Nechako Watershed Roundtable

Large Lakes Monitoring Strategy

Prepared For
Nechako Watershed Roundtable
Suite 507, 1488 4th Ave
Prince George, BC V2L 4Y2

Prepared By
EDI Environmental Dynamics Inc.
3810-18th Ave
Prince George, BC V2N4V5

EDI Contact
Eric O'Bryan

EDI Project
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NECHAKO WATERSHED ROUNDTABLE

EDI
ENVIRONMENTAL DYNAMICS INC.
Down to Earth Biology

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AUTHORSHIP

Contributors who had assisted in preparing this report include:

Todd French MSc.. Author / Project Lead

Chris Cena MSc, RPBio.. Primary Author

Nechako Watershed Roundtable.. Contributing Author

Eric O'Bryan BSc, RPBio.. Senior Review

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1 BACKGROUND

Increasing numbers of observations from lakes across the central interior region of British Columbia (BC) suggest that water quality has progressively degraded over time. The increased incidence of algal blooms has raised concerns regarding the health of aquatic ecosystems. When algal blooms occur at higher-than-normal rates and intensity, water quality degradation is typically caused by an increase in phosphorus and sediment loading. This process is evident from historic sediment cores taken from lakes within this region, which have shown a gradual decline in water quality starting in the 1940's up to the early 2000's, and there is evidence of a more rapid increase in the degradation of water quality among central interior lakes beginning around 2017 when wildfire activity increased in the region. Water quality degradation trends are typically attributed to the cumulative effects of large-scale impacts on a watershed (Christensen et. al. 1996; Schindler 2001). This raises the question of what effect water quality degradation is having on the aquatic health of headwater lakes within the Nechako River watershed, particularly the salmon populations (i.e., sockeye salmon [*Oncorhynchus nerka*], chinook salmon [*Oncorhynchus tshawytscha*], and coho salmon [O*ncorhynchus kisutch*]).

To address the concern of degrading water quality of Nechako Watershed (NW) headwater lakes, the Nechako Watershed Roundtable, through its associated Lakes Monitoring Working Group (LMWG) which includes representation from regional First Nations, federal and provincial governments, and non-governmental organizations, convened to provide direction and guidance on a Large Lakes Monitoring Strategy (LLMS). This strategy is focused on the development of a comprehensive, long-term technical monitoring program to document current water quality trends, building off historical data to determine change over time. This monitoring program intends to identify environmental and ecosystems changes and emerging threats as early detection is vital to preventing further water quality degradation in these lakes.

In developing the LLMS, numerous environmental data sources and literature were reviewed focused on water quality, sediments, fisheries, and other relevant information to identify potential data and knowledge gaps. Compilation and review of this information, in addition to guidance provided by the LMWG, were used to design the Large Lakes Monitoring Strategy priority lakes and rivers (Figure 1), which will be used to establish current water quality conditions and trophic status and track changes over the next three years. Project and strategy updates will be announced on the Nechako Watershed Roundtable website, www.nechakowatershed.ca. All data and literature sources reviewed in preparation of this document will be made available on the Nechako Portal, which is hosted by the Integrated Watershed Research Group (University of Northern British Columbia).

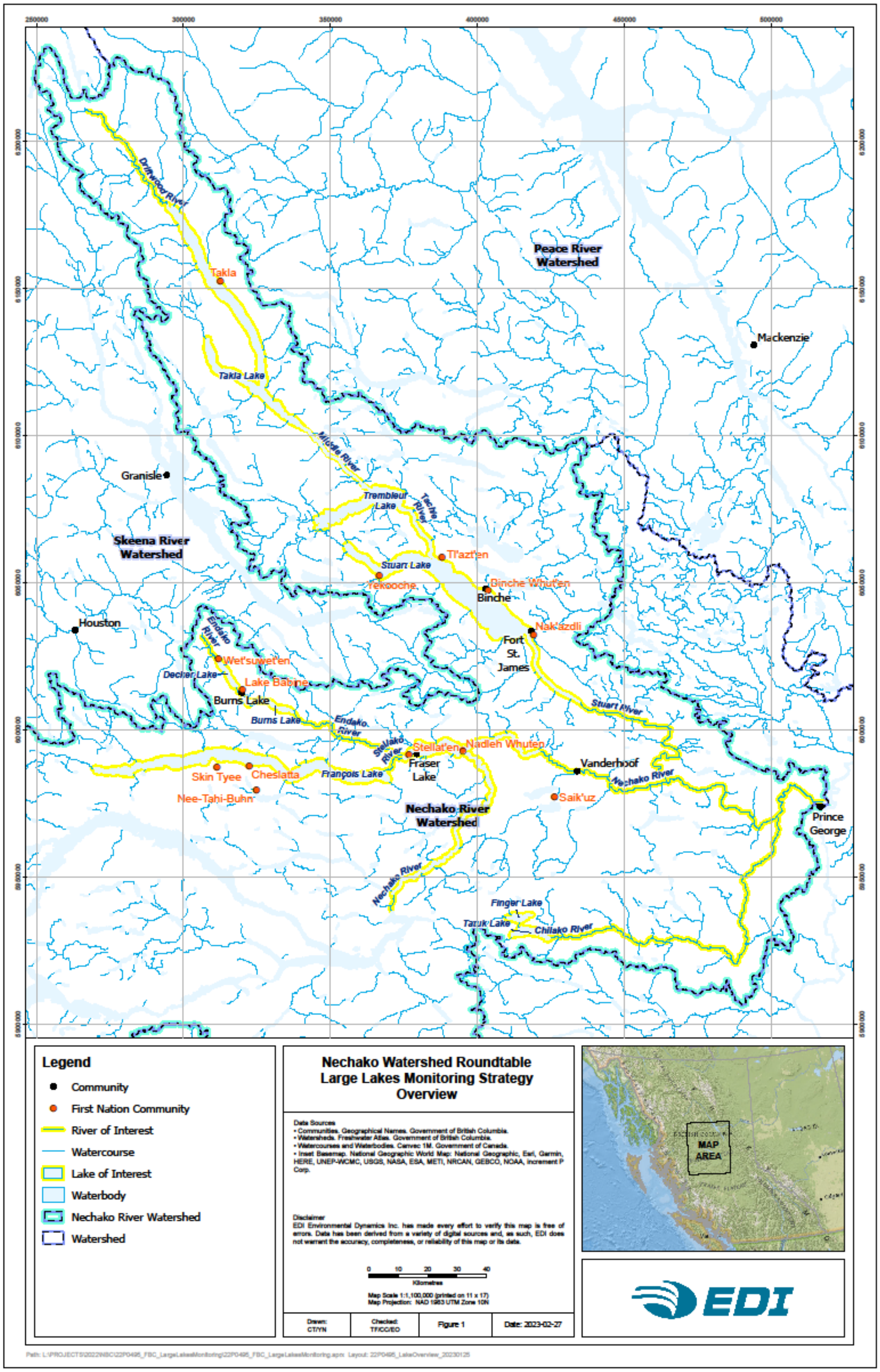

Figure 1. Nechako watershed Large Lake Monitoring Strategy project area.

2 GAP ANALYSIS

The degree to which emerging contaminants are present in NW lakes and outlet rivers is unknown because of limited consistent monitoring by regional water quality programs. The ecological implications are uncertain and require a reliable database to identify and examine nutrient and contaminant loading trends to address emerging issues. These gaps are related to:

- historic water quality data—most headwater lakes and outlets have limited to no data or data are outdated;
- lake indexing or abundance estimates of juvenile salmon—a few smolt projects have been conducted in the last several years; and,
- paleolimnology data from sediment cores—five lakes need updated sediment core data, and four lakes lack sediment core data.

Addressing these data gaps is an important first step in assessing and accounting for the nutrients and contaminants received by the NW headwater lakes and within the outlet rivers. The success of the monitoring program will depend on the collection of scientifically defensible data that can track trends in water quality and aquatic ecosystem health over the long term, and the incorporation of Indigenous Knowledge.

2.1 LITERATURE AND DATA REVIEW

Review of existing literature and data was conducted to assist in identifying knowledge gaps. To date, a total of 153 journal articles and technical reports relevant to the project area have been collected (Appendix C). These articles and technical reports were retrieved from multiple sources and spanned decades (Figure 2; Table 1).

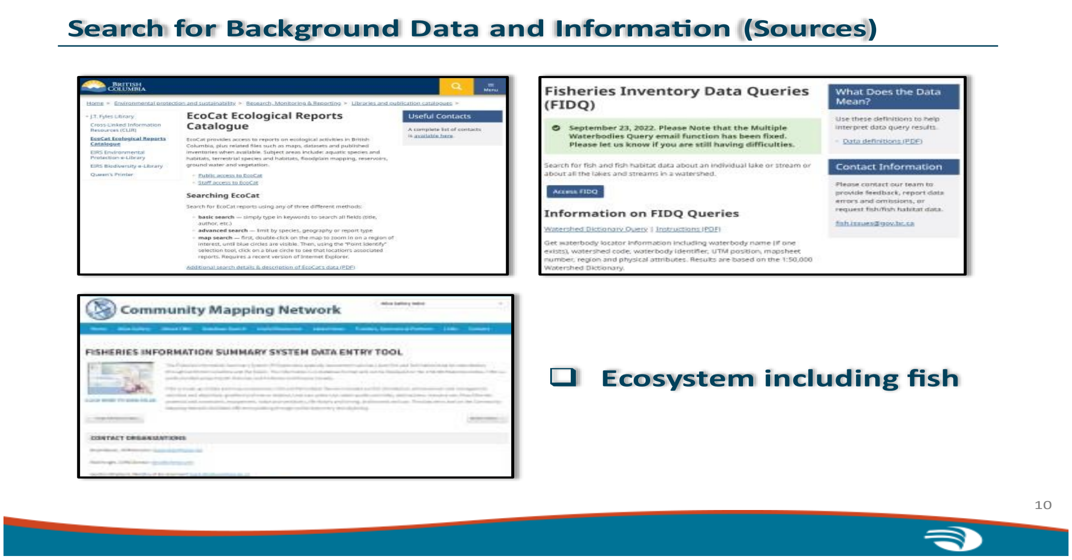

Figure 2. Example database searches for historical data.

Table 1. Background information sources.

Database / Search Engine	Core Collection or Relevant Subject
Clarivate Web of Science	Science Citation Index Expanded (SCIE) Social Sciences Citation Index (SSCI) Conference Proceedings Citation Index (CPCI)
Google Scholar	search using keywords for all online peer-reviewed journals, books, conference papers, theses and dissertations and technical reports
Agricultural Online Access (AGRICOLA)	botany, chemistry, conservation, forestry, ecology, hydrology, pollution, soil science, water quality, weather and climate, wildlife, and zoology
Science Direct	health sciences, life sciences, physical sciences
Ecological Reports Catalogue (EcoCat)	reports on ecological activities in British Columbia
Fisheries Inventory Data Queries (FIDQ)	fish and fish habitat data about an individual lake or stream or about all the lakes and streams in a watershed.
Fisheries Information Summary System (FISS)	provides spatially represented summary level fish and fish habitat data for waterbodies throughout British Columbia and the Yukon

2.1.1 WATER QUALITY GAP ANALYSIS

Upon review of the historic limnological data, it was apparent there has been a collective water sampling bias toward the trophic state variables (e.g., secchi, Chl α, and phosphorous), lakes that are situated lower in drainage networks and easier to access, summer sampling, and "snapshot" data collection efforts with limited temporary and spatial data points (i.e., data collected from one lake and only one data collection event). Trophic data has been the most common type of information collected since eutrophication is a persistent concern (Smith and Schindler 2009) and is the simplest type of water quality data collection for citizen monitoring programs (Bigham Stephens et al. 2015). Scarcities of multiyear records display obvious temporal biases within and among years, limited data availability for other water quality variables such as nitrogen and carbon. While the preference for quantifying phosphorus and it link to being a limiting nutrient of primary production which dictates trophic state (Correll 1998), the lack of monitoring of other nutrients (e.g., carbon, nitrogen) creates gaps that can limit the ability to address potential emerging water quality issues. For example, nitrogen has a role in the occurrence of cyanobacterial blooms (Gobler et al. 2016) and can limit phytoplankton growth (Bergström and Jansson 2006). Historic water quality sampling efforts of lakes and rivers identified for monitoring have been summarize in Appendix Table A-1 and A-2, respectively.

Similarly, historical paleolimnological programs from lakes in the study area have been summarized in Appendix Table A-3. Five lakes have historic records including Burns and Decker, Fraser, Stuart and Francois Lake, collected between 1994 and 2004, prior to many of the large wildfires on record. Tchesinkut Lake was also sampled previously, but has not been included in this program.

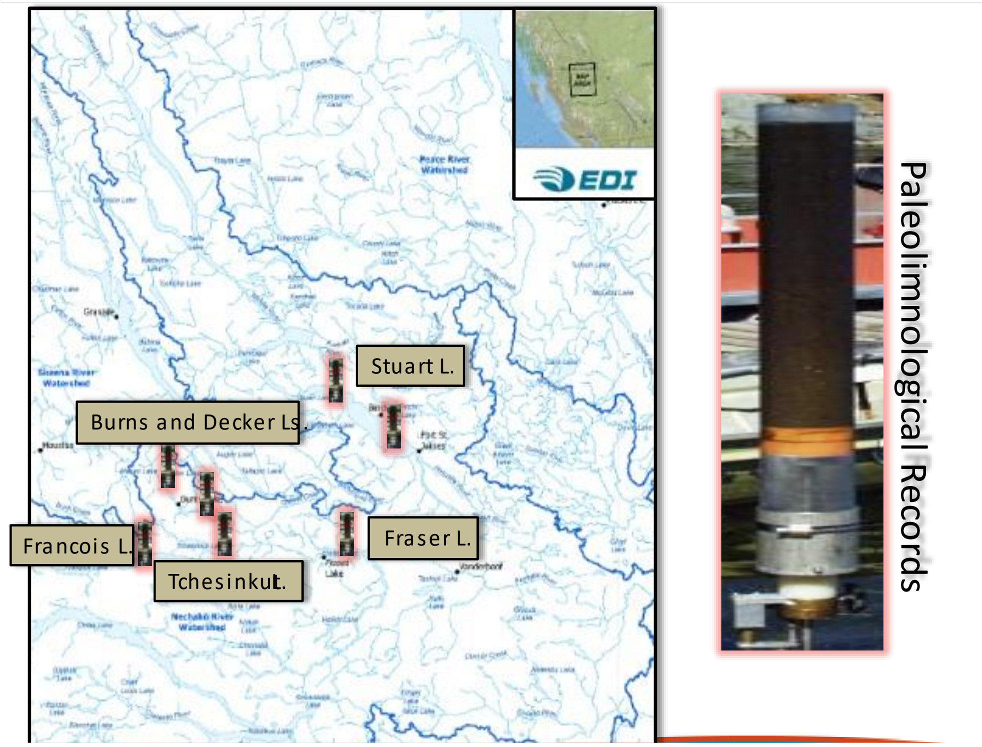

Figure 3. Historic sediment coring data.

2.1.2 FISHERIES GAP ANALYSIS

Despite several at-risk and possibly extirpated salmon populations in the project area research appears to be infrequent. Only 13 more formal studies, spanning a period of 20 years, were identified to have occurred within the NW and had focused on and juvenile sockeye trawl data and factors limiting sockeye production. Fisheries related information was collected from various open sources (Table 1) and from direct requests to the Department of Fisheries and Oceans, other agencies and First Nation sources that have engaged in fisheries projects, where data was not publicly available. While it is likely that other small historic studies and projects exist and are not readily accessible, the literature search suggests that there is a scarcity of information regarding the monitoring and assessment of general population information, nursery lakes, spawning habitat quality and availability, habitat disturbances and environmental stressors appear to be lacking for central interior salmon populations. Compounding the problem of evaluating historic salmon data when available is that the datasets are non-standardized, which makes it difficult to compare or evaluate trends.

Several NW headwater lakes are important sockeye rearing habitat and are the primary water sources for their outlet rivers (Section B) which are used as spawning and rearing habitats for Chinook and Coho. Climate-driven water quality shifts could affect trophic status and changes within trophic levels would be expected to affect freshwater salmon life stages, including the numbers, growth, and condition. The impacts of the recent spate of climate-driven wildfires on BC's salmon populations, including NW populations, are poorly understood. Historic fisheries data and information applicable to the project area has been summarized in Appendix A Table A-4.

3 THREE-YEAR MONITORING PROGRAM

The LLMS was designed to be a scientifically defensible three-year monitoring program that addresses data gaps, evaluates connections between water quality, trophic status and fisheries resources while promoting collaborations with Indigenous communities by providing opportunity for engagement, knowledge sharing, and training. The overarching goals of the LLMS are to:

- provide quantitative information on the wildfire history of NW headwater lake areas and how the ash has influenced the nutrient loading and potential effects on water quality;
- provide quantitative information on the change over time of headwater lake trophic status and likely effects on salmon carrying capacities; and
- initiate an evaluation of sockeye returns and out-migration changes for headwater lakes over time.

Several of the key tasks identified to achieve the above goals include:

- Facilitating community engagement with all NW Indigenous Communities via knowledge-sharing workshops among communities and keyohs within the project area.
- Facilitating one annual regional forum to consolidate knowledge, share information, revise priorities and assumptions, and update approaches for environmental stewardship of NW lake ecosystems.
- Developing and implementing training programs for Indigenous professionals, technicians, and youth so that communities can assume a lead role in the management of the limnological (i.e., water quality) and ecosystem programs;
    - with a focus to implement bi-directional, in situ opportunities for knowledge sharing between resource professionals and Indigenous participants.
- Collecting paleolimnological sediment cores to assess long-term limnological and ecosystem/trophic status changes within the nine NW lake ecosystems and respective outlets.
- Undertaking a three-year limnological assessment of the priority headwater lakes and outlet rivers;
    - assessments would focus on the primary determinants of trophic status and salmon carrying capacity.
- Combining the paleorecords with existing adult sockeye salmon return, lake trawl/acoustic, and out-migration data for juvenile sockeye, chinook, and coho salmon datasets (i.e., Department of Fisheries and Oceans Canada [DFO], Upper Fraser Fisheries Conservation Alliance [UFFCA], and Pacific Salmon Commission [PSC]) to:
    - investigate long-term trends in adult return rates; and,
    - evaluate linkages between juvenile sockeye salmon abundance, condition, and lake/outlet limnology, including trophic status.

The LLMS have been structured with the expectation it will promote planning and collaboration prior to data collection and reporting (Table 2). This project is expected to provide a baseline for future monitoring of water quality and help with setting short- and long-term goals for watershed and salmon recovery and restoration opportunities.

Table 2. Three-year monitoring plan overview for the Nechako watershed.

	Activity	Tasks	Deliverables
Year 1	Large Lakes Monitoring Preparation	• Literature review, gap analysis, scientific study development • Lake limnology sampling protocols & training. • River sampling protocols & training • Benthic sampling preparation and development. • Analytical lab coordination • Training program	• Large lakes monitoring strategy document • Workshop • Develop detailed sampling plans and standard operating procedures (SOPs) for field work
Year 1	Lake Sampling & Data Collection	• Benthic/limnology/water quality sampling. • Paleolimnology sampling	• Raw data summary tables and database updates • Data quality checks
Year 1	Data Analysis & Interpretation	• Benthic, limnology, and water quality data analysis (with existing data)	• Year 1 technical summary report incorporating Indigenous Knowledge • Identify changes for Year 2
Year 2	Lake Sampling & Data Collection	• Benthic/limnology/water quality sampling. • Paleolimnology sampling • Training refresher	• Raw data summary tables and database updates • Data quality checks
Year 2	Data Analysis & Interpretation	• Benthic, limnology, and water quality data analysis (with existing data) • Preliminary paleorecord analysis	• Year 2 technical summary report incorporating Indigenous Knowledge • Identify changes for Year 3
Year 3	Lake Sampling & Data Collection	• Benthic/limnology/water quality sampling • Paleolimnology sampling • Training refresher	• Raw data summary tables and database updates • Data quality checks
Year 3	Data Analysis & Interpretation	• Benthic, limnology, and water quality data analysis (with existing data) • Paleolimnology analysis	• Year 3 technical report with synthesis and interpretation addressing project objectives; incorporating Indigenous knowledge

The sampling program was designed to examine several headwater lakes and their respective outlets in the NW because they serve as nursery habitat for sockeye and Chinook salmon or may have in the past (Table 3). While being important to NW Pacific salmon, these waterbodies are also important to Indigenous communities and recent and potential water quality changes are of increasing concern. Gradual changes to water quality is not uncommon, however, more drastic changes in water quality of area lakes and rivers has been readily observed and partially attributed to the uncharacteristically large and intense wildfires in recent years, which are symptomatic of climate change. The immediate and long-term effects of these fires on headwater lakes and on salmon are unknown.

Table 3. Sampling program summary.

Lake / River	Invertebrates and Periphyton[1]	Zooplankton[2]	Paleolimnology (Sediment Core)[3]	Limnology[4]
Burns Lake	No	Yes	Yes	Yes (UFFCA)[5]
Decker Lake	No	Yes	Yes	Yes (UFFCA)
Finger Lake	No	No	Yes	No
Francois Lake	No	Yes	Yes	Yes (3 sites)
Fraser Lake	No	Yes	Yes	Yes (2 sites)
Stuart Lake	No	Yes	Yes	Yes (2 sites)
Takla Lake	No	Yes	Yes	Yes (4 sites)
Tatuk Lake	No	Yes	Yes	Yes (1 site)
Trembleur Lake	No	Yes	Yes	Yes (2 sites)
Chilako River	Yes	N/A	N/A	Yes
Endako River	Yes	N/A	N/A	Yes
Middle River	Yes	N/A	N/A	Yes
Nautley River	Yes	N/A	N/A	Yes
Stellako River	Yes	N/A	N/A	Yes
Stuart River	Yes	N/A	N/A	Yes
Tachie River	Yes	N/A	N/A	Yes

[1]Invertebrate (community structure, size, distribution, and biomass) and periphyton (chlorophyl *a* [Chl *a*]) sampling will follow Canadian Aquatic Biomonitoring Network (CABIN) methods.

[2]Zooplankton will be sampled using vertical 30-m hauls following Department of Fisheries and Oceans Canada Cultus Lake methods.

[3]Paleolimnology will be sampled via bottom sediment cores at the deep basin. Compaction and %water, diatom stratigraphy, sediment mass accumulated, stable isotopes ([13C], [14,15N]), and 15N enrichment (ϱN) will be documented.

[4]Limnology-depth-stratified profiling for dissolved oxygen, temperature, specific conductivity, turbidity, solids, Chl a (surface strata), Secchi transparency, total and total dissolved phosphorus, and NO2 + NO3- will be sampled four times annually.

[5]UFFCA = Upper Fraser Fisheries Conservation Alliance.

3.1 ENGAGEMENT AND KNOWLEDGE SHARING

Integral to Indigenous peoples in BC, Pacific salmon are embedded in their cultural and ceremonial practices that contribute immeasurably to their independence, self-determination, and overall, well being. As such, the precipitous decline of NW BC salmon populations has resulted in a loss of food security for the regional Indigenous peoples that can no longer rely on salmon returning to natal habitats.

One focus point of the LLMS is to connect Indigenous Knowledge with approaches to resource stewardship and scientific methodology. It is anticipated that the development of the project vision and understanding of mutual priorities through knowledge sharing, capacity building, and training will result in a legacy of bi-directional training for both non-Indigenous resource professionals and Indigenous community participants.

The LLMS will provide (1) opportunities for two-way engagement, where Indigenous participants can share environmental stewardship values and community observations with professional participants; and (2) in situ technical training and participation opportunities with resource professionals for interested community members, prospective environmental technicians, and youth, with the intent to increase employment and participation opportunities throughout the duration of the monitoring program.

Communications pathways will be established, and clear timing of engagement opportunities and knowledge sharing will be developed for each year of the monitoring program.

3.2 PALEOLIMNOLOGY

Paleolimnological data is a useful technique that is often used to reconstruct past environmental conditions and temporal changes for the trophic status of an aquatic system. A sediment core will be collected from the main central deep basin of each of the nine lakes using a gravity corer. These cores will be submitted to the Palaeoecological Environmental Assessment and Research Laboratory at Queen's University in Kingston, Ontario for analysis.

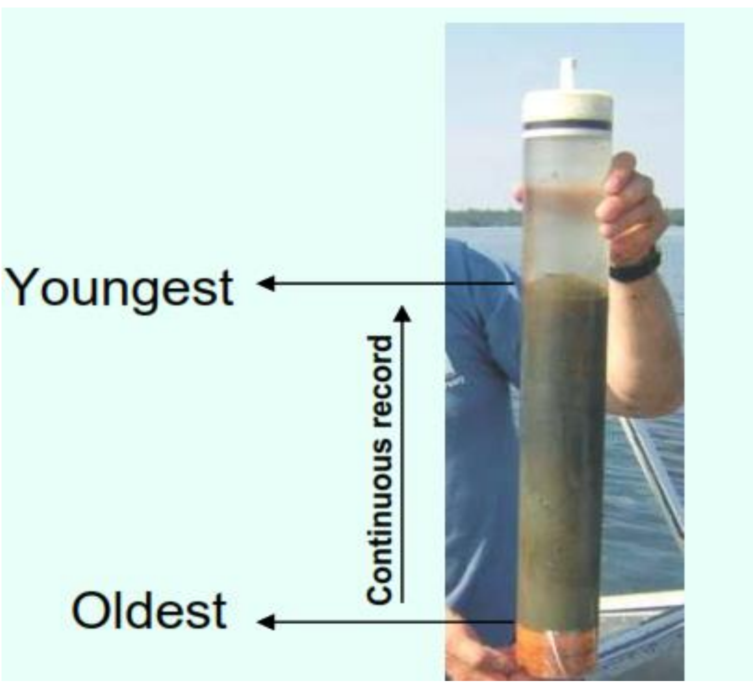

Figure 4. Lake sediment core example.

The sediment cores will be sampled at 1-cm intervals to examine environmental changes within the aquatic environment from the early 1800s (bottom layers) to present day (upper layers). The sediment layers will be analyzed for date, diatom stratigraphy, sediment accumulation, stable isotopes, and nutrients. Analysis of diatom and organic solids will be analyzed to infer lake water phosphorous and trophic status, which are factors that determine the lake carrying capacity and potential effects on juvenile salmon over time. Inorganic solids accumulation will be used to infer sediment delivery to the lakes from the watershed and, when present, wildfire ash layers will be analyzed for metals (via inductively coupled plasma mass spectrometry [ICP-MS]) to estimate phosphorous and metals loading to the lakes. These results will be used to infer the implications of wildfires and climate change on water quality and trophic status in the sampled lakes.

Quantitative data based on the wildfire history within the NW headwater areas is expected to inform how wildfire ash has affected phosphorous and metals loading to the headwater lakes and rivers and provide information regarding potential effects on water quality. This information will provide a long-term data set on sediment loading rates, which will be an indicator of landscape erosion and the cumulative effects of development.

Similar to the quantitative data, local community historical information will be evaluated for observed changes to trophic status and salmon carrying capacity of the NW headwater lakes and rivers over time. By combining Indigenous Knowledge with paleolimnological methods, these reference points should assist in supporting the baseline data.

3.3 LIMNOLOGY

The focus of limnology data collection is to assess the current trophic conditions, water quality, and ecosystem status of the large lakes and respective outlet rivers. Limnological assessments will occur over a three-year monitoring period, including:

- water quality sampling, including chlorophyll *a* (lake and river);
- zooplankton hauls (lakes); and,
- macro invertebrate and periphyton sampling (river).

3.3.1.1 Lake Sampling

Six of the nine lakes within the LLMS will be targeted for water quality assessments (Table 4). Of the three outstanding lakes, the UFFCA is currently conducting limnology assessments on Decker and Burns lakes, and this data will be incorporated into the overall project. Water quality data will not be collected directly from Finger Lake as it is considered a secondary minor basin that is downstream and in close proximity to Tatuk Lake.

Table 4. Headwater lake limnology water quality monitoring stations.

Lake	EMS Site ID	EMS Site Description
Francois Lake	E224945	West end deep station
Francois Lake	E224946	East end deep station
Francois Lake	E271703	Centre deep station
Fraser Lake	0400411	Near middle 3km east of lot 3229
Fraser Lake	E105973	West basin deep station
Stuart Lake	E206956	East (main) deep station
Stuart Lake	Site 2 TBD	N/A
Takla Lake	Site 1 TBD	N/A
Takla Lake	Site 2 TBD	N/A
Takla Lake	Site 3 TBD	N/A

Takla Lake	Site 4 TBD	N/A
Tatuk Lake	Site 1TBD	N/A
Trembleur Lake	Site 1 TBD	N/A
Trembleur Lake	Site 2 TBD	N/A

Notes: EMS = Environmental Monitoring System; TBD = sampling site location remains to be identified; and N/A = not applicable at present.

Each limnological sampling event is intended to capture water conditions during lake turn over and seasonal stratification periods. Sampling is expected to occur four times annually to capture lake profile data during spring mixis, late summer (August), autumn mixis, and late winter (maximum potential for deep-water hypoxia). Parameters to be sampled from depth-stratified profiling are summarized below.

- water clarity via Secchi depth.
- One-metre depth profiles to within 1 m of lake bottom, including:
    - temperature;
    - turbidity;
    - dissolved oxygen;
    - pH; and,
    - specific conductance.
- Chlorophyll *a* (near-surface only).
- Sample collection from three depths (i.e., surface, mid depth, and near bottom) for analysis of:
    - total suspended solids (inorganic and organic fractions);
    - phosphorus (total, total dissolved, and ortho-phosphate); and,
    - nitrite and nitrate (NO_2 and NO_3).

Water samples will be collected from each site and submitted to a designated laboratory for analysis of chlorophyll *a*, total suspended solids (inorganic and organic fractions), total phosphorus, total dissolved phosphorus, and ortho-phosphate.

Lake limnological profiles will be sampled at previously established deep basin sites in Francois Lake (three sites), Stuart Lake (one site), and Fraser Lake (two sites) (Table 2), as per the BC provincial Environmental Monitoring System (EMS), for consistency when comparing data between years. It is recommended that multiple deep stations are sampled (e.g., at least one per arm of a lake) to demonstrate possible spatial and temporal variations and linkages between and within a lake. Multiple limnological assessment sites will need to be established at the deep basin sites in Takla Lake (four sites), Trembleur Lake (two sites), and Tatuk Lake (one site) because there are no regular EMS sampling sites on these lakes. Table 5 provides a summary of the parameters to be collected.

Table 5. Proposed limnological deep station water quality monitoring program.

Parameters Sampled	Sampling Frequency	Sampling Technique
Temperature, dissolved oxygen, oxidation-reduction potential, specific conductance, and turbidity	Quarterly – February, June, August, and December	YSI – 1-m intervals (0 to 50m), 5-m intervals (50 to 100+m) as depth permits

Transparency	Quarterly – February, June, August, and December	Secchi disk
TDS, pH, nutrients (total phosphorus, total dissolved phosphorus, nitrite, nitrate, and ammonia)	Quarterly – February, June, August, and December	van Dorn sampler at surface, mid depth, 5 m off bottom
Chlorophyll *a*	Quarterly – February, June, August, and December	Surface grab and filter
Zooplankton	February, June, and August	Vertical Wisconsin net hauls (30 m depth). Fix with sucrose buffered 4% formalin solution.
Paleolimnology	One time event	0.5 m gravity core

3.3.2 LAKE OUTLET/RIVER SAMPLING

Most of the surface water quality sampling sites can be accessed by vehicles and will be completed at pre-established locations at the lake outlets (e.g., Nautley River, Stellako River, and Stuart River) (Table 6). Sampling protocols are similar to the lake sampling protocols, which will allow for comparisons between sites. Data will be recorded in situ for temperature, turbidity, pH, dissolved oxygen, and specific conductance. Samples will be collected for chlorophyll *a*, total suspended solids (inorganic and organic fractions), total phosphorus, total dissolved phosphorus, and ortho-phosphate at each site and submitted to a designated laboratory for analysis. Technician crews will be responsible for sample bottle requisition and laboratory submissions.

Table 6. Lake outlet/river surface water quality monitoring stations.

Lake	EMS Site ID	EMS Site Description
Chilako River	E249897	100 m u/s of Hwy 16 crossing
Driftwood River	TBD	N/A
Endako River	E209353	ER-1 (Endako River upstream)
Middle River	TBD	N/A
Nautley River	0400404	downstream of crossing near south bank
Stellako River	E206563	500m upstream of Endako River
Stuart River	0400487	2 km downstream of Hwy 27 at campground
Tachie River	E285849	At Tanizul FSR bridge

Notes: EMS = Environmental Monitoring System; TBD = sampling site location remains to be identified; and N/A = not applicable at present.

Outlet sampling sites will be consistent with established BC provincial EMS sites. New sites will be established for outlets that do not have established water quality sites. Canadian Aquatic Biomonitoring Network (CABIN) methodology (Environment Canada 2012) will be used to sample at or near established outlet sites each August when peak biomass is typically expected. Parameters to be sampled include chlorophyll *a* (periphyton) and benthic macroinvertebrates (community structure, size distribution, and biomass). Field data will be merged with historical datasets and used to calibrate paleorecords with water quality measurements.

3.3.2.1 Zooplankton

Vertical 30-m hauls with Wisconsin nets (>160 µm) for zooplankton community structure will be completed during limnological sampling following DFO Cultus Lake methods (Shortreed 2007). Zooplankton sampling will not be conducted during the winter limnology sampling events. Zooplankton and benthic invertebrate samples will be preserved and submitted to an accredited laboratory for identification and analyses.

3.3.3 LAND USE TRENDS

Identified disturbance-related effects (past, present, and projected future) on salmon-bearing headwater systems can be used to forecast future salmon population trends and recommend goals and objectives for adaptation and restoration initiatives. Results from the monitoring program will contribute and build upon research being undertaken by DFO Cultus Lake, Carrier Sekani Tribal Council, and UFFCA on the productive capacity (sockeye salmon) of headwater NW lakes and their outlet rivers. The limnological data collected during the monitoring program will also support research on freshwater fish species that is being undertaken by the provincial government in partnership with the University of Northern British Columbia (UNBC).

3.3.4 FISHERIES

The monitoring program includes lakes and rivers that support anadromous Pacific salmon and or kokanee and will investigate linkages between historic and current limnological conditions, juvenile and adult salmon enumeration, and outmigration enumeration estimates and condition assessments.

It is expected that regression analysis of paleorecords of stable isotopes [^{13}C], [^{14}N, ^{15}N], and ϱN against known adult sockeye salmon return rates will be completed to infer long-term populations trends and baselines. Similarly, paleorecords will be combined with available lake trawl and out-migration data for juvenile sockeye, chinook, and coho salmon (DFO, UFFCA, and PSC datasets) to assess associations between juvenile abundance and body condition and lake/outlet limnology, including trophic status.

Statistical inferences are expected to assist with estimations of an ecosystem's potential carrying capacity for salmon, which will be implemented to develop forecasts based on modeled climate scenarios. Further work will be completed to define carrying capacity parameters for this monitoring program as it can be difficult to predict using traditional methods (i.e., species distribution and abundance). Regression analyses of inferred [P] (paleorecord and data from water samples) with available within-lake sockeye fry and parr densities and body condition datasets (UFFCA and DFO) will be used to assess linkages between densities/condition and lake trophic status. A similar approach will be used to assess available data detailing the abundance and condition of out-migrating sockeye, chinook, and coho salmon smolts.

Similarly, sediment cores will be examined to determine if ocean-derived isotopes can infer historic adult sockeye salmon returns to NW headwater lakes which will assist in evaluating how the trophic status and salmon carrying capacity of the large headwater lakes and rivers may have changed over time. This will be accomplished with advanced paleolimnological techniques that involve stable isotope determinations in dated bottom sediment cores. Stable isotope analysis of sediment cores will also be examined to determine whether Finger, Tatuk, Decker, and Burns lakes were historical anadromous sockeye nursery rearing lakes.

4 PROGRAM MANAGEMENT

4.1.1 DATA MANAGEMENT AND REPORTING

Data and literature will be made available to all participants through the Nechako Watershed Portal. A database may be required to temporarily store, sort and quality check annual field data (benthic, water quality etc.) prior to being uploaded to the Portal. The Nechako Watershed Portal will provide opportunities to easily share program infographics and findings among interested communities.

Annual reports will be prepared at the end of each field season with submissions on or before March 31 of each year.

5 SUMMARY/CONCLUSION

The cumulative effects of watershed development, water use, and climate change (including climate-driven wildfires) have the potential to significantly affect the ecosystem structure and productive capacity of large salmon-bearing headwater lakes and outlet rivers in the Nechako River Basin. The effects of watershed stressors have been quantified for some medium-sized lakes; however, little is known about effects on the large headwater lakes and rivers.

For Indigenous people, the lack of knowledge in this area is a concern as the watershed faces continued development, increased wildfire activity, and declining salmon populations. This 3-year study will increase knowledge of historical events in the watershed, identify and quantify changes to water quality and trophic status and attempt to make linkages to salmon populations and carrying capacity. Collaboration with and involvement of Indigenous communities is integral to all components of the study.

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APPENDICES

APPENDIX A SUMMARY TABLE OF HISTORICAL WATER QUALITY, PALEOLIMNOLGY AND FISHERIES DATA

Appendix Table A-1. Historical data summary tables (lake water quality).

Lake	Location	Sampling Period		# Water Samples	# Results	Parameters[1]
		Initial	Last			
Burns	Middle of west basin	1990-03-13	2010-04-28	59	1,329	Major ions; P; N; C; pH, Colour; Res; Turbidity; Mets
Burns	Near Deadman's Island (station 1, west end)	1990-03-13	2022-08-23	119	2,822	Major ions; P; N; C; pH, Colour; Res; Turbidity; Mets; S
Burns	East end (deep station #2)	2015-05-01	2021-05-01 (active)	33	952	Major ions; P; N; C; pH, Colour; Res; Turbidity; Mets; uS/cm; S
Decker	Across from townsite	1990-05-24	2015-09-28	73	1,857	P; N; C; pH, Colour; Res; Turbidity; Mets; S; Chl a
Francois	West end deep station	1997-02-14	2021-08-17	41	1,966	Major ions; P; N; C; pH, Res; S; Mets; uS/cm
Francois	East end deep station	1997-02-16	2022-08-18	46	2,200	Major ions; P; N; C; pH, Res; S; Mets; uS/cm
Francois	Centre deep station	2008-05-28	2022-08-22	32	1,337	Major ions; P; N; C; pH, Res; S; Mets; uS/cm
Fraser	Near middle of lake	1982-04-08	2022-08-16	326	3,413	Major ions; P; N; C; pH, Res; S; Mets; uS/cm; chl a

[1]Parameters: P = phosphorous; N = nitrogen; C = carbon total organic; Res = residue; Met = metals; uS/cm = specific conductance; S-sulfate/-ide; and Chl *a* – chlorophyll *a*.

Appendix Table A-2. Historical data summary table (river water quality).

River	Location	Sampling Period		# Water Samples	# Results	Parameters[1]
		Initial	Last			
Chilako	Lower mud river bridge	1972-05-23	2001-10-02	65	599	N; P; Tur; DO; uS/cm; C; colour; S; pH; Res; Met
Endako	ER-1 (Endako River upstream)	1988-08-16	2022-08-24	207	8,857	N; P; uS/cm; C; S; pH; Res; Met
Endako	ER-2 (Endako River downstream)	1988-08-16	2022-08-24	207	8,362	N; P; uS/cm; C; S; pH; Res; Met
Endako[2]	ER-3 Endako River at Hwy 16 bridge	2021-11-22	2022-08-24	8	847	N; P; uS/cm; C; S; pH; Res; Met
Nechako	Upstream of Vanderhoof	1974-07-18	2009-03-05	155	875	N; P; pH; uS/cm; C; Tur; Res; Met; DO
Nechako	Downstream of Vanderhoof	1974-07-18	2009-03-05	167	923	N; P; pH; uS/cm; Tur; Res; DO
Nechako	Upstream of Fort Fraser	1976-05-27	2009-03-05	213	2167	N; P; C; pH; uS/cm; S; Tur; Res; Met; DO
Nechako	Downstream of Fort Fraser	1976-05-27	1997-10-29	18	119	N; P; pH; uS/cm; Tur; Res
Nechako	Downstream of Fort Fraser	1976-05-27	2009-03-05	171	953	N; P; C; pH; uS/cm; S; Tur; Res; Colour; DO
Nechako	Upstream of Hwy 27 bridge Vanderhoof	1972-05-05	1985-05-29	29	823	N; P; C; pH; uS/cm; S; Tur; Res; Met
Stellako	Stellako River, 500 u/s Endako River	1982-05-01	1986-08-25	8	100	N; P; uS/cm; pH
Stuart	Hwy 27 bridge east shore	1983-04-19	2010-03-30	121	688	N; P; uS/cm; pH; Res; Colour; DO; Tur;
Stuart	Hwy 27 bridge west shore	1966-08-01	2010-03-30	373	2372	N; P; C; uS/cm; pH; Res; Colour; DO; Tur;

[1]Parameters: N = nitrogen; P = phosphorous; Tur = turbidity; DO = dissolved oxygen; uS/cm = specific conductance; C = carbon total organic; S = sulfate/-ide; Res = residue; and Met = metals.

[2]A recently established site.

Appendix Table A-3. Historic paleolimnological data collected from headwater lakes within the Nechako River watershed.

Lake	Year	Location	Analysis
Burns	2002	East and west basins	Assessment of phosphorous changes
Decker	2002	East and west basins	Assessment of phosphorous changes
Stuart	1994	Main basin	Assess trends of metal composition in sediment
Francois	1997	East and west basins	Assess eutrophication of lakes in region, diatom assemblage
Fraser	1999	Central basin, west basin	Assessment of phosphorous changes
Fraser	2001	Main basin	Assess PCBs and sockeye salmon returns
Fraser	2004	Main basin	Assess geochemical parameters and diatom composition
Finger	-	-	-
Tatuk	-	-	-
Takla	-	-	-
Trembleur	-	-	-

Appendix Table A-4. Nechako River watershed headwater lakes historic Pacific salmon information.

Lake	Year	Location Analysis
Francois	2001	Summary of freshwater factors limiting sockeye production
Fraser	2001	Summary of freshwater factors limiting sockeye production
Stuart	2001	Summary of freshwater factors limiting sockeye production
Takla	2001	Summary of freshwater factors limiting sockeye production
Trembleur	2001	Summary of freshwater factors limiting sockeye production
Stuart	1996–1998	Results of juvenile sockeye trawls
Takla	1996–1998	Results of juvenile sockeye trawls
Trembleur	1996–1998	Results of juvenile sockeye trawls
Fraser	2017–2022	Results of juvenile sockeye trawls
Francois	2017	Results of juvenile sockeye trawls
Francois	2021	Results of juvenile sockeye trawls
Stuart	2018	Results of juvenile sockeye trawls
Stuart	2022	Results of juvenile sockeye trawls

APPENDIX B NECHAKO WATERSHED ROUNDTABLE AND UNBC 'NECHAKO PORTAL' TERMS OF REFERENCE – TO BE FINALIZED SUMMER 2023

APPENDIX C BIBLIOGRAPHY