Environment Canada / Environnement Canada

Integrated Monitoring Plan for the **Oil Sands**

Expanded Geographic Extent for Water Quality and Quantity, Aquatic Biodiversity and Effects, and Acid Sensitive Lake Component

Canada

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EXECUTIVE SUMMARY

On the 16th December, 2010 the Federal Oil Sands Advisory Panel presented its report to the federal Environment Minister, which reviewed current monitoring activities in the lower Athabasca River system. The Panels findings identified key shortcomings, and provided recommendations on what would constitute a world-class monitoring program for the oil sands region.

In response to this report and other concerns, the Federal Minister of the Environment committed Environment Canada to play a coordinating role with the Government of Alberta, to develop a world class environmental monitoring plan for the lower Athabasca River and tributaries, starting with water quality. The Lower Athabasca Water Quality Monitoring Plan – Phase 1 was released on 24 March 2011. This monitoring plan was designed on the core principles recommended by the Federal Oil Sands Advisory Panel of being: holistic and comprehensive; scientifically rigorous; adaptive and robust; inclusive and collaborative; and, transparent and accessible.

The Phase 1 Water Quality Monitoring Plan dealt primarily with the physical (hydrological and climate) and chemical components of the Athabasca River mainstem and its tributary systems. It outlined a comprehensive sampling and analytical approach to quantify contaminant loadings, transport, and fate, from oil sands and other industrial and municipal sources into these systems to monitor water quality in the lower Athabasca.

Building on Phase 1, this document provides details for the additional aquatic ecosystem monitoring components that have been added and integrated with the Phase 1 water quality Plan, and provide an expanded geographic coverage of relevant watersheds, as well as details on the related media-specific (air, water, land, biota) aquatic and terrestrial ecosystem components. In addition, as with Phase 1, the document describes the rationale, the questions/hypotheses to be addressed by the monitoring, and the proposed protocols and sampling designs for each of the new components. Through the addition of these components, a systemic and holistic water quality, water quantity, and aquatic ecosystem effects has been developed for the Lower Athabasca system and downstream regions.

CHAPTER 1. INTRODUCTION

The monitoring components described in this document build on, and integrate with, the Phase 1 Water Quality Monitoring Plan (Environment Canada, 2011). The Phase 1 Plan provided the detailed design for monitoring water quality and quantity along the main stem of the Athabasca River, and its major tributaries, between Fort McMurray to the boundary of Wood Buffalo National Park. It discussed the technical details on When, Where, Why and How to monitor surface water quality and quantity in a more comprehensive and integrated manner, focusing on the physical and chemical components and stressors of the system. Key outcomes of the Plan were to obtain a better spatial and temporal quantitative understanding of the key physical/chemical "stressors" affecting the system, improving knowledge on historical baseline conditions in the region, and providing an improved foundation for the assessment and prediction of cumulative impacts.

This document provides details for the components of an expanded aquatic ecosystem monitoring program that have been added to and integrated with the Phase 1 water quality Plan. With these additions, the Aquatic Ecosystem monitoring components provide a more systemic and holistic approach to assessing and predicting the potential impacts of oil sands developments on water quality, water quantity, and aquatic ecosystem health for the relevant river, lake, deltaic and wetland ecosystems in the Lower Athabasca River, its tributaries, and downstream regions.

Similar to the Phase 1 process, the specific component plans were developed by teams of federal, provincial, territorial and academic scientists who were selected based on their previous involvement in oil sands monitoring review exercises and/or their specific disciplinary scientific expertise. The scientists involved had expertise in: surface and groundwater quality and quantity; hydrology; climatology; environmental chemistry; paleo-limnology; atmospheric transport and deposition of contaminants; oil sands process related contaminant chemistry; aquatic and terrestrial ecology; amphibian, fish, vertebrate and invertebrate toxicology; aquatic and terrestrial monitoring plan design and implementation; cumulative effects assessment; and, statistical design. Many of the scientists that contributed to the Phase 1 plan were also involved in the Phase 2 design process to help ensure appropriate media and ecosystem integration and sampling network design optimization.

1.1 Geographic Expansion and Boundaries

The geographic scope of the aquatic monitoring program described under Phase 1 is now expanded to include other relevant downstream watersheds (e.g., Peace and Slave rivers). More specifically, new sites are proposed downstream along the mainstem of the Athabasca River including locations in the Peace-Athabasca Delta, Lake Athabasca and the Slave River, culminating in the Slave River Delta. With the expansion of the geographic area, however, comes a significant increase in hydrologic and ecological complexity, including the potential for additional natural and anthropogenic contaminant source contributions, as well as the deposition, dispersion, dilution and degradation that can occur through transport over large geographic scales (**Figure 1**).

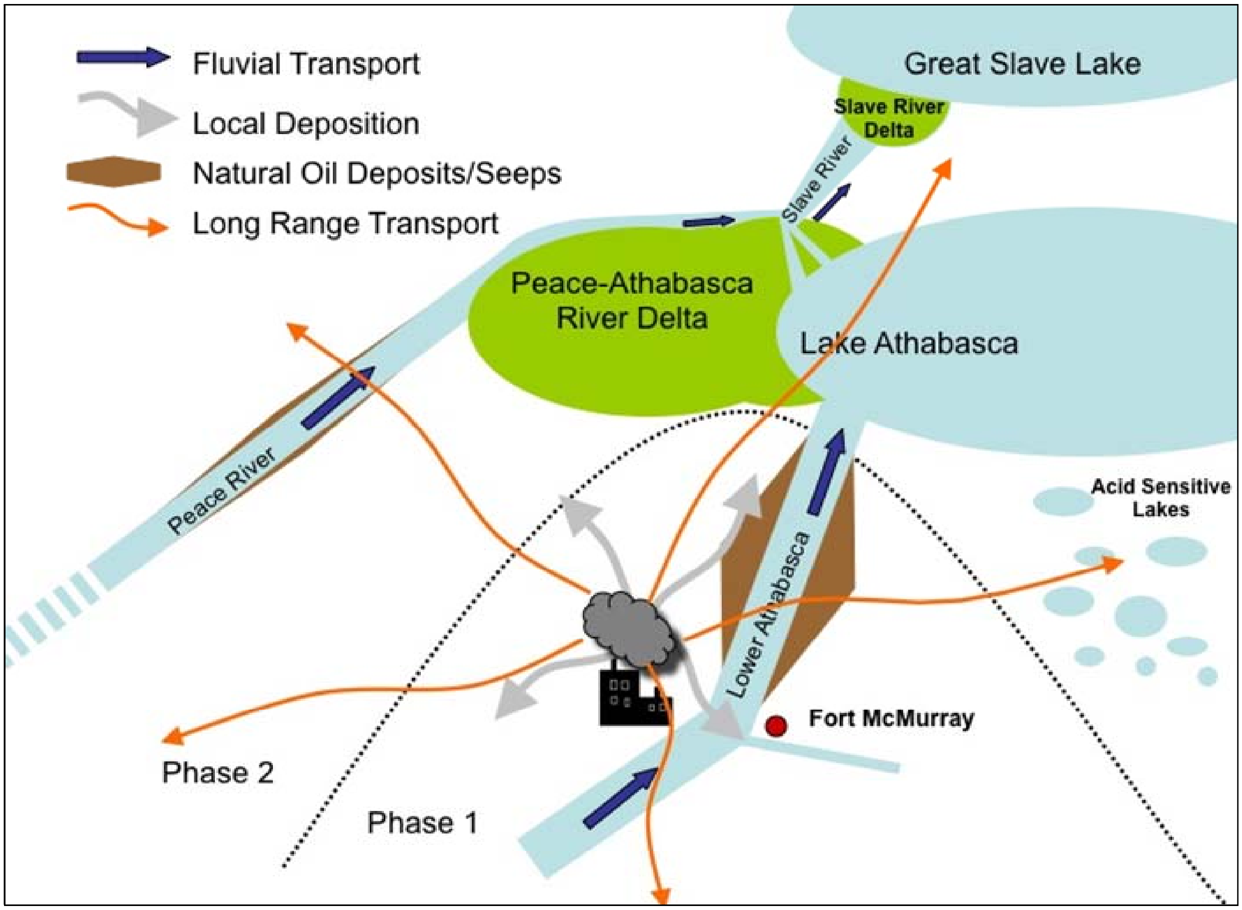


Figure 1. Conceptual model of contaminant pathways (fate and transport) accounted for in the Phase 2 geographic expansion of the Aquatic and Air Monitoring Programs.

In addition, there are portions of the Athabasca Oil Sands region that have headwater areas that drain directly into the Peace Athabasca Delta (e.g., Birch River) as well as directly to the Peace River west of the Wood Buffalo National Park including the Mikkawa and Wabasca rivers (see **Figure 3**). Combined, these drainage systems funnel northward via the Slave River. Some of the oil sands related atmospheric deposition that could influence riverine and lake systems would extend northward into these same environments but also eastward into the headwater reaches of the Clearwater River basin in north western Saskatchewan. The assessment of the potential impacts of acidifying emissions will be expanded by establishing an enhanced tiered network of sites in northeastern Alberta, northwest Saskatchewan and the Northwest Territories.

With the expansion of the geographic coverage of monitoring presented in this document, additional jurisdictions and stakeholder interests become implicated. Examples include the

Mackenzie River Basin Board (MRBB), Wood Buffalo National Park and First Nations Lands. As stressed in the Phase One document, the area covered by the monitoring Plan is important for many Aboriginal groups and local residents who are keenly aware of their environment and share concerns over the potential impacts of the oil sands industry on water quality, quantity and the health of the aquatic ecosystem.

Local people are already active in finding better ways to monitor the environment through initiatives such as the Peace-Athabasca Delta Ecological Monitoring Program (PADEMP) (PCA 2010) and the Slave River and Delta Partnership (SRDP) and activities under the NWT Water Stewardship Strategy. Within the context of the expanded geographic scope considered under Phase 2, communication and engagement with the PADEMP and SRDP programs will be important activities in the implementation of monitoring.

1.1.1 Peace-Athabasca Delta

The Peace-Athabasca Delta (PAD) is a complex receiving environment along the Lower Athabasca River, downstream of the mineable oil sands area. It is located where the Peace, Athabasca and Birch rivers converge at the western end of Lake Athabasca (**Figure 3**). The PAD is one of the world's largest freshwater delta complexes, and is a critical focal point, receiving waters from a drainage area of approximately 600,000 square kilometres in northern British Columbia, Alberta and Saskatchewan. Within the PAD complex itself are four large, shallow lakes (Claire, Baril, Mamawi and Richardson), numerous interconnected channels (both active and inactive), and countless small open water areas. Hydrologic complexity contributes to a naturally variable ecosystem, where periodic flooding brings in sediment, nutrients and results in a disturbance regime that helps to sustain a highly productive aquatic ecosystem (PAD Technical Studies 1996, Peters and Buttle 2010).

The Athabasca River Delta (ARD portion of the PAD), is at the terminus of the Athabasca River and a key node with respect to the fate of sediment and other constituents carried in the flows of the Athabasca River. The ARD has complex fluvial characteristics, with flow in the Athabasca River bifurcating into four major distributary channels that ultimately disperse into Lake Athabasca via the Embarras River, Fletcher Channel, Goose Island Channel and Big Point Channel. The ARD along with Lake Athabasca and Mamawi Lake are primary depositional environments for sediment carried in the Athabasca River. Contaminants associated with the transport of fine sediments have the potential of being deposited into these environments (Carey et al., 1997, NREI 2004, Hatfield 2006).

1.1.2 Peace River

The Athabasca Oil Sands area, and associated geologic deposits of the McMurray Formation, also underlies the headwaters of several tributaries draining directly to the Peace River including the Mikkwa and Wabasca Rivers. In addition to the potential of influence from the Athabasca Oil Sands region on the tributaries to the Peace River, there are other oil sands deposits in the Peace River watershed (**Figure 3**). The Peace River deposit, however, is much smaller and deeper compared to the Athabasca Oil Sands, with far less production activity. The risk to downstream areas from human-caused petrogenic contamination from the Peace River deposit would be considered low at this time, relative to the oil sands related activities in the Athabasca oil sands region. There are areas of natural petrogenic input next to and within the Peace River that could affect baseline water quality conditions. Environment Canada and Alberta Environment both operate water quality/quantity monitoring sites on the Peace River.

1.1.3 Slave River and Slave River Delta

The Slave River originates downstream from where the Peace River joins the Rivière des Rochers, one of the main channels discharging from Lake Athabasca. The Slave River extends only 420 km before discharging into Great Slave Lake. Although the contributing drainage to the Slave River between the PAD and it mouth is only approximately 15,000 km^2 it is the conduit for waters from the Peace and Athabasca watersheds and these, combined with additional drainage to the PAD and Lake Athabasca account for over 615,000 km^2 of drainage. At the mouth of the Slave River is a small delta prograding into Great Slave Lake. Although not as hydrologically or hydraulically complex as the PAD, the Slave River Delta is a depositional environment that is ecologically dynamic and diverse, and is a potential sink for any contaminants carried from upstream (Milburn and Prowse 1998). In addition the Slave River and SRD would provide for a good downstream boundary condition for any future integrative cumulative effects assessment and modeling that would be done on a regional basis.

CHAPTER 2. OBJECTIVES

The objectives under Phase 2 in the development of an integrated and holistic water quality, water quantity, and aquatic biodiversity and effects monitoring components to the Integrated Oil Sands Environmental Monitoring plan were to:

1. Extend the water quality and quantity monitoring described for the lower Athabasca River into a broader, more comprehensive and complex geographic context,

2. Provide detailed designs for an aquatic ecosystem health and effects monitoring program for both lentic (lakes/wetlands) and lotic (rivers/streams) systems, and

3. Address specific considerations for atmospheric deposition arising from oil sands developments by enhancing monitoring acid sensitive lakes in an expanded region.

The sections below provide the technical details for each of the associated monitoring components that address these three objectives.

CHAPTER 3. MONITORING COMPONENTS

3.1 Water Quality / Quantity Monitoring

Building on the questions being addressed by the Phase 1 Plan, the expanded geographic context of water quality and quantity monitoring program addresses three additional overarching questions:

- Are oil sands related contaminants present in the aquatic environment of the Peace-Athabasca Delta, Lake Athabasca, Peace River, Slave River and Slave River Delta?
- What are the long-term trends in contaminant concentrations and fluxes in the Peace-Athabasca Delta, Peace River, Slave River and Slave River Delta?
- What are the cumulative impacts of oil sands development on the water quality (including sediments) and quantity in the Peace-Athabasca Delta, Peace River, Slave River and Slave River Delta?

Central to addressing these questions requires:

- an integrated network of water quality, meteorological and hydrometric stations to provide standard climate and hydrological measurements – necessary for quantification of contaminant loadings, fate, and where feasible, fluxes.
- a spatially distributed network of sampling sites that can be used to diagnose potential source vectors and assess potential fate within the aquatic ecosystems.
- robust QA/QC protocols and Standard Operating Procedures (SOPs) in place for all designated core chemical parameters. Protocols to be developed for new techniques, and for analytical methods for chemicals where protocols do not currently exist or where they require validation (e.g., naphthenic acids).

As stated in the Lower Athabasca Water Quality Monitoring Plan – Phase 1 (Environment Canada, 2011), it is imperative to ensure robust protocols are applied and adhered to for all monitoring activities undertaken. Where new methods or procedures are implemented, they will be thoroughly tested, incorporate strict quality control/quality assurance procedures and where necessary, be scientifically peer reviewed.

3.1.1 Sampling Media

Water and sediment are two key media that are central to the water quality and quantity components of both the Phase 1 and Phase 2 Plans. It has been recognized, that point-in-time, bulk water samples do not always provide for the detection of compounds of interest, particularly when concentrations are at or below available analytical detection limits. In Phase 1, consideration was given to an array of physical, time-integrative artificial passive sampling approaches that potentially allow for the better capture and quantification of oil sands related contaminants over longer time intervals. While various types of passive samplers (e.g., Passive Membrane Device's) have been used in the routine monitoring of the Athabasca River and other large river systems to assess water quality, some uncertainty remains as to their efficacy, reliability and inter-comparability with other sampling approaches. Consequently, the use and appropriateness of time-integrative chemical passive-samplers will be assessed through ongoing research and inter-comparative studies and through comparisons with relevant biologically-based indicators and endpoints.

Surface water samples will be collected and analyzed for the same suite of chemical and sediment parameters, following the same QA/QC and Standard Operating Procedures as described in detail in the Lower Athabasca Water Quality Monitoring Plan – Phase 1 (Environment Canada, 2011), for the identified expanded network of sites. Event-based water quality samples will also be taken at strategic locations to obtain better estimates of non-point source inputs/loadings associated with hydrological episodic events such as spring snowmelt and storm rainfall events.

Surface sediment samples will be collected at core locations to help elucidate the spatial extent of contaminant deposition. In view of the inherent variability of river and delta sediment transport and deposition regimes, replicate samples will be collected at each monitoring location. Since the monitoring locations identified for the collection of surface water samples may not be optimal locations for the collection of surface sediments (primarily because surface sediments should be collected from a depositional environment), it would be appropriate to coordinate surface sediment sampling with other biological monitoring activities, e.g., benthic invertebrate sampling. This approach may also support interpretation of benthic community data, as these communities tend to be sensitive to physical habitat attributes. Monitoring locations will also be considered relative to historic and existing monitoring programs to maintain continuity and capitalize on the existing data record (see Lindeman et al., 2011).

3.1.1.1 Other Time-integrative Sampling Approaches

Other media (e.g., sediments, biological tissues) that integrate contaminant exposure over time will also be used to assess contaminant levels. These include, for example, fish tissue (muscle, organs, etc.) and benthic samples including sediment and invertebrates. These approaches provide for a quantitative measure of the presence/absence of contaminants and do not require the same level of intensity in sample frequency compared to point-in-time bulk water sampling (**Figure 2**). These various temporally integrative sampling media will contribute to a better understanding of the accumulated state of the aquatic ecosystem (Core Result 1 of the Integrated Oil Sands Environmental Monitoring Plan), will contribute to development of relationships between system drivers and environmental response (Core Result 2), and ultimately support regional cumulative effects assessments (Core Result 3).

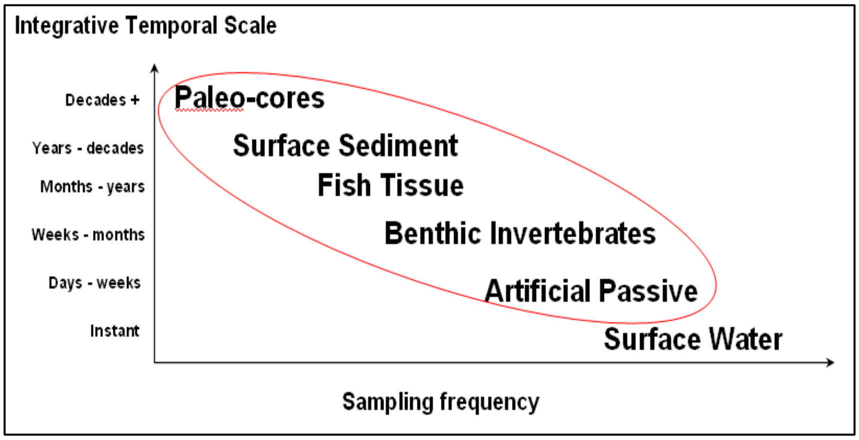


Figure 2. Time integrative sampling approaches. Many of these time-integrated samples can be archived for future analysis or re-analysis (i.e., those that are circled).

3.1.1.2 Sample Archiving

Collection and archiving of samples adds significant value to the monitoring program. This approach was adopted for biotic samples (fish) collected during the Northern River Basins Study (NRBS 1996). Samples would not necessarily require immediate analysis as many of the integrative samples can be archived for future analysis. Archival sampling of sediment, biota and artificial passive samples is an integral component of the proposed water quality monitoring program. These archived samples will also provide important reference information and can be analysed if 'triggered' by other monitoring or methods as new analytical methods and detection limits improve. As new oil sands technologies are developed and implemented, archived samples can also be analyzed to provide background or baseline information on contaminants and related environmental parameters.

3.1.2 Sampling Network Design – Water Quality/Quantity

The expanded water quality and quantity monitoring network builds upon the Phase 1 Water Quality Plan and other existing and historical monitoring programs that have occurred in the broader geographic region. While some information is available (Lindeman et al., 2011), it is generally limited in space and time. The network design takes advantage of the historical information, but recognizes the need for additional monitoring necessary to characterize baseline and reference conditions, and in some cases to support specific hypothesis-based monitoring to enhance understanding of these complex systems. This network design, as in Phase 1, incorporates an adaptive approach that could alter monitoring intensity (spatially or temporally).

3.1.2.1 Mainstem Monitoring

Four key nodes have been identified along the mainstem extending from the Athabasca River to the Slave River and including the Peace River (**Table 1**). Sites are located on the Rivière des Rochers (M10 - the primary outflow channel from the PAD and Lake Athabasca) and on the

Slave River (M11 A and B). The two sites on the Slave River are located in close proximity and are both long-term monitoring sites at which water quality variables are available for various media (water, sediment, fish tissue). Coupling of the information derived from each of these sites allows for an integrated assessment of water quality and quantity for this reach of the river. One site also located on the Peace River (M12) will be used to assess potential watershed contributions from the northwest corner of the Athabasca Oil Sands region as well as contributing areas within the Peace River oil sands area (**Figure 3**).

Sites M10 through M12, like M0 through M9 in Phase 1, will be monitored intensively and consistently. Similar to the Phase 1 mainstem sites, the key nodes in the extended geographic area will be sampled on a monthly to biweekly basis (taking site-specific seasonality into account) for water quality, hydrometric measures, suspended sediments and bottom sediments (in depositional areas and linked to aquatic ecosystem effects monitoring), with passive samplers to integrate and quantify contaminants/compounds of concern.

3.1.2.2 Augmentary Strategic Monitoring Sites

A network of augmentary sites is proposed to provide additional information to better characterize the range and complexity of hydrologic systems in vulnerable areas and, where appropriate, provide reference condition information. These “strategic” sites will be used to provide information to support a more comprehensive site-specific and regional assessment of contaminant loadings using a mass balance approach (as in Phase 1) and allow for improved discrimination of sources of contaminants / compounds of concern. Sites such as upper and lower Buckton Creek, which are located upstream and downstream of a proposed oil sands development provide an opportunity to establish baseline conditions prior to development and accumulated state afterward, based on a Before/After-Control/Impact (BACI) approach. Given the proposed schedules for development, timely initiation of monitoring in such locations is critical.

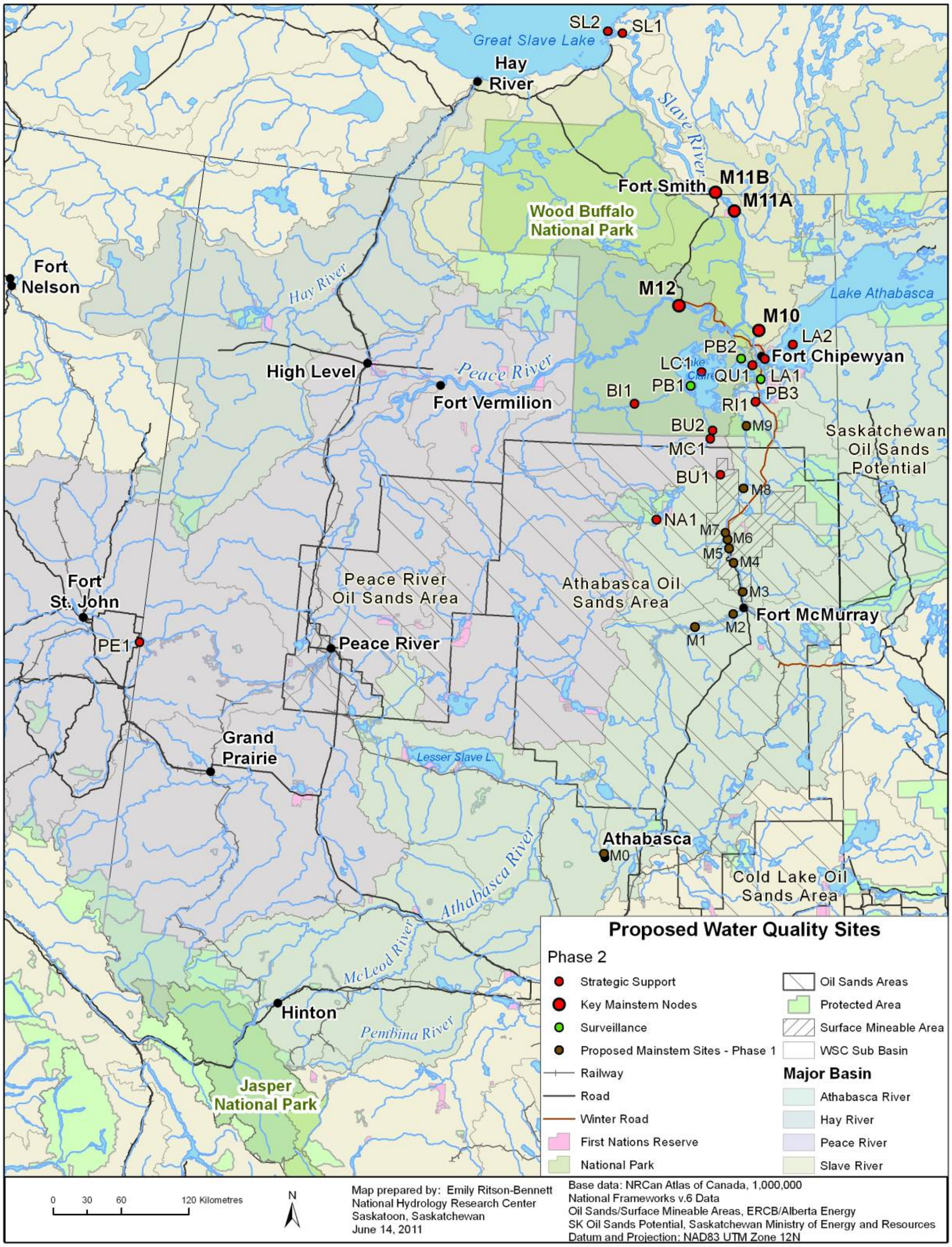


Figure 3. Proposed expanded network of water quality/quantity monitoring sites for Phase 2, plus the proposed mainstem Athabasca River sites from Phase 1.

Some sites will be intensively monitored to generate sufficient data to assess the status of the current accumulated state, by initially undertaking monthly to biweekly sampling (including event-based sampling) of water quality, quantity and sediments. Paleo-limnological approaches will be considered to provide perspectives on pre-development conditions where appropriate. As appropriate biological samples will be collected and either analysed for contaminants or archived for future reference. Subsequent to the establishment of current conditions, the augmentary sites will be monitored less intensively than the key mainstem nodes, employing appropriate time-integrative sampling methodologies, though at a frequency that allows for robust statistical analysis and determination of change in state.

3.1.2.3 Surveillance Monitoring

Surveillance sites have been identified (**Figure 3 and Table 1**) to address knowledge gaps with respect to the hydrologic complexity, historical deposition of contaminants, and to understand the processes affecting the deposition, degradation and dispersion of contaminants in the extended geographic area. Sampling at these sites will support diagnosis and interpretation of changes in water quality and quantity and will be integrated with other surveillance and research activities identified in the context of the Integrated Oil Sands Environmental Monitoring Plan (Environment Canada, 2011). The surveillance sites include perched basins within the Peace-Athabasca and Slave deltas, and depositional areas within lakes. Of particular relevance to these sites is the application of paleo-techniques to determine historical deposition of contaminants. The intensity of sampling at these sites will be hypothesis-driven, allowing for the determination of contaminants and supporting establishment of baseline conditions.

3.1.2.4 Statistical Considerations

An adequate time-series of information is paramount to the success of the water quality and quantity monitoring program, and to the assessment of changes in environmental conditions. Given that many of the new proposed sites do not have a long-term, continuous monitoring legacy, it is recommended that these sites initially undergo intensive monitoring, with sampling on a monthly to biweekly and event-driven basis. This allows for an improved understanding of the range and variability in conditions and improves statistical rigour. This is particularly important with respect to reference sites (sites not affected by development) that may be exposed to potential effects of development in the future. As a time-series of data becomes available, using appropriate multivariate procedures, the sampling network design will be re-evaluated to assess the adequacy of both the spatial distribution and temporal frequency of sampling.

3.1.3 Triggers and Decision Framework

A decision framework supports the provision of accurate and effective information for the assessment of significant changes in water quality and quantity and provides direction for subsequent monitoring responses. As in Phase 1, the decision framework for the Phase 2 water quality and quantity monitoring component is integral to the adaptive design of the program. **Table 2** summarizes the proposed decision framework and associated monitoring responses. Intensity of the sampling program in space and time will be adjusted through the tiered triggers.

Table 2. Decision Framework and Monitoring Response for various Levels of Water Quality/Quantity changes.

Level	Trigger	Magnitude	Response
1	There is a statistically significant change Oil sands-specific marker is present	Small changes identified relative to historic/baseline site-specific range of variability Marker presence in analytical results	Validate the results
2	There is a confirmed, statistically significant change that signals a deterioration in water quality or quantity Oil sands-specific marker is present	**Confirmed** small change relative to historic/baseline site-specific range of variability Marker presence is confirmed	Expand monitoring program to define extent and magnitude of the change
3	There is a statistically significant deterioration in water quality or quantity that is sustained or getting worse Oil sands-specific marker is present on more than one occasion	Changes in consecutive sampling events or a **moderate-large** change relative to historic/baseline site-specific range of variability Marker observed over consecutive sampling events	Investigate cause
Action Level	Water quality criterion exceeded Oil sands-specific marker presence is sustained	Exceedances of site-specific guidelines. Changes in consecutive sampling events and marker is present in various sample media	Possible management action warranted

3.1.4 Research into Alternative Sampling Approaches and Emerging Technologies

In Phase 1 the challenges associated with the remote nature of the region and year-round accessibility were identified. These issues are equally relevant for Phase 2 and in some cases are increased as the monitoring program extends its geographic scope into even more remote areas. Hence, research into the potential use of alternative and emerging technologies will be ongoing to optimize and enhance sampling efforts and data acquisition. Below is a brief description of considered technologies and approaches.

3.1.4.1 Artificial Passive Samplers

Artificial passive integrative samplers can provide time-weighted average (TWA) sampling of dissolved compounds and large volumes of water can be sampled by these devices over prolonged periods of exposure (Alvarez et al., 2008; Vrana et al., 2005). One of the foremost advantages of passive sampling devices (PSDs) is their ability to discriminate between dissolved and bound molecules, enabling measurement of a contaminant's activity in addition to its mere presence or absence in an ambient medium. In this regard, PSDs are thought to reflect (biomimic) vital mechanisms of bioconcentration (Anderson et al., 2008; Sharpe & Nichols, 2007). In addition to bioavailability, the freely dissolved fraction isolated by PSDs is related to the contaminant's toxicity, mobility and degradation processes. A wide array of artificial PSDs is now available, covering a range of both organic and inorganic compounds of particular concern with integrative sampling timeframes ranging from weeks to months. Samples obtained can be archived for future analyses, although there may be a need to undertake long-term stability assessments of the archived samples.

3.1.4.2 Paleo-coring

In Phase 1 it was recognized that there would be a need for paleo-limnological information to better define historical contaminant baseline conditions and trends. With the expansion of the geographic scope of the aquatic monitoring program to include remote areas often lacking in baseline data, (i.e., PAD and SRD), paleo-techniques will be an important addition. The application of these techniques in the context of accumulated state monitoring necessitates the collection of core samples on a periodic basis to be assessed by relevant experts. It is known, however, that the deltaic lake and wetland complex in the Peace-Athabasca Delta and the Slave River Delta regions are hydro-ecological complex environments where caution must be exercised in the sampling design and the interpretation of any paleo-derived information. This is particularly important in the use of paleo-coring data to define historical and/or baseline environmental conditions related to the attribution of source and associated quantified levels of contaminants. Sampling site selection and interpretation of the data will be closely linked to and supported by the hydrological monitoring, modelling and research program also being conducted within the system.

3.1.4.3 Remote Sensing

The Phase 2 monitoring plan would also benefit from the application of satellite-based remote-sensing technologies (visible/infrared and Radar imagery) to monitor the spatial extent and connectivity of surface waters. This is particularly relevant in the Peace-Athabasca and Slave River deltas, but would also have benefit in surrounding areas to identify and confirm hydrologic connectivity across the landscape during ‘pulse’ related events. From an historical perspective, with the use of remotely sensed archival data (LANDSAT) it would also be possible to assess open water extent further back in time (circa 1972). Utilizing remote sensing technologies is an efficient and cost effective method of monitoring in the PAD due to the large size of the wetland complex, and the difficulty of access. This spatial information will be important to the successful diagnosis of contaminant source attribution, given the hydrological complexity where ice jamming and high flow events can cause flooding and flow reversals (e.g., PAD), as well as the intermittent connectivity to otherwise isolated basins (i.e., perched basins). To fully reflect the full range of hydrological conditions, remotely sensed images would need to be captured in the Spring, mid-Summer and into the early Autumn.

Table 1. Water Quality and Quantity Monitoring Sites: Phase 2. (Purple = Key mainstem nodes - monitored intensively over the long-term, linked to mass balance monitoring sites in Phase 1; Orange = Strategic support monitoring sites - monitored intensively initially to establish baseline, then reduced until response is triggered at key nodes; Blue = surveillance sites - hypothesis-driven sampling to fill knowledge gaps; Green = reference / unaffected by development; Bright yellow = new sites; Light yellow = proposed requirements for the new program)

Water Quality and Quantity Monitoring Sites: Phase 2											
Site	**Existing Site Linkages**	**Site ID**	**Site Status**	**Current Sample Parameters**	**Time Series (period of record)**	**Sampling Freq. (current / historic)**	**Remarks / Rationale**	**New Hydro Req.**	**Baseline (Near-term) Sampling Freq (Season Dependent)**	**Long-term Sampling Freq (Season Dependent)**	**Parameters / Media**
M10	WSC	Active Hydrometric WSC 07NA007, 008	Riviere des Rochers	Level	1960 to present	Continuous	Main outflow of the Athabasca; estimate loadings upstream of Peace R. confluence	No	Monthly / Biweekly	Monthly / Biweekly	WQ / Bottom, Susp Sed / Hydromet / Passive / Integrative Samples
M11A	EC/ WSC	EC long-term monitoring AL07NB0001, Active Hydrometric WSC 07NB001	Slave River @ Fort Fitzgerald	Water quality / Water quantity: Flow, Level	1921 to present Water quality: Current Agreement with Alberta: 1988 to present. (limited historic data in the 1960s)	Continuous (Real Time) Water quality: 8 / year as of 2010, approx 6 / year prior to 2010	Estimate loadings from Athabasca and Peace rivers to Slave R.; coupled with long-term sediment quality record from Slave R. at Fort Smith (M11B); coordinated with fish sampling	No	Monthly / Biweekly	Monthly / Biweekly	WQ / Bottom, Susp Sed / Hydromet / Passive / Integrative Samples
M11B	INAC	INAC long-term monitoring	Slave River @ Fort Smith	Water quality / Suspended sediment quality	Water quality: Mid-river: 1990-95, 2000, 2001, 2003, 2006-	Water quality: Approx. 2 / year	Estimate loadings from Athabasca and Peace rivers to Slave R.; coupled with long-term water	No	Monthly / Biweekly	Monthly / Biweekly	WQ / Bottom, Susp Sed / Hydromet / Passive /

					07. Shore: 1982-91, 1992-95, 1996-99, 2000-03, 2006-07.		quality record from Slave R. at Fort Fitz. (M11A); coordinated with fish sampling				Integrative Samples
M12	EC/ WSC	EC long-term monitoring AL07KC0001, Active Hydrometric WSC 07KC001	Peace River at Peace Point	Water quality / Water quantity: Flow, Level	1959 to present Water quality: 1967-1976, 1989 to present.	Continuous (Real Time) Water quality: 10 / year	Estimate loadings on the Peace R. upstream of the PAD and Slave R., including Peace River oil sands area and Athabasca oil sands lease area south of WBNP; coordinated with fish sampling	No	Monthly / Biweekly	Monthly / Biweekly	WQ / Bottom, Susp Sed / Hydromet / Passive / Integrative Samples
BI1	WSC	Active Hydrometric WSC 07KE001	Birch River	Water quality / Water quantity: Flow	1967 to present Water quality: Approx. 2 / year from 1969-1978	Seasonal (Real Time and Reference hydrometric basin network site)	Reference; estimate loadings to L. Claire; coordinated with fish sampling	No	Monthly / Biweekly-Event	Seasonal (archive) / response-based	WQ / Bottom, Susp Sed / Hydromet / Passive / Integrative Samples
MC1	New	N/A	McIvor River	N/A	N/A	N/A	Reference; estimate loadings to L. Claire; coordinated with benthic sampling	Yes	Monthly / Biweekly-Event	Seasonal (archive) / response-based	WQ / Bottom, Susp Sed / Hydromet / Passive / Integrative Samples
BU1	New	N/A	Upper Buckton Creek	N/A	N/A	N/A	Reference; estimate loadings to L. Claire. Oil sands development expected downstream (BACI investigation);	Yes	Monthly / Biweekly-Event	Seasonal (archive) / response-based	WQ / Bottom, Susp Sed / Hydromet / Passive / Integrative Samples

							coordinated with fish/benthic sampling				
BU2	New	N/A	Lower Buckton Creek	N/A	N/A	N/A	Reference; estimate loadings to L. Claire. Oil sands development expected upstream (BACI investigation); coordinated with fish/benthic sampling	Yes	Monthly / Biweekly-Event	Seasonal (archive) / response-based	WQ / Bottom, Susp Sed / Hydromet / Passive / Integrative Samples / Atm Dep
NA1	WSC	Discontinued Hydrometric WSC 07DA021	Namur Lake, Birch Mountains Wildland Provincial Park	N/A	1976-1978	Seasonal	Reference lake; coordinate with acid-sensitive lakes program	Level	Monthly	Seasonal (archive) / response-based	WQ / PaleoSed / Level / Passive / Integrative Samples
LC1	New	N/A	Lake Claire	N/A	N/A	N/A	Surveillance (presence/absence); paleo-techniques to establish baseline	Level	Monthly	Seasonal (archive) / response-based	WQ / PaleoSed / Level / Passive / Integrative Samples
PB1	New	N/A	Birch Delta perched basin	N/A	N/A	N/A	Surveillance (storage/release of contaminants); paleo-techniques to establish baseline; coordinated with fish sampling	Level	Hypothesis-driven	Event-based / response-based	WQ / PaleoSed / Level / Passive / Integrative Samples
PB2	New	N/A	Mamawi Lake perched basin	N/A	N/A	N/A	Surveillance (storage/release of contaminants); paleo-techniques to establish baseline	Level	Hypothesis-driven	Event-based / response based	WQ / PaleoSed / Level / Passive / Integrative /integrative Sample
PB3	New	N/A	Big Egg	N/A	N/A	N/A	Surveillance	Level	Hypothesis-	Event-based	WQ /

			Lake perched basin				(storage/release of contaminants); paleo-techniques to establish baseline; consideration to be given to previous studies in the basin		driven	/ response-based	PaleoSed / Level / Passive / Integrative Samples
RI1	WSC/ RAMP	Active Hydrometric WSC 07DD002, RAMP ARD-2	Richardson River	Water quantity: Flow	1970 to present	Seasonal (Real Time and Reference hydrometric basin network site)	Reference; estimate loadings to PAD; coordinated with fish/benthic sampling	No	Monthly / Biweekly-Event	Seasonal (archive) / response-based	WQ / Bottom, Susp Sed / Hydromet / Passive / Integrative Samples
QU1	WSC	Active Hydrometric WSC 07KF003	Quatre Fourches	Water quantity: Level	1971 to present	Continuous	Complex mixing zone, key to diagnosis and aquatic ecosystem effects; coordinated with fish/benthic sampling	No	Monthly / Biweekly-Event	Seasonal (archive) / response-based	WQ / Bottom, Susp Sed / Hydromet / Passive / Integrative Samples
LA1	WSC	Active Hydrometric WSC 07MD001	Lake Athabasca West	Level	1930 to present	Continuous	Surveillance (presence/absence); loadings to PAD; potential sampling from water intake for community of Fort Chipewyan; coordinated with fish/benthic sampling	Level	Monthly	Seasonal (archive) / response-based	WQ / Level / Passive / Integrative Samples / Atm Dep
LA2	WSC	Discontinued Hydrometric WSC 07MD002	Lake Athabasca near Bustard Island	Level	1975-1995	Continuous	Surveillance (presence/absence); baseline for loadings from the east to Lake Athabasca	Level	Monthly	Seasonal (archive) / response-based	WQ / PaleoSed / Level / Passive / Integrative Samples
PE1	EC/ WSC	EC long-term monitoring BC07FD0005	Peace River above	Water quality / Water quantity:	1974 to present	Continuous (Real time)	Estimate loadings upstream of Peace River oil sands area;	No	Monthly / Biweekly	Seasonal (archive) / response-	WQ / Bottom, Susp Sed /

		and WSC 07FD010	Alces	Flow, Level	Water quality: 1984 to present	Water quality: 13 / year	control for Peace River; transboundary site; coordinated with fish sampling			based	Hydromet / Passive / Integrative Samples
SL1	INAC	INAC long-term monitoring	Slave River upstream of Slave R. Delta	Water quality	1982 to present	Water quality: Approx. 2 / year	Estimate loadings from Slave R. at Smith to Great Slave Lake; boundary conditions downstream of oil sands areas; coordinated with fish/benthic sampling	Yes	Monthly	Seasonal (archive) / response-based	WQ / Bottom, Susp Sed / Hydromet / Passive / Integrative Samples
SL2	New	N/A	Slave River Delta	N/A	N/A	N/A	Surveillance (presence/absence); paleo-techniques to establish baseline ; depositional and vulnerable areas; consideration to be given to previous studies in the delta; coordinated with fish/benthic sampling	Level	Hypothesis-driven	Seasonal (archive) / response-based	WQ / PaleoSed / Level / Passive / Integrative Samples / Atm Dep

3.2 Biomonitoring – Invertebrates and Other Biota

The integrated aquatic ecosystem health and effects monitoring components for lentic (wetlands/lakes) and lotic (rivers/streams) systems involves designing a biomonitoring program for relevant aquatic taxa. In general, aquatic biomonitoring provides a direct measure of change in biotic populations and communities in relation to benchmark or reference condition and can help identify ecological effects of cumulative stressors such as oil sands (OS) development. Used together with the water chemical and physical monitoring components, this component delivers an integrated approach to assess whether biological and ecological affects are occurring in response to oils sands developments.

The aquatic biomonitoring component focuses on the use of key indicator biota such as fish, invertebrates and algae. Fish as a biological group are known to be good integrators and indicators of contaminant exposure and environmental stress, and have well-established morphological and physiological endpoints to quantify potential effects. In addition, primary producers such as benthic periphyton have short life cycles, high productivity, and can be affected quickly by short-term exposures to nutrient and contaminant stressors. Benthic macroinvertebrates in streams and rivers are relatively sedentary, can be sensitive to multiple stressors, are critical components of fish habitat, and are the most common aquatic group used for aquatic bioassessments globally (Rosenberg and Resh 1993). Similarly, the highly diverse invertebrate and plant communities in wetlands exhibit a range in sensitivity to multiple stressors and thus will be used as indicators of effects of OS development in downstream deltaic wetlands.

Section 3.2 describes the design details for the invertebrate and other biota monitoring component in mainstem rivers, small steams and rivers and deltaic wetlands and Section 3.3 addresses fish populations and associated indicators.

3.2.1 Existing Invertebrate Monitoring Programs

Benthos monitoring implemented by RAMP (Regional Aquatics Monitoring Program) has been reviewed by Ayles et al. (2004), Dillon et al. (2011), and Main et al. (2011). All reviews cite the benefits of existing macroinvertebrate data sets as background information and highlight the challenges of study design, data collection, analysis and interpretation. Key recommendations included the following: standardized sampling protocols were needed monitoring in the Athabasca River mainstem was essential; the program needed to be based on an effects-based monitoring framework, and assessments should integrate water quality, benthos and fish monitoring program information. Main (2011) also suggested revising the sampling design for tributaries to focus on clearly defined habitat, modify statistical methods to reduce noise and variability, and the development of a conceptual model to provide a benchmark against which test sites can be evaluated. The designed invertebrate biomonitoring program has considered the short-comings identified by the various reviews.

3.2.2 Monitoring Questions and Objectives

Together, the described invertebrate monitoring components provide the necessary data and information to address key questions related to the effects of OS development on the environmental integrity of the Athabasca, Peace and Slave River mainstems, small streams and rivers, and deltaic wetland/lake complexes. The questions underlying the monitoring designs are:

Ecosystem health

1. What is the current status of benthic communities in these ecosystems?
    a. What is the baseline against which future change will be assessed?
    b. What baseline data need to be collected in areas of future development?
    c. Are there significant changes since historical studies?
2. Are there existing differences in benthic communities among reference and potentially impacted sites?

Cumulative effects

3. Do predictive relationships exist that link system drivers (including development stress) and variability within sites in benthic community responses?
4. Is there evidence of cumulative effects of development on benthic communities in the Lower Athabasca River?
5. Is there evidence of cumulative effects further downriver?

The above questions are designed to provide information on the "Accumulated State" of these ecosystems (Core Result 1) and the cumulative effects of activities associated with OS development (Core Result 3). Priority areas are identified for mainstem, small streams and rivers, and deltaic wetland/lake habitats.

3.2.3 Athabasca River Mainstem

3.2.3.1 Rationale

Although mainstem sampling of benthic invertebrates occurred sporadically during AOSERP (Alberta Oil Sands Environmental Research Program) and RAMP, both Ayles et al. (2004) and Main et al. (2011) indicate that ***sampling the Athabasca River mainstem upstream and downstream of the OS receiving environment should be a priority in future biomonitoring designs***. A clear lesson learned is that the establishment of benthic macroinvertebrate and algal sampling programs in a large river such as the Athabasca River near Fort McMurray (6th order system; >150,000 km^2 basin area) presents numerous difficulties related to spatial scale and sampling logistics. It can be difficult to obtain a standardized and representative sample for bioassessment from such rivers because of the: (1) diversity of habitat types (e.g., back channels, deep channels); (2) limited ability to identify reference conditions to assess effects caused by multiple stressors; and (3) hazardous conditions associated with deep, swift waters (Flotemersch et al., 2006). Because of the high turbidity of the Athabasca, sampling using bottom grabs must be done with little or no knowledge of the specific substrate type being sampled, and these samplers may be ineffective on hard substrates or when woody debris or stones are present. Although information collected by Barton and Wallace (1980) on mainstem benthic macroinvertebrates provides background information on presence and absence of taxa and community structure in sandy/silty habitats of the four areas sampled, the sampling approach and study design has not provided sufficient rigor to assess if impacts have occurred (Ayles et al., 2004 and Main et al., 2011).

While benthos sampling in the mainstem Athabasca has had very limited success, it is important to fully consider the application of benthic sampling approaches for the Lower Athabasca Biodiversity and Effects Monitoring Program (Phase 2). Benthic organisms, including algae and invertebrates, are exposed to both sediment and waterborne contaminants over their life history and are widely used globally as response indicators that integrate the cumulative effects of multiple stressors. A recent USEPA synthesis on bioassessment approaches for large rivers provides a broad overview on scientifically defensible and statistically robust protocols specifically designed for large river bioassessment (Flotemersch et al., 2006). Active methods, including near-shore sampling approaches for algae and benthic macroinvertebrates, are promising because these techniques sample biota associated with sediments, thereby providing direct linkages between biota and human-induced habitat change (e.g., contaminants, nutrients). Additionally, these approaches are related to ongoing Canadian bioassessment schemes (i.e., Canadian Aquatic Biomonitoring Network, CABIN). Incorporation of these methods would permit benthic bioassessment at all of the mainstem sites identified in the Phase 1 Water Quality Monitoring Plan (i.e., sites M0-M9 – **Figure 3**).

Passive methods, such as water column sampling of drifting invertebrates and algal biomass, may also provide an assessment of biological effects along the gradient of Phase 1 mainstem sites if flow is adequate in near-shore areas. Drift sampling has recently been used successfully in the Red River in North Dakota (Zheng 2010) as well as in Manitoba for bioassessments of this large river. In fact, compared to bottom grabs, night time drift samples collected a greater diversity of organisms and reduced variability (B. Parker 2011, unpublished data).

Artificial substrate samplers can also be used in turbid rivers with unstable bottoms comprised of mud and sand. However, this technique assesses the effect of water quality on colonization potential rather than effects on the resident benthic assemblages. It also poses considerable logistical challenges in riverine areas with highly mobile stream beds such as the Athabasca River.

Finally, although RAMP sampling of the mainstem was not continued, Ekman or Ponar grabs can be useful to assess those communities which reside in soft, silty bottom areas of rivers. We propose that, after some preliminary testing, these four sampling techniques can be used in a multi-habitat sampling approach, thus providing a more complete picture of the invertebrate assemblages in the reach while partitioning the variability noted earlier with differences in habitat.

3.2.3.2 Sampling Network Design

The design for assessing ecological effects on benthic biota will incorporate the proposed sampling sites on the Athabasca River mainstem from the Phase 1 Plan (Environment Canada, 2011). This approach will improve spatial and temporal resolution of the data being collected, and increase the power to detect change. By positioning sites along the river from upstream of Fort McMurray to near the boundary of Wood Buffalo National Park, ecological responses can be described in relation to point and non-point sources of pollution along the mainstem. The design will assess the biological quality at each site and determine the accumulated state relative to least disturbed condition (Stoddard et al. 2006) in the mainstem. In response to the most recent scientific review of RAMP (Main et al. 2010), the design expands sampling along the mainstem Athabasca River, focuses sampling on specified habitats in order to reduce variability and will deliver the data essential to the development of models for ongoing test site evaluation.

Timelines for implementation of the study design include an initial reconnaissance year so appropriate sampling locations that support the richest assemblage of benthic biota can be associated with Sites M0-M9 of Phase 1. Near-shore sampling of benthic invertebrates and algae will be collected using both active and passive sampling approaches to compare and contrast sampling method efficacy. To facilitate comparison of biological attributes among sites, a single, relevant habitat type will be chosen in order to reduce variation within and among sites as discussed by Plafkin et al. (1989). If a single habitat type is not available at all sites, then a proportionally stratified design as described in the USEPA protocol for large rivers will be adopted (Flotemersch et al., 2006). Following the reconnaissance year, a 3-year program of assessment will be initiated with annual assessments of the response indicators (described below) undertaken at all sites. During this initial 3-year sampling cycle, it is recommended that the power of the study design to detect effects be evaluated and additional replication and site locations be added as required. The robust design will facilitate quantitative analysis through both univariate and multivariate approaches with statistical considerations such as effect size, Type I and II errors and power determined as in Glozier et al. (2002). It is envisioned that this standard benthic bioassessment program will continue indefinitely. However, after the first 3-year cycle, results should be interpreted via the framework outlined in **Table 3** so that more in-depth levels of bioassessment are triggered when ecological effects are established. This tiered approach to bioassessment using a standardized decision process will confirm if the effect is related to OS development, whether the magnitude and geographical extent of the effect is known, and if the possible causal agents associated with observed degradation arising from oil sands development can be determined.

Table 3. Decision "Triggers" for invertebrate monitoring program

Level	Trigger	Magnitude	Consequence
1	Effect detected	Statistical change	Seek confirmation
2	Confirmation of effect	Statistical change in same endpoints and direction	Increase spatial and temporal resolution around site of interest; add higher tier response variables
3	Exceeds critical effect size	Exceeds ±2SD for benthic invertebrate community endpoints or divergent from reference community in RCA models	Investigate potential source and cause of effect
Action Level	Exceeds critical effect size and is getting worse	Prolonged exceedence of critical effect size	Possible change in management actions warranted

3.2.3.3 Site Locations and Sampling Frequency

Assessments of benthic biota will use site locations designated in the Phase 1 Water Quality Plan (i.e., Sites M0 to M9 and Phase 1 groundwater emergence points; **Figure 4**) to facilitate harmonization and integration of the monitoring components as recommended in the RAMP 2010 review (Main 2010). Although the wadeable near-shore zone accounts for a small proportion of the river channel, these shallow margins are often the most productive habitats of large rivers as a result of higher light penetration for primary producers and greater accumulation of organic detritus (Wetzel 2001; Flotemersch et al., 2006). Specific areas for sampling along the wadeable near-shore zone will be determined during the reconnaissance year with additional sites added as determined through an assessment of study design power during the initial 3-year cycle. We recommend standardizing definitions of sample site terminology as follows. Each site will consist of a 500 m right and left bank area that contains appropriate wadeable near-shore zone habitat to accommodate 5 replicate sampling stations for each bank (**Figure 5**). Flotemersch et al. (2006) indicate that for large rivers such a 500 m area provides representative samples and is logistically manageable for investigators. Each area should be a fixed sampling reach with defined GPS coordinates. Replicate stations within an area will be located every 125 m, giving sufficient physical separation between stations to maximise statistical independence. Final selection of site locations will be made upon consultation of experts with local knowledge.

Benthic macroinvertebrate and algal communities, and algal biomass, associated with the river bottom and artificial substrates will be sampled along the near-shore area (**Figure 5**). Within the 500 m area of a site and along the right and left banks, five replicate samples of

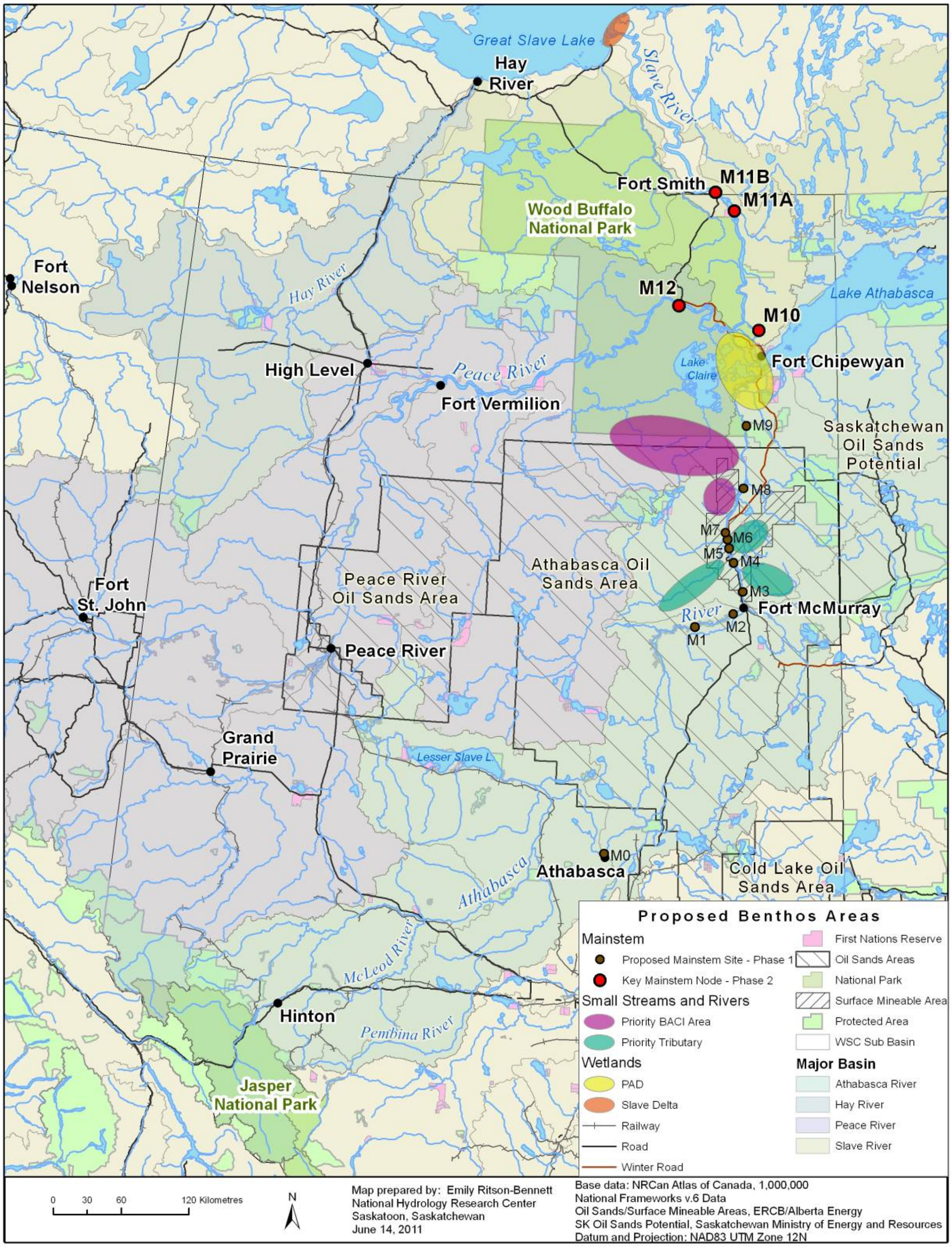


Figure 4: Proposed Invertebrate (Benthic) Community Monitoring Locations.

benthic macroinvertebrate and algae composition, and benthic algal biomass, will be collected using standard river bottom and artificial substrate methods. Right and left bank areas can be analyzed separately (n=5) or used together to describe the ecological quality of the entire site (n=10). Phase 1 data will support the biological data as is feasible. However, additional supporting variables, including current velocity, substrate composition and standard CABIN site variables (Environment Canada 2010), will be collected at the time of sampling as required.

3.2.4 Peace and Slave River Mainstem

In addition to the Athabasca River sites, sampling areas will also be located on the Slave River which originates downstream from the Peace River confluence with the Rivière des Rochers, one of the main channels discharging from Lake Athabasca. Sampling areas will also be located on the Peace River to determine potential effects on the Slave from upstream influences (**Figure 4**). The Slave River assessment will provide information on downstream boundary conditions for any future integrative cumulative effects modeling that may be done on a regional basis. Sampling rational, design and methodology will follow the approaches outlined for the Athabasca River. Finally, given the distance from OS impacts and the potential of dilution capacity, sampling on the Peace and Slave River mainstems are of lower priority than sampling on the Athabasca River mainstem.

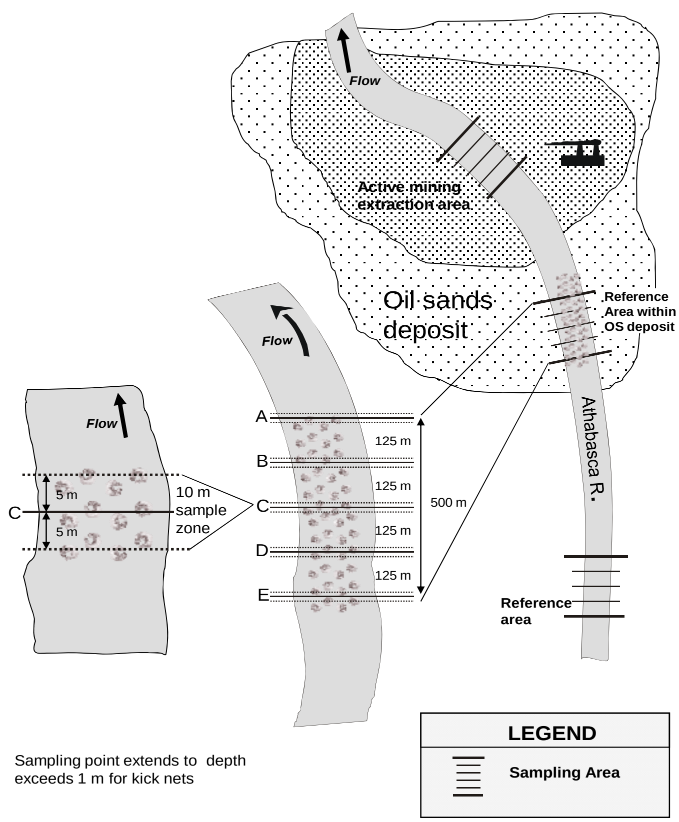


Figure 5: Athabasca Mainstem River benthic invertebrate sampling schematic.

3.2.5 Small Streams and Rivers

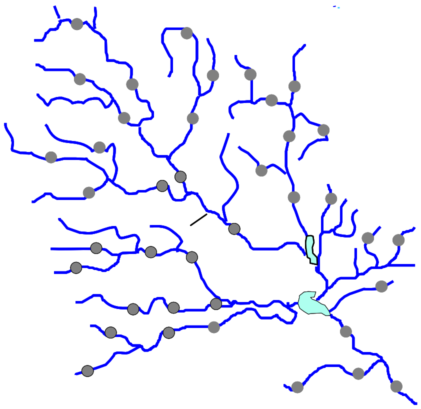
3.2.5.1 Rationale

It is important to establish the baseline / reference condition for small streams and rivers within and outside the OS area in order to assess potential impacts at test sites. These ecosystems have variable catchment size, stream order and dominant habitats (erosional, depositional) typical of the Mid-Boreal Uplands, Slave River Lowland and Wabasca Lowland ecoregions of the Boreal Plains Ecozone. Thus, there are challenges in designing a sampling program that has the statistical power to detect change. The proposed sampling design incorporates protocols of the national CABIN program (Environment Canada 2010), and addresses the concerns of Main (2011) regarding the suggestion that samples should be collected from clearly defined habitats in order to reduce variability of sample estimates. Additionally, the design introduces response indicators such as periphyton biomass and community composition, functional assessments of food webs, ecological traits analysis and assessment of contaminant levels in biota and sediments to produce a more detailed and robust monitoring program. The incorporation of historical data will be included in model development and BACI assessments where protocols are determined to be transferable. This integration will improve continuity with RAMP information. Sampling of small streams and rivers in the OS area has occurred since the mid-1970s including work on the Steepbank and Muskeg rivers by Barton and Wallace (1980), Brua et al. (2003) and RAMP (Ayles et al., 2001; Main 2011). All available biotic data will be compiled in a usable database for future development of benchmark conditions and potential assessment of longer-term changes through time.

3.2.5.2 Sampling Network Design

A primary criticism of previous OS benthic studies was that habitat-specific reference conditions were not developed (Ayles et al., 2004; Main et al., 2011). In addition, revised statistical approaches were suggested in order to account for inherently high variability that produced low power for detecting impacts at test sites. The design outlined in this section addresses these concerns by characterizing the natural range in benthic community structure at reference sites to permit more appropriate testing of potentially impacted sites based on common habitat characteristics. This is a key assumption of the Reference Condition Approach (RCA) (Environment Canada 2010; Rosenberg et al., 1999; Reynoldson et al., 1997). RCA categorizes reference communities based on predictable habitat relationships and reduces the need to find appropriate reference areas upstream or even within the same watershed (**Figure 6**). Although there is an intensive initial sampling effort required to establish the reference database, historical data within the OS area may be valuable for this purpose. Moreover, RCA models may include data from reference sites available within the same Ecoregion, but not necessarily within the LAR basin (Boreal Upland Ecoregion, Glozier and McIvor 2010).

A: RCA Field Sampling Design Prior to Modelling



B: RCA Site Groupings (colour coded) Identified by Modelling.
Stressor discharge and test site (X) to be evaluated.

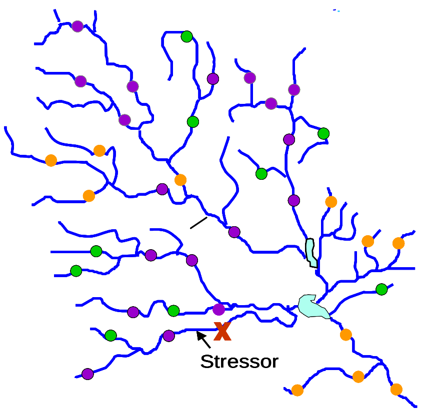


Figure 6: Small stream monitoring schematic using the Reference Condition Approach (RCA).

The proposed design addresses key objectives for the bioassessment of small streams and rivers in the OS area. First, the reference condition of benthic communities within the OS area will be developed with a focus on habitats that are relevant to current or future OS activities. The presence or absence of the underlying geology of the OS McMurray formation complicates this design; therefore reference condition models based on data from either inside and outside the McMurray formation will be created. This exercise will further the information of Brua et al. (2003) regarding the effects of naturally exposed bitumen in stream catchments. Thus, the models will account for the relationships between habitat and benthic communities and will determine whether benthic communities within and outside the OS geology are similar. In addition, the models will be used to determine if test stations within the OS geology which have OS activities upstream, are *divergent* (99-99.9th) or *highly divergent* (>99.9th) from the predicted reference condition. If differences are noted, then potential causes will be investigated and suggested actions considered (**Table 3**).

Timelines for implementation of the invertebrate monitoring program include an initial reconnaissance year (preferably 2011) so that appropriate sampling areas and habitats can be determined. Over the course of the next three years as many reference and test sites as feasible will be sampled for all response and supporting variables described. The number of reference sites required to develop the predictive model is not pre-determined as it is dependent on how many benthic groupings are present in the study area. CABIN guidance suggests a minimum of 10-20 sites per grouping (Environment Canada 2010). In addition previous work in the Boreal Plains Ecozone (Glozier and McIvor 2010) have described at least 3 distinct groupings. Therefore, for model development a minimum target of 60 sites will be established for each potential stream habitat (erosional and depositional). During the initial three year study period, preliminary models will be developed after years 1 and 2 to ensure that sufficient numbers of sites within each community grouping are obtained for final model building as well to obtain sufficient statistical power for planned comparisons.

Two final considerations are whether erosional habitat sampled in the fall is the focus of these models, or if a combination of erosional and depositional habitats should be sampled during multiple seasons. A focus on erosional habitats in the fall for northern streams and rivers will likely reduce the variability within the model as communities will be more similar and well established and fall sampling has been used successfully for several decades for Canada's CABIN program. However, depositional habitats may be important to assess in the OS area as contaminants may accumulate in these habitats and historic information is likely available. In addition, evaluation of effects on spring communities may be warranted as contaminants have been reported to accumulate in the snow pack (Kelly et al., 2009; 2010). These habitat and seasonal aspects are likely best addressed by designing smaller sub-projects within the overall monitoring program. After the initial three years, the monitoring program, reference models and the assessment results will be evaluated and subsequent phases determined.

3.2.5.3 Site Locations and Sampling Frequency

The monitoring area for small streams and rivers includes watersheds that drain into the Athabasca River from M0 to M9 mainstem locations (Phase 1) and those which drain into the Peace-Athabasca Delta (i.e., Birch River and Lake Claire). These include watersheds sampled during RAMP and several sub-watersheds within the Clearwater and Christina River drainages that may have useful historic information. Development of the RCA model may also include reference sites located in similar ecoregions that are outside the Athabasca River basin.

Site locations will be determined inside and outside the OS deposits in a similar manner as that described for CABIN study design (e.g., **Figure 5**). Reference sites are chosen *a priori* (before the data is collected) with selection based on non-biological measures. The approach captures variability in community structure resulting from habitat characteristics, and includes: 1) determining relevant sub-areas (e.g., ecoregions, physiographic zones, bedrock geological classifications, climate zones); 2) stratifying sub-areas with another large scale variable such as stream order or functional process zone to account for additional levels of variation. Finally, within each of the available stratified sub-areas, sampling sites are selected randomly with an additional pool of over-sample sites to be used as replacements if a random site is deemed unacceptable. Alternately, a modified probabilistic sampling design could be used, in which sites are randomly selected, but if the site is unsuitable for a variety of reasons, the closest suitable location within the river to that random location could be used (Millar et al., 2009). Test sites (i.e., those potential impacted by oil sands-related

contaminants or disturbance) will be selected based on the most recent land disturbance satellite imagery as well as the previous tributary reaches assessed under the RAMP.
It is recommended that all reference and test sites be sampled annually for the first three years with higher priority given to several areas (**Figure 4**). Priorities are based on urgency for attaining "before" sites in a BACI design, establishment of long term reference sites, and assessing previously sampled sites with the recommended CABIN sampling protocol. ***Priority areas include stream reaches that: 1) are currently in reference condition but are scheduled for OS activities in the near term; 2) are currently in reference condition and are not planned for OS activities (i.e., long term reference sites); or 3) have been sampled consistently under the RAMP program (e.g., Muskeg, Steepbank, McKay rivers and others).*** Final selection of site locations will be made upon consultation of experts with local knowledge.

In addition to the overall sampling design that uses RCA, it is recommended that a ***Before-After-Control-Impact (BACI) design be implemented as a priority for those specific watersheds where OS activities are scheduled to begin in the next five years.*** As an example, the BACI design, with appropriate replication, could be used to assess the potential effects of OS activities on select tributaries of the Lake Claire Watershed where OS activities are scheduled to begin within 5 years. This would include 16 tributary streams in the southwest region of the Lake Claire Watershed. According to current plans for OS activity, four of the 16 streams would continue to serve as reference streams (i.e., sub-watersheds not subjected to OS operations), with OS operations anticipated in the remaining 12 streams. All sites will initially be incorporated in the development of the RCA model for the Athabasca River basin and, as OS activities proceed, some sites will become test sites. This approach could also be utilized for other tributaries as future OS approvals and are identified.

3.2.6 Wetlands

3.2.6.1 Rationale

Wetlands represent substantive, highly productive ecosystems in the lower Athabasca, Peace and Slave mainstems and deltas. The physical, chemical and biological properties of these deltaic wetlands are profoundly influenced by lateral and vertical exchanges with river discharge during floods. Lateral exchange of materials from these rivers leads to the wetlands being major sinks for contaminant discharges from OS operations and from natural bitumen deposits. Despite clear linkages between contaminant loading and depositional habitats within deltas and their associated wetlands, efforts to monitor the effects of these contaminants have been limited. The development of a monitoring program capable of detecting the ecological effects of OS developments in these delta complexes will be challenging because deltas are hydrologically complex (this is particularly true for the Peace-Athabasca delta), there is limited scientific hydroecological knowledge for these systems, and effects of OS operations co-occur within larger scale stressor regimes (i.e., climate-driven reductions and alteration in water volumes and river flow regimes; Wolfe et al., 2008).

The primary objectives of the biomonitoring program component for these wetlands are to: 1) describe the current status of the aquatic ecosystems of wetlands in the Peace-Athabasca and Slave deltas, 2) track potential shifts in their ecological status through time, and 3) determine the extent to which delta ecology is affected by OS operations. Delta wetland status will be quantified by monitoring the biological diversity of plant and benthic macroinvertebrate communities, and contaminant loadings in select ecosystem components.

3.2.6.2 Sampling Network Design

A phased approach will be used with activities in Years 1 and 2 characterizing wetland types and their related hydro-ecology, describing plant and benthic macroinvertebrate communities to refine and optimize sampling methods, and quantifying biotic relationship among wetland types. Initial monitoring efforts will build on previous studies (Brock et al., 2007; Wolfe et al., 2007) to broaden the classification of wetlands types; quantify current loadings of contaminants in water, sediments and benthic macroinvertebrates; and quantify relationships between wetland types and plant and benthic macroinvertebrate communities that will serve as biodiversity indicators. This information will serve as the basis for the stratified sampling design that will be fully deployed in Year 3.

Effects of OS operations on biodiversity and contaminant burdens in wetlands in the Peace-Athabasca and Slave River deltas will be evaluated using a stratified sampling design to recognise and account for variance in hydrological connectivity between wetlands and the mainstems of the Peace, Athabasca and Slave rivers. The monitoring design will include sampling a randomly chosen suite of wetlands within each of the four wetland types in the Peace-Athabasca River delta (Wolfe et al., 2007) and three wetland types in the Slave River delta (Brock et al., 2007). This approach recognises that the potential effects of OS developments on wetlands will differ, in part, due to variation in the hydrological connectivity between mainstream reaches of each river system. Wetlands that experience high levels of water exchange with the mainstem may be strongly affected due to reduced flows compared to those that receive appreciable inputs of water from other sources. The study design recognizes and accounts for wetland specific responses to OS operations. Specific hypotheses and the overall sampling design will be refined over Years 1 and 2 as data from the synoptic surveys provide an increased level of understanding of delta wetlands and the extent of hydrological connectivity with the mainstem rivers.

3.2.6.3 Site Locations and Sampling Frequency

Wolfe et al. (2007) classified wetlands within the PAD into four types (closed drainage, restricted drainage, open drainage, shallow rainfall) based on the major factors that control their water balances. Brock et al. (2007) identified three wetland types in the Slave River delta (flood dominated, evaporation-dominated, exchange dominated). These different wetland types could potentially support different biological communities, and differences in water balance could also affect their susceptibility to potential effects of OS operations. For example, aerial deposition of contaminants may have a greater influence on systems that are hydrologically isolated.

The ecological health of wetlands will be assessed by monitoring plant and benthic macroinvertebrate communities following the sampling designs of McIvor et al. (2009) and Bailey and Reynoldson (2009). Both designs are semi-rapid bio-assessment approaches that use multiple transects within a wetland to identify specific zones and sites within each zone for monitoring. Benthic macroinvertebrates will be sampled from the emergent and submergent zones using a standard three minute travelling kick method. Assessments of wetland health will be augmented with analyses of water, benthic sediments and benthic macroinvertebrate tissues (e.g., mussels), and small-bodied fish for contaminants and toxicology testing where appropriate. Water and sediment samples will be analyzed for the broad suite of nutrients, ion and cations, and contaminants.

Wetlands will be divided into four zones (marginal, emergent, submergent, open-water) with specific monitoring components for each zone. The sampling method may be modified for large wetlands (e.g., Richardson Lake), wetland complexes or multi-wetland basins as noted by Bailey and Reynoldson (2009). In Years 1 and 2 of the developmental phase of the program, the biodiversity of plant communities will be described in three of the four wetland zones of marginal, emergent, and the submergent zones (i.e., 3 of the 4 wetland habitats zones). Descriptions of species occurrence and relative cover will be quantified in four randomly chosen sites within each of these zones. These data provide the opportunity to quantify the extent that plant communities differ among zones, thereby warranting subsequent monitoring, or whether sampling could be restricted to fewer zones without substantial information loss.

In summary, focal activities in Years 1 and 2 will include defining wetland types using isotopes and water chemistry, describing current loadings of contaminants in water, sediments and benthic macroinvertebrates and developing quantitative and predictive relationships between wetland types and plant and benthic macroinvertebrate communities that will serve as biodiversity indicators in the delta (**Figure 1**). Wetland invertebrate communities will be sampled in areas that have been shown in previous studies to support the highest diversity of taxa. Sampling will include sweeps through littoral macrophyte assemblages that typically include pelagic insects (e.g., midge larvae), zooplankton as well as those invertebrates which are associated with surface sediments (amphipods). This strategy, similar to the streams and rivers monitoring program, allows assessments to be made on highly diverse communities that exhibit a range in sensitivity to multiple stressors, are critical components of fish habitat, and are commonly used for aquatic bioassessments. In Year 3 the fully functioning wetland monitoring program will likely be comprised of semi-annual sampling of 30-40 wetlands in the Peace-Athabasca delta and 20-30 wetlands in the Slave River delta.

3.2.7 Indicators and Endpoints

3.2.7.1 Response Indicators

This section describes benthic response indicators that are recommended for assessment of OS effects along with the justification for indicator choice. The primary components to be assessed are the macroinvertebrates, algae and macrophytes associated with the benthic environment (**Table 4**). Benthic macroinvertebrates are widely used in biomonitoring programs because they are ubiquitous, abundant, relatively sedentary and long-lived (i.e., weeks to 1 year or more) (Rosenberg and Resh 1993). These qualities allow metrics based on benthic macroinvertebrates to integrate short-term disturbances and reflect long-term site condition. The diversity of macroinvertebrate ecological traits related to life history, morphology, mobility and ecology can help provide mechanistic linkages of biotic responses to environmental condition, and consistent descriptors or metrics across broad spatial scales (Culp et al., 2011). Similarly, benthic algae are a basal food resource for riverine food webs and have long been recognized as having utility for biological assessments because pollution can change algal community structure (Stevenson and Rollins 2006). Macrophytes are also sensitive to environmental changes such as flow regime modification and nutrient enrichment. Finally, macroinvertebrate drift and sestonic algal biomass will be assessed because these water column response variables may produce more robust assessments if these samples have inherently lower variance and more uniform taxonomic composition than samples from benthic habitats.

A variety of analytical approaches will be used, including, for example: DNA-based biodiversity analyses; multivariate statistical approaches, and community-based endpoints such as total density, taxa richness, Simpson's diversity, evenness and the Bray-Curtis Index (Glozier et al., 2002). These later summary metrics will be used to assess a range of possible responses that may result from OS disturbance, including changes in productivity, species composition and biodiversity. Many other descriptive metrics are available in the literature and will be used where applicable (e.g., Rosenberg and Resh 1993; Stevenson and Rollins 2006).

Besides the structural response variables discussed above, the program will measure variables assessing ecological function (e.g., food web pathways, river metabolism). Benthic food webs will be characterized through stable isotope analysis (SIA) of carbon and nitrogen (Peterson and Fry 1987), as well as community-wide measures of trophic structure (Layman et al., 2007). Algal and macroinvertebrate community data will be analyzed using ecological traits approaches as shifts in the composition of these traits at sites impacted by stressors may be diagnostic of exposure to particular stressor regimes (Culp et al., 2011). Decomposition of organic material will be measured using standard bioassays of degradation of cotton strip material strips as a leaf surrogate (Tiegs et al., 2007). Finally, river metabolism will be estimated via diel shifts in dissolved oxygen and grab samples of oxygen isotopes (Wassenaar and Koehler 1999) will provide an estimate of whether the riverine food base is responsive to human-induced stressors (Young et al., 2008).

Table 4. Summary of the response variables proposed for the Athabasca, Peace and Slave river mainstems, small streams and rivers and deltaic wetlands, the justification for measurement and where in the river they will be measured.

Response Variable	Justification for Measurement	Near-shore Mainstem	Small Streams and Rivers	Deltaic wetlands
Macroinvertebrate assemblages	• ubiquitous, abundant, sedentary • reflect longer term site condition • taxa specific response to stressors	• river bottom • artificial substrates	• river bottom	• wetland habitats
DNA/RNA- extracted biodiversity profile	• comprehensive snapshot of local community (from microbes to metazoa)	• river bottom	• river bottom (subset of sites)	• wetland habitats
Macroinvertebrate drift	• ubiquitous, abundant • composed of benthic organisms • taxa specific response to stressors	• water column		
Attached algal assemblages and biomass	• basal food resource, abundant • reflect longer term site condition • taxa specific response to stressors	• river bottom • artificial substrates	• river bottom	
Macrophyte assemblages	• reflect longer term site condition • responsive to nutrients and hydrologic condition			• wetland habitats
Sestonic algal biomass	• basal food resource • responsive to nutrients	• water column		
Decomposition bioassay	• basal food resource • key ecosystem function	• artificial substrates	• artificial substrates	
Carbon and nitrogen isotopes in food web	• C indicates food web pathways • N delimits trophic levels	• river bottom • artificial substrates	• river bottom	• wetland habitats
Diel shifts in oxygen concentration and isotopes	• indicates level of primary production and ecosystem respiration	• water column	• water column	

3.2.7.2 Supporting Environmental Variables

Supporting environmental variables provide important explanatory evidence for interpretation of the ecological response indicators. Much of this information will be available from data collected as part of the overall water quality program for co-located sampling sites. However, there will be additional site-specific information required during the benthic invertebrate field program including habitat descriptors such as bankfull width and substrate composition.

To provide supporting evidence of potential OS impacts as a cause of site deviation from background/reference state, it will be necessary to conduct toxicity assessments as per the established triad approach (Chapman 2002). In years 2 and 3, and with reference to Year 1 results, a general toxicity measure - Microtox (based on the response of a luminescent bacterium to the presence of toxic substances), which has a low sensitivity, but is cheap and rapid, will be applied in conjunction with freshwater invertebrate bioassays e.g. amphipod (*Hyalella*), mayfly (*Hexagenia*) or worm (*Tubifex*) bioassays, using organisms held in long-term laboratory culture at Environment Canada or other accredited laboratories.

3.2.8 Supportive Research into New and Emerging Technologies

All monitoring programs should seek to develop an extensible and dynamic design, and should be able to incorporate research innovations as they emerge. Such new technologies may be in development for full deployment at the time of study design implementation, or they may be on the horizon. This section briefly reviews a number of key tools and techniques which are likely to make a significant contribution to the OS biomonitoring program, either through an ability to do key jobs more efficiently and cost-effectively (e.g., DNA-based biodiversity analysis), or to explore areas of ecosystem impact which are not well-covered by existing methods (e.g., ecosystem functional measures), and which have the potential to link ecosystem damage with societal benefits through appropriate valuation of the goods and services provided by the ecosystem.

(i) DNA/RNA-based biodiversity analysis: the advent of high capacity DNA sequencing technologies, coupled with major computational advances in bioinformatic analysis has brought the era of inexpensive, rapid and accurate taxonomic processing of biomonitoring samples closer to reality (e.g., Hajibabaei et al., 2011). Environment Canada has an ongoing project in Wood Buffalo National Park with researchers from Parks Canada and three universities that are developing a biomonitoring analysis platform based on high-resolution DNA information. These analyses aim to provide information on all biota in the habitats sampled (microbes, fungi, protists, plants, invertebrates and vertebrates) using a novel multi-gene approach that supersedes previous techniques using single-gene 'DNA barcoding'.

(ii) Traits-based ecological risk assessment: this approach focuses on the use of ecological, physiological and morphological attributes of biota in the development of stressor-specific diagnostics (Culp et al., 2011), by exploring mechanistic linkages between exposure/effects data and biota attributes. The approach aligns closely with the types of biological data being collected using CABIN program methods, and thus is highly suitable for use with the biomonitoring data generated through this component.

(iii) Ecosystem functional measures: ecosystem degradation is often measured simply in terms of changes in structure (i.e., the occurrence and abundance of specific biota). However, it can be argued that in situations of anthropogenic disturbance, it becomes important to link ecosystem structural changes to their underlying influence on the capacity of the ecosystem to deliver key services (e.g., waste processing, flood abatement, ecological support for a fishery). New techniques focusing on river ecosystems include measures of (a) river metabolism estimates of community metabolism and gross primary production (Yonge et al., 2008), (b) decomposition processes through the use of novel cellulose bioassays (Teigs et al., 2007), and (c) food web structure through stable isotope analyses of carbon, nitrogen and oxygen.

(iv) Environmental '-Omics': Two rapidly developing fields are (a) metabolomics - which explores the patterns of metabolite production under exposure to specific environmental stressors, using nucleo-magnetic resonance (NMR) spectrometry within exposed biota (e.g. macroinvertebrates, fish); and (b) transcriptomics- which explores patterns in gene expression under exposure to specific environmental stressors. These approaches have the potential to provide diagnostic bioassessments that link to traits-based ecological assessment.

(v) Musselwatch: the use of freshwater mussels as contaminant monitors is well-established. Local mussels can be used *in situ* for population analysis or transplanted and deployed to assess rates of accumulation of PAHs, and allow a link to aquatic food webs and traditional diets in some communities.

3.3 Biomonitoring – Fish

The objectives of the fish component of the aquatic monitoring program are to provide the necessary data/information to address key questions related to both environmental health of fish populations and fish health issues that can be used to inform human use and consumption. Considerations of lessons learned from past monitoring of fish populations and reviews of those programs have guided the development of the design.

The questions underlying the fish monitoring design are related to the status and health of fish populations in the Lower Athabasca River including an expanded geographical extent. Data will be collected to provide a baseline against which future changes in fish populations will be judged, and be compared to data from historical studies to assess change over time to the current state. Data will also be collected in areas of new oil sands development, to develop baseline data for future site-specific comparisons, contribute to an expanded geographic basis of the overall monitoring plan, and contribute to an improved ability to examine cumulative effects. Over time, the site-specific information will be used to develop a site-specific cumulative effects monitoring approach, and contribute to the development of better predictive capabilities for oil sands environmental impact predictions.

The data will assess whether there are existing differences in fish populations among sites in the Lower Athabasca River. Endpoints considered will include assessments of overall fish health, fish distributions, contamination (fish tissue and bile) and abnormalities within the mainstem Athabasca, its tributaries, and downstream reaches. Fish from high-use fishery areas will be assessed to determine the status of populations, for comparisons to historical levels and future changes. Detailed population assessments of individual fish will include the assessment of age, growth, liver size, gonad size, and abnormalities. Young of year (YOY) fish will also be assessed for growth, abundance, size and abnormalities and fish populations will be assessed for species presence/absence, and ages/sizes of fish in a particular habitat. Cumulative effects will be assessed by relating measured endpoints (YOY size or abundance, fish gonad size, etc.) to environmental predictors (water temperature, rainfall, climate, etc.). Building models will allow prediction of normal change in fish characteristics that are related to environmental drivers, and will allow the determination of whether development exceeds these predictions resulting in management decisions.

Fish sampling will be linked to invertebrate sampling as well as water quality sites (Lower Athabasca Water Quality Plan – Phase 1 and the expanded geographic expansion) so that maximum information is obtained and the programs are integrated.

3.3.1 Limitations and Strengths of Existing Fish Monitoring

The review of the fish monitoring component by Ayles et al. (2004) focused on determining if existing monitoring could characterize variability in individual and population-level metrics for fish, identify cumulative effects, if the information collected could verify environmental impact assessment predictions, and if the fish monitoring program could be improved. Overall it was concluded that fish monitoring lacked a clear focus and clear hypotheses, the program had suffered from inconsistencies in study design, study area, sampling methods, and quality control practices, and it did not provide a useful assessment for discerning current impacts or for setting a benchmark for assessment of future impacts.

Species inventories were used to characterize existing variability yet the inventory varied significantly due to changes in sites, seasons and sampling methods. For many of the larger species, there were seasonal differences in size of individual fish, suggesting migration into the study area of larger individuals from outside the system. This emphasized the crucial need to understand fish migration patterns so that any effects on fish related to oil sands developments could be assessed. It was also stated that local evaluations needed to use fish whose life-history characteristics and performance attributes reflected local conditions. Migrating fish make linkages to development difficult. Further radio-tagging studies for the purpose of effects-based assessment should not collect post-spawning fish or immediately pre-spawning fish. The importance of fish fences for estimates was identified but issues related to operation and maintenance of the fence for this purpose were also stated. The fish abnormalities studies were not consistently applied from year to year, and reporting was inconsistent.

In 2011, Main et al. (2011) reviewed RAMP again and similar comments were made of the fish monitoring including the following improvements: use of probabilistic fish sampling methods to capture temporal and spatial variability within the watershed; use of physiological indicators to assess exposure; increase in the number of reference sites for sentinel species; definition of reference areas in the Athabasca River mainstem; use of age-based demographic analysis; use of individual fish analysis rather than means in statistical analyses of metals in fish tissues; exploration of alternative sampling methods to enhance capture of small-sized fish; conducting full assemblage sampling while collecting sentinel species; return to lethal sampling of sentinel species so that the gonadosomatic index endpoint, fecundity and tissue analyses could be done to maximize information for the effort; inclusion of all available historical pre-RAMP data; and improvements needed to integrate the fish monitoring with other monitoring (e.g., water quality and benthos).

Reviewers identified the advantages of using background historical data that pre-existed the formation of RAMP to develop an understanding of baseline conditions. This of course refers to AOSERP monitoring conducted in the late 1970s. Reviews also stated that the use of fish fences be critically evaluated as their operation was intermittent at best due to fluctuating flow conditions. If fish fences cannot reliably be operated in the smaller rivers, a technique that will yield catch per unit effort (CPUE) demographic samples, relative abundances of species and tissue samples should be employed.

Dillion et al. (2011) also reviewed RAMP fish monitoring for the Provincial Monitoring Panel review. They stated that the difficulties of obtaining good information on abundances of different species of fish merited close examination due to the fact that fish abundance is highly variable in space and time even in the absence of disturbing factors such as contamination from oil sands operations. High natural variability exacerbated by changes in methods for sampling fish would negate the potential to measure the effects of oil sands development on fish. Reviewers suggested effort in obtaining better estimates of contaminant levels in fish in the lower Athabasca River and its delta, and perhaps better data on tumours, lesions and other indicators of poor fish health.

RAMP fish abnormalities data was collected as part of their fish inventory collections that were not designed specifically to examine the abnormality endpoint. These data have been incorporated into collections conducted prior to RAMP. It is difficult to interpret data among years and across sites as fishing effort, sites sampled, seasons sampled, and species included have changed, and the index is subjective in nature with different individuals performing the assessment over time. This significantly reduces the ability to detect significant change and decreases the overall power of the assessment. External abnormalities have also never been correlated to contaminant concentrations suggesting tumour assessments may be a better indicator of contaminant effects. The identified shortcomings have been used to guide the development of the fish monitoring component discussed below.

3.3.2 Monitoring Questions and Objectives

The objectives of the fish monitoring components are to provide the necessary data/information that address key questions related to both environmental health and fish health issues related to use and consumption. The questions underlying the monitoring designs are:

Environmental health

- What is the current status of fish populations in the Lower Athabasca Region?
    - What are the baseline conditions for fish populations against which future change will be judged?

    - Which baseline data need to be collected in areas of future oil sands development?
    - Are there significant changes since historical studies?
- Are there existing differences in fish populations among sites in the Lower Athabasca Region?
- Are there any trends/changes in fish health?

Human use

- What is the status of fish populations in high use areas?
- Is the incidence of fish abnormalities elevated or changing?
- What are contaminant levels in fish?
    - How do they compare to historical levels?
    - Are contaminant concentrations in fish increasing or decreasing downstream of oil sands development or in areas of natural geological exposure?
    - Does other development influence these concentrations?
    - Are contaminants at levels in the fish that are safe for human consumption?

Cumulative effects

- Are there any predictive relationships between system drivers (including development stress) and variability within sites in fish responses?
- Is there evidence of cumulative effects of development on fish in the Lower Athabasca Region?
- Is there evidence of cumulative effects further downriver?

3.3.3 Athabasca River Mainstem

There are many challenges with monitoring in the Athabasca River. It is a large river system with access issues in a northern climate. The challenges to designing and implementing a "world class" effects monitoring program include issues related to seasonal sampling, high flow events, shifting substrate, migratory fish species, low species richness, limited access and transportation on the river, habitat change upstream, and continual loss of reference areas to development.

3.3.3.1 Sampling Network Design

Two goals drive the monitoring program and study design:

1. developing a baseline to understand the significance of future changes, and;
2. assessing whether change is happening in the system using fish performance and integrative endpoints.

It is important to get an understanding of present-day fish distributions. Hence, the current status of fish communities will be assessed by index netting and seining to establish a baseline that can be used in the future if the surveillance monitoring programs suggest that changes are occurring. Fish communities will be assessed by index nets of 6 mesh sizes – 1, 1.5, 2, 2.5, 3, 4, 5, and 6 in, 25 ft per panel in 24 hr sets. These sets will follow the protocol of Morgan (2002). As well, young of year (YOY) fish will be caught using seining or by using smaller mesh (0.5 and 0.75 in) linked index nets.

The sites to be used on the mainstem (initially) include sites with overlap with long-term water quality monitoring sites (M2, 3, 4, 6, 9), as well as sites further upstream of Fort McMurray (**Figure 7; Table 5**). The upstream water quality sites include one at Athabasca that correspond to the far field site for the ALPAC pulp mill (M0 – Athabasca). Sites will also be included on the Clearwater River (CL1, 2, 3) to generate the accumulated state of fish populations in this system.

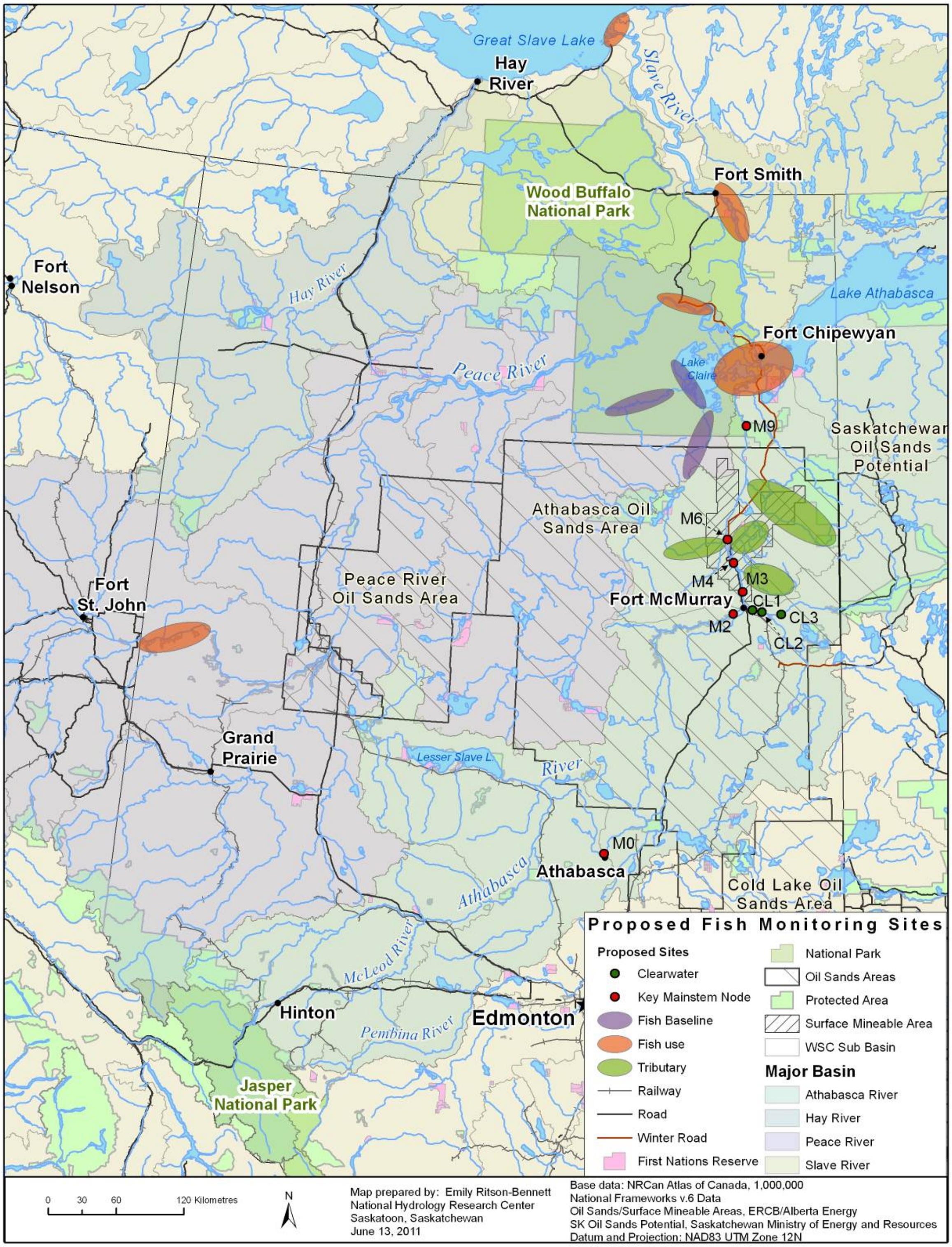


Figure 7. Proposed fish monitoring sites.

Table 5. Proposed sampling regimes for fish populations in the oil sands region.

Rationale	**Place**	**Type**	**Sites**	**Endpoints**	**Species**	**Frequency**
Baseline	Mainstem	Index netting, seining	M0,2,3,4,6,9,	Length, weight, age, tissue, bile, DELTs and abnormalities	As captured, contaminants on priority species	Initially, and when triggered in due to impacts
	Large tributaries		CL1,2,3			
	Historical sites (mainstem)	Gillnetting and seining	AOSERP site u/s and d/s Fort McMurray	Size distributions, growth, fecundity	Focus on lake whitefish, with reduced data from others	Once in initial period
	Historical sites (tribs)	Counting fences	Steepbank, Muskeg	Size, timing, abundance	All	When possible
	Future sites (lake)	Index netting and seining	3 sites on Lake Claire	Lake sites – AB Env't methodology, index netting	All	Prior to start of any development, fall sampling
	Future sites (tribs)	seining and efishing	6 sites on tributaries in the Lake Claire watershed (3 planned dev't, 3 not)	Tribs (EEM and YOY)	Slimy sculpin, longnose dace (if available)	Prior to start of any development, fall sampling
Surveillance/ performance/ accumulated state	Mainstem	Efishing	M0,2,3,6,9	Length, weight, gonad size, liver size, age, fecundity, EROD, bile contaminants, tissue contaminants	White sucker Trout-perch Whitefish yoy	Annually in fall for first 3 years, sites triggered out when possible
	Large tributaries	Efishing	CL1,2,3			
	Small tributaries	Efishing	Steepbank, Firebag, Muskeg, Ells, (Same tribs as WQ stations) Reference on Birch River system		Slimy sculpin, longnose dace YOY (species?)	Annually
Fish use	Expanded	Community index netting	M2,6, PAD (Jackfish, Dog camp, Dog head), Peace River (us and ds SAG D), Slave River, Slave Delta	Length, age, weight, contaminants, abnormalities,	Lake whitefish, walleye (muscle and bile), burbot liver	Seasonally
	Historical		Consistent with previous studies	Contaminants (metals) and bile PAHs	Pike, walleye, goldeye, lake whitefish, burbot	Once as new baseline

Reports of species captured (and any external abnormalities) in the index nets will be generated. At the mainstem long-term sites, several sites overlap with community fishing sites. At the other long-term sites (M0, 3, 4, 9, CL1, 2, 3) fish will be sampled in the fall only when water temperatures are between 10-15°C. Index nets will be assessed in detail for fish species and size (length, weight, and age). Tissue and bile samples in selected relevant species will be collected in order to assess concentrations of contaminants. Fish abnormalities will be classified, counted, and samples sent for histological identification /confirmation.

Overall fish populations will be evaluated in the mainstem Athabasca River and the Clearwater River using Adult Fish Assessment Protocols in order to assess the accumulated state of the fish populations in the river (**Figure 7; Table 5**). A large bodied species such as the longnose or white sucker will be sampled at selected water quality sites selected for Phase 1 of the monitoring program. Sucker species are known to be fairly site-specific outside of their spawning migration and they will be sampled during the fall of the year to incorporate site-specific inputs on a larger scale. Sucker species are benthic feeders, so assessment of these will link directly to the invertebrate community surveys. Trout perch will be used as a second sentinel species. These can be used on a finer spatial scale based on their reduced mobility relative to the sucker species. These adult fish surveys are lethal surveys with the following endpoints collected: age, weight, length, GSI, LSI, condition factor, and EROD as an indicator of exposure. Otoliths will be collected for aging and for micro-chemical analysis of metals. This will provide temporally-resolved exposure data. Abnormalities will also be assessed in these species.

Large bodied fish sampling will occur annually for a three year period and will then move to a three year cycle and sites will be triggered in or out depending on fish population responses. Small-bodied Trout perch populations will also be sampled annually for a three year period, followed by a three year cycle.

3.3.3.2 Historical Sampling Efforts

There are three major historical sampling programs that have valuable baseline data. The fish sampling program, where possible and practical, will follow historical sampling methods to provide comparable data.

<u>AOSERP</u>
There are some AOSERP historical fish population surveys using gill nets and seining on the Mainstem Athabasca River. These 1970-1980 studies provide valuable baseline, pre-oil sands development data on fish distributions and fish health (fish size at age). The studies will be repeated using the same methods to assess whether fish communities and health have changed (Project AF 4.8.1; Jones et al., 1978; Project AF 4.3.2; Bond, W.A. 1980).

Northern River Basins Study (NRBS)

NRBS provided an assessment of environmental conditions in the Peace, Athabasca and Slave River basins in the face of a rapid expansion in the pulp mill industry in the region (1991-1996). Contaminant data (PAHs in bile) from wild fish captured on the Peace River in the mid 90's provide a valuable comparison for similar studies on the Peace River. After upstream Athabasca studies in 1992–93, a basin-wide fish survey was conducted in late 1994 (Jacobson & Boag, 1995). Burbot, northern pike, longnose sucker, and flathead chub were collected from 23 sites in the basins, focusing on contaminant levels (NRBS Technical Report No. 129 Muir, D.C.G. and G.M. Pastershank. 1996). Summaries of the fish studies can be found in Cash et al. (2001). Although most fish studies concentrated in the upstream areas around pulp mills, studies did record elevated hepatic MFO (EROD) activities near the Fort McMurray and Wabasca oil sands sites.

Regional Aquatics Monitoring Program (RAMP)

RAMP has been conducted in the oil sands area since 1997. From 1997 onwards, RAMP studies provide more recent fish population and abnormality data (from their Fish Inventory Studies) and fish growth and health data in the Mainstem Athabasca River and tributaries. This dataset will be assessed to determine if there are data that may be useful as a baseline for comparisons of new data collected in this monitoring program. While the RAMP fish components have changed over time, collections have been made at many sites. Data from RAMP will be assessed to examine sites and measurements taken from relevant species.

Other Scientific Studies

Other specific studies have assessed fish health in detail (e.g., Tetreault et al., 2003). These will be assessed to determine if there are relevant historical data to provide comparisons for data collected in this new expanded monitoring program.

3.3.3.3 Decision Tiers and Triggers

Table 6 defines decision tiers and triggers for examining the extent, magnitude and identifications of cause. If an effect on fish is found, its magnitude and geographical extent will be evaluated through additional focussed monitoring. As well, other focused studies may be triggered in (e.g., lab studies, additional chemical monitoring), that will help to identify the cause of the effect which is determined through Investigation of Cause (IOC), the scope of which will depend on the results of the previous studies.

Table 6. Decision "Triggers" for fish monitoring program

Level	Trigger	Magnitude	Consequence
1	Effect detected	Statistical change	Seek confirmation
2	Confirmation of effect	Statistical change in same direction and endpoints	Increase spatial and temporal resolution around site of interest; add higher tier response variables
3	Exceeds critical effect size	25 % for GSI, LSI, weight-at-age, age; 10 % for condition; exceeds 2 SD for chemical/biochemical	Investigate potential source and cause of effect
Action Level	Exceeds critical effect size and is getting worse	Greater than 25 % for GSI, LSI, weight-at-age, age; 10 % for condition; exceeds 2 SD for chemical/biochemical, and getting worse	Change in management strategy warranted

Monitoring will initially be conducted at all sites on the mainstem for the first few years to generate the database and to allow for the development and validation of predictive relationships. Then, sites that are determined to show no significant statistical change could be discontinued or monitored on a reduced scale or frequency until triggered back in. When an effect is noted and confirmed, sites would be placed back in (with potential increased frequency) to get a better focus on the potential impacts at those sites. Baseline and performance monitoring will follow similar protocols for new developments. If new sites are being developed on a tributary where site locations on the mainstem are not sufficient to address the new development, additional sites will be added to the mainstem studies both upstream and downstream of the tributary in order to address potential additional change.

3.3.4 Small Streams and Tributaries

3.3.4.1 Sampling Network Design

The primary objective of the tributary/stream fish monitoring program is to assess the current ecological condition of populations to establish reference/baseline and to quantify and track future changes.

Fish populations will be evaluated in several tributaries (**Figure 8; Table 5**) using two different methods, the adult fish survey as used in the Mainstem Athabasca River as well as a non-lethal YOY fish survey. The adult fish surveys work very well for tributary streams and have been used previously in the oil sands area to examine fish health (Tetreault et al., 2003). The program will also include measurements of liver enzymes (ethoxyresorufin-O-deethylase, EROD) in these fish as an indicator of exposure. The adult fish assessment protocol endpoints include age, weight, length, GSI, LSI, condition factor, and EROD.

YOY sampling will be incorporated at these sites for determination of growth rates in the species present in these systems. The YOY sampling protocol for the tributary streams serves two purposes. Most tributaries have few species, so this approach gives us more information on the sentinel species used including abnormality rates. As well, it will help us develop models to predict impacts on fish further into the program.

3.3.4.2 Historical Sampling Efforts

<u>AOSERP</u>
AOSERP studies were conducted in the Steepbank (Machniak and Bond, 1979; 61), and the Muskeg rivers (Bond and Machniak, 1979) using fish fences and seine net captures. Similar methods will be used to compare fish distributions.

<u>RAMP</u>
RAMP studies have also utilized a fish fence on the Muskeg river in 1998, 2001, 2006 and 2009. These studies should be compared to the earlier AOSERP studies for comparison.

3.3.4.3 Sampling Frequency and Locations

For accumulated state assessment, the program would start with sampling all tributary sites every year for the first three years. This would include upstream sites outside of the deposit, within the deposit upstream of development and downstream of the development (**Figure 7**). The program would then move into a 3 year cycle with sampling of each tributary staggered. This would be done for the adults and the adult fish health assessment endpoints. In order to develop the predictive relationships (See below), reference site collections would be conducted every year using the YOY non-lethal protocols. For new site developments (baseline and performance monitoring will follow similar protocols), similar data will be collected. Data collected from these new sites will then continue and fit into this monitoring plan.

Young of Year sampling would be best conducted in the autumn for spring spawning species. Biological consideration will be given to determine when is best to sample the various adult species present in the tributaries.

3.3.5 Areas of Future Development and Downstream High Fish Use Areas

3.3.5.1 Future Development Areas

Baseline data will be collected in several tributary, river and lake sites that may be affected by future *in situ* mining (**Figure 7; Table 5**). Sampling will be conducted at six sites on tributaries in the Lake Claire watershed (in Birch River drainage basin, two tributaries selected, three sites on each) and on two sites in the Peace River for identification of cause studies. Three sites will also be assessed in Lake Clair. Fish distributions will be assessed by index nets using the Alberta protocol (Morgan, 2002). As well, YOY will be caught using seining or by using smaller mesh (0.5 and 0.75 in nets). On the tributaries of the Birch River, small-bodied fish will be assessed for fish health indices (length, weight, GSI, LSI, as well as EROD etc). YOY will be sampled similar to those on the Athabasca tributaries using either seines or electrofishing and catch-and-release data taken on abundance/density and CPUE. YOY will also be assessed for external abnormalities (curved spines, lesions, etc.) (as per protocols for the adult fish health assessment and YOY abundance/growth assessment) on tributaries of the Athabasca River.

For the two sites on the Peace River, baseline fish community data will be collected using approaches similar to those above. This information will be used as a baseline for potential effects from future SAGD mining around the Peace River.

3.3.5.2 High Human Use Areas

The current status of fish distributions will be assessed by index netting. One way of accomplishing this is in collaboration with aboriginal/local fisherman who fish year-round in several areas in the PAD that are biological areas of interest. This sampling will also be conducted on the Athabasca mainstem overlapping with sites M2 and M6. For this sampling we recommend 3 sites in the Biological Areas of Interest (BAI) at Dog Head in the Peace-Athabasca Delta/Lake Athabasca area (at Jackfish, Dog Camp and Dog Head) (**Figure 7; Table 5**). Reports of species captured (and any external abnormalities) in the index nets will be generated. Several times during the year (spring, summer, fall, winter), index nets will be assessed in detail for fish species, size (length and weight if possible) and tissue and bile samples (for contaminants) in selected relevant species. Abnormalities will be classified, counted, and samples sent for histological identification.

Abnormalities will be assessed in fish collected from index nets as well as in sentinel species from the adult fish health assessment on the Mainstem Athabasca River and tributaries. Abnormalities will be recorded, photographed, and samples taken for histological analysis. Liver tumour presence/absence will be used in the sucker species. Over the last several years a large database on reference rates of liver tumours has determined that a general acceptable reference rate of liver tumour prevalence is 2% (Bauman et al., 2011). This reference database will be utilized to investigate the presence of liver tumours in sucker species in the lower Athabasca River. This work could also be applicable to Lake Athabasca and the lower delta. As well, abnormalities will be assessed (by visual examination) of YOY fish in the mainstem.

In order to assess the accumulated state of abnormalities in the tributaries, all YOY captures will be assessed on the tributaries for external abnormalities. If abnormalities in larvae are important to fish populations in the tributaries, decreased abundance of YOY in fall collections will be apparent. If no differences are present in YOY abundance or YOY external abnormalities one can assume that exposure is not sufficient to impact the population.

Many residents in the oil sands region consume fish as a staple of their diet. Species that are consumed include whitefish, walleye, goldeye, northern pike and burbot (Crozier 1996). At the five index netting sites, located upstream of Fort McMurray, at Fort MacKay, and at Jackfish, Dog Camp and Dog Head in the Peace Athabasca Delta, samples of whitefish, walleye and burbot dorsal muscle tissue and bile and burbot livers will be collected during late summer for contaminant analyses. To collect burbot, long lines may need to be set in addition to index nets. The species of interest may be adjusted based on catch information derived from baseline sampling, and input from community members. This same sampling regime will be repeated at downstream communities on the Slave River (Fort Smith), Slave River Delta (Fort Resolution) and Peace River upstream and downstream of future oil sands development. Two muscle samples will be collected from each fish sampled. One muscle sample will be analyzed for a suite of metals (see water quality monitoring plan), while the other will be archived. Archived muscle samples will be analyzed for naphthenic acids when that technology becomes available. Otoliths will be analyzed for metal contaminants on a minimal basis initially, and samples will be catalogued and archived so that future analysis can be placed in historical context. Liver samples will be analyzed for the same suite of metals as dorsal muscle samples. Bile samples will be collected from each fish and archived for future PAH analyses, once the technique is more developed.

There have been several studies on the Lower Athabasca River and surrounding areas that resulted in data on contaminant concentrations in fish. By far, the parameter most widely analysed for has been mercury. A database of contaminant data for fish species sampled within the Lower Athabasca River, Peace-Athabasca Delta, Peace River, Slave River and Slave River Delta will be compiled. Studies that will be mined for data will include: Northern River Basins Study, Northern Rivers Ecosystem Initiative, Slave River Environmental Quality Monitoring Program, EIAs, RAMP and Environment Canada. AOSERP data will be assessed and included if detection limits and methodology allow for comparison.

To assess contaminant trends over time, data mined from the previously described exercise would be compared to more recent fish contaminant data. Also, fish sampling will occur upstream of development and downstream of development on the Athabasca River and selected tributaries. Thus, changes over time will be assessed where there is no impact of development and where there is the potential for development to have an effect. Fish health assessments, index netting and other fish studies will be conducted to assess whether development influences contaminant concentrations in fishes (large and small bodied species).

3.3.6 Cumulative Effects

The primary goal of this cumulative effects monitoring program is to develop a series of predictive relationships among the abiotic drivers of ecosystem performance, using the fish populations as indicators. These predictive relationships will be developed using all of the supportive water quality and chemistry data, compared against the fish information collected. They would include such things as comparisons of flow, temperature, current velocity, on biological indicators such as GSI, growth, YOY size, density, size distributions, etc.

Ideally, cumulative effects monitoring involves comparison between the predicted ecosystem response (from a site-specific defined relationship) and an observed response (i.e., this year's predicted size of YOY in October from this summer's water temperatures, versus the observed size). This designed fish monitoring program allows for a much higher sensitivity in detecting multiple stressor-induced changes in the ecosystem.

The potential impacts downriver will be further evaluated through engagement with community-based monitoring initiatives. The monitoring in the PAD and Slave Rivers through the expanded geographic model will have the objective of detecting long-range changes that could be correlated with changes happening upriver. It will include the described combination of index netting, development of predictive models with YOY and development of tissue archives for potential future analysis.

The long-term goal of the monitoring is to develop a sufficient level of understanding of the factors affecting performance of fish, within a site, to allow models to be developed that would allow prediction of potential impacts. This would be most critical on the mainstem sites, which is why annual sampling is required to build the information database to begin the process of developing the model. Much of the development of these methods and models is still in the research realm, but the collection of consistent, annual monitoring data will be critical to allow it to proceed in the future.

3.3.7 Information Gaps

There is a need to improve the understanding of the aquatic food web structure and interactions, fish population dynamics, and stressor-based responses in northern river systems. As early as the NRBS studies, research efforts have avoided tackling the issue of population dynamics of fish within the basins, despite the acknowledgment of this need for assessing impacts of anthropogenic developments and other stressors. At that time, it was felt that the issue was too complex, time-consuming and costly to be effectively addressed within the scope of the NRBS studies (Mill et al., 1996). If such extensive population studies are to be undertaken, it is recommended that they be undertaken in Lake Claire, prior to the development of the resources in that area.

As discussed, collecting and archiving samples would add significant value. This approach was used during the Northern River Basins Study for biota samples and some historical cores. One of the issues identified with previous oil sands monitoring is the lack of available high-quality baseline data. Archived samples will provide valuable information for addressing current concerns, and for the future. Since proper collection, treatment, storage and inventory protocols are crucial requirements, standard operating procedures and QA/QC protocols will be developed to ensure sample integrity.

Archiving samples could significantly reduce front-end costs associated with monitoring. Samples would be collected, and analyses may be triggered in at a later date. For example, if an effect was identified during routine monitoring, archived sediment or biota samples could be analyzed to help determine why an effect has occurred and could help to define the geographic extent of the impact. Samples of fish muscle and liver tissue could be archived with appropriate aging structures for future analysis. These samples would be valuable for comparing contaminant concentrations over time in the future when analytical methods or detection limits have changed. As new contaminants of concern arise, archived samples could be analyzed to provide background or baseline information. Archiving other samples that may be analyzed in the future by emerging technologies (i.e., bile, selected fish and invertebrate tissue samples for 'omics' that have been preserved in DNA or RNA later) will be considered.

Recent research on the Athabasca River has identified significant alterations in parasitic loads in resident fish populations. Because parasites have complex life cycles and are transmitted by predator-prey interactions, they can be used as indicators of environmental stress, food web structure and ecosystem health (Marcogliese, 2005). In addition, anthropogenic and natural stressors may interact to further compromise aquatic animal health. A second component of this work would determine how cumulative natural (parasites) and anthropogenic stressors (i.e., pollution resulting from oil sands operations) affects fish health.

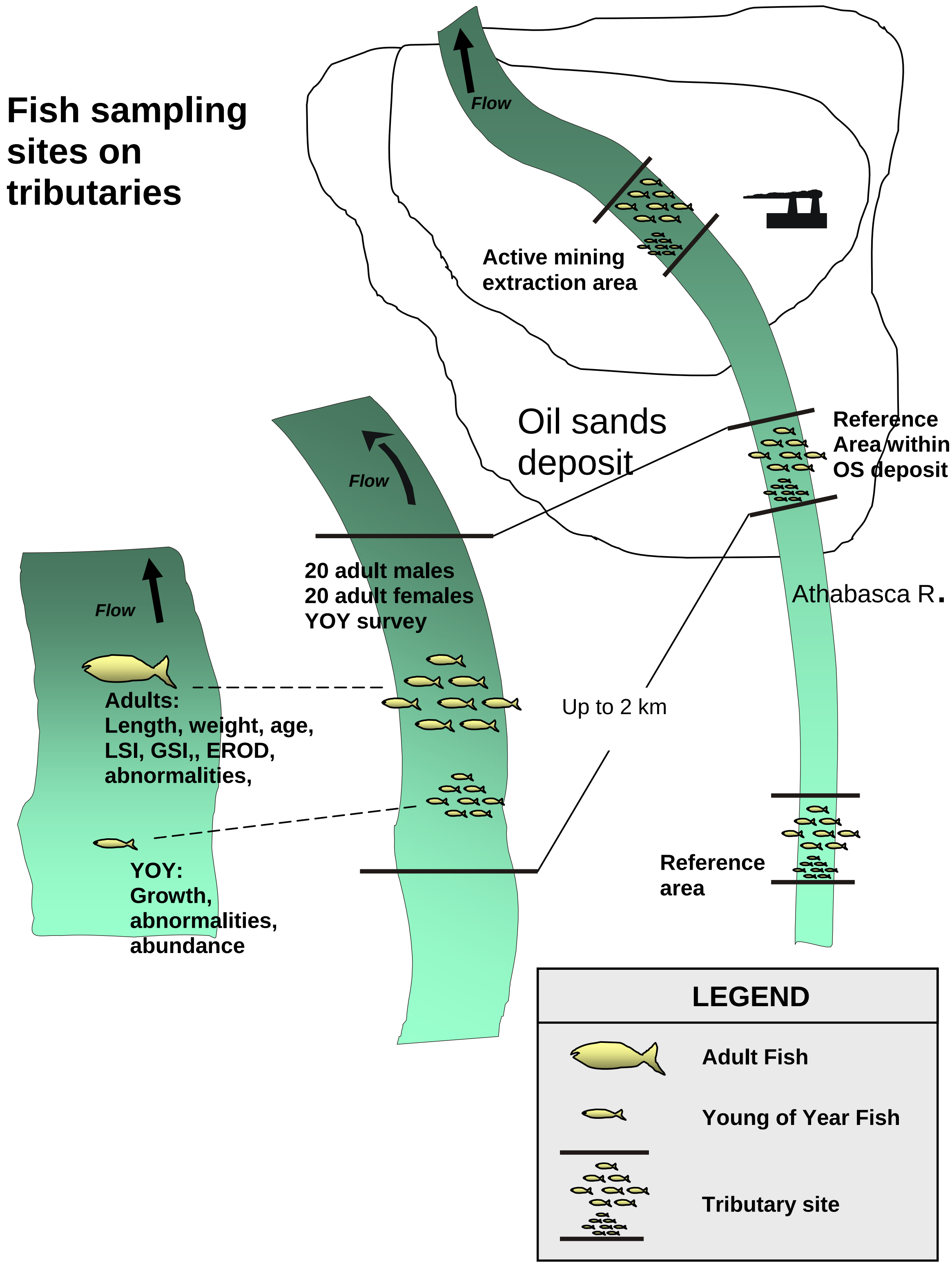


Figure 8. Schematic of oil sands sampling sites on tributaries.

3.4 Acid Sensitive Lakes

3.4.1 Introduction and Rationale

Acidification of aquatic ecosystems has been a concern in south-eastern Canada for more than 30 years. The concern engendered development of monitoring networks and research activities that have been the foundation of three national "acid rain" assessments (RMCC, 1990; Jeffries, 1997; Jeffries et al., 2005) and a voluminous scientific literature. While this eastern focus was justified by regionally-elevated emissions of sulphur and nitrogen pollutants and the resultant acid deposition "bulls-eye" centered on eastern North America, increasing trends in western Canadian emissions now raise the possibility of aquatic effects there. In fact by 2009, Alberta's total SO_x emissions (374 kT) exceeded those of Ontario, with 131 kt (35%) of the former's originating from oil sands industry (NPRI, 2011). Recent statistically-based surveys (Scott et al., 2010; Jeffries et al., 2010) have identified large numbers of lakes located on the Boreal Shield east (i.e., downwind) of the oil sands region that are very sensitive to anthropogenic acidification. Therefore the potential for aquatic acidification in this region is clearly established. It is incumbent on government to establish a monitoring system that is sufficient to track acid inputs to and responses in sensitive lakes, assess the degree and trend of their ecosystem effects, and recommend appropriate ameliorative action. The monitoring framework must be capable of explicitly separating acidification effects from effects caused by other non-point source stressors such as climate change.

3.4.1.1 Conditions Necessary for Anthropogenic Lake Acidification

An area of concern for anthropogenic acidification is defined by the geographic coincidence of elevated S and N deposition and geologically sensitive terrain. Early reports (e.g., WNLTC, 1987) defined regions of sensitivity in western Canada that were subsequently displayed in the National Atlas of Canada (1995) as a map entitled "The potential of soils and bedrock to reduce the acidity of atmospheric deposition" (see cropped portion in **Figure 9**). It identifies most of the northern half of SK into the NWT (the boreal Shield) as uniformly sensitive, i.e., having weathering resistant bedrock and shallow soils, and hence, a low ability

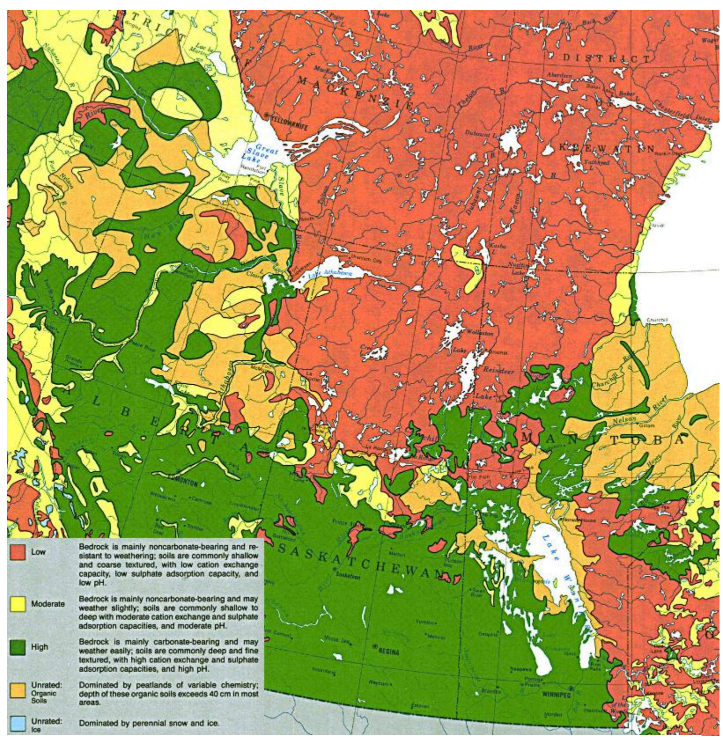


Figure 9. Location of acid sensitive (red) terrain in western Canada. Cropped and adapted from the National Atlas of Canada (1995).

to reduce incoming acidity. It also shows that the terrain in north-eastern AB has much more complex and variable sensitivity including large areas of "unrated organic soils".

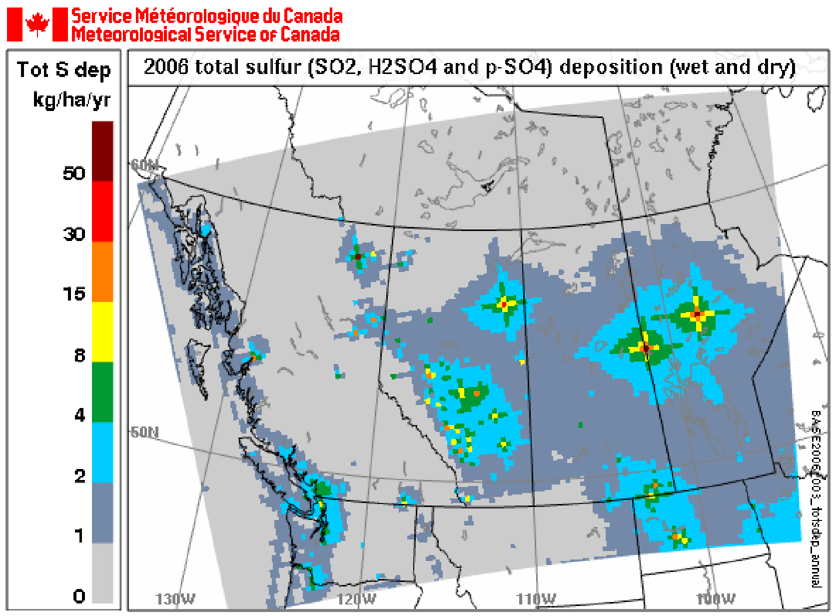


Figure 10. AURAMS model result of wet + dry deposition of sulphur (in kg/ha/yr) in western Canada for 2006. Multiply deposition in kg S/ha/yr by 62.4 to obtain eq/ha/yr, e.g. 4 kg S/ha/yr = 250 eq/ha/yr or 12 kg SO_4^{2-}/ha/yr. Note that the large point source (smelter) at Flin Flon, MB responsible for the elevated deposition in eastern SK closed in 2010.

The influence of oil sands SO_2 emissions on atmospheric deposition in the region is evident in **Figure 10.** Note that total NO_x emissions from oil sands industry are also significant (41.9 kt in 2009; NPRI, 2011) which may affect ecosystem nutrient status. However, because virtually all N deposition is retained within the lake catchments in this area (NO_3 levels in remote lakes are low), S deposition is by far the most important acidifying agent. Using 2006 emissions as input, AURAMS predicts high total S deposition (500 to more than 1800 eq/ha/yr) in the immediate vicinity of the oil sand industry. It declines rapidly in all directions, although values ≤250 eq/ha/yr extend into SK where aquatic critical loads can be very low (2-53 eq/ha/yr; Jeffries et al., 2010). Modeled total S deposition north of Lake Athabasca into NT is lower (≤62 eq/ha/yr), but little is known of critical loads in this area – a knowledge gap to be resolved by this monitoring plan.

3.4.1.2 Existing Monitoring Activities

The plan developed here is informed by many surveys, temporal monitoring networks, research programs and assessments that defined the acid rain issue for more than 30 years and were instrumental in justifying the emission reductions that have occurred in eastern Canada. First, statistically-designed (i.e., stratified random) lake surveys conducted in Nordic Europe (Henriksen et al., 1998), the U.S.A. (Landers et al., 1988), Quebec (Dupont, 1992), and most recently northern SK (Scott et al., 2010; Jeffries et al., 2010) gave point-in-time assessments of the acidification status of lake populations and permitted calculation of their critical loads of acidity. Data compilations such as Neary et al., (1990) in Ontario, WRS (2004) in AB and Jeffries et al. (2005) nationally have served much the same purpose, but without the ability to provide population-level estimates with a known uncertainty. Second, temporal monitoring networks in Europe and North America (e.g., Shaw, 1995; Kemp, 1999; McNicol et al., 1996; Stoddard et al., 1999; Skjelkvåle et al., 2005; RAMP, 2007) have permitted evaluation of chemical and in some cases biological changes occurring in the lakes. Finally, intensive monitoring conducted at research catchments such as Hubbard Brook (New Hampshire), Kejimkujik (Nova Scotia), Lac Laflamme (Quebec), Dorset, Turkey Lake and the Experimental Lake Area (Ontario) has provided the information necessary to distinguish trends related to acidic deposition from those influenced by other environmental stressor. Integrating these levels of monitoring lies at the heart of the hierarchical program proposed below.

3.4.1.3 Recommendations of the Federal Oil Sands Advisory Panel

Recent reviews of monitoring in the oils sands region (e.g., Federal Oil Sands Advisory Panel, 2010; Alberta Innovates Technology Futures, 2010; Royal Society of Canada, 2010; Schindler et al., 2011) offer many criticisms and recommendations in common, and some emanating from the Advisory Panel pertinent to this plan are noted here:

- Present monitoring activities (principally the Regional Aquatics Monitoring Program, RAMP) have not been adequately communicating results and have not led to a consensus on oil sands impacts.
- Due to insufficient replication in time and space and ill-defined or undefined baseline conditions, present monitoring has been unable to distinguish oil sands impacts from impacts by other stressors.
- A clearly focused set of objectives and statistically sound decision-making process do not exist.
- There is a lack of coherent data management.
- There is little formal coordination among WBEA, CEMA and RAMP monitoring.
- A need for "more rigorous acid deposition quantification including transboundary deposition in Saskatchewan" was specifically noted. Though stated only in terms of deposition monitoring, the need for associated effects monitoring is obvious.
- The Advisory Panel's overarching recommendation for monitoring was that "a shared national vision and management framework of aligned priorities, policies and programs be developed…" which are holistic and integrated, adaptive, scientifically credible and transparent and accessible.

The component design presented below has these characteristics.

3.4.1.4 CARA3 Acidification Effects Activities

The third generation of the federal government's Clean Air Regulatory Agenda (CARA3) will be implemented in 2011. Elements of the CARA3 work plan related to this monitoring plan include: collaborating with SK Environment (SK ENV) to establish temporal monitoring and research of selected lake ecosystems in west-central SK; quantify air pollution effects on the chemistry and biology of aquatic ecosystems with special emphasis on oils sands emissions, and maintain research into the influence of oil sands emissions on selected lake ecosystems in west-central SK.

3.4.2 Monitoring Questions and Objectives

The objectives of this plan development include:

- Establish a monitoring network of representative lake ecosystems in acid sensitive regions of SK, AB and NWT that are (potentially) influenced by SO_x and NO_x emissions from oil sands industry;
- Recommend determination of current, and if possible, historic baseline conditions;
- Devise a sampling and assessment plan sufficient to detect chemical and biological changes from baseline condition; and
- Recommend a small number of intensive monitoring-research sites where the cause of observed changes can be explored and explained.

3.4.2.1 The Integrated Monitoring Hierarchy

In a review of the Integrated Monitoring Program established by the United Nations Economic Commission for Europe under the LRTAP Convention, Nihlgård et al. (1992) succinctly summarized the monitoring philosophy espoused here: "…a statistically-based regional survey of lakes, if occasionally repeated (approximately once per decade) and integrated with an organized hierarchy of temporal monitoring and site-specific research, will provide all the information needed to accurately estimate resource-level status and change, identify the causes of change, and predict future conditions".

The hierarchy is composed of three levels at a minimum. Level 1 is a statistical regional survey of several hundreds or even thousands of lakes (usually using a stratified random design) to establish spatial variability and population-based estimates of current status. Lake surveys with a target population ≥4 ha in surface area (e.g., Henriksen et al., 1998) typically try to sample approximately 1% of the population. Surveys that sample smaller lakes as well (e.g., Jeffries et al., 2010 which included water bodies as small as 1 ha) typically sample a smaller percentage of the population due to logistical and financial constraints. Level 1 surveys should be repeated every five to ten years to detect gross regional changes in chemistry (and biology if such measurements are included). Level 1 surveys also help to identify regions or hotspots for higher temporal monitoring.

Level 2 is a temporal monitoring network of many tens of lakes sampled at least annually to establish year-to-year variation and detect trends. Level 2 lakes should be selected from a Level 1 sample population. As recommended below, the Level 2 network is often divided into two or more sub-levels with different sampling frequencies, one having annual (or bi-annual) sampling and another having a higher sampling frequency (seasonal to bi-monthly) to establish within-year variability. The number of lakes in this level can be expanded or contracted according to pre-defined measurement triggers.

Level 3 is a small number of lakes (two to four) in which as many ecosystem components as possible are monitored with a frequency sufficient to fully quantify natural variability (including snowmelt or other episodes) and to develop (or evaluate) process-based ecosystem impacts models. Mass budget determination is typically an ongoing goal meaning that all lake inputs (including detailed estimates of both wet and dry deposition) and outputs should be measured. Biological populations are monitored and researched here as well. This monitoring level permits evaluation of the cause of change detected in Level 2 and prediction of future conditions. Ideally these lakes should also be selected from the survey sample population, but logistical/financial constraints may prevent this. Mass budget measurement also places constraints on the physical and hydrological characteristics of the selected lakes.

Ultimately the goal of the monitoring system is to collect enough information that statistically significant ecosystem trends can be distinguished from natural, temporal variability, and to provide a basis for predicting impacts from future proposed emissions. Another important condition is that monitoring be viewed as a long-term activity (multi-decade minimum).

3.4.2.2 Lakes vs Lake "Ecosystems"

This component pointedly refers to "acid sensitive lake ecosystems". This is done to emphasize the fact that a lake cannot be divorced from it drainage catchment. In most cases acid rain entering a lake does so through a soil (terrestrial) pathway. The acidification process depletes the soil base cation pool mobilizing potential toxic metals (e.g., aluminum). For lakes with a catchment area substantially greater than the lake area (the rule rather than the exception), soil acidification is occurring well before alkalinity decline is detected in the lake. Hence the monitoring plan will include components related to the lakes' catchments.

3.4.2.3 Relationship to Phase I Plan and Air Quality Monitoring

Section 8 (Next Steps) of the Phase 1 report (Environment Canada, 2011) noted that "a key requirement will be to expand the existing program to include consideration and implementation of appropriate effects-based biological and ecological monitoring…". This component is a direct response. It encompasses baseline monitoring, accumulated state monitoring and surveillance monitoring as described in Section 2.1 of the Phase 1 Report.

The success of this monitoring component for acid sensitive lake ecosystems will depend on information supplied by the air quality monitoring program. This includes:

- Site-by-site regional estimates of annual total S and N deposition through time;
- Modelling estimates of future (scenario based) annual deposition for exceedance assessments, and estimates of historic deposition to support process-based hydrogeochemical modelling;
- Good meteorological information to evaluate the effect of a climate change co-stressor;

- Co-location of active or passive deposition monitors at lake monitoring sites, particularly the intensive (Level 3) sites would be beneficial. Such daily to weekly deposition estimates will be useful when evaluating short-term variation in surface water chemistry;
- Information from other AQ monitoring may also be useful, e.g., ground-level ozone (effect on forests), UV levels (DOC lake dynamics).

3.4.3 Background

Component development is influenced by existing regional data sets (**Figure 11**). Both Environment Canada (EC) and SK ENV have recently conducted lake surveys east of the oil sands. Jeffries et al. (2010) reported a survey conducted in north-central SK and north-western MB in 2007 and **Figure 11** shows an additional survey conducted in northern SK in 2009 with the same sampling protocol. Survey lakes were selected using a stratified-random sampling design in 17 sampling blocks from the population of lakes ≥1 ha in surface area. Data for 453 lakes from Blocks G, H, I, J, T, S, U, V and W (**Figure 11**) were deemed useful to this plan development. The sampling block design was used to minimize the helicopter costs associated with visiting the lakes, collecting physical data, water and sediment samples.

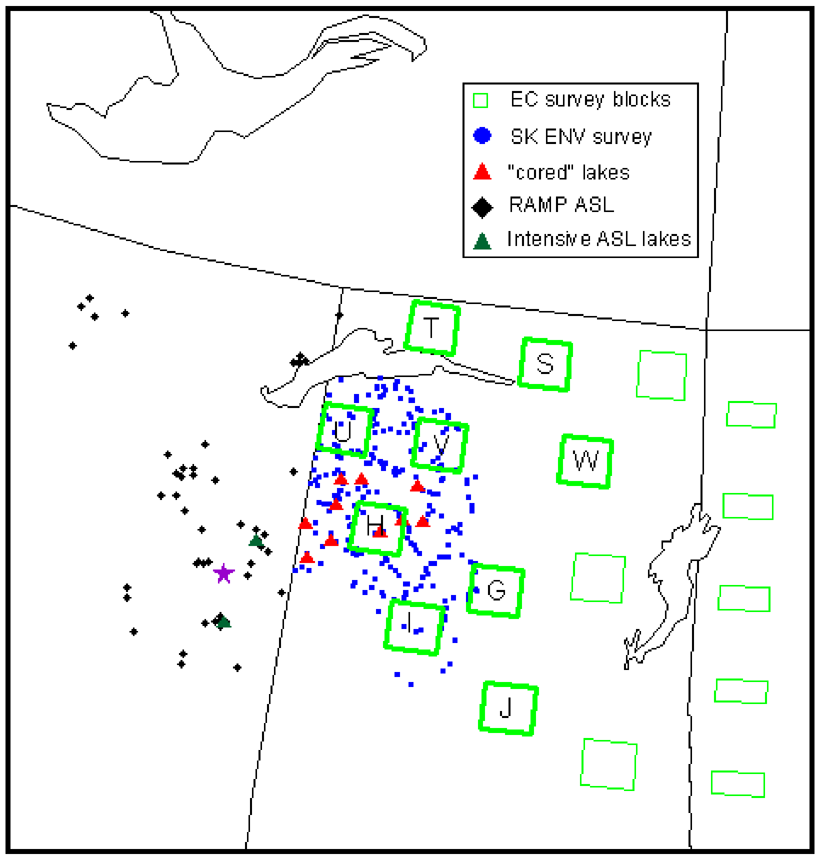


Figure 11. Location of existing lake surveys in SK and temporal monitoring in AB (see legend and text for description). For geographical reference, the Fort McMurray town site is indicated by a star.

Scott et al. (2010) reported a lake survey conducted within SK in 2007 and 2008 using a domain defined by a 300 km radius extending into Saskatchewan from the estimated centroid of the active Athabasca Oil Sands Region. The survey domain was divided by 10 degree azimuth angle increments, and intersected at 25 km radial intervals. Lakes in the size range 10 to 400 ha were randomly selected from an alternating subset of distance-direction segments. One hundred and forty-eight lakes were sampled by helicopter in 2007 and 200 were sampled in 2008, of which 86 were repeats (**Figure 11**). The same 200 lakes were resampled in 2009. Ten of the lakes have been selected for paleolimnological analyses and sediment cores were collected in 2010 (red symbols in **Figure 11**). All of the lakes will be re-sampled in the autumn of 2011. Both of the SK surveys collected water isotope samples for hydrological evaluation, i.e., water yield (W_y) as per Gibson et al. (2002).

The Regional Aquatics Monitoring Program in AB initiated an Acid Sensitive Lakes component (RAMP ASL) in 1999 (Hatfield Consultants, 2009). Thirty-two lakes were sampled annually from 1999 to 2001. In 2002 and subsequently, the ASL program expanded to 50 lakes (**Figure 11**). The lakes were selected from a compilation of 1158 lakes (Saffran and Trew, 1996) according to several criteria, including (but not limited to): Alkalinity <400 μeq/L; a range in organic content; accessible by float plane (probably limiting lake area to at least 50 ha; smaller lakes requiring helicopter access were added in 2002); representative of all the physiographic sub-regions within the oil sands area (Birch Mountains, Caribou Mountains, Muskeg Mountain Uplands, Canadian shield); and low critical loads.

Because lakes in the Athabasca oil sands region were initially surveyed on the basis of their presumed acid sensitivity based on geology and topography it is presumed that the sub-set selected by RAMP for long-term monitoring is representative of the most sensitive lakes in the region. However, this physiographically-based presumption of sensitivity cannot be validated against the regional population because this population was not sampled at random. Nevertheless, the decade-plus data record available for these lakes provides an important record that supports trend analysis and hypothesis testing. In addition, two of the ASL lakes have been the subject of more intensive monitoring and assessment (Whitfield et al., 2010a), including application of the MAGIC model (Whitfield et al., 2010b), hydrological evaluation including groundwater fluxes, evaluation of peat land nutrient enrichment, and on-site deposition monitoring.

No survey data are available for sensitive terrain in NT north of the AB and SK boundaries.

3.4.4 Scope

3.4.4.1 Monitoring Domain

The combination of lake sensitivity and atmospheric deposition is expressed by the current critical load exceedances for lakes shown in **Figure 12**.

$$\text{“N-leaching Exceedance”} = \text{Total S Deposition} + NO_3 \text{ leached} - \text{Critical Load} \qquad (1)$$

Positive exceedances (warm-coloured grid squares in **Figure 12**) occur in a large block in north-western SK where even relatively low S deposition exceeds the extremely low aquatic critical loads prevalent in this area. Isolated grid squares with positive exceedances also occur in north-eastern AB, presumably reflecting more variable terrain sensitivity and perhaps localized higher deposition levels nearer emission sources. The monitoring domain is approximately defined by the red oval on **Figure 12**. Note that the domain extends into NT where presently, there is no critical load information.

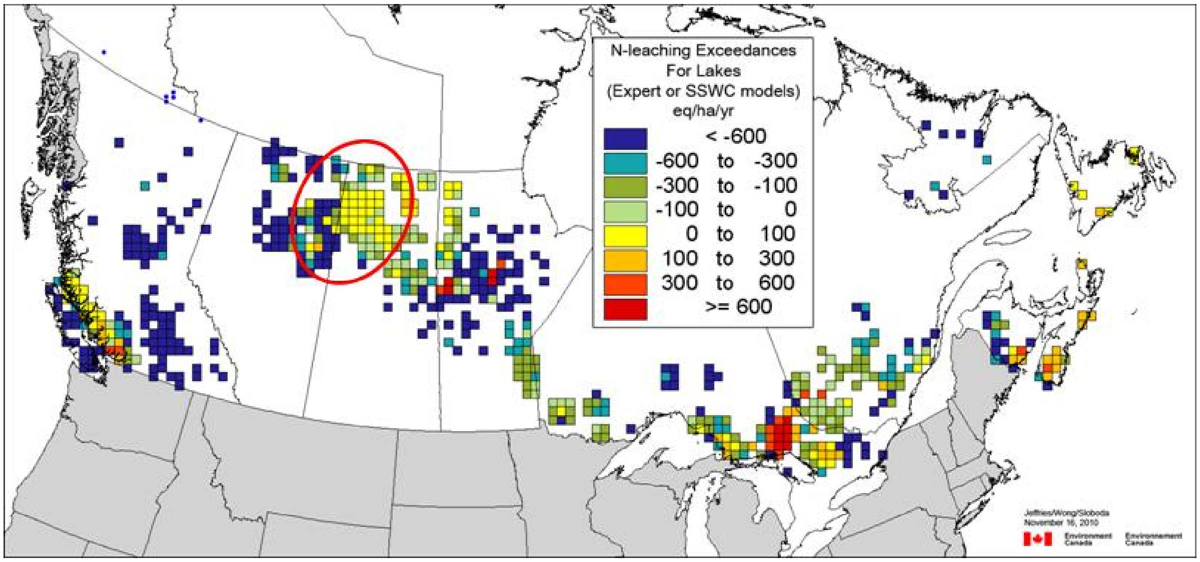


Figure 12. Location of aquatic critical load exceedances (eq/ha/yr) in western Canada determined using SSWC-derived critical loads and AURAMS 2002 deposition estimates (Jeffries et al. 2010). Exceedances were mapped using the 42 km AURAMS grid. Saskatchewan exceedances were determined for the lakes sampled by Jeffries et al. (2010) and Scott et al. (2010). Alberta exceedances were determined for the data set used by WRS (2004).

3.4.4.2 Lake Ecosystem Selection

The three data sets that can contribute lake data to this monitoring program were described above. **Table 7** provides information on the acidification sensitivity of sample populations for selected Blocks from the EC survey (labeled blocks in **Figure 11**), as well as the SK ENV survey and 2009 RAMP ASL data set. The results presented in **Table 7** show that there is considerable regional variability in lake sensitivity as expected. Blocks U, V, W, G and to a lesser extent H contain the highest proportions of sensitive lakes (i.e., those with base cations <100 µeq/L and alkalinity <50 µeq/L). Lakes within and surrounding these Blocks should be the focus for initial selection to the Level 2 monitoring network. The SK ENV lake population is less sensitive overall, but it will still provide candidates for the initial selection. Note that Blocks V, W, H and G are also the ones with the highest proportion of clear water lakes (DOC <4 mg/L). The RAMP ASL lake population is comparatively less sensitive than the EC and SK ENV populations and dominated by high organic acidity (largest proportion with DOC >10 mg/L). The decade-plus data record that already exists for the RAMP ASL lakes will make some of them attractive candidates for selection to the monitoring network, but others should be identified from the sample population of a new survey as recommended below.

Table 7: Percent of sampled lakes meeting specified threshold criteria for the sum of base cations (Ca+Mg+Na+K), Gran Alkalinity, pH and dissolved organic carbon (DOC). The threshold values for the first two variables are commonly used indicators of lake acid sensitivity while DOC is an indicator of natural organic acidity. "Block" refers to the sample populations associated with the sampling areas shown in **Figure 11**. "SK ENV" refers to lakes sampled in both 2007 and 2008. "ASL" refers to RAMP ASL lakes sampled in 2009.

Data set (n)	**Σ base cations (μeq/L)**		**Alkalinity (μeq/L)**		**pH**		**DOC (mg/L)**	
	<400	<100	<200	<50	<6	<5	<4	>10
Block T (66)	42	0	4	0	1	0	0	55
Block S (66)	62	0	33	1	0	0	2	60
Block U (40)	60	23	40	27	12	1	4	60
Block V (39)	98	41	98	43	26	5	33	20
Block W (35)	100	34	99	32	19	5	38	17
Block H (51)	96	7	73	19	9	1	17	34
Block G (67)	97	19	76	22	13	2	27	21
Block I (43)	71	0	52	4	4	0	2	32
Block J (46)	57	0	52	7	9	1	1	75
SK ENV (262)	85	10	70	12	2	0	29	18
2009 ASL (49)	49	1	52	17	19	4	0	96

The two statistically-based surveys in SK provide sufficient information from which to choose Level 2 (temporal) and possibly Level 3 (intensive) lake ecosystems for monitoring in the acid sensitive part of that province south of Lake Athabasca. Assuming that these existing survey lakes are affected only by long-range sources of acidity, selection criteria for Level 2 lake ecosystems should include:

- Have no or minimal development in their catchments.
- Cover a range in atmospheric acid deposition levels.
- Cover the range of lake sensitivity as reflected by base cation and alkalinity concentrations (specific conductivity may also be useful). Such chemical criteria should also reflect the range in catchment characteristics, i.e., geology, soils, recreational or agricultural land use (hopefully little or none), topography, hydrological setting, etc.
- Cover the range in organic acidity as reflected by DOC.
- Be first or second order lakes (lakes that are part of a larger flow-through system are not suitable candidates).

- Cover the range in lake and drainage basin sizes up to a maximum that is amenable for baseline characterization, say lake area ≤100 ha. Large lakes by their nature are less likely to be acid sensitive and less likely to respond in the short-term (decades) to acidic deposition.
- Cover the range in lake depths.
- Consider distance from the oil sands industry and transboundary issues, i.e. greater network density closer to the industry. This criterion will also help to reduce sampling costs and simplify logistics. Similar to the sampling strategy employed by Jeffries et al. (2010), lakes could be selected in blocks moving away from the oil sands industry.
- Likely to be in reasonable equilibrium with their catchments, e.g., not recently burnt.
- Have fish populations in at least the larger end of the lake size spectrum. Some fishless lakes are to be expected in the smaller end of the size spectrum.

Other advantageous but non-essential characteristics would include co-location with other AQ or WBEA monitoring activities and on-ground access. The ultimate goal of the selection process is to have a sufficiently large sample population that it reflects the variability present in the acid sensitive component of the lake population. The actual number of network lakes is yet to be determined, but similar temporal monitoring networks in Quebec and Atlantic Canada have 46 and 66 lakes respectively. Recalling that mass budget and catchment biogeochemical process determination will be a goal for the Level 3 (intensive) lake ecosystems, selection criteria should include:

- Be a suitable candidate for the Level 2 network.
- Have on-ground accessibility to minimize logistical costs and promote research co-location.
- Be as hydrologically simple as possible, i.e., not too big (lake area <50 ha, inflows and outflow suitable for gauging, a water-tight catchment, etc.
- Have reasonably uncomplicated bedrock and surficial geology, forest, etc.
- Have aquatic biota reflective of the populations observed in the Level 2 lakes.
- Be suitable for paleolimnological analyses.
- Have the potential for obtaining a "protected' status so that within-catchment anthropogenic activities (e.g., logging, mineral exploration, recreational fishing, etc.) are prevented in the long-term.

Other advantageous characteristics would be availability of power for instruments, field laboratory, etc., and reasonable proximity to a population center (housing for on-site personnel).

The situation in AB and NT differs from SK. While some of the RAMP ASL stations from four of the acid sensitive physiographic regions should be included in the Level 2 network to take advantage of their existing decade-plus data record, we do not know whether they represent the regional situation. Candidates from the Caribou Mountain ASL lakes have been consciously excluded from the Level 2 network because they are located outside of the study domain. Recent fire in the Caribou Regions also appears to have altered flow paths and base cation export through permafrost melting. Note, however, that impacts from fire are relatively frequent and extensive in this region and few catchments are unaffected, so fire cannot be a major criterion for exclusion from monitoring. Hence a statistically-based lake survey should be conducted in the blocks identified in **Figure 13** so that regionally representative candidates can be selected for the Level 2 network as per the criteria above. Representativeness of the ASL lakes can also be evaluated once the statistically-based survey is completed. When assigning boundaries to the Canadian Shield block in **Figure 13,** inclusion of a part of Wood Buffalo National Park was contemplated since monitoring stations within the Park would have the advantage of being protected from direct anthropogenic activity. However, we decided against including Park lands after evaluating their bedrock geology and considering the lake chemistry reported by Wiklund et al. (2010) which showed no evidence of acid sensitivity. Jeffries et al. (2010) provide the process for designing and conducting the lake surveys. Consideration should be given to possibly including one of the intensive ASL lakes shown in **Figure 11** in the Level 3 set of lakes.

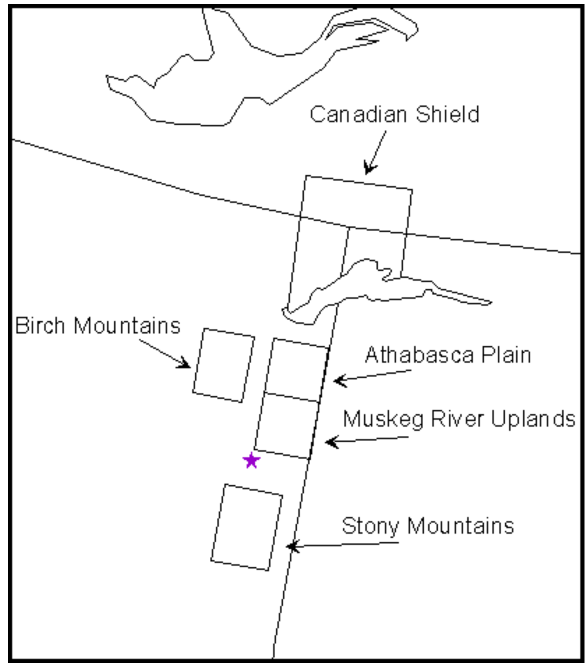


Figure 13. Location of proposed lake survey sampling blocks in AB and NT where either no data exist or regional representiveness of existing data is unknown.

Classification and selection of survey lakes for the Level 2 (temporal monitoring) network should include a number of “spares”, particularly in the monitoring domain that is further away from the oil sands industry. This would allow immediate inclusion of new network sites should increasing critical load exceedances trigger an expansion of the network density. Conversely, stability in acidification status for more than a decade may trigger a reduction in sampling frequency.

3.4.4.3 Choice Implications

The process of selecting Level 1 and Level 2 lakes so that they are representative of the regional population virtually ensures that they will only be accessible by air – most likely by helicopter unless the lake area is at least 50 ha. This means air charters will be by far the largest ongoing cost of the monitoring program. The need for frequent visitation to the Level 3 sites demands that they be ground accessible and that staff be dedicated to their day-to-day field program.

3.4.5 Lakes, Catchments and Baseline Determination

What to measure in this monitoring program is defined by the fundamental geochemical "insult" provided by acidic deposition. Simplistically, normal weathering is an acidifying process involving the slow dissolution of primary minerals by a weak acid (e.g., carbonic acid). The base cations liberated by this process are adsorbed onto soil particles (contributing to the soil's "base saturation") and/or leached into waters that have bicarbonate (or alkalinity) as the predominant anion. Introduction of the sulphurous or sulphuric acids (HSO_3 and H_2SO_4) present in acid rain modifies this process. The rate of primary weathering of the silicate minerals that predominate in the bedrock of acid sensitive terrain changes little due to kinetic limitations. However, soils are relatively quickly acidified as adsorbed cations are leached yielding waters that now have sulphate as an important anion. Hence, measurement of the major ion chemistry of waters is a prerequisite. This should include ammonium, nitrate and dissolved organic carbon so that other acidifying agents are covered as well. The nutrient status of lakes can affect their response to acid inputs so that total phosphorus and total nitrogen should be measured as well. Labile, inorganic, aluminum, silica and some metals (e.g., manganese) also provide information on acidification status and effects. Samples of certain isotopes of water or the ions dissolved in water will provide important hydrological or process information. Water samples for all of the above are easily collected during a brief site visit by helicopter occurring every decade (Level 1 lakes) or annually/seasonally (Level 2 lakes). The Level 3 sites should be sampled at least monthly, preferably more often during period of high water flux such as spring melt.

Monitoring soils and sediments should occur also. Their frequency of collection will be less than for water (see below). Monitoring of certain groups of organisms should be used to follow biological effects. Certain biota such as zooplankton can be collected during the brief visits to sample water, while others will require separate, longer and less frequent visits. Evaluation of aquatic biota across all trophic levels should occur at the Level 3 lake ecosystems.

It is important to establish the standard or reference point against which chemical or biological change is evaluated. One technique is the "reference condition approach" in which one or a group of "background" or unaffected sites are monitored, and change observed in the affected sites is evaluated against their responses. This approach is commonly used when monitoring ecosystems affected by a point or easily defined source. Acidic deposition is a diffuse pollutant that does not lend itself to this methodology however. Moreover, the large variability in chemical (and probably biological) characteristics present in the proposed Level 2 network would make impossible to select a group of background sites to represent their starting point. The scientific team therefore recommends that a thorough baseline characterization of the monitoring sites (as described below) be made at the beginning of the program to act as the reference point for each one. Later on, if some lakes are seen to acidify while other do not, the ecosystem properties quantified during the baseline characterization may be useful in providing explanations, particularly if the evaluation is performed in concert with observations taken and models developed at the Level 3 sites.

3.4.6 Modelling

The current and future impacts of acidic deposition (and lake acidification) will be assessed using the critical loads 'effects-based' approach. Critical loads, defined as the maximum deposition that will not cause ecosystem damage (citation), has been widely used to support the development and assessment of air pollution control strategies in Canada and the United Nations Economic for Europe (URL: icpmapping.org). The monitoring program will incorporate steady-state and dynamic (time-dependent) models providing both spatial and temporal assessments of the impacts of acidic deposition on a regional site-specific catchment scale.

Steady-state models, such as the Steady-State Water Chemistry (SSWC) model, the First-order Acidity Balance (FAB) model and the Integrated Assessment Model (citations), will underpin wide-scale regional assessments of lake acidification. In general, Steady-state models require water chemistry and hydrology as inputs; as such, they have been widely used in regional critical load assessments across Europe, North America and Asia owing to their modest data requirements. Accordingly, steady-state models will be applied to all (statistical: Level 1 and 2) lake surveys to identify regions or catchment 'hot spots' that require more sophisticated (time-dependent) dynamic modelling.

Lake catchments are not in equilibrium with present acidic depositions, since there are 'buffer mechanisms', which delay equilibrium (or steady state) for years, decades or even centuries. Dynamic soil-acidification models attempt to estimate the time required for a new (steady) state to be achieved or more importantly, to evaluate the future (chemical) response of soils and surface waters to changes in acidic deposition. Several dynamic (hydro-chemical) models, such as Model of Acidification of Groundwater in Catchments (MAGIC: Cosby et al., 1985, 2001), Soil Acidification in Forest Ecosystems (SAFE: Warfvinge et al., 1993) and Simulation Model of Acidification's Regional Trends (SMART: De Vries et al., 1989), have been extensively applied at site-specific and regional scales to predict changes in soil and surface water chemistry (e.g., De Vries et al., 1994; Alveteg et al., 1995; Aherne et al., 2003; Wright et al., 2005). Several of these models have been included in model evaluation and comparison studies (Tominaga et al., 2010, Forsius et al., 1998). In addition to water chemistry, dynamic models typically require information on soil chemistry, climate, soil percolation, and forest uptake (see Aherne et al., 2008 for detailed description of regional inputs). The application of dynamic acidification models will be confined to the Level 2 and 3 sites (or sites with available soil information), in addition to 'hot spots' delineated though steady-state models. The monitoring plan will integrate surface water, catchment soil and atmospheric deposition monitoring programs using process-oriented dynamic acidification modelling to evaluate the future (chemical) response of soils and surface waters to changes in acidic deposition.

The determination of exceedance of critical loads is strongly dependant on the availability of mapped fields (or estimates) of total sulphur, nitrogen and base cation deposition. In addition, dynamic modelling requires historic (pre-acidification) and future time-series of acidic deposition. It is anticipated that these data will be provided through the Air Monitoring Plan.

3.4.7 Lake Catchment Monitoring Components

Due to remoteness of most lakes in the target region, sampling from rotary or fixed wing aircraft will be necessary. Typically, physical-chemical measures should be achievable during a relatively brief visit (usually < 10 minutes) for cost effectiveness, while meeting crew safety at all times. The level of information that can be collected is constrained by: (1) time allocated per lake – this is fundamental if a set number of lakes need to be sampled within a fixed sampling budget or time window; (2) the stability of the sampling platform with respect to horizontal movement and degree of wave/wind action; (3) space and weight capacity available for sample accrual, and to manage cables for ease of deployment and retrieval, any winches and booms, and data loggers, etc.; (4) whether the technician is restrained in the seat while sampling.

For lakes with sufficient depth to form a seasonal thermocline, sampling during the spring or late fall mixing periods is preferred to take advantage of the vertical homogeneity in lake water chemistry (fall is preferable for zooplankton sampling). However, since monitoring periodicity tends to be fixed (for temporal consistency), lakes may be encountered that are at different stages of the thermal cycle in different years. The representativeness of a single chemical sample on the basis of assumed vertical homogeneity may vary more in stratifying lakes. However, this variation may be acceptable in terms of time and cost constraints imposed by the aircraft. It is therefore proposed that a single discrete sample of lake water be collected from the initial lake survey and that spatial and temporal variability in the chemistry of the lake water column be documented during baseline determination and at the intensively-monitored sites.

3.4.7.1 Lake Physical Measurements

Appropriate in-situ physical and chemical measures for the Level 2 monitoring network include GPS sampling coordinates, water depth, snow and ice depth if winter sampling, water and air temperature, Secchi disc depth, colour, dissolved oxygen and conductivity. At any monitoring site, deployment of dataloggers (e.g., simple submersible pressure-logger options, +1 year) should be considered to track lake water level (and temperature). While this is not required for low-intensity monitoring, such data may complement time-series hydrology measures based on isotope mass-balance, and some facet of flow or lake elevation measurements at intensively monitored sites. Field observations should include weather conditions, and the characteristics of the lake basin, e.g., lake and watershed vegetation, presence of roads, buildings, beaver dams, logging activities, forest fires, etc. or any other characteristic that may have changed since baseline determination.

3.4.7.2 Lake Chemistry

For Level 2 lakes, the acid deposition and lake-catchment chemical response variables to monitor are: pH, calcium, magnesium, sodium, potassium, Gran alkalinity, sulphate and chloride as well as nitrate, ammonium, DOC, aluminum, manganese, iron, zinc and conductivity, and possibly mercury. This suite of variables permits calculation of electrochemical charge balances and other QA/QC variables. Macro-nutrients including total and total filtered phosphorus and nitrogen, should also be monitored as ecosystem state variables. Monitoring labile aluminum fractions may be relevant, particularly in lakes with pH <6. Surface sediment sampling (e.g., organic content, nutrients and metals, algal pigments, and possibly hydrocarbons) may be infrequently collected. In summary, as the Level 2 monitoring network is defined, the sampling protocols should be tailored based on lake depth and time of year that sampling will occur - accuracy, consistency and standardization being the paramount goal. A trigger may cause a shift in sampling strategy for a particular lake. Implementation of sampling and processing QA/QC requirements for the program should follow a common set of protocols, adapted specifically for rotary or fixed wing collection platforms.

3.4.7.3 Lake Biology

Anticipated inputs from lake water chemistry monitoring are chemical and physical data that are representative of the status and trends in the population of lakes within the monitoring domain. Base cations, alkalinity, DOC and aluminum will be the primary focus of water chemistry interpretations with respect to lake sensitivity and response to acidifying deposition. Although pH is the focus of much of the acid rain literature, the proposed biological monitoring and research should also seek to associate biological responses to this broader and more geochemically meaningful interpretation of lake response. Efforts should also be made to ensure that results and samples from the biological monitoring and research activities are useful to other studies (e.g. geochemical-biological modelling, economic valuation, mercury).

The proposed program assumes that the goal of monitoring is to contribute to informed policy and the selection of monitored biota should be guided by the degree to which the resulting samples will address policy needs. Concern about pollution effects on the biology of lakes tends to relate to one of three partly inter-related themes: biota that are of particular interest to humans, the maintenance of biological diversity, and the health of biota and what that indicates about lake health. The approach to designing the proposed biological monitoring program is intended to contribute to regulations and policies by addressing these themes. The ecological functioning of lakes is used here as a means of inferring ecosystem health and as a method for organizing monitoring elements. It is expected that biological samples will be drawn in a manner that ensures the resulting information is representative of the population of lakes in the monitoring domain. The approach outlined here assumes that monitoring will be conducted at each of the three levels of intensity.

The impacts of acidification and related stressors on iconic species or those of social or economic importance can help indicate, and communicate, progress on pollution control. Impacts to sport fish populations in parts of eastern Canada and northeastern U.S., for example, helped galvanize concern about the acid rain issue in the early 1980s. Although the primary motivation may be due to their human economic, subsistance and recreational importance, loss of sport fish may also have important implications for lake biodiversity and ecological function. Although ecosystems may be more resilient to the loss of other charismatic species, its value to society and First Nations may be such that monitoring ecosystem responses is desirable to represent the full consequences of pollution and control efforts.

Through the loss of sensitive species, acidification and related chemical and biological changes affect biological diversity by altering the composition of biological communities. Although loss of species is undesirable from an inherent value perspective, removal of certain species can also lead to ecosystem impacts such as a decreased resistance to invasive species, altered algal productivity, or impaired food web support.
Acidification stress, through complex effects on survival, growth and reproduction, can alter many aspects of biological assemblages. Many of these effects can have important consequences for the ecological functioning of lakes. The selection of biota that allow strong inference about ecosystem function is often made more difficult because these consequences are frequently indirect and mediated through several species. Monitoring that is focused on sampling biota with known strong relationships to one or several ecosystem functions will be necessary to efficiently make biological inferences about lake health. Research will be required to inform and adjust monitoring, explore and generate mechanistic hypotheses, and to support predictive modelling.

Where to monitor**:** The sampling universe is defined as all those lakes within the monitoring domain that have been sampled for water chemistry. Ideally, all lakes sampled as part of Level 1 surveys should be sampled or surveyed for aquatic biota. Level 2 lakes for biology work should be drawn in a probabilistic manner and include sufficient numbers of sites to ensure the subsets remain representative of the sampling universe. Selection criteria should include inferred fish presence (determined through paleolimnology methods) as strata in the selection procedure. The resulting set of sites may be augmented by sites of particular interest (e.g. overlap with Level 3 lakes). Simulations, using existing data, should be used to quantitatively determine the expected information gain (i.e. accuracy, precision) obtained under various scenarios that include the number of sampled lakes and the number of sample sites per lake. The final design should strive to minimize the risk of type II errors, i.e., failing to recognize a change that has occurred. In addition, early warning indicators which the zooplankton can provide should be distinguished from compliance indicators provided by long-lived fish species.

When to sample**:** The frequency of sampling should recognize the reporting cycle timing and the desired level of certainty for status and trend estimates but must also relate to the temporal scale of the biota and measurements selected. Although the seasonal timing of sampling should be as consistent as possible, phenological variation among years should be assumed. To the extent possible, biological inferences should be based on species and life history stages that are most informative but are also relatively stable with respect to this variation. Indices of phenological variation (e.g. estimates of spring arrival dates) should also be collected during sampling and be incorporated as covariates in trend and other analyses.

***What to sample*:** the biota proposed here for monitoring are summarized in **Table 8**. Assuming that inference at the scale of the entire lake is desired, careful consideration should be given with respect to distribution of sample locations with respect to water depth and habitat/substrate types. Research projects and existing data should be used in simulations to help define the optimal number and location of sample sites within lakes.

Table 8 : Proposed entities for biological monitoring related to the themes mentioned above

Interpretation	Sampled entities	Measurements	Advantages	Disadvantages	Comments	Design notes
Function: Broad-scale estimates of lakes with and without fish	Chaoborus midge remains	Number and species composition of Chaoborus mandibles in top layer of surface sediments	Helicopter-based, rapid sampling of surface cores of sediments	Inferences to composition of fish assemblages not currently possible	Ekman dredge and sampling tube deployed from helicopter on floats.	Conducted at all Level 1 lakes. Results will help inform design of more intensive sampling conducted at subsets of lakes so should be part of initial baseline surveys.
Biodiversity: Zooplankton species at risk. Function: Grazers on primary production; Food web support to higher trophic levels.	Zooplankton	Number and species composition per unit area sampled	Species-rich and responsive to water chemistry. Helicopter-based, rapid sampling using vertical net haul	Abundance and composition of some groups are temporally variable.	Vertical net haul with flow meter??	Conducted at all Level 1 lakes. Could be part of baseline sampling but should also occur annually or semi-annually to provide trend estimates.
Biodiversity: Fish species and populations at risk. Function: Predators on lower trophic levels and food web support to piscivores.	Cyprinids and other small fish	Number and species composition per unit effort (trap hours) in baited minnow traps	Physiological response to water chemistry. Relatively easy trap deployment and retrieval.	Not all fish are well sampled; Requires return to lake	Deployed by invertebrate sampling crew, retrieved by brief helicopter visit following day.	Subset of lakes drawn from those Level 2 lakes identified as having fish by baseline paleo work. Results could help develop paleo-based indices that estimate composition of fish assemblages.
Biodiversity: Macroinvertebrate species at risk. Function: Grazers, decomposers, predators, and food web support to higher trophic levels.	Nektonic and benthic macroinvertebrates	Number and species composition per unit effort or sample quantity	Species-rich, responsive to water chemistry.	Also responsive to fish and macroinvetrate predators. Requires ~2hr on-lake visit by sampling crew. Some species, life history stages are temporally variable.	Sampling crew, inflatable and gear dropped at lake by helicopter, left for 2h, relocated to next target lake. Other on-lake sampling could be incorporated if necessary.	All lakes monitored for cyprinids and other fish plus approximately equal number of randomly selected lakes drawn from fishless lakes (per broad-scale Chaoborus baseline).
Iconic: Occurrence and health of sport fish populations	Subsistence sport fish	Species composition, age/size class	Valued by First Nations and sport fishers.	Cost	Could be integrated with mercury assessment.	Subset of lakes estimated by baseline paleo work to have fish, augmented by work in selected sport fish lakes

3.4.7.4 Lake Hydrology

The long-term monitoring plan for acid lake ecosystems needs to include an assessment of the hydrological balance of each lake. Estimates of runoff (water yield, W_y) are required for steady state water chemical models (SSWC) and the Freshwater Acidity Balance (FAB), and more general information on sources and magnitude of water and solute fluxes to lakes is expected to support understanding of geochemical cycling. Remoteness and lack of gaugeable streams in the region make application of traditional hydrological methods impractical for most lakes. However, the objectives of this survey could largely be met using tracer-based techniques supported by hydrometric monitoring at Level 3 sites.

Isotope mass balance (IMB) using stable isotopes of hydrogen and oxygen (^{18}O, ^{2}H) has previously been applied for estimating lake-specific W_Y and its variability across the region (e.g. Gibson et al. 2010ab, Bennett et al. 2008). IMB utilizes evaporative heavy isotope enrichment in lakes compared to background in precipitation to estimate flushing rates for each lake (evaporation/inflow or E/I). Interpolated precipitation and lake evaporation rates are then used along with E/I to estimate the volume of inflow derived from lateral runoff, which is then converted to a depth-equivalent runoff over catchment area. Given information on lake volume, IMB can also help to constrain residence times, which are important for evaluating temporal processes and time-to-effects (Gibson et al., 2002). Important assumptions and justification for use of IMB in regional surveys has been discussed elsewhere (Gibson et al., 2002, 2010ab). As IMB is a first-order approximation, caution should be used when interpreting results for individual lakes. Nevertheless, constraining W_y using IMB is informative as it is the watershed hydrological process most directly linked to export of dissolved/suspended loads and, therefore is important in buffering lake chemistry and acidification potential. W_Y estimates based on IMB are also suitable for incorporation into SSWC or other models (Jeffries et al., 2010; Scott et al., 2010).

For western Canada, assessments using IMB (e.g. Gibson et al., 2010ab; Jeffries et al., 2010, Scott et al., 2010) have typically shown a higher degree of hydrological variability than predicted by climatic interpolation methods, revealing in many surveys a population of lakes that are weakly connected to the landscape, and therefore inherently poorly buffered from acid deposition. W_Y is strongly correlated to landscape units in the AOSR (e.g. uplands, fens, bogs, permafrost bogs) as the proportion of these units is a key determinant of the local runoff regime and hence lake balance. Detailed land cover surveys including differentiation of wetland classes are therefore recommended. The monitoring network should also include a subset of reference lakes ideally with automated micro-meteorological stations, and where possible, with water levels tied to local datum so that inter-annual volumetric changes can be tracked. Seasonal process studies would also be informative, although this might be done in selected ecosystems to reduce cost.

Routine geochemical parameters combined with tracers like radon-222 might be applied to assess groundwater/surface-water interactions for individual lakes (e.g., Schmidt et al., 2010). In general, the majority of shallow boreal lakes in the AOSR are only weakly connected to deep groundwater flow systems, but this influence increases considerably in areas near incised or buried channels. The presence of aquitards like shales or bitumen-saturated units also influences the magnitude of groundwater/surface exchange.

3.4.7.5 Catchment Soils

Lake catchment land-cover is typically dominated by terrestrial (soil) ecosystems; as such, soils control the response of lakes to acidic deposition. However, there is a paucity of soil data for northern Saskatchewan. The soil monitoring component is designed to address two strategic objectives in relation acidic deposition: to assess the sensitivity of soils to acidic deposition, and changes in their chemical status over time using large-scale surveys and long-term plots. The large-scale survey will focus on one-time soil sampling at the Level 2 sites, with the purpose to assess basic information on the chemical soil status and secondly to assess soil properties which determine the catchment soils sensitivity to acidic deposition. The long-term monitoring plots will be established at the Level 3 sites and at a sub-set of Level 2 sites to monitor changes in soil chemistry over time (e.g., changes in soil pH, exchangeable base cations (Falkengren-Grerup, 1987)), with a sampling frequency of five to ten years. In addition, long-term vegetation plots should be established in conjunction with the long-term soil plots to assess changes in vegetation associated with nutrient deposition. Both soil surveys will provide essential inputs for process-oriented dynamic acidification models.

A minimum of five sampling pits representative of the dominant soil type within each catchment will be selected for sampling (dependent on soil variability across the catchment). At each pit, five sub-samples will be collected (and composited) by horizon or fixed depth for analysis. The sampling protocols will follow well established methods, e.g., International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests operating under the UNECE Convention on Long-range Transboundary Air Pollution (URL: www.icp-forests.org). A core set of physical and chemical analysis will be carried out on all soil samples, e.g., bulk density, particle size, pH, loss-on-ignition, exchangeable base cations, etc. In addition, soil mineralogy and surface area will be measured at a sub-set of the sites for the assessment of soil chemical weathering using soil geochemical models, such a PROFILE (Warfvinge and Sverdrup, 1992). The long-term response of soil to acidic deposition and their critical load is strongly dependent on the soil base cation weathering rates (Warfvinge and Sverdrup, 1992).

The plan will establish a soil archive for the storage of samples from the long-term plots (using air-tight containers without preservative under normal room conditions with minimal temperature and humidity fluctuations, shielded from incident light). The samples will be stored at least until the next soil inventory.

The role of wetland soils in sequestering sulphur and nitrogen will also be a critical area for inquiry, especially given the aerial extent of wetlands in the monitoring domain. Wetland soils tend to sequester nitrate and sulphate by the oxidation of organic matter and subsequent production of metal sulphides or elemental nitrogen. These processes may mitigate the effects of acid deposition in wetland catchments by serving as net sinks for acid forming constituents. Conversely, the emission of ammonia and organic and inorganic sulphides from wetland soils, particularly under hydrologically driven variation in the depth of the active layer (acrotelm), may also extend the potential area of influence of anthropogenic emissions.

3.4.7.6 Catchment Forest

Critical loads of acidity may also be estimated for terrestrial ecosystems, such as forests. Mapping assessments show low critical loads of acidity for forest soils in northern Saskatchewan in concert with low critical loads for surface waters (Aherne et al., 2011). Critical loads of acidity for forest ecosystems will be estimated at all Level 2 sites with soil information incorporating supplemental data on forest biomass stocks. The determination of exceedance of critical loads is strongly dependant on the availability of mapped fields (or estimates) of total sulphur, nitrogen and base cation deposition. These data will be provided by the Air Quality Monitoring component.

As previously noted, one of the Oil Sands Advisory Panel's observations was "... little coordination among WBEA, CEMA and RAMP monitoring" (Federal Oil Sands Advisory Panel, 2010). Acidification is a multi-pollutant problem as sulphate, nitrate as well as ammonium are known to contribute to ecosystem acidification. In eastern Canada, due to relatively higher amounts of precipitation, acidifying compounds are predominantly deposited in a soluble form. In comparison, long term average precipitation amounts in northern AB and SK are very low, and deposition of acidifying substances downwind of the mining, upgrading and in situ processes is estimated to occur ~50% in the dry mode (Davies, 2010). Thus, dry deposition measurement should have a high priority during monitoring to assess aquatic effects, and calculate critical loads.

Critical loads have been derived for aquatic ecosystems based upon lake chemistry, and chemical/physical characteristics of the surrounding forested catchment to which there can be surface flow and hydrologic linkages. With dry deposition as the primary vector for acidifying compounds to lakes in the proposed network, forest canopy interception will have a more important role in understanding processes, determining cause-effect linkage for aquatic effects, and validating dynamic model performance. For instance, one secondary product from emissions can be ozone (O_3), whose concentrations have been shown through passive monitoring in the remote boreal forest to be higher with increasing distance from source. Ozone at certain doses (concentration x time) can not only alter plant physiology, but has been linked in the field to changed water relations causing altered stream hydrologic flow (McLaughlin et al., 2007a,b).

Critical load calculations to date have relied largely on steady-state modelling that has the advantage of being relatively simple, with limited data requirements (Driscoll et al., 2010). Ecosystems require application of dynamic models (e.g., MAGIC) to improve critical load calculation, quantify effects, and predict change under emission control strategies. Process level knowledge of forest ecosystems, soils, and lake chemistry linkage has been greatly enhanced since the advent of watershed-scale experiments such as those conducted at

Hubbard Brook, (new Hampshire), Dorset, Turkey Lakes and the Experimental Lakes Area (Ontario). Key to the success of these projects, has been air, terrestrial, and aquatic linkage developed through a coordinated, science based approach. An extensive retrospective review (McLaughlin and Percy, 1999) on the roles of air pollution and climate change on North American forests concluded that increased understanding and measurement of essential processes as well as their linkage was critical to inform policy.

This plan recommends establishment of a small number of intensive monitoring-research (Level 3) sites where the cause of observed changes can be explored and explained. The forest canopy intercepts acidifying substances along with other compounds to which it is exposed. Dynamic models (i.e., MAGIC) include, among other parameters, atmospheric deposition, nitrification, denitrification, mineralisation, uptake by plants, immobilization into soil organic matter and export in discharge water. To address the goals outlined for Level 3 monitoring, measurement of air quality, above- (tree canopy, understory), below-ground (organic, mineral soils), biomass in standing forest, nutrient cycling, etc., hydrology, and lake chemistry should be co-measured in time and space at a sufficient number of appropriate sites in order to understand potential aquatic effects, trends and evaluate/improve dynamic models used for the assessment of acidification.

Instrumented, solar-powered forest towers equipped with above and within canopy continuous meteorology sensors, and co-situated (<100 m) open-fetch sensors will be required to monitor inter-annual trends in climate. Continuous and passive techniques will be used to measure deposition inputs. Co-location of continuous and time-integrated (passive) measurement techniques will allow not only analysis of uncertainty in passive data, but also placement of less expensive, passive installations at a number of Level 2 lake sites. The use of stable isotope techniques to trace emissions and help discriminate source is recommended. Above-ground parameters to be measured intensively should include at least input variables required to drive dynamic models, along with others (i.e. stable isotopes) already in use to understand and apportion source type contribution. Sensitive, robust, regionally-representative, and resilient indicators of change are already verified and in use in an extensive forest health monitoring program (WBEA) that includes over 30 plots accessed by helicopter in the Athabasca Oil Sands region, including several plots into Saskatchewan. Eight plots are being instrumented with 30 m solar-powered, sensor equipped towers, along with active and passive measurements for tree condition, soil parameters. It is recommended that consideration be given during the planning cycle for co-location of these air, forest, and soil measurements with hydrological and lake measurements at one site in Alberta and one in north-western Saskatchewan.

3.4.8 Sampling Site Baseline Characterization

3.4.8.1 Lake and Catchment Characteristics

Characteristics that should be quantified include:

- Lake morphometry to establish standard physical characteristics such as lake volume, mean and maximum depth (the latter being the most appropriate long-term sampling point), and confirm lake area and shoreline length obtained from maps during the lake selection process.
- Catchment topography and drainage network/patterns.
- Wetland occurrence and type.
- Bedrock and surficial geology including estimates of soil depth.
- Soil chemistry through a within-catchment survey.
- Forest type, structure and condition.
- Lake profile chemistry (at least top and bottom) collected during each season minimum.
- A census of aquatic biota (population structures at all trophic levels).

In addition to the above, there should be a visual evaluation of shoreline character, emergent macrophytes, evidence of fire, land-use changes, etc. during the first helicopter visit, and periodically during subsequent visits.

3.4.8.2 Paleolimnology

One of the biggest challenges faced by environmental scientists is the lack of long-term monitoring data. Without such data, it is difficult to determine pre-impact conditions, the trajectories of environmental change, and to distinguish between natural and human-induced ecosystem changes. Fortunately, sediments archive a large suite of physical, chemical and biological indicators that can be used to track past changes in limnological conditions as well past aerial deposition of contaminants in lakes. Paleolimnological approaches are now routinely used to assess a wide spectrum of environmental issues (Smol 2008), and the applications of these approaches are especially amenable to the challenges faced in the oil sands region where direct monitoring data are not available.

Lakes (and the biota they support) in the oil sands region are potentially being affected by wide spectrum of environmental stressors related to the oil sands, as well as other changes that are more global in nature (e.g., climatic change). Paleolimnological approaches, as noted below, can be used to disentangle the effects of these multiple stressors.

Although deeper lakes often preserve sediment profiles that offer higher temporal resolution (i.e., are less likely to be mixed), sediment cores from shallower lakes have now been shown to also archive sedimentary records that are of sufficient temporal integrity to be of considerable value to lake managers (Smol 2008). Hence, in general, the same procedures can be applied to deep and shallow lakes. Protocols for sampling sediments from both deep and shallow lakes are now well established and largely standardized in the international paleolimnological community, as are the methodologies for dating sediment cores, and then studying and interpreting the myriad of physical, chemical and biological proxies contained in sediments (Last and Smol 2001a,b; Smol et al., 2001a,b).

3.4.8.2.1 Sampling Network Design

Regional assessments of environmental change: Detailed, high-resolution paleolimnological studies can be time consuming. Therefore, high-resolution studies are typically not an option for studies where a large number of sites are being sampled. For regional assessments that require a large number of sampling sites, paleolimnologists have developed the so-called "top-bottom paleolimnological approaches" whereby only two samples per core (i.e., the surface sediments = the "top" sample, and then sediments that were deposited before human impacts = the "bottom" sample) are analysed when a large number of lakes must be studied. This type of study was conducted on 40 of the RAMP acid sensitive lakes (Curtis et al 2008). High-resolution gravity cores (see Glew et al., 2001) are taken and extruded (Glew 1988) using the same protocols developed for detailed paleolimnological studies (see below). The major advantage of this "before and after" type of paleolimnological assessment is that a large number of lakes can be analysed. The major disadvantage of this approach is that only two samples (time slices) per lake are analyzed, and so no information is available on the timing and trajectories of changes. For such studies, detailed paleolimnological studies are required.

High-resolution assessments of environmental change: For lakes that will be chosen for detailed study, high-resolution sediment cores should be taken and extruded at close intervals (e.g. 0.5 cm or less), dated using 210Pb geochronology, and the sediment samples analysed for proxy indicators to reconstruct the temporal trajectories of past environmental change.

In the context of the proposed program, the top-bottom approach will be applied to level 1 lakes (to the extent that the survey is repeated) and the high resolution approach will be applied to the level 2 lakes. This use of the top-bottom approach on level 1 survey lakes offers the additional potential for compilation of a validation set against which existing calibration models can be assessed.

3.4.8.2.2 Proxy Indicators

A wide spectrum of physical, chemical, and biological indicators is available for paleolimnological assessments (Smol 2008). The most commonly used approaches for reconstructing past lakewater pH trends are from the analysis of fossil diatom assemblages in lake sediments. These proxy indicators often form the mainstay of many paleolimnological studies. Powerful transfer functions are available linking the species composition of diatom assemblages to lakewater pH, as well as nutrient levels and climate-related variables (Smol and Stoermer, 2010). A transfer function has been developed from sediments collected from lakes in northeastern Alberta (Curtis et al., 2008) although it may be necessary to use or develop a different transfer function for lakes located on the Canadian Shield. Validation of the available inference models will be necessary. Fossil chrysophyte scales can be used in a similar manner. Other biological indicators that would be highly relevant to these studies include cladoceran fossils, which can be used to track a variety of limnological variables, including declining calcium levels (Jeziorski et al., 2008), which was recently identified as important indicators.

Past changes in fish populations remains an important challenge to paleolimnologists, because fish fossils are generally rare. However, by studying the fossil distribution of *Chaoborus* mandibles, fishless conditions can often be inferred by the presence of C. *americanus* (Sweetman and Smol, 2006). Chironomid headcapsules represents another indicator group frequently used in paleolimnological studies, which are especially known for their paleoclimatic potential.

Whilst the above indicators track changes in lake biota, and indirectly past limnological conditions, the potential stressors to lake environments can also be directly studied in lake sediments using a variety of geochemical and isotope approaches (see approaches described in Last and Smol 2001b). For example, reliable methods are available to track past aerial deposition of PAHs, other persistent organic compounds, metals, mercury, black carbon, as well as many other contaminants.

3.4.8.3 Isotope Geochemistry

Tracers useful for constraining sources of nutrients in lake water include $\delta^{34}S$ and $\delta^{18}O$ in dissolved SO_4, which can help to distinguish between major sulfur sources in the AOSR including atmospheric deposition, weathering of pyrite in shale, and seepage of groundwater containing dissolved evaporites (Gibson et al., 2011, p. 38). The isotopes of nitrogen (^{15}N and ^{18}O in nitrate, ^{15}N in NH_4) and carbon (^{13}C) can also be potentially informative for analysis of deposition sources, food web structure, energy flows, buffering capacity, and bioaccumulation of toxins. Analysis of nitrogen, carbon, and oxygen isotope records in lake sediment also allow for study of historical changes.

3.4.9 Summary

Atmospheric emissions of acidifying pollutants (most importantly SOx but also NOx) from oil sands industry in AB have been increasing, as has the associated regional acidic deposition. Terrain in the immediate oil sands region exhibits variable acid sensitivity that is complexly distributed across the landscape. In contrast, acid sensitive terrain occurs fairly uniformly throughout the boreal Shield of northern SK into NT, and very sensitive lake ecosystems have been identified in north-western SK downwind of the oil sands emissions. The coincidence of elevated or increasing deposition levels and acid sensitive receptors is prescriptive for an acid rain “region of concern” where monitoring should occur to determine aquatic ecosystem health and detect any changes that happen. The monitoring domain considered here was defined by present occurrences of aquatic critical load exceedances (north-western SK and north-eastern AB) and geologically sensitive terrain where no aquatic critical load information exists (NT just north of the AB-SK boundaries.

The Federal Oil Sands Advisory Panel identified areas where additional monitoring and research is needed, including assessment of interactions between aerial (e.g., acidic) deposition, water quality and ecosystem impacts. Oil sands-related acidification monitoring in Alberta is presently conducted by RAMP through its Acid Sensitive Lakes (ASL) program (RAMP 2010), and in Saskatchewan by intensive lake survey programs initiated independently by the Government of Saskatchewan (Scott et al., 2010) and by Environment Canada (Jeffries et al., 2010). Acid deposition effects monitoring has not yet been conducted in the Northwest Territories in relation to emissions from the Athabasca Oil sands. Given that all three existing monitoring programs reflect concerns related to impacts associated with a common deposition domain, there is a need to assure coordination of monitoring design and assessment methodology across the shared boundaries of Alberta, Saskatchewan and Northwest Territories. Coordination will assure comparability of monitoring endpoints and exceedance calculations. This plan presents such a coordinated design.

Oil sands-related acidification monitoring is presently conducted by RAMP in AB through its Acid Sensitive Lakes (ASL) program. Recent reviews (e.g., by the Federal Oil Sands Advisory Panel) have been critical of the program's design and performance, in particular noting that present monitoring has been unable to distinguish oil sands impacts from impacts by other stressors, and there is a need for "more rigorous acid deposition quantification including transboundary deposition in Saskatchewan". The plan presented here addresses these shortcomings.

The monitoring component presented here is guided by over 30 years of similar activity in eastern Canada, the U.S.A and Europe. Scientists already recognized the potential threat that oil sands emissions hold for downwind aquatic ecosystems when they conducted statistically-based lake surveys in northern SK in 2007 through 2009 to establish current acidification status and lake population sensitivity. The information obtained during the surveys is a foundation for the monitoring plan developed here.

The objectives of component's development are (a) to establish a monitoring network of representative lake ecosystems in acid sensitive regions of SK, AB and NWT that are (potentially) influenced by SO_x and NO_x emissions from oil sands industry; (b) recommend determination of current or "baseline" conditions; (c) devise a sampling plan sufficient to detect chemical and biological changes from baseline condition and predict future potential changes; and (d) recommend a small number of intensive monitoring-research sites where the cause of observed changes can be explored and explained.

The monitoring design recommended here is a multi-level hierarchy composed of occasionally repeated, statistically-based (stratified-random) regional surveys of hundreds of lakes (Level 1), integrated with a temporal network of tens of lake sampled annually or seasonally (Level 2), plus two or three sites for intensive, mass budget monitoring and research (Level 3). This monitoring hierarchy will provide all the information needed to accurately estimate resource-level acidification status, detect change, identify the causes of change, and predict future conditions. This component recognizes that a lake cannot be divorced from its terrestrial drainage basin; the entire lake ecosystem must be considered when specifying monitoring activities.

Given that statistically representative (Level 1) physical and chemical data already exist for 715 lakes from north-western SK, the Level 2 temporal monitoring network for this area can be immediately selected from this survey population using a specified set of criteria, e.g., coverage of the observed range in (a) sensitivity (as reflected in base cation and alkalinity concentrations), (b) natural organic acidity (reflected in dissolved organic carbon concentrations), (c) lake depth, (d) lake and drainage basin area, etc. The random nature of the selection process for survey lakes virtually guarantees that they (and the Level 2 candidates selected from them) will be remote, only affected by atmospheric deposition, and requiring air access (generally by helicopter) for sampling.

The 50 RAMP ASL lakes were not selected from a stratified random sample. Because the domain for the regional surveys from which the RAMP lakes were selected is heterogeneous with respect to acid sensitivity, selection of the ASL subset of lakes was intentionally biased towards only those presumed to be most sensitive based on geology and topography. This selection approach differs from that used in SK and presupposes that the initial presumptions regarding acid sensitivity were correct – a presumption that can only be verified using a stratified random approach. Hence, a statistically-based survey of lake chemistry similar to that available in SK should be conducted in five identified blocks of acid sensitive terrain in north-east AB that includes the Canadian Shield north into NT (where there are no data at all). Once this Level 1 component of the monitoring hierarchy is established for AB and a small part of NT, the Level 2 temporal network can be selected as above. Since the RAMP ASL lakes do have the advantage of an existing decade-plus data record, it will be wise to include some of them in the revised Level 2 network in AB when it is established.

The small number of Level 3 lakes will be selected with logistical considerations in mind. The intensive monitoring and research to be conducted at these sites demands that they be ground accessible to minimize operational costs. They will most likely be located in west-central SK where the most sensitive terrain has been identified already; although one of the two intensively studied RAMP ASL lakes may also be a candidate for Level 3 status because of the wealth of information that already exists.

The reference condition approach to monitoring was rejected by the scientific team because variability is too high across the monitoring domain in both terrain sensitivity and the influence of other stressors. Rather, gradients in chemical and biological conditions across the domain were identified and lakes within this range were selected to reflect the gradients. A thorough baseline characterization (physical, geological, hydrological, chemical, and biological) is recommended for each monitored lake and its catchment to define the point-in-time condition against which future change is evaluated and other monitoring triggers are activated. Paleolimnological analyses of lake sediments will define historical conditions and how they differ from the present.

Sampling for Level 2 lakes will occur during brief annual to seasonal visits by helicopter. A temperature, pH, conductivity and dissolved oxygen profile will be measured at lake center, and collection of a water sample for analysis of major ions (including organic anions via dissolved organic carbon), nutrients, some metals (notably labile aluminum), and water isotopes for evaluation of catchment water yield. Biological sampling will involve zooplankton collections and less frequent collections of lake sediment for analysis of invertebrates. A routine for sampling fish and macroinvertebrates from Level 2 lakes should also be developed. Soil surveys in Level 2 catchments and sampling of long-term plots in Level 3 sites are also anticipated. The same measurements will occur at Level 3 lakes, but with a much higher frequency so that within-year variability is established and mass budgets determined. Atmospheric input to the Level 3 lake ecosystems (particularly dry deposition) must be obtained, preferably through measurements made by the air quality monitoring program or associated partners, e.g., WBEA.

Chemical analyses will be performed by CAEAL accredited laboratories and internal QA procedures (e.g., charge balance, calculated conductivity) will be used to ensure data accuracy. All data will be publicly available following QA/QC verification.

Overall, the monitoring program recommended here, focusing on lakes located downwind of most of the oil sands atmospheric emissions, should allow us to detect and explain changes in lake acidification and advise on appropriate ameliorative action. Linkage to Air Quality monitoring is crucial since regional acidic deposition estimates are a prerequisite for the assessment of impacts.

3.5 Data Management

As outlined in the Lower Athabasca Water Quality Monitoring Plan – Phase 1 (Environment Canada, 2011), it is necessary to ensure robust protocols are applied and adhered to for all monitoring activities undertaken.

Similar to other components, the aquatics ecosystem monitoring information will be integrated into a common data management framework, have established and validated QA/QC procedures and data archiving and open accessibility. Chemical analyses will be performed by CAEAL accredited laboratories and QA procedures will be established and followed (e.g., charge balance, calculated conductivity) to ensure data integrity. All data will be publicly available following QA/QC verification. Biological field sampling protocols, sample preservation, and subsequent laboratory processing and analytical procedures will follow standard operating procedures that will be fully defined and openly communicated.

3.6 Monitoring Priorities

Synoptic fish population monitoring will be initiated assessing fish health (e.g., tissue contaminant levels of metals, PAHs, morphological abnormalities). Sampling will focus on priority sites where historical data obtained from previous fish monitoring programs in the region (e.g., AOSERP) can be used to assess changes in status and trends of fish health indicators and endpoints.

Reach-intensive tributary and stream sampling will be initiated to better identify and quantify fish habitat so as to improve estimation of population metrics such as abundance and recruitment.

Benthic macroinvertebrate community sampling will be conducted at defined locations in the Lower Athabasca mainstem, tributaries, associated streams and regions of the Peace-Athabasca and Slave River Delta's to better spatially define oil sands "impacted" and "non-impacted" sites (reference) sites. Where still possible, sampling will include sites used by historical monitoring/research programs (e.g., AOSERP, NREI, RAMP) to allow for trends assessments.

Reconnaissance surveys and associated analyses will be performed to confirm site selection for the monitoring network of representative lake ecosystems in acid sensitive regions of SK, AB and NWT that are (potentially) influenced by SO_x and NO_x emissions from oil sands industry.

Enhanced monitoring of water quality parameters (water, sediments) will be initiated in the Athabasca River and downstream regions, including the installation and testing of passive chemical samplers and automated water quality monitoring systems.

Enhanced event-based water quality sampling will be conducted in selected watersheds (e.g., Muskeg River) to quantify the relative importance of "pulse" hydrological events (i.e., spring snow melt, heavy rainfall events) in affecting ambient water quality and associated toxicity to aquatic biota.

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