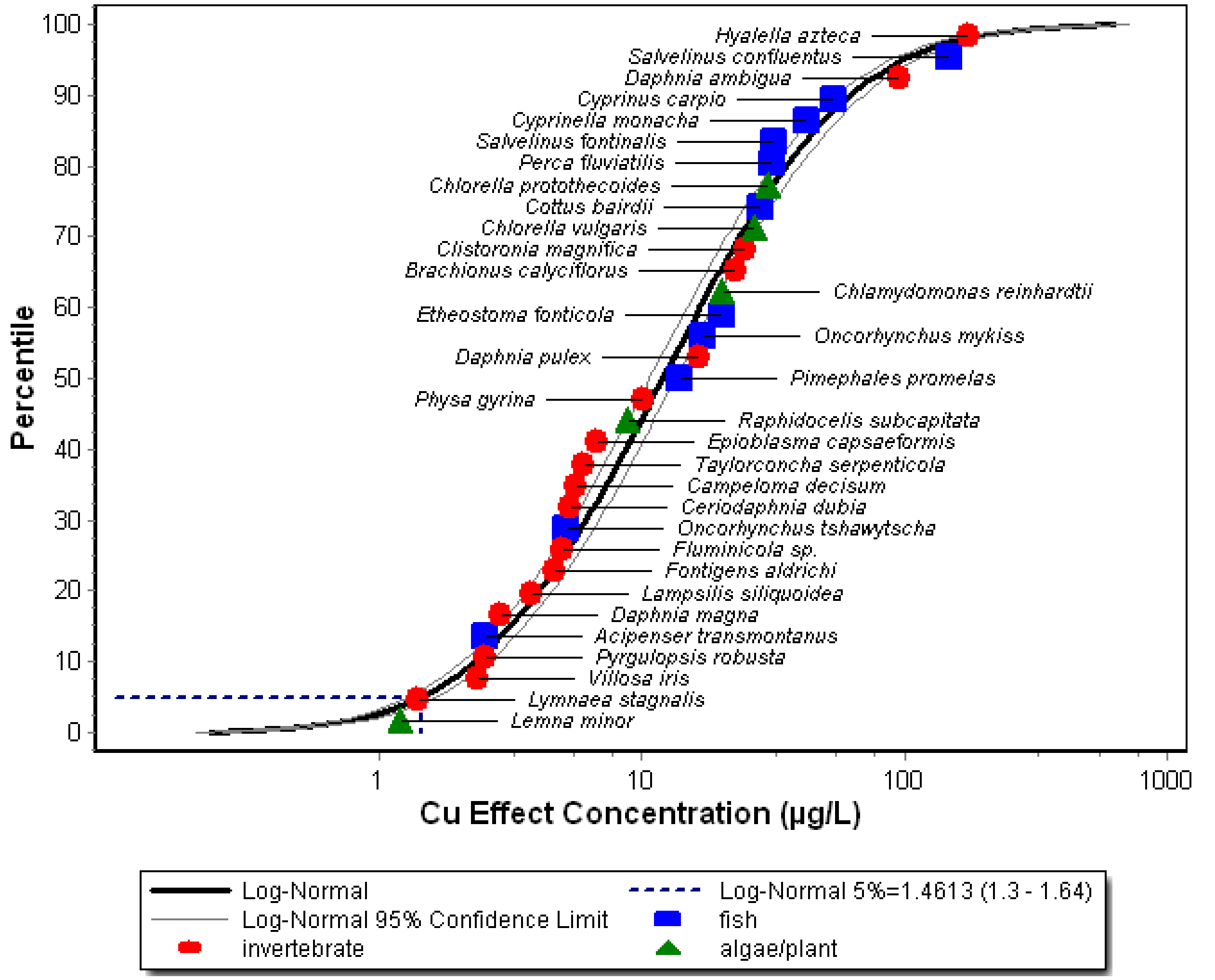

Figure I-1: Species Sensitivity Distribution (SSD) for Dissolved Copper Based on Conditions in the Mackenzie River Upstream from Norman Wells from 2018 to 2025

Table I-2: Example of Toxicity Modifying Factor (TMF) Values Used to Calculate Guidelines for Bosworth Creek and the Mackenzie River

Toxicity Modifying Factor	Units	Mackenzie River	Bosworth Creek
Temperature	°C	20	20
pH	pH units	7.12	8.27
Dissolved organic carbon	mg C/L	2.8	2.4
Calcium	mg/L	29.3	77.5
Magnesium	mg/L	9.2	31

Toxicity Modifying Factor	Units	Mackenzie River	Bosworth Creek
Sodium	mg/L	7.7	24
Potassium	mg/L	0.83	1.1
Sulphate	mg/L	34	160
Chloride	mg/L	8.05	28
Alkalinity	mg/L $CaCO_3$	85.2	190
Hardness	mg/L $CaCO_3$	110	330
Copper Concentration*	**ug/L**	**1.2**	**1.0**
Copper FEQG	**ug/L**	**1.3**	**5.9**

Notes: *Average copper of upstream sites in Mackenzie River and Bosworth Creek from 2018 to 2025 is provided to show how background concentrations compare with the calculated guideline.

Suitable analytical methods are those with reportable detection limits (RDLs) below the applicable guideline. Typical laboratory RDLs for several variables are listed Table I-3. CCME FAL, FEGQ and Health Canada Drinking Water Guidelines are presented to demonstrate that these detection limits are suitable for purpose.

Table I-3: Typical Detection Limits and Guidelines

Parameter	Detection Limit (mg/L)	CCME FAL (mg/L)	HC Drinking Water (mg/L)	FEQG (mg/L)
Benzene	0.00040	0.37	0.005	0.590
Toluene	0.00040	0.002	0.06	0.03
Ethylbenzene	0.00040	0.09	0.14	0.07
Xylenes	0.00089		0.09	0.07
Acenaphthene[1]	1×10^{-6}	0.0058		
Acenaphthylene	1×10^{-6}			
Acridine	0.000040	0.0044		
Anthracene	1×10^{-6}	0.000012		
Benzo(a)Anthracene	1×10^{-6}	0.000018		
Benzo(a)Pyrene	1×10^{-6}	0.000015		
Benzo(b,j)Fluoranthene	1×10^{-6}			
Benzo(c)Phenanthrene	2×10^{-6}			
Benzo(e)Pyrene	1×10^{-6}	0.000015	0.00004	
Benzo(g,h,i)Perylene	2×10^{-6}			

[1] Detection limits for PAHs are based on SPMD analysis. Note that environmental quality guidelines currently do not exist for alkylated PAHs.

Parameter	Detection Limit (mg/L)	CCME FAL (mg/L)	HC Drinking Water (mg/L)	FEQG (mg/L)
Benzo(k)Fluoranthene	1×10^{-6}			
Chrysene	1×10^{-6}			
Dibenzo(a,h)Anthracene	2×10^{-6}			
Fluoranthene	1×10^{-6}	0.00004		
Fluorene	1×10^{-6}	0.003		
Indeno(1,2,3-c,d)Pyrene	2×10^{-6}			
Naphthalene	1×10^{-6}	0.0011		
Perylene	2×10^{-6}			
Phenanthrene	1×10^{-6}	0.0004		
Pyrene	1×10^{-6}	0.000025		
Quinoline	0.00020	0.0034		0.15
Nitrate (as N)	0.010	2.9	10	
Nitrite (as N)	0.010		1	
Chloride	1.0	120		
Sulphate	1.0			
Aluminum	0.0030	0.005*		Equation
Arsenic	0.00020	0.005	0.01	
Chromium	0.0010	0.0089	0.05	0.005
Copper	0.0010	0.002*	2	BLM calculator
Iron	0.060	0.3		Equation
Lead	0.00020	0.001*	0.005	Equation
Manganese	0.0040	Equation	0.12	
Mercury	0.0000019	0.000026	0.001	
Molybdenum	0.00020	0.073		
Nickel	0.00050	0.025*		
Selenium	0.00020	0.001	0.05	
Silver	0.00010	0.00025		
Thallium	0.00020	0.0008		
Uranium	0.0001	0.015	0.02	
Vanadium	0.0010			0.12
Zinc	0.0030	Equation		

Notes: *Presented value is a variable guideline that changes according to the characteristics of the receiving environment; presented value is the most conservative possible guideline.

I.2.6 Passive Water Sampling

The PAH and aPAH concentrations will be calculated from the quantification results provided through SPMD analysis. Laboratory results for PAHs and aPAHs are provided as a total mass per strip. Calculations developed by the United States Geological Survey (USGS 2000) will be used to estimate concentration in water for measured PAHs and aPAHs where chemical-specific properties are available to allow for estimation.

The PAH concentrations calculated from SPMDs will be used to determine total PAH concentrations for each sample. In addition, the profile of PAHs and aPAHs is presented in bar charts to visually compare their abundances among sites. Concentrations reported will be blank corrected where concentrations are observed in the method blank to prevent potential effects from the analytical method. The relative contribution of petrogenic and pyrogenic PAHs is summarized by calculating a Pyrogenic Index (PI) for each sample using Equation (1) as described in Lévesque et al. (2023) (PAH abbreviation definitions listed in Table 3-2). The PI will be used for comparing the potential sources of PAHs among sites during the AEMP.

Equation 1 $$Pyrogenic\ Index\ (PI) = \frac{\Sigma(AN,AC,BA,BaP,BbjFl,BeP,BG,BkFl,DA,FL,IP,PR)}{\Sigma(N0-4,PA0-4,F0-3,D0-3,BaAC0-3)}$$

I.2.7 Background Dataset Development

A dataset of upstream water quality spanning from 2017 to 2025 has been developed to support the AEMP through historical monitoring activities. This dataset is the basis for calculating normal ranges for comparison with results from downstream sites. Data will be added to the upstream dataset and control limits updated when the data meets the following conditions:

- At least eight new data points are available from the upstream location.
- Greater than or equal to 40 percent of data are detectable.
- An increasing or decreasing trend is not present for the respective variable (determined via Kendall tau with ATS slope).
- Verified outliers have been removed from the dataset.

An outlier is defined as a value originating from a different statistical population than the rest of the sample. Outliers will be identified using Tukey's Box Plot Method, which is suitable for non-normally distributed data (USEPA 2009). Only extreme outliers will be removed, and a valid reason for removing the outlier is required before it can be removed. The following are defined as valid reasons for outlier removal from the dataset:

- Anomalous concentrations recorded because of sampling conditions that alter sample integrity (e.g., insufficient water depth was available under ice during winter sampling, substrate was disturbed during sampling leading to higher suspended sediment in water sample).
- An error in transcription, dilution or analytical procedure, etc. that could be identified, but the error could not be corrected.

- The value was part of a group of parameters with one-time detections that were not replicated in subsequent follow-up verification sampling or any other sampling event.
- Values for multiple parameters in a field duplicate sample were atypical relative to the parent sample and were not confirmed by subsequent monitoring results.
- The value was a one-time detection that was more than one order of magnitude greater than the reportable detection limit.
- One parameter reported over multiple samples from different sampling locations in one sampling event was high- or low-biased.
- The data quality of anomalous KIP concentrations could not be verified due to historically incomplete files.

Trends in upstream data will be assessed on a per-location basis to determine if they are indicative of wider environmental changes that should be accounted for in the background data or if they are location-specific. As upstream locations are not site-influenced, trends in upstream data would not be attributable to site-related activities. Due to the lack of potential site influence, data may be added to the background dataset before a trend is observable (data added every two years); if trends are identified after further sampling, then data may be removed from the dataset. To account for potentially changing river conditions in upstream locations, control limits will be calculated using recent data (eight data points) and using data from the last 10 years to assess for changing natural ranges without past conditions skewing statistical results. A detailed description of how background data will be assessed for the AEMP is provided in Appendix G.

I.3 Fish Health Assessment Methods

Results from the SFS and LFS are intended to address the following questions:

- Do fish endpoints indicate that energy availability or allocation is altered in fish at downstream monitoring locations?
  - Compare fish length, liver weight, and gonad weight (relative to body weight) among sites upstream and downstream to identify potential **spatial changes** related to fish health.
  - Compare fish length, liver weight, and gonad weight (relative to body weight) over time at each monitoring location to identify potential **changes over time** related to fish health.
- Do chemical concentrations measured in fish tissue show spatial or temporal changes that provide exposure context?
  - Compare tissue concentrations of metals and PAHs among monitoring areas; SETAC effects-threshold comparison is limited to large-bodied fish.
  - For each KIP, establish background dataset for tissue chemistry and control limits for comparison with tissue chemistry at sites downstream from the NWO.
  - Use statistical hypothesis testing (e.g., ANOVA) to compare tissue concentrations among monitoring locations upstream from the NWO to downstream locations.

- Compare the concentration (or activity) of CYP1A protein among upstream and downstream sites to investigate potential exposure of fish to PAHs.

I.3.1 Fish Health Analysis

Statistical analyses for the SFS and LFS are based on methods used for assessing fish health during EEM programs established under Canada's Metal Mining and Effluent Regulations (MMER; Environment Canada 2012). Given the differing physiology between males and females, statistical analyses will be completed independently for each sex. Mean comparison tests (e.g., t-tests, ANOVA, and Analysis of Covariance [ANCOVA]) will be used to determine if there is a statistical difference between control and potentially exposed monitoring locations downstream. Permutation tests were used to compare fish metrics among sites if data distributions do not meet statistical assumptions and data transformation is ineffective.

The ANCOVA method will be used to compare fish length, liver weight, and gonad weight (relative to body weight) among sites for each sex and fish species. This analysis is a stepwise procedure that determines if sites are comparable over space and/or time by comparing the linear model slopes and intercepts. Slopes which are not parallel provide the basis for evaluating statistically significant changes between sites. Linear models are first analyzed with an interaction term included to investigate whether the relationship between covariates is altered by a site effect (i.e., are the slopes significantly different among sites). These models take the form provided in Equation (2), where:

- The first term (β_0) describes the model intercept.
- The second term (β_1) describes the strength/slope of the regression between covariates.
- The third term (β_2) describes the distance between the regression models for each site.
- The last term (β_3) describes the interaction between the covariate regressions and the site.

Equation 2

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 (x_1 * x_2)$$

It is notable that a significant interaction between the covariates and the site is typically either a change in the direction or the magnitude of the relationship between the covariates among sites. If there is no interaction between the covariate relationship and the site, it is assumed that sites are comparable. In these cases, the percent difference between the reference and downstream site will be calculated according to Equation (3).

Equation 3

$$\%\, difference = \left(10^{\beta_2} - 1\right) * 100$$

If a significant interaction is observed, the methods outlined in the EEM technical guidance (Environment Canada 2012) will be followed. Alternatively, percent differences based on independent means (observed or adjusted) will be calculated by dividing the difference between the experimental site and reference site (experimental - reference) by the reference mean as described for EEM programs (Environment Canada 2012).

Percent differences between sites will be calculated and compared with critical effect sizes (CES) indicative of effects on fish (Table I-4).

Table I-4: Critical Effect Sizes (CES) for Fish Health and Tissue Endpoints

Health Metric	Critical Effect Size
Fish length relative to body weight Condition	10%
Liver weight relative to body weight (Liversomatic Index [LSI])	25%
Gonad weight relative to body weight (Gonadosomatic Index [GSI])	25%
Notes: CES values adopted from Environmental Effect Monitoring (EEM) technical guidance (Environment Canada 2012).	

I.3.2 Tissue Chemistry and Liver Protein

Visual representation of data will be accompanied by supplementary summary statistics (i.e., minimum, median, 25th percentile, 75th percentile, 95th percentile, maximum, mean, standard deviation and detection frequency) for various comparisons. Survival analyses (e.g., rROS or MLE) that account for the proportion and level of censored results will be used to compute appropriate summary statistics for parameters with results below detection.

Data for KIPs will be plotted so that new monitoring data can be compared with established tolerance limits based on fish collected from upstream sampling reaches. Tabulated results will be accompanied by graphics to help visualize and distinguish any changes or trends over time. With the understanding that large-bodied fish have large home ranges, tissue analyzed from upstream sampling reaches is assumed to be unaffected by NWO and representative of naturally occurring conditions (i.e., normal range). Like water quality, this normal range will be established based on the 95% prediction intervals that set the UCL and LCL for each KIP (Section I.2.1). These limits will establish the CES for tissue residue concentrations at downstream sampling locations. Survival analysis methods including rROS (when sample size is less than 50) or MLE (when sample size is larger than 50) will be used to incorporate measurements below detection into statistical analyses.

Mean comparison hypothesis tests including ANOVA and censored regression ANOVA will be performed on biological tissue data to evaluate whether there are significant differences in the chemical concentrations in fish tissues near NWO and those collected from upstream reaches. MFO enzyme activities and protein contents in liver tissues of fish of the same sex from potentially exposed sites and reference sites will also be compared using ANOVA and censored regression ANOVA.

Notably, KIPs with more than 60% of the results below detection will be presented but not included in further statistical analysis given the high proportion of censored data.

I.3.3 Large-Bodied Fish SETAC Effects Thresholds

For the LFS only, indicator-metal concentrations measured in large-bodied fish tissue from the Mackenzie River may be compared with no-observable-effect thresholds in the SETAC Linkage of Effects to Tissue Residues database (SETAC 1999), where relevant thresholds are available. These ecological effects thresholds are supporting context and are not food-consumption guidelines or a determination that fish are safe or unsafe to eat.

Table I-5: SETAC Effects Thresholds for Indicator Metals in Large-Bodied Fish Tissue

Indicator Metal	SETAC (1999) Threshold
Aluminum	1.2 mg/kg
Arsenic	2.6 mg/kg
Barium	---
Cadmium	0.02 mg/kg
Chromium	0.58 mg/kg
Copper	3.4 mg/kg
Mercury	0.7 mg/kg
Molybdenum	---
Nickel	0.82 mg/kg
Selenium	0.25 mg/kg
Uranium	---
Zinc	4.5 mg/kg

Note: SETAC (1999) thresholds are based on wet-weight tissue residue concentrations and are retained only as supporting ecological context for the LFS.

Concentrations of PAHs and aPAHs measured in tissue residues during the SFS are based on composite samples of multiple fish to meet tissue quantity requirements for laboratory analysis. Therefore, only one sample is analyzed from each site annually for slimy sculpin from Bosworth Creek, and no statistical comparisons are possible. For the LFS, the PAH concentration in subsamples from ten fish from each target species will be compared between the three respective communities. In addition, PAH concentrations will be measured in loche liver samples and compared among the communities.

Total PAH will be calculated for each fish by summing the concentrations of all PAHs and aPAHs measured. Total PAH concentrations will be presented as a range between a lower limit where totals are calculated by replacing censored values with zero and an upper limit that replaces censored values with the detection limit. This approach avoids substitution of measurements that are below detection limits by presenting the best-case and worst-case scenarios. Although it can be overly conservative (Helsel 2012), statistical analyses comparing total PAH concentrations among sampling reaches will use the worst-case scenario to apply a precautionary approach.

I.4 Evaluation of Statistical Power

Statistical power is the capacity of a sampling design to detect differences or trends should they occur. Any monitoring program should be evaluated for its statistical power to detect change. A monitoring program must have the capacity to detect effects of specified magnitude, and examination of statistical power quantifies the relationships among sample size (adequate spatial and temporal coverage), inherent variability (noise), effect size, confidence, and power. Power may be determined analytically for some simpler designs but may have to be evaluated using simulations or re-sampling. A target statistical power for change detection in this program is set at 80%.

Samples collected are representative of the system being monitored, but they are subject to statistical error. Whereas variability reduces the ability of monitoring to detect change, this diminishes as the number of samples taken brings the estimate closer to its true value. Because variability means that metrics calculated from a sample may deviate from the values they approximate, it is possible that inference based on such samples may be incorrect. It is possible that the program in its analysis of data may conclude that there has been a change or that there is a trend when this really is only because metrics calculated from the sample differ purely because of statistical sampling error – this is a Type I error (false positive). Conversely, there may in fact be a change or developing trend, but the vagaries of sampling result in it not being detected – this is a Type II error (false negative). An appropriate monitoring program will have sufficient collection of samples (both temporally and spatially) to be able to adequately balance these two types of errors.

The AEMP will follow the recommendations established in EEM technical guidance by setting the cut-off for identifying a significant effect (alpha [α] = 0.10) equal to the power level (1-beta[β]), resulting in a target power of 0.80. This guidance recommends that 20 mature males and 20 mature females are assessed to ensure sufficient statistical power for fish health metrics. Based on previous sampling, the power increases little when sample sizes are increased above this recommended sample size. Meanwhile, eight samples from each site are recommended for comparing tissue concentrations among sites to achieve 95% power based on EEM guidance (Environment Canada 2012). Statistical conclusions will be supported by post-hoc power analyses so that the potential of a false negative (which estimates the risk to the environment) can be readily understood.

The AEMP will strive to ensure that sufficient data are collected to support quantitative effect detection while protecting against false positives (risk to industry) and false negatives (risk to the environment). Statistical power afforded by sufficient sampling intensity and frequency can provide protection from persistent changes that go undetected and have the potential to translate into broader and more significant effects. Reducing variability is a more effective measure to improve power than increasing sample size (Environment Canada 2012); therefore, methods to reduce variability will be used to improve statistical analyses with limited power before additional sampling is proposed.

Pooling data across sampling years may be used to increase statistical power for some metrics (e.g., gonad size relative to body size); however, available data will need to be checked for potential systematic changes between years before pooling.