Environment Canada
Environnement Canada

Lower Athabasca

Water Quality Monitoring Plan

Phase 1

Canada

Lower Athabasca Water Quality Monitoring Program

PHASE 1

Athabasca River Mainstem and Major Tributaries

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COVER TEXT

On the 16th December, 2010 the Federal Oil Sands Advisory Panel presented its report to the federal Environment Minister. They reviewed current monitoring activities in the lower Athabasca River system, identified key shortcomings, and provided recommendations on what would constitute a world-class monitoring program for the oil sands region (http://www.ec.gc.ca/pollution/default.asp?lang=En&n=E9ABC93B-1).

In response to this report and other concerns, the Federal Minister of the Environment committed Environment Canada to lead, in collaboration with the Government of Alberta, the development of a preliminary surface water quality monitoring plan for the lower Athabasca River and tributaries, and to complete this task within 90 days. Subsequent steps would expand the plan to other environmental media like air and biodiversity and would ensure the media-specific plans are integrated into a single, holistic, ecosystem-based approach.

The monitoring plan presented in this document is a first step towards a comprehensive, integrated monitoring program for the oil sands region. This Phase 1 plan deals with surface water quality monitoring in the mainstem of the Athabasca River, and its major tributaries, between Fort McMurray to Wood Buffalo National Park Boundary. It focuses on the physical and chemical attributes of water quality. Subsequent phases in the development of the water quality monitoring program will include biological endpoints and “effects-based” monitoring and assessments, and the expansion of the geographic scope to include environments further downstream in the Athabasca River system where appropriate, and upland lakes in the air shed that could be affected by aerial contaminant deposition from oil sands development.

Contributors to Phase 1 plan development had expertise in: surface and groundwater quality and quantity, hydrology, climatology, environmental chemistry, paleo-limnology, aerial deposition and contaminants, oil sands related contaminant chemistry, ecosystem-based monitoring program design and cumulative effects assessment, and statistical design. Each contributed significantly to the development of the Phase 1 plan and the production of this document.

This document presents a technical monitoring plan about when, where, why and how to monitor surface water quality. It does not present a complete monitoring system that includes specific elements like data management, and reporting. In the implementation of this plan, key principles articulated by the Federal Oil Sands Advisory Panel will be followed. The full plan will be holistic and comprehensive. It will be adaptive and robust. All data will be publically available in a standardized, accessible format. Stakeholders will be involved and their interests and concerns fully taken into account as data are analyzed and the meaning and impacts of conclusions are determined.

As with all responsible science plans, and in keeping with the guidance of the Federal Panel, this plan will be continuously updated and refined to ensure its relevance and technical competence.

This plan presents a marked change in approach to oil sands monitoring. Although the individuals involved in developing this Plan had solid technical backgrounds and most have experience in the oil sands region, this plan can be improved by incorporation of traditional knowledge.

1 INTRODUCTION

> ***The proposed water quality monitoring program is ecosystem-based, and focuses on the Lower Athabasca mainstem and its tributaries.***
>
> ***It is designed to be adaptable and has the ability to expand and contract its spatial and temporal coverage, and revise its procedures and protocols to address new and emerging issues as they arise.***

The monitoring plan presented in this report is based on the principles recommended by the Federal Oil Sands Advisory Panel and is the first of several phases in the design of an integrated, comprehensive and holistic monitoring program for the Lower Athabasca system.

The purpose of the monitoring program is to obtain scientifically credible information that will allow:

- Improved description of baseline conditions and ecosystem structure and function;
- Assessment of changes in ecosystem condition and trends;
- Effects investigation and impact assessments;
- Performance measurement and State of Environment (SOE) reporting;
- Evaluation of environmental and human health risk;
- Support and feedback for modeling, management, and policy development;
- Stakeholder input

1.1 Monitoring Questions

Environmental monitoring and assessment programs must be designed to provide data that can be used to answer specific questions.

Over the years, a number of consultative processes have occurred within the lower Athabasca River basin (e.g., the Northern River Basins Study (1991-1996), Northern Rivers Ecosystem Initiative (1998-2004)). Key stakeholder questions have emerged and been identified as pertinent to understanding the impacts of the oil sands and other industrial developments on water quantity, quality and ecosystem health in the Athabasca basin. **Box 1** provides examples of the nature and scope of environmental concerns and key questions that have been raised by First Nations, basin residents, government agencies and NGOs.

This monitoring plan is designed to provide comprehensive data that can be used to answer a full suite of key monitoring questions. Specific questions can be answered, or hypotheses tested, by performing targeted analyses on sub-sets of data collected under this monitoring plan.

Stakeholder issues and concerns must be revisited on a regular basis to ensure appropriate focus.

Box 1: Examples of key questions to be answered by the monitoring program:

- ✓ What is the current state of the water quality of the Athabasca River basin?
- ✓ Which contaminants and levels are entering the Athabasca River directly or indirectly from oil sands operations?
- ✓ What is the distribution of contaminants in the aquatic ecosystem with particular reference to water and sediments?
- ✓ Can contaminant types and loads be attributed to specific sources?
- ✓ Are toxic substances such as mercury, naphthenic acids, PACs increasing or decreasing and what is their rate of change?
- ✓ Are the substances added to the rivers by natural and man-made discharges likely to cause deterioration of the water quality? What is the relative importance of both inputs?
- ✓ What are the cumulative effects of land use alterations and man-made discharges on the water and aquatic environment?
- ✓ Do current contaminant loads or concentrations pose threats to human health or subsistence?

1.2 Phases of the Monitoring Program Design

The Federal Minister of the Environment committed to have a preliminary water quality monitoring plan within 90 days after the tabling of the Federal Oil Sands Advisory Panel report in December 2010. Given the scientific complexities involved with adequately addressing the geographic scope, and associated environmental stressor- and effects-based monitoring program design components, the water quality monitoring program is being developed in several integrated phases that chronologically and progressively build upon one another (**Figure 1**).

This report (Phase 1) is concerned with the physical (hydrological and climate) and chemical components and stressors of the system. The primary goal of this technical plan is to present a comprehensive and integrated approach that quantifies and assesses the sources, transport, loadings, fate, and types of oil sands and other industrial and municipal contaminants into the Athabasca River system. Phase 1 is targeted at obtaining a better spatial and temporal quantitative understanding of the key physical/chemical "stressors" affecting the system and also improving knowledge on historical baseline conditions.

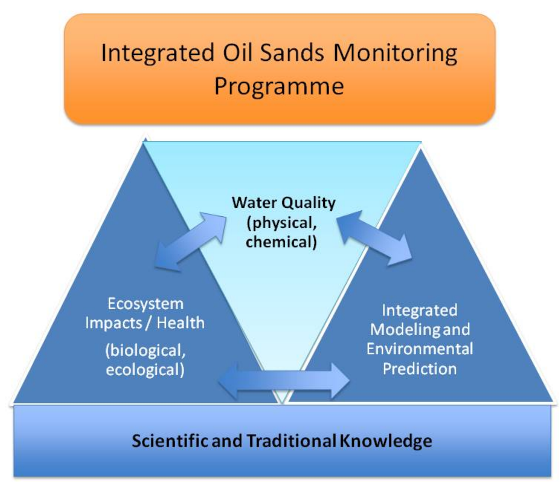


Figure 1. Components of a monitoring program design for the Lower Athabasca system.

Phase 2 will address the "so what" question by identifying key biological and ecological endpoints that will be monitored and used to assess local and regional impacts, including cumulative effects. The development of this phase will provide data that can be used to answer overarching questions such as, whether fish have changed in ways that make them undesirable (e.g. malformations), whether fish and/or other aquatic organism health has been affected, whether key species have been lost or ecosystem function impaired, and whether current guidelines for individual contaminants are useful for detecting ecosystem impairment?

The development and validation of new integrated modelling and environmental predictions systems that allow for improved assessment and projection of site-specific and regional impacts is also an important component of the design. The "cause-effect" relationships that will be developed through the concurrent implementation of Phases 1 and 2 will be used ultimately to predict cumulative environmental impacts and inform the requirements for subsequent cumulative effects monitoring. This component will be an ongoing and iterative scientific process that continues to improve and advance the modelling frameworks through incorporation of new scientific knowledge obtained from the monitoring programs themselves and other sources.

1.3 Geographical and Development Context

The Athabasca River system originates from the eastern slopes of the Rocky Mountains in Alberta, flows northeast and drains an area of approximately 160,000 km^2, eventually flowing through the Peace-Athabasca Delta and discharging into Lake Athabasca and the Slave River, which crosses into the Northwest Territories. The Peace-Athabasca Delta within the Wood Buffalo National Park is also recognized by the RAMSAR convention on Wetlands and is a UNESCO World-Heritage Site (Wrona et al. 2010).

Figure 2. Alberta Oil Sands Region (source: Wikipedia, created by Norman Einstein, 2006)

Primary environmental concerns regarding water quality, quantity and ecosystem health related to oil sands development are within the lower portions of the Athabasca River, primarily downstream of Fort McMurray, Alberta, although they are potentially farther reaching. This lower portion of the Athabasca River drains an area of approximately 58,000 km^2 and includes numerous river tributaries and sub-catchments (**Figure 2**). In this area, the Athabasca River and tributaries flow through the Athabasca oil sands deposits, eroding the oil-containing sands and interacting with groundwater systems also in contact with the oil formations.

The Athabasca River Basin is located in a constantly changing and dynamic landscape that has seen significant rates and magnitudes of change in cumulative land use and industrial development in recent years (e.g., Suncor in 1967, Syncrude in 1978, major expansion in 1998 with Suncor Steepbank, the early 2000s with Shell MRM, Syncrude Aurora, Suncor Millennium and, proposed developments such as the Joslyn mine.

Similar to other existing and emerging energy sources, oil sands development has multiple potential environmental impacts on the air, water and land related to stack and particulate emissions (e.g., mine dust, coke stockpile, etc.), mine fleet and greenhouse gas emissions, water use (both surface and groundwater), production of waste streams including tailings ponds and associated contaminants, potential groundwater contamination, land disturbance and associated alterations in hydrological connectivity, and habitat loss and fragmentation.

1.4 Legislative Context

The monitoring program must also be designed to inform pertinent legislative and regulatory action. In this context, Box 2 summarizes the primary federal and provincial legislative authorities that the water quality monitoring system can inform. Government representatives were queried for their respective surface water quality monitoring data needs. These data needs are accommodated in this monitoring plan.

BOX 2: Key Federal and Provincial Legislative Authorities

Government of Canada - Legislative Authorities

- **Canadian Environmental Assessment Act**
- **Canadian Environmental Protection Act**
- **Canada Water Act**
- **Fisheries Act**
- **Migratory Birds Convention Act**
- **Species At Risk Act**
- **Canada National Parks Act**
- **First Nations Land Management Act**

Province of Alberta - Legislative Authorities

- **Alberta Environmental Protection and Enhancement Act**
- **Alberta Water Act**
- **Alberta Land Stewardship Act**
- **Lower Athabasca Regional Plan – Water Quality Component**
- **Oil and Gas Conservation Act**

1.5 Limitations of Existing Monitoring Programs

There is monitoring currently conducted in the lower Athabasca River region. The Province of Alberta and the Government of Canada have monitoring stations, industry monitors as a condition of their license or approval to operate, and additional monitoring is performed by the industry-funded Regional Aquatic Monitoring Program (RAMP). However, there is a lack of integration of these activities. This lack of integration has been reflected in a number of independent science reviews or journal papers (e.g., Timoney and Lee 2009; Kelly et al. 2009, 2010; Giesy et al. 2010; Schindler 2010) and expert reviews conducted by the Royal Society of Canada (RSC 2010), the RAMP program (RAMP 2004, 2011), the Federal Oil sands Advisory Panel (2010); and, the Alberta Water Monitoring Data Review Committee – Final Report (2011)). Key criticisms of the RAMP monitoring design are that it:

- often does not adequately measure change relative to a defined background or baseline state;
- does not measure change cumulatively over space or time;
- lacks consistency and integration;
- changed its design questions resulting in changed data collection and loss of discriminating power;
- has not adequately developed a design that accounts for the reality that contaminants can have both natural vs. anthropogenic sources in the oil sands region;
- has not had sufficient spatial and temporal sampling coverage to allow discrimination of anthropogenic impacts from natural heterogeneity;
- has not adequately accounted for variability and changing environmental conditions (e.g., climate variability, mixed land use);
- does not utilize results-based decision-making in an organized, systematic, adaptive, transparent manner.

Collectively, the above reviews found that the current monitoring system did not deliver data of sufficient quantity or quality to detect or quantify the effects of oil sands development. In addition, current oil sands monitoring of air, groundwater and surface water have not been integrated in a source, transport and fate construct.

It is important to note that, although widely criticized and in need of redesign, past monitoring activities have yielded data at some sites and during some time periods that will be critical to the optimal functioning of the new monitoring plan. The goal of this new plan is to incorporate the sound components of existing monitoring and improve data collection activities to facilitate holistic assessment of contaminant sources, their transport in the environment and their ultimate fate. With this, risk-based assessments to aquatic and human health can be made.

1.6 Water Quality Monitoring Program: Phase 1 – Scope

Phase 1 deals with surface water quality monitoring in the main stem of the Athabasca River, and its major tributaries, between Fort McMurray to the Wood Buffalo National Park Boundary. Phase 1 targets sampling designed to quantify fluxes of contaminants from point and non-point sources.

Phase 1 deals with surface water quality monitoring in the mainstem of the Athabasca River, and its major tributaries, between Fort McMurray to Wood Buffalo National Park Boundary. Phase 2 will expand the geographic scope to include the Peace-Athabasca Delta, Lake Athabasca, the Slave River systems, and upland lakes in the region that could be affected by aerial deposition.

Current and projected environmental pressures stemming from oil sands development on the lower Athabasca River are a culmination of historical land use alterations, and enhanced levels of industrialization, coupled with broader environmental changes linked to altered hydrological conditions arising from a warming climate and enhanced climatic variability.

Figure 3 summarizes various point and non-point source contaminant pathways entering the Lower Athabasca river system. Each of these pressures has direct and indirect consequences on water resources and there are many interactions among them at local and regional scales.

Thus, an appropriately designed and adaptive integrated, multi-media monitoring and research program is required to understand, predict and report on the status and trends of water quality and quantity, accumulated state, changes in ecosystem structure, function and health and ultimately determine cumulative impacts. This document gives the monitoring plan for a portion of the Athabasca mainstem and its tributaries as a first step in the development of such an integrated monitoring plan.

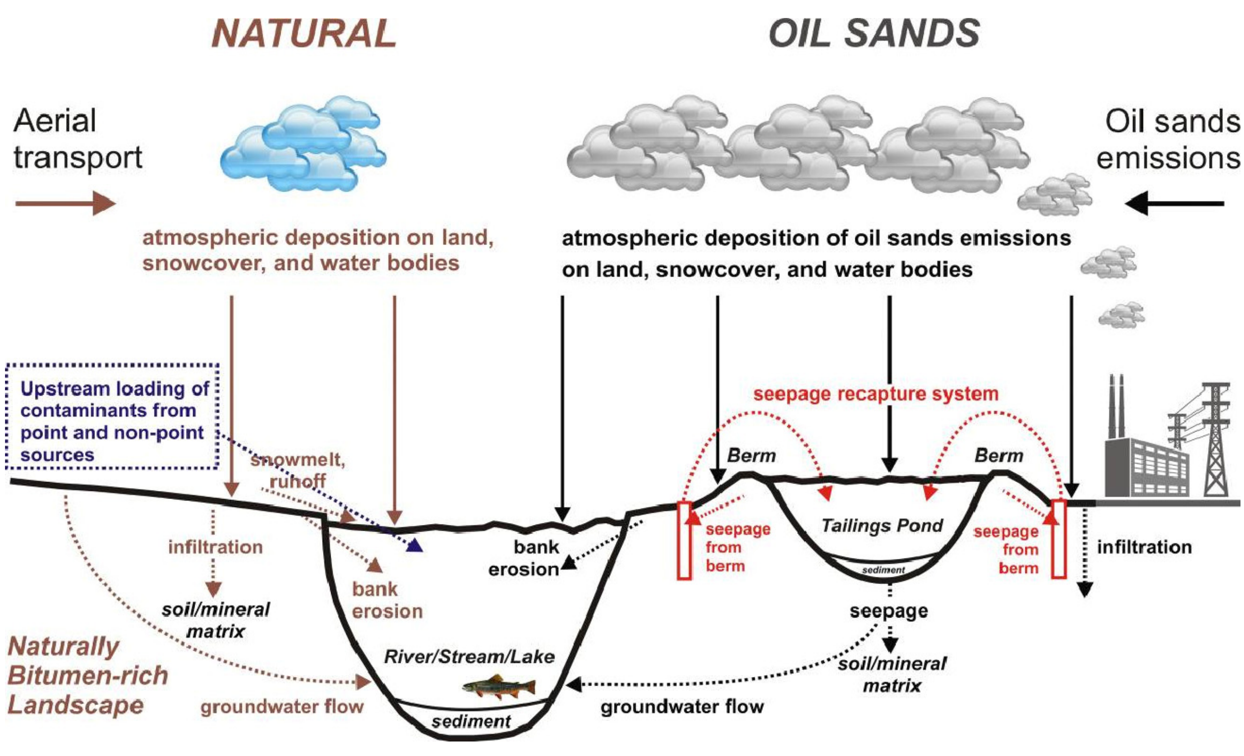


Figure 3. Key Direct and Indirect Contaminant Pathways into the Lower Athabasca River

2 CORE ELEMENTS FOR A NEW MONITORING PROGRAM

The design and successful implementation of an effective, water monitoring program requires several core elements, including:

- ***an Integrated Regional Monitoring Program;***
- ***the Production of Core Results;***
- ***Triggers for Decision-Making; and,***
- ***Scientific Excellence and Tools for Implementation.***

The design and successful implementation of an effective, monitoring program requires several core elements. Below we describe each of these elements and how they are incorporated in the new monitoring program design.

2.1 Integrated Regional Monitoring

Data collection and data management are currently fragmented. Strategic decisions for environmental protection (including water quality) and industry sustainability cannot be made under such conditions. An integrated regional monitoring framework needs to be implemented where the various types and sources of monitoring are linked to provide the information required to inform decision-making.

The new integrated regional oil sands monitoring program will consist of a series of inter-related types of monitoring that have specific objectives. There is a plethora of monitoring definitions, many of which are interchangeable. The definitions used in this document are:

Baseline Monitoring quantifies background levels of physical and chemical parameters at locations that are least-developed or ideally "non-impacted" by anthropogenic disturbance. Baseline monitoring is critical as it establishes the benchmark to compare to sites potentially impacted by development. In previous monitoring in the oil sands region, very few fixed-location, long-term monitoring sites existed (those that do, are operated by government agencies and primarily located outside of the active oil sands mining region), and many sites that did have pre-development information were either discontinued or gradually absorbed by an expanding industrial development footprint. The new plan will increase the number of long-term monitoring stations at appropriate spatial and temporal scales in the catchment to assess regional baseline.

Still, defining "baseline" or "reference" conditions in a region that has undergone, and is continuing to undergo, change in its environmental regime poses significant challenges. Very few regions of the basin, if any, are now untouched by some form of direct or indirect anthropogenic influence (e.g., aerial deposition of contaminants). In addition, the richness of the bitumen ore body is heterogeneous, as are the areas of natural exposure or contact with streams and rivers, further complicating a "control/impact" approach to impact assessment.

To address these challenges, the new monitoring framework will employ new approaches that will integrate synoptic information from long-term monitoring locations, with modelling and other predictive tools to assess changes in the environmental state. A key requirement to the enhancement of our understanding of regional and localized "baseline" conditions, will be to ensure that there will be adequate pre-development, site-specific monitoring data, against which environmental change can be measured, and that post-development monitoring will continue for the long-term. Consideration could also given to establishing additional, long-term reference areas/sites within the oil sands region that could be used to further define "baseline" or "reference" environmental conditions. A complicating factor is that remaining "reference" watersheds within the bitumen-bearing McMurray formation are either larger or smaller than impacted streams, which would limit their ability to function as a "baseline".

The proposed use of sediment coring and related paleo-analyses may also further help discriminate medium-term (i.e., decadal) from long-term (i.e., multi-decadal) environmental change and variability. Also, existing hard copy and electronic reports will be mined for historic data and archived in the monitoring system database.

<u>Accumulated State Monitoring</u> measures changes in the aquatic environment that are outside of both local and regional baseline. It identifies "hot spots" of change in space and "hot moments" of change over time. It is conducted at local and regional scales relative to local and regional baseline. This monitoring requires use of baseline monitoring data and identifies changes outside of baseline, their magnitude and direction. It is fundamental monitoring for management decisions. The first component of accumulated state monitoring is also commonly called effects-based monitoring. The effects monitoring program operates consistent with the baseline monitoring suite of parameters.

Accumulated state monitoring also measures changes on the landscape occurring over space and time. This includes quantification of changes in land use as well as synthesis of point and non-point source loadings. The second component of accumulated state monitoring is also commonly called stressor-based monitoring.

<u>Compliance Monitoring</u> involves facilities monitoring of specific parameters to determine whether the site is in compliance to its operating approvals and related licensing/permitting conditions. This monitoring is currently conducted in the oil sands, although not integrated into a regional monitoring program. This information potentially contributes to cumulative effects and must become available, transparent, and integrated with electronic reporting mechanisms in a timeframe that aligns with the reporting requirements of the integrated regional program.

<u>Performance Monitoring</u> is site/facility-specific and would be conducted after development has occurred. This type of monitoring would be used, for instance, to verify and/or validate whether predictions made through the Environmental Impact Assessment (EIA) process were accurate. Currently, little performance monitoring is conducted and the indicators and parameters used during the EIA process have little to no connection to the local accumulated state and effects monitoring discussed above. It is critical that performance monitoring be conducted or there will be no mechanism to improve ability to predict impacts of specific developments or to identify whether EIA predictions were accurate.

Cumulative Effects Monitoring is the largest and most integrated of monitoring components. It is fundamentally the most critical for managing regional development-related change. Cumulative effects monitoring involves comparison between the predicted ecosystem trajectory towards the future state of the system against the observed conditions and trajectory. It is implemented at a regional scale following a cumulative effects assessment, but is not currently conducted in an effective manner in the oil sands region.

Surveillance Monitoring is generally hypothesis driven and addresses specific knowledge gaps about system processes or attempts to ascertain a mechanistic understanding of causality. This type of monitoring is often both time (short-duration) and spatially limited (sites and attributes being measured follow an explicit experimental design). An example of surveillance monitoring is the use of "synoptic surveys".

2.2 Production of Core Results

Currently there is no consistent reporting in a format needed to track environmental change, track industrial development on the landscape, and understand existing or future threats to environmental protection (including water quality). Regional monitoring must produce three Core Results on a consistent and ongoing basis:

- ✓ Assessment of accumulated environmental condition or state;
- ✓ Improved understanding of the relationships between system drivers and environmental response; and,
- ✓ Cumulative effects assessment.

In the absence of these Core Results, cumulative change cannot be detected, predicted, managed, or mitigated.

Oil sands monitoring to date has functioned as a series of independent monitoring programs conducted for specific and independent reasons. Where it has failed, is in integrating and converting the sum total of the data being generated to a knowledge base to support approaches to dealing with cumulative effects.

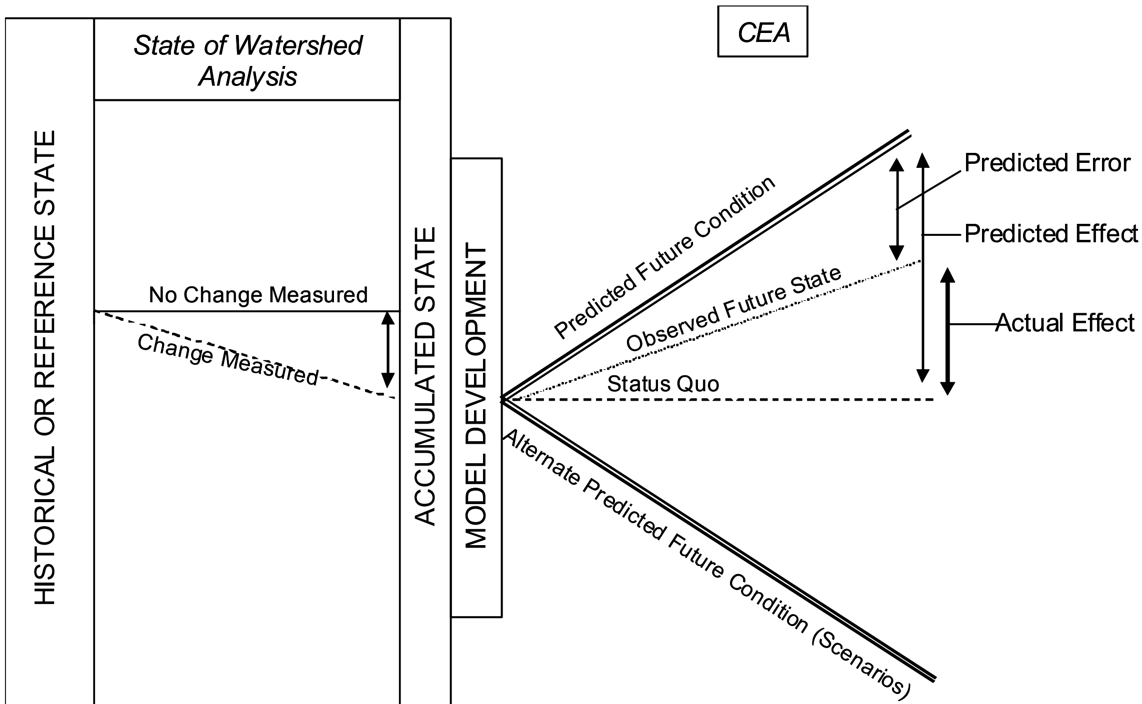


Figure 4. A "world-class" monitoring program measures how much environmental change has already occurred (Assessment of accumulated environmental state), as well as helps define what caused the change (Relationships between system drivers and environmental response), and uses this information to plan the desired landscape for the future by predicting the outcomes of different development trajectories (Cumulative Effects Predictive Modelling).

A regional monitoring framework provides a consistent regional approach in terms of sampling strategy, endpoints, and protocols, such that monitoring efforts become more coordinated, approaches become standardized for related components, and data become regionally available.

Thus, in addition to meeting program-specific objectives, the monitoring programs must be integrated to achieve the three Core Results given above and shown in **Figure 4**.

Ultimately the goal of having an integrated monitoring framework is to move towards the implementation of an integrated cumulative effects assessment approach. Such an approach reduces the focus from assessing effects (both stressor-specific and cumulative) on a project-specific basis, and instead provides a regional basis for addressing key questions of concern. This provides opportunities for cost-efficiencies, develops synergies by focusing questions, and reduces duplication of effort in existing monitoring requirements. The result is a framework that underpins the ecological assessment components required for Environmental Impact Assessment (EIA), focuses research, provides regional baselines, develops thresholds for responses, and detects cumulative effects.

Cumulative Effects Monitoring then follows cumulative effects assessment and essentially determines if the observed future state followed the expected trajectory. This is a comparison of the expected (or predicted) to the actual response (Figure 4).

2.3 Triggers for Decision-Making

Adaptive program design - alterations in spatial coverage and temporal sampling frequency are linked to science-based (and policy-relevant) decision-triggers. A key objective is to maintain required statistical rigour to detect and predict effects and assess trends in environmental parameters. The program design is continually assessed and refined based on stakeholder feedback and new science findings.

It is not necessary to monitor everything, everywhere, all the time. The monitoring system must incorporate a decision-support system that will provide clear direction on when and where monitoring intensity should change based on monitoring results and what actions should be taken if monitoring reveals significant effects to ecosystem health. The decision-triggers will allow opportunities to increase or decrease monitoring frequency, ensuring the best possible information is available for making management decisions and optimizing the efficiency of the monitoring network. In addition, triggers are defined that when a monitored parameter reaches a predetermined threshold of concern, it is inspected to determine if and what types of management actions are warranted.

Within each monitoring activity, a “decision framework” will be developed and incorporated so monitoring efforts and intensities (i.e., tiers) can be adjusted or triggered “on or off” for specific monitoring stations and related data acquisition activities depending on the decision threshold. Triggers will be used to both increase and decrease monitoring intensity and would link back to factors such as the rate of development and restrictions to it, such as reducing airborne emissions.

Conceptually these triggers would occur when there is an observed effect (e.g., a significant statistical change), a warning sign (e.g., a critical effects size is exceeded and is confirmed for an environmental stressor), or a response sign (e.g., a critical threshold or effects size is exceeded and is getting worse). Hence the monitoring program will be adaptive with tiers and triggers that move, focus and optimize monitoring efforts throughout the basin, according to needs (**Table 1**).

Table 1. Examples of decision “Triggers” that would be place to adjust monitoring program design, sampling intensity, in a tiered, hierarchical manner. In this manner the monitoring programs would adapt to information needs.

Level	Trigger	Consequence
Effect	Significant statistical change	Seek confirmation
Warning Sign	Exceeds critical effect size, and is confirmed	Increase monitoring frequency to define extent and magnitude of change
Response Sign	Exceeds critical threshold effect size and is getting worse	Investigate cause
Action Level	Passes probable effects level or water quality criterion	Change in management strategy warranted

It is expected that all sites for baseline monitoring can be triggered to lower frequencies or tiers of monitoring, and reduced parameter lists, once the ability to predict relevant levels becomes possible (i.e., if the status at monitoring station 3 can be adequately estimated from data collected at stations 2 and 4, then monitoring at station 3 can be reduced). Such monitoring would be triggered back into operation if appropriate threshold levels were surpassed in subsequent monitoring. This triggering "on and off", and changes in intensity of monitoring, are essential for the proper operation of an adaptive monitoring program, and function as a first level of defining the extent and magnitude of changes, and as a first step towards localizing the potential impact and identification of causative factors.

Once a predictive model for assessing cumulative effects is developed, it will be possible to track the system's performance to compare the predicted and observed outcomes. When there is a sufficient signal difference between the predicted and observed state, increased monitoring frequency can be triggered (**Table 1**).

2.4 Scientific Excellence and Tools for Implementation –

A comprehensive, integrated monitoring framework and open and transparent data management system are necessary to produce and archive data/information that is used to predict the trajectory(ies) of changes in water quality, quantity and ecosystem health. Comparison of predicted modeled trajectories with reality increases insight into system function and ultimately improves management decisions.

The proposed monitoring program, along with subsequent monitoring plans for other environmental media, must be supported by a highly efficient, integrated database and a systems-based, decision-support framework. Database and decision-support software must be consistent with the format of, and output from, each type of monitoring program in the framework, as well as the integration products (relational analysis, cumulative effects assessment, cumulative effects monitoring). As mentioned above, this aspect of regional monitoring and assessment has been largely ignored, resulting in inefficiencies and a lack of coordination and responsive action to detected change. In the absence of such a facilitation system, this program will not meet its target of being “world-class”.

In addition, there is recognition for the need of strong and explicit relationships between pertinent research, monitoring and modelling activities. Linkages among these activities will ensure better interpretation of monitoring data and maintenance of an optimal monitoring system design. Hence, the production of timely, peer-reviewed scientific publications of key findings must also be an ongoing required deliverable of the program.

Testing and the incorporation of new and emerging monitoring technologies (e.g., new sensor-based integrative samplers, gene-array chips as biomarkers of exposure, remote-sensing and satellite-linked automated sampling networks) should be continually assessed for their applicability to improve data acquisition efficiencies and interpretability in the program.

3 WATER QUALITY MONITORING SAMPLING NETWORK DESIGN

Proposed design addresses identified scientific and design shortcomings of previous monitoring programs – the monitoring program design builds upon existing programs/sites where deemed appropriate and expands the range of core water chemistry parameters, the spatial coverage and sampling frequency.

Water quality monitoring in large and complex freshwater systems presents many challenges, particularly in cold-regions such as the Athabasca River and its tributaries. Climatic and hydrological conditions along with chemical concentrations can vary substantially over scales of space and time. A plethora of monitoring programs has been implemented in the lower Athabasca river region, and many active sites currently exist (**Figure 5**).

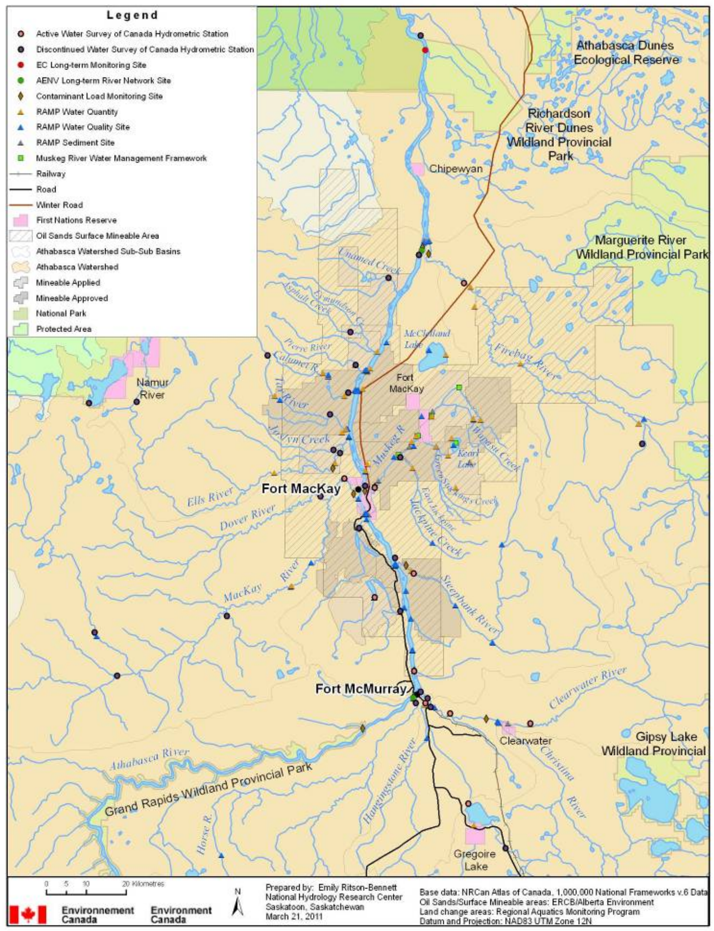


Figure 5. Summary of existing water and Hydromet monitoring programs/sampling sites in the oil sands region

These sites were selected for program-specific purposes such as, to assess "upstream-downstream" impacts, quantify areas of significant contaminant loading sources, and to assess medium- to long-term trends in water quality at focused locations (e.g., RAMP 2010; Alberta Environment 2010 - Contaminant Load Study); AENV 2009 - Muskeg River Watershed Integrated Water Quality Monitoring Program). However, many of these locations might not have been adequately assessed from the standpoint of biological relevance. In all large systems there will be "hotspots" of damage where fish spawn or feed at the same locations where contaminants are deposited or habitat otherwise destroyed (Choy et al. 2008; Fowlie et al. 2008). Sampling site selection may need refinement based on validation that will occur in Phase 2 which will ensure sites are important not only from a water quality perspective, but also from a biological perspective.

A comprehensive overview of past and current monitoring activities in the oil sands regions is provided by Lindeman et al. (2011).

Recent 2010-11 external science reviews and scientific publications have been unanimous in highlighting that existing monitoring programs have generated a significant amount of information over the past four decades. However, they have also identified primary shortcomings and concerns related to:

- the rigour in their statistical designs (e.g., inadequate spatial coverage of sites and/or related sampling frequency);
- lack of clear objectives and hypothesis driven analyses;
- lack of consistency in the breadth of media and environmental parameters sampled;
- QA/QC issues related to the inter-comparability of data;
- open data accessibility;
- scarcity of timely, peer-reviewed publications;
- lack of cumulative effects assessment; and,
- lack of transparency and accurate public reporting.

The proposed program is designed to improve both the spatial and temporal resolution of the data being collected. This will improve our ability to detect change and predict effects, and adaptively manage for changing environmental conditions. Not only will this increase our power to detect change, but we will be in better position to understand the variability and responses in the system in relation to point and non-point sources, natural versus mined bitumen deposits, and cumulative effects.

Ultimately, the monitoring program must be able to detect contaminant loading and/or concentration trends that exceed key biological thresholds. Since biological thresholds will likely always be more sensitive than chemical guidelines (e.g., Palmer et al. 2010), it will be important to ensure the final design of the program utilizes biological/ecological endpoints as key indicators of stress and impacts. The integration of such endpoints into the current water quality design will occur in Phase 2.

3.1 A Mass-Balance Approach

> ***A mass-balance approach was used to define the network of sites to be monitored for key water quality, hydrometric and aerial deposition variables. The approach allows for the quantification and modelling of sources, fate and loadings of contaminants in the Lower Athabasca system.***

A mass-balance approach has been used in designing the monitoring network assessing the quantity, movement, and cycling of materials in the watershed. Applying this approach within the lower Athabasca River system requires an expansion of the current water quality and quantity monitoring sites to include a more systematic and comprehensive quantification of the sources, transport, flux, and fate of materials and contaminants entering the watersheds. The major contaminant input sources that must be considered are:

- direct surface-water point sources (i.e., industrial/municipal end-of-pipe inputs)
- diffuse non-point sources from the landscape (i.e., indirect aerial deposition, overland flow, site drainage, erosion)
- groundwater inputs (including seepage/leakage from tailings ponds and groundwater-surface water interactions)
- direct aerial deposition

Quantification of oil sands related contaminant loadings and fluxes by necessity requires a more comprehensive network of hydrometric and suspended and bed sediment measurements, better quantification of historical background or “baseline” conditions, and improved estimates of atmospheric contributions. In addition, standardized QA/QC analytical procedures and Standard Operating Protocols (SOPs) must be implemented, along with proper data archiving and reporting.

The proposed monitoring program expands an existing suite of lower Athabasca River monitoring sites of “state” to a formal integrated network. This will allow quantification of the reach-specific and regional-scale accumulated state, and the spatial and temporal status and trends in contaminant loadings. The design builds on Alberta Environment sites that since 2008 have been the foundation for a regional Contaminant Load Study (CLS) and more focused reach-specific efforts in the Muskeg River watershed.

In addition, RAMP sites that have been deemed to have relevant site-specific and spatial and temporal coverage characteristics have also been incorporated. New sites have been proposed to enhance spatial coverage where necessary. The program proposes increased sampling frequency, for both existing and new sites, to address issues of past designs, with respect to temporal variability and statistical power.

Consideration will also be made of adding additional tributary locations as they are important habitat and support 17-24 species of fish, including thousands of migrating fish each year, and have a high diversity of invertebrate taxa (Barton and Wallace 1980; Bond 1980; Machniak et al. 1980). These areas will likely be hotspots for assessing impacts in Phase 2 of Plan design and would complement the physical/chemical network design.

3.2 Statistical Considerations

The geographic and geological settings, along with the scope, both in the rate and magnitude of the oil sands development, poses significant challenges in evaluating and attributing observed change in environmental conditions and related impacts on ecological conditions. An ongoing constraint and challenge to understanding and predicting the long-term causes of water quality changes in the oil sands region has been the difficulty identifying appropriate "reference" sites or "baseline" conditions because of the lack of reliable historical records. To address this challenge, the proposed water quality monitoring program incorporates a combination of existing medium- to long-term sites, and establishes an enhanced network of core locations that will serve to better define regional "baseline" or "reference" conditions. Hind-casting approaches will be used to define historical "baseline" conditions. An assessment will be performed of the applicability of all potential hind-casting techniques including paleo-sediment coring and tree ring analyses. Appropriate techniques will be used at strategically selected sites to assess the historical levels and trends in hydrological conditions, general water chemistry and contaminants where applicable.

Within the Lower Athabasca Basin, and in particular in the oil sands region, both "pulse" and "press" environmental stressors, and related impacts, are occurring (**Table 2**). These affect the temporal variability in observed responses and will influence the spatial and temporal replication necessary to detect impacts with sufficient statistical power (Stewart-Oaten, et al., 1986). The proposed increase in the number of long-term, standardized monitoring sites (each having a common suite of measured environmental parameters along with an increased temporal frequency of sampling) will enhance the statistical power to assess status, trends and impacts. Detecting "press" related environmental impacts (e.g., a regime shift in parameters such as climate, flow or sediment loads) requires a large number of spatially distributed "baseline" or reference sites, while, shorter-term "pulse" impacts (e.g., detection of enhanced contaminant loadings from point source discharges) are best detected when the number of periods sampled is maximized.

TABLE 2. Planned sampling design to detect different types of impacts (*after* Underwood and Chapman 2001; Bulleri et al. 2008)

Potential Impact to Detect	*Design should*
Long-term ‘‘press’’ response to disturbance (e.g., slow and long-term changes in contaminant concentrations in water and/or sediments resulting from diffuse, non-point source discharges)	Incorporate numerous control locations (i.e., maximize the number of “baseline” or reference sites)
Shorter-term ‘‘pulse’’ response to disturbance (e.g., rapid or short-term changes in contaminant concentrations in water and/or sediments resulting from site-specific, point-source discharges)	Incorporate numerous periods in sampling (i.e., maximize the number of periods being sampled - seasonality)
Changes in temporal variation or very short-term ‘‘pulse’’ responses to disturbance (e.g., severe storm event and related contaminant flux)	Incorporate as many times of sampling in each period sampled, or increase the number of periods sampled (i.e., maximize periods or frequency of sampling within a period)

3.3 Monitoring Program Components

The monitoring program is designed around three integrated environmental components (hydrology and sediments, water quality, air deposition), allowing for an improved capability to address hypothesis-driven questions related to current and projected reach-specific and regional impacts of oil sands developments on water quality.

This water quality monitoring plan is structured around three integrated core components:

1) Climate, hydrology, hydraulics and sediment kinetics;

2) Ambient surface water quality, sediment quality and groundwater interactions;

3) Loading from aerial and terrestrial (non-point) sources.

For each of these components and related monitoring system types, we describe the proposed new spatial and temporal coverage of sampling locations within the overall Athabasca catchment, the Lower Athabasca mainstem reach (LMR) in the vicinity of the oil sands developments, and for key tributaries (Sections 4 to 6). We further provide the rationale behind the proposed design addressing *What, Why, Where, When* and *How,* and discuss how the design is an improvement over the existing system(s) (e.g., What information is gained?) (**Box 3**).

The proposed design utilizes the following schematic representation of the lower Athabasca River system and its major tributaries (Figure 6). The design follows a statistical framework that allows for both reach-specific and cumulative loadings and water quality/quantity to be quantified and characterized with sufficient power. Notably, approximately 55% of the Athabasca River flow exiting the LMR at M9 originates from flow entering the LMR at M0, reinforcing the need to also understand upstream hydro-climatic drivers.

Box 3. Rationale for Monitoring Program Design:

What water quality/quantity parameters/processes need to be sampled
Why - are the chosen parameters important to quantify (linked to data use and issues/concerns to be addressed), and why is the chosen sampling design being used (statistical considerations)
Where - spatial resolution & replication, by sub-catchment/drainage basin, by media (surface water, pore water, sediment)
When - temporal resolution (discrete time vs. event-based vs. continuous)
How - what sampling and analytical methodologies should be used

Figures 6 and 7 illustrate the locations of the proposed water quality monitoring sites in the Lower Athabasca system and **Table 3** (***see page 57***) provides detailed descriptions of each site. **Appendix A** also contains additional related information.

This stratified sampling is a fundamental shift in monitoring approach. By dividing the Athabasca River and tributaries into specific reaches or segments and monitoring in those reaches, quantification and assessment of site-specific loadings and therefore isolation of potential sources on contaminants is possible.

A standardized and enhanced suite of water quality and quantity variables are integrated into the monitoring program design, focusing on environmental parameters relevant to assessing oilsands development impacts.

Figure 6. Schematic representation of proposed sampling sites on the Athabasca River mainstem and major tributaries

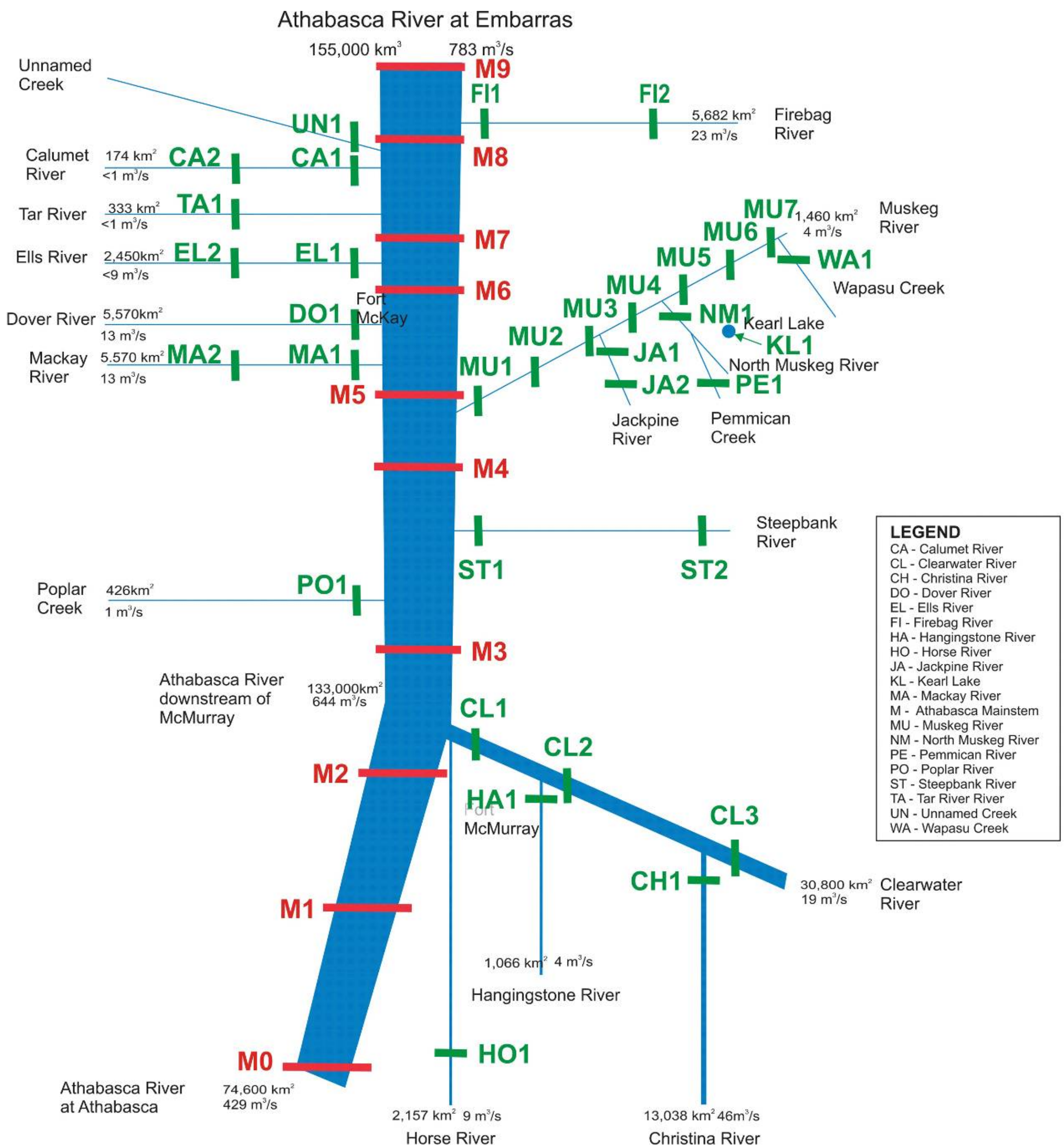
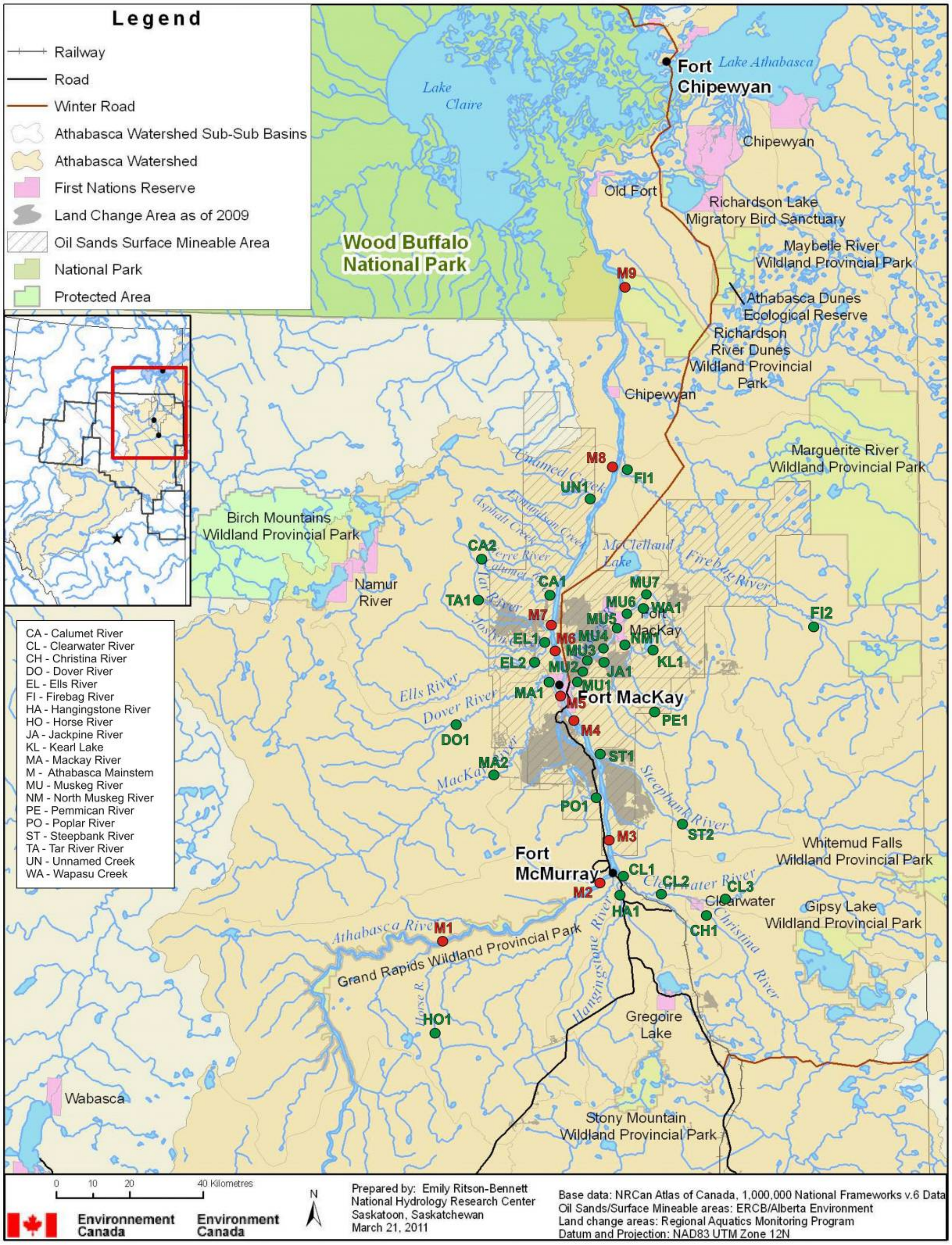


Figure 7. Proposed monitoring sites on the Athabasca River mainstem and major tributaries



4 CLIMATE, HYDROLOGY AND SEDIMENT MONITORING

The hydrological and climatic conditions affecting the overall Athabasca catchment need to be understood, because of the strong control the upper part of the catchment and associated tributaries have on downstream river flow.

Sediment dynamics play an important role in the fate and transport of contaminants in the system.

An understanding of the hydrological and climatic conditions affecting the overall Athabasca catchment is required, because of the strong control the upper part of the catchment has on downstream river flow. In addition, river-ice dynamics play a major role in physical and chemical processes (e.g., sediment transport, mixing regimes, flushing flows, background chemistry) in the LMR (e.g., AENV 2010). Furthermore, knowledge of the controlling hydro-climatic systems (e.g., synoptic climatic patterns and atmospheric teleconnection patterns) is also key to understanding the hydrologic processes affecting the LMR and its tributary catchments (e.g., snow accumulation/runoff, extreme events, etc.).

Information obtained from the hydrometric/sediment monitoring program will address the following questions:

- What is the historical, current and projected-future spatial and temporal variability of water flow and sediment transport into and through the LMR and from tributaries?
- What are the water and sediment budgets for the LMR and tributaries, considering upstream source regions?
- What are the effects of various oil sands development activities on the spatial and temporal variability of water and sediment yields from the LMR tributaries to the Athabasca River?
- Based on improved physically-based knowledge and modelling capability, what have been the conditions and changes in the environment that have created current state of flow and sediment conditions on the Athabasca River system, and what are the projected possible outcomes of future development?

The hydrology and sediment monitoring program, while described separately, is linked to the surface water quality monitoring program (section 5.0 below). Sediment dynamics (i.e. erosion, transport and deposition) can be a significant driver of contaminant dynamics since many contaminants partition strongly to fine sediments, with resulting influences on benthic communities. This linkage allows quantification of sediment/contaminant loadings to downstream environments and permits better understanding and management of sources, fates and effects of these contaminants.

4.1 Core components

To quantify and characterize the hydrologic fluxes entering the LMR, ongoing analyses need to be conducted of the upstream major source-water hydrologic regimes and types (e.g., nival, pluvial and glacial regimes). Specifically addressed will be the importance of each regime to seasonal flow contributions at M0, their sensitivity to variations in current and future climatic drivers, and potential to generate extreme events within the LMR (e.g., low flows, open-water floods, river-ice breakup surges). The latter type of extreme has previously been identified as a transport mechanism for major fluxes of material beyond that possible under open-water conditions (e.g. Milburn and Prowse 2002; Prowse and Culp 2003; Beltaos et al. 2011). For this, a companion focus on the advancement of, and effects from, ice breakup through the LMR will also be required.

To properly quantify and characterize the hydrological and sediment regimes/budgets within the LMR, the following core components are needed:

- pre-freshet snow surveys to determine the amount of water stored on the landscape prior to the onset of spring melt. Information from the snow surveys will provide quantification of the hydrologic "pulse" of contaminants resulting from spring snowmelt. Snowmelt can be the dominant source of water for several weeks in tributaries.
- river-ice monitoring (M0 to M9 inclusive) for its effects on flow and under-ice sediment transport (especially during the dynamic periods of freeze-up and break-up).
- measurements of surface flow and related sediment transport from the landscape to the tributaries and directly to the Athabasca mainstem.
- assessment of groundwater interactions with surface flows (this component is part of the proposed Surface Water Quality monitoring program described below in section 5.0), recognizing that there could be significant delays in the response of groundwater to watershed disturbance because of flat terrain and long travel times.
- discharge, sediment yield (bed + suspended) and particle size measurements from the tributaries into the Athabasca River. This will permit quantification of tributary fluxes to the main stem and provide the basis for evaluating the effect of various degrees and types of oil sands developments on tributary flow and sediment yield.
- a suite of cross-sectional sediment survey sites (suspended sediment, particle size and bed load transport) along the LMR (M0, M2, M3 and M9) to permit sub-reach mass-balance calculations of sediment augmented by period sonar profiling of the LMR river bed for validation/correction of mass balance calculations.
- Incorporation of conservative source tracers measurements for ongoing water balance determination (e.g. Deuterium and ^{18}O isotopes).

4.2 Meteorological Stations

Climate parameters will be monitored by an enhanced network of regional meteorological stations. These stations will provide necessary site-specific and synoptic regional information on the climatic drivers of hydrological and landscape-related processes. The meteorological stations will provide finer spatial resolution data for process-based studies (i.e., focused monitoring), and contribute to hydrological and sediment transport model development and validation. In addition, an enhanced network of precipitation/snow gauges will be installed for evaluating meso-scale variability during events such as intense convective rainfall events and those affecting winter snow dynamics (distribution, sublimation, etc.). These stations are part of the meteorological network identified in Section 6.0 for the aerial deposition monitoring program.

4.3 Hydrology

Flow (hydrology) has been reasonably quantified over the past 40 years in the Lower Athabaska River (LAR) at Fort McMurray. Hydrologic, hydraulic and river-ice modelling has been performed elsewhere in the Mackenzie basin that could be applied to the LAR (e.g., Beltaos and Prowse 2009; Hicks and Beltaos 2008; Hicks 2009). The RAMP program has provided an expanded spatial hydrometric network in the region; however, enhanced continuous time series (particularly improvements on winter monitoring) are required. The requirements of the Instream Flow Framework for the LAR (AENV 2007) have enhanced winter monitoring of flow at existing Water Survey of Canada sites, however, daily representative monitoring of major tributaries, their primary sub-catchments and the LAR at strategic locations between Fort McMurray and Old Fort are required. This monitoring program requires daily discharge estimates for all major tributaries and the LAR upstream (M0 and M2) and downstream of Fort McMurray (M3), and downstream of the Firebag River near Embarrass airport (M9) on a continuous basis. We further specify a design where flow uncertainty does not exceed 5% during ice cover, or explicitly report uncertainty with flow estimates where a 5% uncertainty cannot be achieved.

Low flows in the LAR occur during late winter and have been identified as potentially having adverse impacts to the aquatic ecosystem (CEMA 2009). These impacts may occur at flows near 100 m^3/s, and, with industrial withdrawals managed between 4 and 15 m^3/s – accuracy of river flow estimates needs to be within this range. Achieving this level of accuracy in flow estimates under ice is a challenge but can be achieved with advanced monitoring systems. EC and AENV have committed to developing a number of advanced monitoring technologies through space-based telemetry and through-ice Doppler systems. Space-based systems will evaluate the entire LAR at critical junctures (evaluating feasibility of monthly estimates), thereby help identifying access restrictions into critical side-channels and tributary habitats. Doppler systems could be deployed during low flow winter conditions (e.g., when flows are below 120 m^3/s) when yellow conditions/thresholds are reached (see AENV 2007).

In order to quantify contaminant mass balance, there is a need for accurate hydrologic mass-balance calculations. This will be achieved through hydrologic modelling using changes in stable isotope ratio (Deuturium & ^{18}O) mass balances, and using improved regional data on relevant hydrological input and outputs such as evaporative flux, precipitation, source ratios. These data will be collected at suitable meteorological stations in the region.

4.3.1 Hydraulics and Sediments

The behavior of waters as they mix in the lower Athabasca river controls the site-specific characteristics and the transport of contaminants downstream. Hydraulics are described by a number of reasonable models and the impact on transport are understood generally through lateral mixing of dissolved or suspended species and Shields equations for transport of sediment-bound compounds. Hydraulic behavior, in the context of understanding contaminant fate and transport, will be better quantified and assessed in this program through monitoring of cohesive and non-cohesive sediment transport. Research programs have already been identified within EC and AENV to address unknowns in the science of cohesive and non-cohesive sediment transport. These programs are essential to the long-term success of the monitoring program.

4.4 Site Locations, Parameters and Sampling Frequency

4.4.1 Lower Mainstem Reach (LMR)

Mainstem sites provide upstream and downstream boundary conditions for the LMR through the oil sands development region. Where possible, the sites were selected to include (active) hydrometric stations with historical hydrologic data (river flow; suspended sediment data). In addition, sites were co-located where possible with other existing medium to long-term monitoring activities (e.g., AENV LTRM Water Quality Monitoring Sites; AENV Contaminant Load Monitoring Sites, RAMP sites) to build upon additional historical and present-day water quality data.

Four long-term integrated hydrological/suspended sediment monitoring stations are recommended for the LMR. Sampling stations are proposed for sites M0-at Athabasca, M2-upstream of Fort McMurray, M3-downstream of Fort McMurray and the Clearwater River, and M9-downstream of Firebag River and near Embarras Airport (Figures 6,7; Table 3). At each of these locations, in addition to the water quality parameters identified in Section 5 (below), suspended sediment-related parameters to be measured include Total Suspended Sediment (TSS), Turbidity, Sediment particle size distribution, % Organic Content and standard Water Survey Canada hydrometric data (e.g., flow, discharge, water levels, temperature).

Hydrometric and site-specific meteorological data will be collected on a continuous time scale. Sampling for other physical suspended sediment parameter such as TSS, particle size determination, etc., will be conducted at a minimum monthly, but the frequency will be adjusted to weekly or bi-weekly as necessary to capture variation through hydrograph rise, peak and recession. Bulk-time integrated suspended sediment sampling will be conducted following Philips et al. (2000) and Macdonald et al. (2010).

4.4.2 Tributaries

Estimation of the magnitudes and variability in tributary hydrology and related sediment dynamics is necessary to estimate the transport and relative contributions of materials from upper catchments into the LMR. These include sites located near the confluence with the Athabasca mainstem to provide necessary information on the water and sediment inputs (quantity, quality) to the mainstem and their variability over various time-scales (individual storm events, seasonal, annual regimes, inter-annual variability, trends, etc.). Tributary sites also provide reach-specific information on the impact of oil sands development on tributary water and sediment regimes in addition to providing mass-balance loading estimates to the Athabasca River.

Eight primary tributary sampling stations have been selected for continuous hydrometric and suspended sediment sampling. Proposed sites include: CH1, CL2, ST1, MU1, MA1, EL1, CA1 and FI1 (**Figures 6,7**). The mouth of the Tar River was also originally considered, however, this river is now actively being “relocated” as part of an oil sands development project. Information on similar hydrometric and suspended sediment parameters will be collected as described above for the mainstem sites. Tributary sites provide important information for closing the water and sediment budgets for the Lower Athabasca (using a mass balance approach).

Tributary sites have been spatially distributed in the Athabasca basin to include catchments that are highly, moderately and minimally impacted by oil sands development. Tributary catchments minimally impacted by development may be the closest approximation to a “baseline” or “reference” condition before approved oil sands development commence, although defining a true, unimpacted “reference” system is probably no longer possible to find.

Tributary sites also provide information on the possible effects of different oil sands developments/technologies on water and sediment delivery to the Athabasca. Hence sites have been identified that include catchments minimally affected by oil sands development, affected by mining, affected by SAGD, and affected by a combination of mining and SAGD activities. To improve our understanding and modelling/prediction capabilities in unmonitored tributaries, the selected tributaries and sites also cover a range of catchment size and runoff regimes.

Table 3 provides specific details on site descriptions, sampling regimes, the rationale for the chosen spatial and temporal resolution. A summary of other design and implementation considerations/issues is also provided in **Appendix B**.

4.5 Application of New and Emerging Technologies

Given challenges in year-round accessibility of sites and in quantifying river flow and sediment loads during dynamic periods of ice conditions, new and developing technologies will be incorporated into the monitoring program to address these types of issues. These include:

- satellite and other remote-sensing technologies are proving to be useful tools for river ice and flow monitoring, determining snowpack SWE (snow water equivalent) – if on relatively flat terrain and not too deep, sediment transport in rivers (tracking of plumes; Total Suspended Sediments (TSS)), atmospheric conditions (dust), etc. These technologies will be implemented where possible to improve the spatial and temporal resolution of required measurements.
- the use of instrumented buoy systems will be assessed for deploying in the river course. An Acoustic Doppler Velocity Profiler (ADCP) on a buoy can provide vertical velocity profiles (and allows determination of bed shear stress); water quality sondes can provide turbidity measurements which can be converted to TSS via establishing a rating curve (the sondes also measure other parameters important to water quality monitoring, such as dissolved oxygen, water temperature, conductivity, etc.); a meteorological instrument cluster on the buoy can act as an additional meteorological station.
- increased use of passive and/or integrative sampling devices. Shown below (**Figure 8**) is an integrated suspended sediment sampler that is effective for flow and time integrative sampling (i.e., one week, one month, etc.) of bulk samples for chemical/biological assessment and experimentation (partitioning, particle size-contaminant relationships). Such integrative samplers will be used where appropriate for both the Athabasca mainstem and its tributaries.

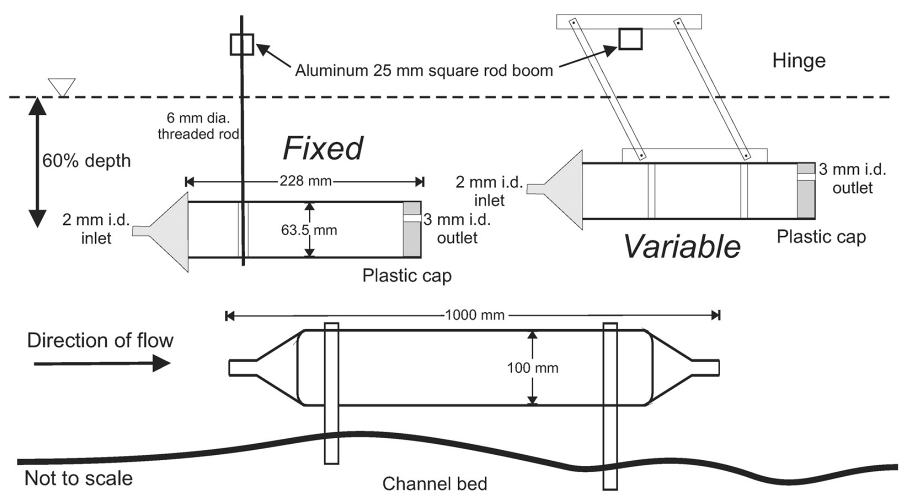


Figure 8. Schematic diagram of the fixed (left) and variable (right) model traps in cross-section. For comparison, a schematic diagram of the Phillips et al. (2000) trap design is shown (bottom figure). Note that the figure is not to scale (from McDonald et al. 2010).

5 SURFACE AND GROUNDWATER WATER QUALITY MONITORING

An integrated and standardized surface and groundwater quality monitoring component has been designed to ensure to provide the necessary data/information to assess and predict current and future impacts of oil sands development on water quality (including sediments) in the Lower Athabasca mainstem and its tributaries.

The ability to assess changes in reach-specific and regional water quality conditions is directly dependent on the availability of standardized data obtained at sites located at relevant spatial and temporal scales. The objectives of the surface and groundwater quality monitoring components are to provide the necessary data/information that address the questions:

- What are the impacts of oil sands development on water quality (including sediments) in the Lower Athabasca mainstem, and its tributaries?
- What are the impacts of individual oil sands development activities on surface water quality?
- What is the relative importance and contribution of groundwater quality and quantity to surface waters?
- Is there groundwater seepage from tailings ponds and/or other oil sands industrial operations entering the surface water system?
- What are the non-point contaminant sources (e.g. atmospheric deposition) related impacts on surface water quality? This links with the Air Deposition to Water Monitoring component described below in Section 6.0 (below).
- What are the long-term trends in contaminant concentrations and fluxes for selected sampling sites?

Although this component of the monitoring program deals specifically with surface and related groundwater quality parameters in the Lower Athabasca and its tributaries, it is directly linked to the hydrometric/sediment monitoring component (above) from which contaminant fluxes will be calculated, the air deposition-water quality component (Section 6) which provides information on atmospheric contaminant deposition directly to the aquatic environment and to the adjacent landscape (i.e., onto snow in winter; on the landscape); and, to future biomonitoring and effects-based monitoring programs that will be added in the upcoming Phase 2 of the Lower Athabasca Water Quality Monitoring Program.

5.1 Core components

To adequately quantify and characterize the water quality in the Lower Athabasca and its tributaries, the following core components are needed:

- an integrated network of meteorological and hydrometric stations to provide standard climate and hydrological measurements (see Section 4 above).
- identification of the various classes and types of contaminants directly related to oil sands operations, with capabilities to separate from natural bitumen compounds (e.g., via chemical/biological analytical fingerprinting methods).
- quantification of contaminant loadings, transport and fate (environmental fluxes via mass-balance approach).
- robust QA/QC protocols and Standard Operating Procedures (SOPs) in place for all designated core chemical parameters. Protocols will need to be developed for new techniques, and for analytical methods for chemicals where protocols do not currently exist or require validation (e.g., naphthenic acids). Standard operating procedures will include not only laboratory handling but also sample collection, chain of custody and archiving of data and samples (if appropriate) (see Section 7, below)
- direct measurement of groundwater quality discharging to surface water (e.g. Roy and Bickerton 2010 - provides a sensitive and reliable method for the detection of tailings seepage effects to surface water and aquatic ecosystems). Surface water sampling alone is unlikely to reliably detect seepage effects (confounded by dilution effects; particularly in the Athabasca) from tailings impoundments except in extreme cases.

5.2 Site Locations, Parameters and Sampling Frequency

5.2.1 Detection Limits – New Sampling Approaches

> ***State-of-the-art sampling/environmental data acquisition systems will be implemented and validated to improve spatial/temporal coverage and data interpretation.***

Concentrations of chemicals, both naturally occurring and industrial inputs can vary substantially over time and space within any system. A confounding challenge also arises when compounds of concern are at concentrations at or below analytical detection limits or are at levels where the concentrations are at or close to the threshold of concentrations known to have an observable biological and/or ecological effect. For example, in the RAMP program, many temporal trends in PAC concentrations in the Athabasca River could not be statistically assessed with sufficient confidence because levels were at or below analytical detection limits (RAMP 2010). In such cases, standard point-in-time bulk water sampling may not adequately measure potentially ecologically relevant exposure concentrations to biota. Hence, with the exception of spring melt pulses (where metals and acids in the first few days of melt can be higher than average), the implementation of integrative passive sampling and related analytical procedures could improve the quantification of such compounds, which includes metals, PACs, NAs, and other oil sands or industrial related contaminants.

Bulk water sampling frequency at these sites will be monthly, although provisions will be made for enhanced daily, weekly or bi-weekly sampling to capture variations through hydrograph rise, peak and recession and to capture key contaminant loading events such as aerial deposition through spring snow melt. In addition to conventional grab water sampling, a series of integrated passive samplers will be deployed to better quantify environmental concentrations of oil sands related organics contaminants, trace metals and naturally occurring petroleum compounds.

Building on the experience gained in the AENV Contaminant Load Study (AENV 2010), the Muskeg River Water Quality Program (AENV 2009), and Environment Canada's integrated oil sands research program, the proposed design will utilize and assess the efficacy of new passive sampling systems at each major tributary mouth and at key main stem locations (Table 3) to better integrate and quantify contaminants/compounds of concern. Passive sampler types will include:

- SPMDs (Semi-Permeable Membrane Device) will be used to measure of bioavailable, lipophilic pollutants in water such as petroleum constituents such as Polycyclic Aromatic Hydrocarbons (PACs) and aliphatic hydrocarbons, etc. SPMDs are currently deployed by several program or Polyethylene membranes (PEM, deployed in Kelly et al 2009). The PEMs require less lab work since no triolein is involved. For quantitative work both types of samplers will need calibration (i.e., using performance reference compounds and taking in to account water temperature);
- POCIS (Polar Organic Chemical Integrative Sampler) – for polar compounds with log octanol-water partition coefficient <4. Consists of a solid phase absorbent held between microporous polyethersulfone membranes. Same considerations need to be concerning calibration as with SPMDs.
- Diffuse Gradients in Thinfilms (DGTs) will be used to sample bioavailable trace metals.

SPMD and POCIS samplers also enable *in situ* extraction and isolation of trace organic contaminant mixtures for future toxicity assessments and toxicity identification evaluation (TIE) approaches as necessary.

5.2.2 Lower Mainstem Reach (LMR):

The core Lower Athabasca River mainstem sampling stations are proposed for locations M1-M9 (**Figures 6,7; Table 3**), which would quantify key tributary-specific loadings. In addition to the hydrometric/meteorological and sediment data being collected at these locations (see Section 5.0), bulk water samples will be taken to measure the following chemical parameters: major Ions, nutrients, dissolved and particulate organic carbon, metals, and organic contaminants (e.g., PACs, Naphthenic Acids). Measurements of trace metals will include both total and filtered forms, and methyl mercury. Sample types for organic contaminants and metals include:

- particulates on filters (if analysed; were not analysed in Kelly et al 2009) – this could be run for hydrophobic compounds (e.g., PACs and OSPW related chemicals);

- unfiltered water –the multi-element suite is run on this sample by acidifying the sample and analysing the digest by ICP-MS;
- dissolved phase (<0.45 um) – normally the multi-element suite is run on this phase and fraction on particles = unfiltered – filtered. This approach is also appropriate when TSS is high, however, alternative methods may be needed when low (e.g., Droppo and Jaskot 1995);
- surface water samples for selected organics – e.g., for naphthenics or other anionic substances if POCIS does not give broad spectrum. Collected by hand or by submersible pumping system.

Appendix B provides summary of the preliminary core chemical analyte list for the suite of chemical elements and compounds to be tested.

Water sampling will be done at fixed depths with Nislin samplers or with portable battery-powered submersible pumps, at multiple points at a given site and subsamples may be pooled to obtained cross-sectionally averaged samples.

Monthly (final frequency to be confirmed from preliminary sampling) cross-sectional composite bulk samples using Ponar grabs of surficial sediments will also be taken at each location (frequency is to be determined). Analysis of the samples will provide information on the physical and chemical characterization of surficial sediments (e.g., lithology, grain size, and trace-metal distribution). The final selection of sites will need to consider the biological relevance and contaminant deposition.

Certain physical parameters such as lithology can be subsequently compared between locations to define spatial and temporal change in status and trends. Sediments will also be analyzed for oil sands organic contaminants and trace metal, providing additional information on possible exposure concentrations and pathways to aquatic benthic biota and fish early life stages.

5.2.3 Lower Athabasca Tributaries

Figures 6,7 and **Table 3** summarize the proposed sites for tributary sampling. In addition to these, sites located in smaller catchments such as Clarke Creek, McLean Creek and Fort Creek on the east side of the lower Athabasca mainstem and Emundson Creek on the west side will be considered.

Surface water chemical parameters to be measured at all tributary stations are the same as for the mainstem stations indicated above (section 5.2.2) and outlined in Appendix B. Passive sampling of contaminants will only be conducted initially at tributary mouths as discussed above.

5.2.4 Groundwater Seepage Quality and Surface Water Interactions

Estimation of groundwater seepage and possible surface water interactions requires a broader synoptic approach to spatial sample placement and related temporal frequency. A series of distinct geographic (mainstem and tributary) sampling regimes will be conducted to characterize the groundwater quality (and its variability) discharging to the reach under examination (with an appropriate number of replicates taken for QA/QCs purposes). For example, in areas more distant from oil sands operations and tailings ponds, spatial sampling will be less dense. Sample densities proximate to tailings ponds (e.g., Suncor Pond 1) will be approximately 50-150 m apart (i.e., based on preliminary Environment Canada studies in the vicinity of Suncor's Pond 1; about 70 samples along the 4 km shoreline). Adjustments to site spacing will be conducted if deemed necessary after preliminary analyses. Within the Athabasca mainstem, riverine groundwater sampling will build on existing tailings pond studies and sites currently being used by Environment Canada and Alberta Environment. Riverine groundwater samples will be collected during four time intervals (summer, spring, autumn, winter), with the initial proposed levels of site replication focused on operations closest to surface water and new areas scheduled for development.

Groundwater chemical analytes to be measured will be the same as described for the surface water stations (**Appendix B**). **Table 4** summarizes groundwater quality and quantity indicators that can be used to describe the potential impacts of oil sands developments on local and regional groundwater resources.

Table 4. Proposed Integrated Groundwater Monitoring Approach

Indicators		Condition indicator	Development indicator
Quality	Primary	pH, conductivity, dissolved oxygen, redox; major anions/cations, trace metals (e.g., As, B, V, Se. U), ammonia/ammonium, naphthenic acids, TDS	Density of mine-related seepage sites for relevant aquifers. Density of disposal operations in a given area.
	Secondary	BTEX (benzene, toluene, ethybenzene, xylenes) - (near ponds and upgrading operations); stable isotopes (deuterium and O18)	
	Tertiary	PACs, other stable & radiogenic isotopes (e.g., C14, S36, N15,)	
Quantity	Primary	Temporal change in groundwater surface elevation in an aquifer management unit at an established monitoring location. Changes in measured baseflow (tributaries) in receiving waters. (determined from hydrometric gauging)	Density of dewatering activity in overburden and basal aquifer for mine development.
	Secondary	Impact to sensitive water body or wetland as demonstrated by water level changes. Accuracy of modelled versus measured conditions in established monitoring wells.	

5.2.5 Paleo-coring and determination of historical/baseline conditions

An assessment of potential paleo techniques that could be used to provide historical contextual information to aid in monitoring data interpretation will be performed. If appropriate, historical levels and trends in trace metals, mercury, and organic contaminants will be assessed using sediment core samples obtained from suitable depositional areas. The cores will be age dated using standardized methods (e.g., ^{210}Pb and/or geochronological methods) and analyzed for relevant contaminants. Profiles of stable metal isotopes, metal ratios, and changes in various organic compounds will provide information on historical deposition to the region and help quantify the influence of emissions from oil sands activities on contaminant burdens in sediments. The potential for spatial variability in sediment contaminant loading necessitates collection of cores from multiple locations (e.g., lakes) within the Athabasca region.

5.2.6 Oilsands Contaminants of Concern - Naphthenic Acids (NAs)

Particular focus will be placed on quantifying the types, sources, transport and fate of contaminants of concern such as Naphthenic Acids (NAs). NAs are a large class of cyclic, organic compounds that are associated with oil sands operations and have been determined to be a significant source of toxicity of oil sands process water (OSPW) (Giesy et al. 2010). NAs are a complex mixture of compounds that have been difficult to characterize, but progress is being made by Environment Canada's oil sands fingerprinting research program using state-of-the art analytical procedures to identify and characterize this group of contaminants. Monitoring and analyses of NAs will be tightly linked to these research efforts.

5.2.7 Linkages of Water Quality Measures to the Prediction of Toxicological Effects

Many of the PACs that will be measured in the proposed water quality program (see Appendix B for analyte list) have at present, no established effects thresholds. Hence, limitations exist in taking water chemistry information and using concentration values to predict toxicological effects. For example, for compounds such as alkylated PACs, it is not yet possible to conduct a proper risk assessment linking measured ambient concentrations with potential levels of toxicological response. Such issues will need to be further clarified in relation to how the water chemistry information can be subsequently used and interpreted to assess biological and ecological impacts.

Water quality criteria for metals that are designed to be protective of aquatic life, can at times be over-protective as a result of natural, site-specific differences in water chemistry. Such differences can affect metal speciation and bioavailability, which are fundamental to toxicity assessment. Many studies over the last two decades have strengthened our understanding of metal chemistry in water, and their toxicity to organisms. Our awareness of processes that can mitigate toxicity through formation of organic and inorganic metal complexes, and sorption of metals to organic matter has also increased considerably.

The biotic ligand model provides a quantitative framework for assessing metal toxicity over a range of hardness, pH and dissolved organic carbon (DOC) levels, and allows for the prediction of the degree to which site-specific water chemistry will affect metal toxicity. As a result, it becomes important for aquatic monitoring programs to track changes in these characteristics in time and space as proposed in this program.

Using this approach the toxicity potentially associated with a given measured metal concentration can be successfully predicted. Recent studies such as Paquin et al. (2000) have outlined the potential utility of this approach to metal monitoring, for establishing site-specific water quality criteria, that take into account local differences in water chemistry parameters that affect the partitioning and speciation of heavy metals. Such an integrated perspective will need to be considered during the Phase 2 design of the water quality program.

5.2.8 Application of New and Emerging Technologies

Given the spatial heterogeneity and difficulties associated with accessing sites, new sampling technologies should be constantly assessed in terms of their possible implementation in the program. New buoy-based water quality sondes, satellite imagery for monitoring changes in cryospheric conditions (river ice; snow distribution and depth; snow water equivalence), and automated instrumentation that can transmit real-time data via satellite are examples of developing technologies that have potential applicability in the program.

With respect to connectivity with groundwater, remote sensing technologies may be applied to further focus and optimize monitoring efforts. In particular, connectivity of basal water (i.e., groundwater in contact with the bitumen ore body) with surface waters is believed to provide a conduit for organic contaminants, whether naturally occurring or anthropogenic. Given that the basal water typically has an elevated saline component relative to surface water, there may be an opportunity to apply remote sensing technologies to identify saline seeps. Alberta Environment has commissioned such preliminary surveys for sections of the Athabasca River using electromagnetic induction to identify areas of higher conductivity in the river bed, thereby inferring connectivity with saline aquifers. In addition, airborne geophysics using electrical of electromagnetic spectrometry, for example, could be applied to the Athabasca River and its tributaries to further constrain the location of saline seeps. When properly validated (e.g., by electromagnetic induction), this information could be used to focus the surface water monitoring program, especially in relation to the identification of areas of greater or lesser impact (e.g. positive controls, reference areas), and to populate surface water quality models with more detailed boundary information.

6 AERIAL DEPOSITION MONITORING

Aerial deposition of stack emissions, mining operations particulates and emissions from tailings ponds has been identified as a possible significant source of both direct and indirect oil sands contaminant loadings to the Athabasca River basin.

Aerial deposition of stack emissions, mining operations particulates and emissions from tailings ponds has been identified as a possible significant source of both direct and indirect oil sands contaminant loadings to the Athabasca basin (Kelly et al. 2009, 2010). This research also identified some of the key gaps in data and the importance of having better regional estimation of aerial inputs and their relationship to changes in water quality parameters. Moreover, it reinforced the need for integrated air, hydrometric, and water quality sampling at appropriate spatial and temporal scales.

The goal of the air deposition monitoring program is to provide the necessary data to address the following questions:

- What is the direct aerial deposition of the identified contaminant species (in analyte list, Appendix C) to the surface of the Athabasca River and its tributaries?
- What is the aerial deposition to the landscape in the Athabasca River Basin from Fort McMurray to the Athabasca delta?
- How does the aerial deposition to the landscape affect water quality in the tributaries and mainstem?

In order to answer the third question above, the program includes studies within selected catchments to provide the necessary information to determine key processes affecting transport and fate of material deposited aerially to the landscape and to quantify the contribution to surface and groundwater.

6.1 Existing Regional Air Quality Monitoring Programs

Table 5 (***see page 63***) and **Appendix C** summarize the current air quality stations operating or being installed in the region or adjacent areas. Data collected at these sites are currently being used by four air sampling programs operating in the oils sands region:

1. National Air Pollution Surveillance Program (NAPS) (Environment Canada and Alberta Environment);
2. Wood Buffalo Environmental Association (WBEA) (broad stakeholder involvement): industry compliance and general surveillance, some data reported to NAPS;

3. Canadian Air and Precipitation Monitoring Network (CAPMoN): currently installing downwind sites in Saskatchewan and upwind in Alberta for the purpose of monitoring for acidifying pollutants near acid-sensitive lakes; broad regional scope; and,
4. Environment Canada Air Quality Research Division Surveillance Study for determining atmospheric deposition of polycyclic aromatic compounds (PACs) and particulate metals: three active sampling sites near sources and approximately 17 passive sampling sites in region for Dec 2010 to June 2011. Sampling and laboratory analysis protocols are closely linked with NAPS and the Integrated Atmospheric Deposition Network. We propose to continue these measurements as Part 1 of implementation plan.

The above programs form a solid basis upon which to build a more comprehensive regional atmospheric monitoring program in support of the determination of atmospheric deposition of toxic or potentially toxic organic substances and metals emitted from oil sands development.

6.2 Core components

To determine atmospheric deposition pathways, there is a need to know both dry and wet deposition. Inputs related to dry deposition to the mainstem Athabasca River may be variable; wet deposition to the river may be elevated for episodic periods during spring snow melt, spring freshets and major rain events. Hence, associated watershed sampling must occur to calculate actual concentrations and loading coefficients.

Snow collections serve to quantify winter deposition but are subject to uncertainties due to melting and loss of chemicals. There has been only limited comprehensive snow collection (Kelly et al. 2009, 2010; Alberta Oil Sands Environmental Research Program (AOSERP) studies in the late 1970s/early 1980s – Barrie and Kovalick 1980; Murray 1981) for pollutant inputs and given the importance of snow melt inputs in this climate zone more systematic transect watershed sampling of snow will be integral part of the air monitoring program.

Since estimation of contaminant flux to surface waters is a core objective, paleo-environmental approaches will be explored to quantify present and historical baseline conditions. The potential for spatial variability in sediment contaminant loading necessitates the collection of cores from multiple lakes. Parallel analysis of surface water samples for a temporal assessment of dissolved and suspended contaminant concentrations is also necessary.

6.3 Monitoring Program Design

The air deposition monitoring component is designed to address two strategic objectives in relation to quantifying the distribution, fate and magnitude of the deposition of aerial contaminants on the Athabasca mainstem and primary tributary catchments. The two program objectives are:

1. **Regional loadings of aerial contaminants to the terrestrial and aquatic surfaces, and;**
2. **Assessment of the distribution and fate of aerial contaminants upon entry to terrestrial systems.**

Figure 9 summarizes the proposed new and expanded sites for the air deposition monitoring program described below.

6.3.1 Regional/Synoptic Aerial Deposition

What is the direct deposition of oil sands related contaminants to the surface of the Athabasca River and its tributaries?

A new synoptic network of monitoring sites will be established. Building on the three sites in the core region established under the current regional surveillance study, two new sites will be added downstream along the Athabasca (one near Firebag River and one near the boundary of the Wood Buffalo National Park) to look at expansion to the north. One site in the existing core industrial region would continue as a long-term station and the two new sites would be both long-term. Two of the existing sites could prove to obtain better estimates of spatial heterogeneity and variability in deposition patterns. The new sites will also be supplemented with passive samplers as indicated by the surveillance study that is underway. The final latitudinal and longitudinal coordinates of the proposed new sites will be determined by modelling scenarios of current and future development and demonstrating the impact of the data from each site to the quality of deposition maps produced. Active, continuous measurement sampling sites will require locally-clean power and an operator. “Passive sites” do not require power and will be visited on a monthly and/or seasonal basis. The preliminary proposed “analyte” list for all active and passive sites is provided in **Appendix B**.

What is the deposition to the landscape in the Athabasca Basin? How does this deposition affect water quality in the tributaries and main stem?

In addition to the sites outlined above and as informed by modelling, up to eight new sites will be installed. The proposed locations include: one south of Fort McMurray; two to the east and two to the west of the mineable area, along the boundary of the mineable area; one along the western edge of the Athabasca basin; one at the Alberta/NWT border; and one at the Saskatchewan border. Each of the sites will also be supplemented with passive samplers as used by the current surveillance study. The sites will be co-located where possible with sites monitoring air for criteria air contaminants (particulate matter, sulphur and nitrogen compounds and volatile organic substances) as directed by the forth-coming development of the monitoring plan for air in Phase 2. The amount and timing of precipitation to the landscape and the contribution of snowmelt to the aquatic system will be determined through measurements made in support of Section 6 above, remote sensing and modelling with loadings determined using measured concentrations from the monitoring sites.

6.3.2 Spatial and Temporal Resolution Rationale

The proposed synoptic sampling design includes a large number of sites within a relatively small geographic area, when compared to monitoring in other areas of Canada. Many spatially-distributed sites are necessary because of:

- the fast pace and changing extent of development (mining and *in-situ*) and the technologies and processes they use;
- the large amount of variability within the landscape, including distribution of parameters in bitumen and surface water;
- the need to identify and quantify various point-source emissions, deposition and potential effects on surface water quality; directly to a water body or indirectly on the landscape at the watershed scale;
- significant spatial gaps in air quality information. Air quality is currently not monitored between Fort MacKay and Fort Chipewyan or at the AB-SK and AB-NWT borders, where there are concerns about atmospheric deposition and potential effects on surface water quality;
- the current air quality monitoring program being relatively restricted to locations near the Athabasca River on a north-south trajectory between Fort McMurray and Fort MacKay. Sampling farther to the east and west would help identify the aerial extent of increased deposition related to oil sands development.

Both wet and dry deposition need to be measured over a far larger geographic area than currently done by WBEA. For atmospheric deposition the key issue is having background sites for gas phase, particles and wet precipitation outside of the immediate or proposed development area – N, S, E and W. Also atmospheric deposition sites are needed at the outer edge of development to assess more direct regional emissions and deposition including dust and pollutants from mining itself (e.g., vehicles). Currently the atmospheric deposition from WBEA is only along the developments near the river.

Since the region is expected to undergo rapid expansion of industrial activity and the information will be needed on short time lines (e.g., changes over 1-year compared to decadal for more spatially distributed networks), the additional sampling sites will be needed and sampling frequency will be high (as frequent as possible for detection of deposition pathways and magnitudes).

Precipitation sampling will be event-based where access to the site permits and every two weeks or monthly at sites difficult to access. If insufficient volume for analysis is available, samples will be added for analysis.

We will attempt to model dry deposition based on observed gas and particle phase concentrations, since it is difficult to measure directly. Additional air particle measurements will be made to provide the input needed for modelling. A large number of hydrocarbons co-exist in gas and particle phase. The dry deposition for gases is different than for particles; furthermore, the size of the particles affects their deposition rates. To avoid large uncertainties in dry deposition calculation, it is recommended that the total ambient concentrations, gas-particle partitioning and the particle size distributions should be measured.

In all cases, data analysis would be performed taking back-trajectory into account. By this means, measurements at a single site will be used to characterize different sources in the area. Sampling frequency will need to be high for this purpose. Key parameters to quantify must include core meteorological attributes (e.g., wind speed and direction, temperature, relative humidity) and fast-response plume indicators such as PM2.5 number concentration and NO_2 and SO_2 mixing ratios.

6.3.3 Catchment-specific Deposition and Transport Monitoring

To what extent are atmospherically deposited contaminants from oil sands mining and upgrading and in-situ extraction exported from select catchments in the Athabasca River basin?

To better identify and model transport pathways, efficiency, transformation, and export of atmospherically deposited contaminants within small catchments in the Athabasca oil sands area, two sub-catchment monitoring networks will be established. One will be situated in an ”undisturbed” landscape to assess baseline or background conditions and the other will be in an industrially modified landscape. Information from these catchment-specific networks will be used to estimate aerial deposition related contaminant transport to surface water at a landscape scale, based on deposition estimates from atmospheric transport models and from directly measured deposition rates.

The “undisturbed” catchment must be located within a physically undisturbed area of relatively high deposition of organic contaminants and heavy metals from sources within the mineable oil sands area. Ideally the site must have a defined surface water flow pathway (defined stream channel or lake) and must contain hydrologic response areas that are representative of the larger study region, although this might be difficult to attain except in headwater areas.

Alternatively, if an appropriate fluvial system cannot be identified, monitoring could focus on wetland-dominated catchments on the assumption that precipitation on upland areas goes to storage and that there is no export of contaminants. A lake-based catchment may be the ideal study location in that contaminants that are exported to surface waters are not immediately exported from the catchment. An analysis of contaminant flux using lake sediment cores or sediment traps may also be possible.

Wet deposition of key contaminants (hydrocarbons, metals and their degradation products) will be measured throughout the catchment. Deposition may be further characterized by type (rain, snow, adsorptive, dustfall, etc.) and composition (particle size, major ions). Analysis of contaminants of concern in peatland vegetation may provide a robust assessment of actual deposition rates and composition. Consideration however, must be given to the transformation of metals in the highly reducing peatland environment. Providing that metals deposited in peatlands are initially in relatively insoluble forms, they may be mobilized as they transition into a reducing or acidic environment with continuing biomass accumulation at surface. In this context, export of metals from peatland-dominated catchments may be delayed. Analysis of metal concentration and speciation in peat cores may be appropriate.

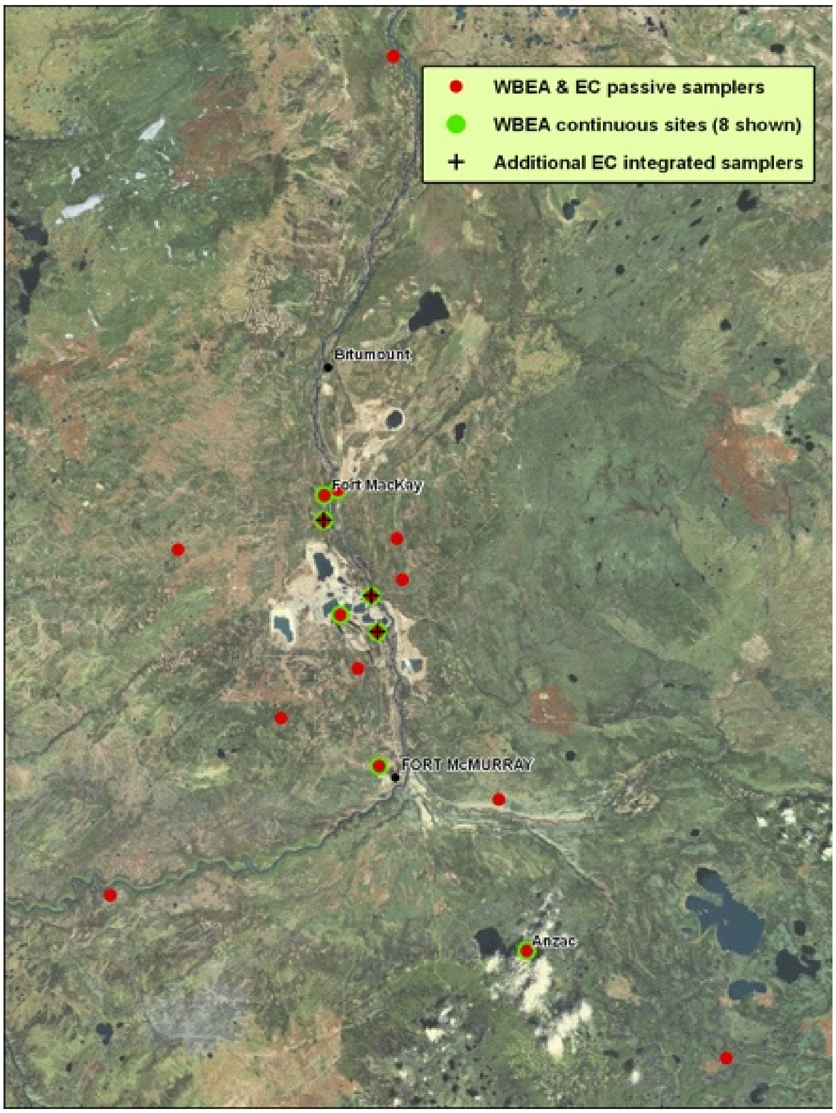


Figure 9. Map showing the proposed locations for an expanded sampling network. Red dots are WBEA and EC (2010) passive air samplers, and Green dots are WBEA sampling sites, currently in use for the surveillance study. + signs are proposed additional powered hi-volume air and precipitation monitoring.

6.3.4 Paleo-limnological Reconstruction and Analysis of Historical Contaminant Trends

What is the historical deposition of selected oil sands contaminants in the Athabasca River basin region and are there chemical markers of anthropogenic emissions?

An assessment of the potential for paleo-limnological reconstruction of historical contaminant trends will be performed. There is concern that variable sediment deposition rates may bias results, with a consequent poor ability to use paleo data as contextual information with which to evaluate contaminant trends over time. If appropriate, collection of lake and pond sediment cores from the region within 50 km of major developments would support the atmospheric deposition study as well as provide information on transformation and mobilization of contaminants. This work has begun (e.g. Curtis et al. 2010; Hazewinkel et al. 2008) and can possibly be extended to provide geographical coverage of the region. Careful consideration will be made regarding the final selection of sites to ensure areas are representative of good historical records.

Sediment cores would be collected from deep areas of the lakes and ponds and dated (using ^{210}Pb, ^{137}Cs) and sedimentation rate estimated with dating models. Selected cores would be analyzed for the same contaminant suite as for atmospheric deposition and a historical profile constructed. Interpretation of the data would be aided by ancillary measurements such as organic carbon, diatoms and other microfossils and algal pigments. The potential for spatial variability in sediment contaminant loading, due to factors such as size of the lake catchment, changing water levels particularly in smaller water bodies, necessitates the collection of cores from multiple lake basins.

7 QA/QC, ANALYTICAL METHODS, STANDARD OPERATING PROCEDURES, STATISTICAL POWER

> ***Open, transparent analytical standards and data access: QA/QC protocols, Standard Operating Practices will be clearly defined and implemented.***
>
> ***State-of-the-art analytical procedures will be utilized and developed through qualified laboratories.***

7.1 QA/QC

Many good QA/QC methods exist for organic and inorganic contaminants in water, biota and atmospheric samples and the QA/QC approach in this program will adopt the best available practices. Examples are the National Air Pollution Surveillance Network and the integrated Atmospheric Deposition Network (PACs, heavy metals), the Northern Contaminants Program (mercury, heavy metals), and QUASIMEME (selected metals biota and sediment), Alberta Environment (2007) and Environment Canada's EOALRSD Laboratory Services for the Oil Sands Project (Environment Canada 2011).

In general, a robust quality assurance program for chemical analysis will:

- be designed to assure comparability among participating laboratories in the analysis of a broad range of analytes and to take action when lab results are out of line with consensus or reference values.
- evaluate lab performance annually for a core list of OS related contaminants following ISO guidelines.
- be designed to demonstrate that the high quality is maintained over the lifetime of the program.
- include appropriate handling procedures regarding sampling, chain of custody, data reporting, and archiving of data/samples/extracts.
- encompass inter-lab comparison of all media of interest.
- involve a QA audit program that will be run by an independent accredited laboratory.
- recruit other accredited labs conducting similar work on PACs and multi-element analyses in environmental samples(e.g., USGS, Ontario Ministry of Environment, Environnement Quebec, Norwegian Institute for Air Research etc. to improve statistical comparisons of the program.)
- evolve and take on new analytes as analytical methods are developed and new discoveries of contaminants are made.

- include a portfolio of state of the art analytical instrumentation for the analyses conducted.
- include evaluation of sampling methodologies.
- support focused studies for sampling or analytical method development when required.

7.2 Analytical methods -

Sample analyses will be carried out by government or private sector labs qualified (e.g., accredited by CALA to the standards of ISO/IEC 17025) for the analysis of metals and PACs in environmental samples. It is anticipated that multiple analytical laboratories will be involved in the program due to the large numbers of samples to be analyzed and wide range of analytes.

To encourage continuous innovation in method development no single analytical method for given analytes is recommended. However for PACs and multi-element analysis well established methodology exists for sample extraction/digestion to isolate analytes and for instrumental quantification. Method performance will be evaluated by the QA an inter-lab comparison program

PACs:

A large suite of polycyclic aromatic compounds (PACs) have been determined in river water, snow and sediments (e.g. Kelly et al 2009; RAMP database 2011). The methodology generally follows USEPA 8100 for determination of PACs by GC-MS. However more analytes are possible. For example, alkylated phenanthrenes and dibenzothiophenes have been found to comprise more than 70% of the alkylated PACs in the oil-sands extractable material but have not yet been measured routinely (Yang et al. 2010). RAMP surveys (2002-2004) showed non-detectable PACs in river water (Detection Level = ~ 1 ug/L) for all 50 PACs but most of the same suite of PACs are reported in Athabasca River sediments (RAMP database 2011). While approximately 46 PACs are listed in the RAMP and 42 were determined by Kelly et al (2009), a larger suite could be determined if suitable analytical standards were available. There is also a lack of reference materials certified for a large number of PACs, particularly alkylated isomers, and for S and N- containing heterocyclics. This can be solved by repeated analysis of suitable laboratory control samples and inter-laboratory comparisons with the eventual goal of certifying one or more existing commercial reference materials for the full suite of organic analytes. The monitoring and identification of alkylated PACs will also be useful for fingerprinting or identification of main sources (e.g., when the ratio of alkylated to non-alkylated PACs is high, this identifies a petrogenic source. In contrast for low ratios, a pyrogenic source is suggested (i.e., forest fires, combustion processes)).

Multi-elements:

Multi-element analysis should follow USEPA Method 200.8 and EPA 1669 for determination of trace elements in water and wastewaters. Most recent studies (e.g. RAMP 2010; Kelly et al. 2010 and unpublished; Headley et al. 2005), have utilized this methodology and determined up to 32 elements. Additional elements are desirable in order to develop the best multi-element profile possible. Limitations to this are the need for reference materials certified for the large suites of elements. This can be solved by repeated analysis of suitable laboratory control samples and inter-laboratory comparisons with the eventual goal of certifying one or more existing commercial reference materials for up to 50 elements.

Naphthenic Acids (NAs):

RAMP (2011 database) has routinely determined "naphthenic acids" in river water and concentrations in the µg/L range (< ~10 – 3000 µg/L) have been reported. However the naphthenics and related heterocyclic acids are a very complex mixture for which only a limited number of analytical standards exist.

A tiered approach is recommended for the naphthenic acids as follows: (a) Total naphthenic acids reported as total extractable oil sands organic acids - low resolution MS is sufficient for this measurement using electrospray ionization, and the instrumentation is widely available in most laboratories. (b) Specific classes of oil sands acids reported as their relative concentrations.

High resolution Mass Spectroscopy is needed for this measurement and is available in limited number of laboratories. The species should include organic acids containing the O_2 class (often assumed to be naphthenic acids) along with other species: containing O_n where n = 1-16; NO_n and N_2O_n where n = 1-13; and O_nS and O_nS_2, where n = 1-10; and 1-8 respectively.

Information from above will be required for fingerprinting purposes. As the Program progresses there will likely be a need to fine tune the classes in (b) above.

The detection limit for total naphthenic acids in water is 1 mg/L based on 100mL sample. However, reporting the NAs according to compound classes is difficult. There are no commercially available authentic standards for these classes and thus the analysis at the present time is qualitative and at best semi-quantitative based on the relative abundances.

Total and methyl mercury:

Total and methyl mercury sampling and analysis procedures will follow US EPA methods 1631 and 1630, respectively. Briefly, environmental samples are collected into acid-cleaned glass, polyethylene, or fluoropolymer jars using clean hands-dirty hands ultra trace sampling techniques. Total mercury analysis is carried out by bromine oxidation digestion, tin chloride reduction, purge and trap, thermal desorption, and cold vapor atomic fluorescence spectrometry. Methyl mercury analysis in water is carried out by distillation, aqueous phase ethylation, purge and trap, thermal desorption, pyrolysis, and cold vapor atomic fluorescence spectrometry. Methyl mercury analysis of solids such as biological samples, sediments, and vegetation is similar but includes digestion rather than distillation. Detection limits for total and methyl mercury in water are 0.2 ng/L and 0.02 ng/g, respectively and for solids are 0.1 ng/g.

Other organic analytes:

RAMP (2011 database) has determined selected phenolics (nitrophenols, cresols) at multiple sites and N- containing polycyclics (Acridine, quinoline) in river water at a single site (Steepbank River (mouth, STR-1), in 1997. Phenolics were detectable (1-2 µg/L) in the

Athabasca River at Donald Creek ATR-DC-CC and STR-1. Further surveillance for these contaminants could be conducted. Emissions from the wastewater treatment plant at Fort McMurray could include pharmaceutical and personal care products, which are found in receiving waters downstream of all WWTPs. Selected chemicals may be useful tracers of that effluent (e.g. artificial sweeteners) as well as the additional effluents associated with all mining operations. These efforts will support biological effects studies on fish in the Athabasca River and associated tributaries. No recommendations for methods are made here but it should be a subject of future discussion.

7.3 Standard Operating Procedures (SOPs)

Analytical:

Standard operating procedures for core analytes will be determined by the participating laboratories tasked with the monitoring. A chemical monitoring analysis management group with representatives from each participating laboratory should jointly decide on which procedures are to be used, and if current SOPs are satisfactory for the new program. Where SOPs do not exist these should be developed among this group or external assistance sought if required. It is expected that SOPs for chemicals emerging from continuous research will be integrated as necessary. SOPs should conform to those developed by international bodies such as ASTM, OECD and ISO. Protocols exist both federally and provincially for many routinely collected water quality parameters (e.g. dissolved organic carbon), however protocols for other methods exist in research laboratories only (e.g. C1-C4 PACs, naphthenics and other acid extractable compounds) and will require additional validation for full implementation as discussed above.

Field Sampling and Sample Handling, Processing:

A variety of field sampling protocols are being used in the monitoring program (e.g., AENV 2006). Documented ASTM, USEPA, USGS and Environment Canada SOPs methods will be followed and noted. Any alterations of methods will be approved through an expert consultation process and include a period of inter-calibration with older methods.

Example SOPs to be listed include:

ASTM, 2002. Standard Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations, ASTM Standard D6771-02, ASTM International, West Conshohocken, PA.

ASTM, 2005. Standard Guide for Direct-Push Ground Water Sampling for Environmental Site Characterization, ASTM Standard D6001-05, ASTM International, West Conshohocken, PA.

ASTM, 2005. Standard Guide for Field Filtration of Ground-Water Samples, ASTM Standard D6564-05, ASTM International, West Conshohocken, PA.

ASTM, 2005. Standard Guide for Field Preservation of Ground-Water Samples, ASTM Standard D6517-05, ASTM International, West Conshohocken, PA.

ASTM, 2009. Standard Practice for Detecting Hot Spots Using Point-Net (Grid) Search Patterns, ASTM Standard D6982-09, ASTM International, West Conshohocken, PA.

Field sampling for mercury/methyl mercury and multi-element analysis will follow the clean-hands dirty hands protocol described in USEPA Method 1669 (US EPA 1996)

7.4 Statistical Power Analyses

Power analyses have been used conventionally in monitoring programs to determine the levels of spatial and temporal replication necessary to detect change or impacts. In the context of a monitoring assessment, the main issue is the establishment of effect size (i.e., the deviation from baseline or "reference" condition that needs to be detected) and the relative importance of associated Type I and Type II statistical errors. The proposed spatial network of long-term, standardized sites in this program, along with associated increased temporal sampling frequency, allow for more rigourous development and application of suitable power analyses methodologies. These analyses will include conventional approaches to statistical inference where applicable (i.e., the power associated with the detection of water quality threshold exceedances), but also new and emerging approaches dealing with environmental gradient design and prediction (i.e., the power associated with detecting rates of change and trends).

8 NEXT STEPS

Effects-based Monitoring, Multiple-stressor and Ecological Impacts –

Phase 1 of the water quality monitoring plan concentrates on the physical/chemical attributes in the Lower Athabasca river system. Ultimately, the Athabasca River Water Quality Monitoring plan must address not only surface water quality, but also assess the aquatic and relevant terrestrial ecosystem components holistically. It would also involve monitoring and understanding of all components of the aquatic ecosystem, such as benthic biota, fish and other aquatic species.

A key requirement will be to expand the existing program to include consideration and implementation of appropriate effects-based biological and ecological monitoring that directly addresses questions related to the assessment of oil sands impacts, and other point- and non-point source contaminants, on the structure (biodiversity), function and health of relevant aquatic and terrestrial environments.

Determination of observed and projected biological and ecological effects on aquatic biota such as fish and wildlife are of utmost importance to residents in the region, particularly First Nation communities. It will be important to ensure that appropriate validation and consultation occurs to properly inform the design and implementation of Phase 2 to ensure that valued ecosystem components are appropriately addressed in the monitoring plan.

Integrated Process-based Modelling and Environmental Prediction –

Modelling past, current and projected environmental conditions and impacts is a necessary complementary activity of the monitoring program (**Figure 1**). Modelling serves two main functions: 1) data integration and testing our process-based understanding of ecosystem structure and function; and, 2) provide a predictive, decision support tool such as cumulative effects assessment. Process-based modelling can also be used to identify where and when we need to improve the monitoring efforts and focused surveys. The monitoring activities should therefore be constructed and integrated in such a way as to support the development, calibration, and operation of hydrological and water quality models for the lower Athabasca River system. Currently several models are being used by Alberta Environment and Environment Canada in the Lower Athabasca River (e.g., EFDC, river-ice dynamics and 2-D flow). Ultimately an improved integrated environmental prediction framework should result.

Other Monitoring Locations - Altered or reclaimed aquatic habitats -
Although this document focuses on surface waters, in particular particularly the Athabasca mainstem and tributaries, future phases of the sampling program design must consider other types of water bodies in the region. Given the requirement for the oil sands industry to reclaim existing and future open pit mines and tailings ponds, a systematic monitoring program of these altered or reclaimed systems must also occur. The objective of these monitoring efforts would be to assess the compliance and performance of these reclaimed

systems and to evaluate their conditions and success. Examples of such aquatic systems include: re-constructed stream courses; impoundments; fisheries compensation waters; and constructed wetlands. A prime example of such systems is the Beaver Creek Diversion system (implemented in 1977) and the upcoming construction and use of End Pit Lakes.

9 CONCLUSION

The water quality monitoring program framework and proposed sampling design fully meet the key principles that were identified by the Federal Oilsands Advisory Panel for the design and implementation of a "world-class" oilsands monitoring program. Although the overall monitoring plan is being designed in phases given the geographic and sampling complexities involved, assurances are being taken that the program will be one that is: ***holistic and comprehensive, scientifically rigorous, adaptive and robust, inclusive and collaborative, and transparent and accessible.***

An integrated, ecosystem-based approach was used that incorporated multiple essential components of the system (hydrology, surface and groundwater quality and quantify, climatology, sediment dynamics and quality, snow and river-ice, regional air deposition) as well as the relationships among the components. Sites were chosen to integrate multi-scale, spatial measurements (tributary and mainstem catchments, impacted vs. baseline), recognizing the importance of addressing the temporal variability, and improving the ability to define "baseline" or historical environmental conditions.

A best available science-based approach was used to select the chemical, hydrological and atmospheric variables to be measured, methodologies for field sampling and laboratory analyses, and field and laboratory quality assurance and quality control. Standardized reporting, including peer-reviewed and plain language publications, was identified as a core required outcome of the program.

The new water quality monitoring framework builds upon and integrates existing monitoring efforts into an adaptive, and holistic system. Decisions regarding the sampling locations and the types of associated analyses will be evaluated using science-based and policy-relevant decision triggers, and revised as new knowledge and technologies become available and needs and circumstances change. The proposed design moves the current monitoring program paradigm from being "retrospective" to one that will be "prospective" in assessing current and projected multiple stressor impacts and ultimately cumulative effects. In addition the program design is based on a mass-balance conceptual framework, allowing for hypothesis-driven analyses to be conducted and models to be developed to assess the fate, distribution, transport and loadings of oil sands related and other contaminants in the lower Athabasca River system. This stressor-based program forms the foundation for a comprehensive, a geographically expanded effects-based monitoring plan to be developed in Phase 2. Air quality and terrestrial biodiversity monitoring plans, and their integration, will follow.

Although phased in its design, the approach recognizes the importance of ensuring the monitoring program addresses the key issues, questions and concerns of stakeholder groups, First Nations and governments at all levels. This includes recognition of the need for appropriate validation with concerned parties in the design and execution, including the prioritization of issues and setting of monitoring objectives.

The concepts presented in this plan necessitate a dramatic change and improvement from the current monitoring regime, and the actions needed to implement this plan require a significant increase in monitoring effort. The plan will therefore need a suitable transition period in which to implement the proposed actions.

9.1 Scientific Team (alphabetical)

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- **Environment Canada; Research Professor, University of New Brunswick**
- **Aquatic ecotoxicology, biomonitoring program design, aquatic biodiversity**

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- **Cold Regions hydrology and microclimatology**

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- **Alberta Environment, Water Resources**
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- **Government of North West Territories , Environment and Natural Resources**
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- Aquatic ecology, cold regions hydro-ecology, biostatistics, quantitative ecology

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Table 3. Specific details on selected monitoring sites for the Water Quality Monitoring program. (Green shading = "Baseline/Reference" Sites; Red = Sites affected by development; Dark Yellow = New Sites; Light Yellow = proposed requirements for the new program)

Monitoring Sites - Phase 1										
Site	**Existing Site Linkages**	**Site ID**	**Site Status**	**Current Sample**	**Time Series**	**Sampling Freq.**	**Remarks**	**New Hydro Req.**	*** Sampling Freq (Season Dependent)**	**Parameters**
M0	WSC-Hydat/ AENV	07BE001	Athabasca R at Athabasca	** WQ/ Hydromet	Hydromet 1913-pres WQ: 1971 - pres	Monthly	Estimates Athabasca River Water Quality prior to Oilsands Region	No	Monthly/ Bi-weekly	WQ /Bottom, Susp Sed/ Hydromet/Passive Samplers (SPMD, POCIS, DGTs)
M1	AENV-CCL 1	CCL Site 1	Upstream Ft McMuray	** WQ/Sed	WQ; 2009-pres	Monthly; Seasonal	Athabasca River near Mountain Rapids	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
M2	AENV-CCL 2-LTRN; RAMP	CCL Site 2; ATR-UFM; AB07CC0030	Upstream Ft McMuray	** WQ/ Sed/ Hydromet	WQ: 1975-pres	WQ - Monthly	Estimates Athabasca River Water Quality immediately U/S Ft. McMurray	Yes	Monthly/ Bi-weekly	WQ /Bottom, Susp Sed/ Hydromet / Passive Samplers (SPMD, POCIS, DGTs)
M3	AENV-CCL 3 ; RAMP; WSC Hydat	CCL Site 3; ATR-DC-E; ATR-DC-W; ATR-DC-M; ATR-DC-CC; 07DA001;	D/S Ft.McMurray U/S OS develop-ment	** WQ/ Sed/ Hydromet	WQ: 1997 - pres Hydromet: 1957-pres	Hydromet - Cont.; WQ - Seasonally Sporadic Water/ Sediment	Estimates Athabasca River Water Quality D/S from Ft. McMurray and Clearwater R	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
M4	RAMP	ATR-MR-M; ATR-MR-E; ATR-MR-W	D/S of Steepbank R U/S of Muskeg R	WQ/Sed	WQ/Sed: 1998-pres	Hydromet - Cont.; WQ - Seasonally Sporadic Water/ Sediment	Estimates Athabasca River Water Quality D/S from Syncrude/ Suncor Operations & U/S Ft. McKay	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
M5	New	New	D/S of Muskeg R U/S of MacKay R	N/A	N/A	N/A	Estimates Athabasca River Water Quality D/S from Muskeg R and U/S MacKay R	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)

Monitoring Sites - Phase 1										
Site	**Existing Site Linkages**	**Site ID**	**Site Status**	**Current Sample**	**Time Series**	**Sampling Freq.**	**Remarks**	**New Hydro Req.**	*** Sampling Freq (Season Dependent)**	**Parameters**
M6	New	New	D/S of MacKay U/S of Ells R	N/A	N/A	N/A	Estimates Athabasca River Water Quality D/S from MacKay R and U/S of Ells R (TOTAL Joslyn North Mine Project)	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
M7	New	New	D/S of Ells R U/S of Tar R	N/A	N/A	N/A	Estimates Athabasca River Water Quality D/S from Ells R/ TOTAL Mine/ CNHR and U/S of Tar River	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
M8	AENV-CCL 5-LTRN; RAMP	AB07DA0980; ATR-FR-CC	D/S Calumet R, U/S Firebag R	** WQ/Sed/ Hydromet	2008-pres	Continuous Monthly except PACs & Petroleum Hydrocarbons (4x per year)	Estimates Athabasca River Water Quality downstream from Calumet R and upstream of Firebag River	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
M9	New	New	D/S of Firebag and near Embarras Airport	N/A	N/A	N/A	Estimates Athabasca River Water Quality D/S from Firebag R and U/S of Embarras R	Yes	Monthly/ Bi-weekly	WQ /Bottom Sed/ Suspended Sed/ Hydromet / Passive Samplers (SPMD, POCIS, DGTs)
CL1	New	New	Mouth Clearwater R	WQ/Sed	2011-pres	N/A	Estimates Contributory Loadings from Entire Clearwater Watershed	Yes	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
CL2	AENV-CCL; RAMP	AENV-CCL 7; CLR-1; 07CD001	Upstream of Hanging-stone R	** WQ/Sed/ Hydromet	Perodic 2001-pres	Sporadic Seasonal/ Annual	Estimates Contributory Loadings from Clearwater Watershed	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)

Monitoring Sites - Phase 1										
Site	**Existing Site Linkages**	**Site ID**	**Site Status**	**Current Sample**	**Time Series**	**Sampling Freq.**	**Remarks**	**New Hydro Req.**	*** Sampling Freq (Season Dependent)**	**Parameters**
CL3	RAMP	CLR-2	Upstream of Christina R confluence	WQ/Sed	2001-pres	Seasonal sporadic	Estimates Contributory Loadings from Clearwater Watershed to Hangingstone	No	Monthly/ Biweekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
CH1	RAMP	CHR-1	Mouth of Christina R	WQ/Sed	Periodic 2002-pres	Sporadic Seasonal/ Annual	Estimates Contributory Loadings from Christina R Watershed	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
HA1	WSC/RAMP	07CD004	Mouth Hanging-stone R	WQ/Sed/Hydromet	Continuous Hydromet 1965-pres	Continuous	Currently hydrometric station only	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
HO1	RAMP	HOR-1	Upstream Horse R	N/A	2010-pres	-	U/S Baseline for Horse R catchment	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
P01	RAMP	POC-1	Mouth Poplar Creek	WQ/Sed	2000-pres Impact Site	Sporadic Seasonal/ Annual	Estimates Contributory Loadings from Poplar Creek	Yes	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
ST1	AENV-CCL; RAMP; WSC	AENV-CCL 8; 07DA006; STR-1	Mouth Steepbank R	** WQ /Sed/ Hydromet	1972-pres	Sporadic Seasonal/ Annual	Estimates Contributory Loadings from Steepbank R	No	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
ST2	RAMP	STR-3	Steepbank R U/S site	WQ/Sed	2002-pres	Seasonal 2005-08 Annual 2008-pres	U/S of OS development - baseline	No	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
MU1	AENV- CCL; RAMP; WSC	AENV-CCL 10; 07DA008; MUR-1	Mouth Muskeg R	** WQ/Sed/ Hydromet	Hydromet 1974-pres; 1997 - WQ	Sporadic Seasonal/ Annual	Estimates Contributory Loadings from Muskeg R Watershed	No	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
MU2	AENV-MR/RAMP	M2 AB07DA061/MUR-2	Muskeg R Upstream of Canterra Road	WQ/Sed/ Hydromet	1998 - Impact Site; 2008 -	Continuous Seasonal/Monthly WQ 2008 -	Joint AENV/Industry WQ Station	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)

Monitoring Sites - Phase 1										
Site	Existing Site Linkages	Site ID	Site Status	Current Sample	Time Series	Sampling Freq.	Remarks	New Hydro Req.	* Sampling Freq (Season Dependent)	Parameters
			Crossing							
MU3	RAMP	MUR-3	Muskeg R D/S of Alsands Drain	-	-	-	We have no information on this station	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
MU4	AENV-MR/RAMP	M3 AB07DA0595 MUR-4	Muskeg R Upstream of Jackpine Creek	WQ/Sed/ Hydromet	1998-pres Impact Site	Continuous Seasonal Water Quality/ Sporadic Sediment	Estimates Cumulative Loadings between Jackpine Creek and North Muskeg Creek/Shell Jackpine Mine	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
MU5	AENV-MR/RAMP	M4 AB07DA2750 MUR-5	U/S Muskeg Creek; D/S Stanley Cr	WQ/Sed/ Hydromet	1998 - 2003 Baseline; 2004 - Impact Site	Sporadic Seasonal/ Annual	Estimates Cumulative Loadings from Muskeg R below Stanley Creek	No	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
MU6	AENV-MR	M4.5 AB07DA2754	Muskeg R Downstream of Wapasu Creek	WQ/Sed/ Hydromet	WQ 2008-pres	Continuous Monthly	Estimates Cumulative Loadings from Muskeg River and Wapasu Creek Drainage	No	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
MU7	AENV-MR	M6 AB07DA0440 Linked to MUR-6	Muskeg R Upstream of Wapasu Creek	WQ/Sed/ Hydromet	1998-2007 Baseline; 2008-pres Impact Site	Sporadic Seasonal/ Annual	Estimates Cumulative Loadings from Muskeg Watershed	No	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
JA1	AENV-MR	T3.1 AB07DA0600	Mouth of Jackpine Creek	WQ/Sed/ Hydromet	2008 -	Continuous Monthly	Estimates Cumulative Loadings from Jackpine Creek	No	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
JA2	New	New	Upper Jackpine Creek	N/A	N/A	N/A	Estimates Cumulative Loadings from upper Jackpine Creek - New possible baseline	Yes	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)

Monitoring Sites - Phase 1										
Site	**Existing Site Linkages**	**Site ID**	**Site Status**	**Current Sample**	**Time Series**	**Sampling Freq.**	**Remarks**	**New Hydro Req.**	*** Sampling Freq (Season Dependent)**	**Parameters**
NM1	AENV-MR	T5 AB07DA2755	Mouth North Muskeg Creek	WQ/ Hydromet	2008-pres	Continuous Monthly	Captures North Muskeg Creek Cumulative Loadings	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
PE1	New	New	Upper Catchment Pemmican Creek	N/A	N/A	N/A	Estimates Cumulative Loadings from upper Pemmican Creek - New possible baseline	Yes	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
WA1	New	New	Mouth Wapasu Creek	N/A	N/A	N/A	Estimates Cumulative Loadings from Muskeg Watershed	Yes	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
KL1	AENV/RAMP	KL-1 AB07DA2210K EL-1	Kearl Lake	WQ /Sed/ Lake Level	1998-pres Baseline	Sporadic Seasonal/ Annual	Baseline Lake	No	Seasonal (WSSF)	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
MA1	AENV-CCL 9; WSC /RAMP	07DB001/ MAR-1	Mouth MacKay R	** WQ/Sed/ Hydromet	Hydat 1972-pres; WQ 1998-	Sporadic Seasonal/ Annual	Estimates Contributory Loadings from MacKay R Watershed	No	Monthly/ Bi-Weekly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
MA2	RAMP	MAR-2	MacKay R U/S of Petro Canada MacKay	WQ/Sed	WQ 2002-	Sporadic Seasonal/ Annual	Baseline Site upstream of OS development projects. Possible ox-bow lakes for paelo study.	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
D01	New	New	Upper Dover River Catchment U/S from OS mineable area	N/A	N/A	N/A	New location to capture reference baseline conditions in upper Dover catchment	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
EL1	RAMP	ELR-1/S14	Mouth Ells R	WQ/Sed	1998-2002 WQ Baseline 2002-Impact Site	Sporadic Seasonal/ Annual	Provides contributory loadings from the Ells River	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)

Monitoring Sites - Phase 1										
Site	**Existing Site Linkages**	**Site ID**	**Site Status**	**Current Sample**	**Time Series**	**Sampling Freq.**	**Remarks**	**New Hydro Req.**	*** Sampling Freq (Season Dependent)**	**Parameters**
EL2	AENV-CCL; RAMP	AENVCCL 11; ELR-2; S14A	U/S Ells R Catchment U/S of CNLR lease	** WQ/Sed	2000-pres Baseline WQ	Sporadic Seasonal/ Annual	Provides baseline upstream of oilsands projects	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
TA1	RAMP	TAR-2/S34	Upper Catchment Tar River	WQ/Sed	WQ 2004 -pres	Sporadic Seasonal/ Annual	Provides baseline upstream of oilsands projects	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
CA1	RAMP-CNLR	CAR-1	Mouth Calumet R	WQ/Sed	WQ 2002-04 Baseline; 2005-pres Impact Site	Sporadic Seasonal/ Annual	Provides contributory loadings from CNLR Devel.	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
CA2	RAMP	CAR-2/S18A	Calumet R U/S of CNLR Horizon	WQ/Sed	2005-pres WQ Baseline	Sporadic Seasonal/ Annual	Provides baseline upstream of CNLR Devel.	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
FI1	AENV-CCL; RAMP	AENV-CCL 12; FIR-1; S27	Mouth Firebag R	** WQ/Sed	1971-pres Hydromet; 2002-pres WQ/ Impact Site	Sporadic Seasonal/ Annual	Provides contributory loadings from Suncor/ Firebag Devel.	No	Monthly/ Bi-weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
FI2	RAMP	FIR-2	Upstream of Suncor of Firebag Devel.	WQ/Sed	2002-pres Upstream of Suncor Firebag	Sporadic Seasonal/ Annual	Provides baseline upstream of Suncor Devel.	No	Monthly/ Event Based	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)
UN1	**New**	New	Lower catchment Unamed Creek	N/A	N/A	N/A	Provides basline information	Yes	Monthly/ Bi-Weekly	WQ /Bottom Sediment/Passive Samplers (SPMD, POCIS, DGTs)

* New sampling frequency: April-September, once per month or bi-weekly if necessary; October- March, maximum once per month

** WQ/DGTs: Metals, Major Ions, Nutrients (Monthly); Sediment/SPMDs: PACs (4/yr); POCIS: NAs (Monthly); Petroleum Hydro (4/yr)

Table 5. Locations and sampling details on current and proposed monitoring sites for atmospheric deposition studies. Further details on measurements by WBEA at their sites are provided in Appendix D.

Site Name	Lat.	Long.	Operated By	Access	Remarks		Parameters	Sampling Freq
Mannix	56.97	-111.48	WBEA	Road	close to highway	Precipitation (filtered/unfiltered)	PACs, metals	Monthly
						Hi vol air and particles on filters		24 hr, 1 day in 6
						Air using PUF passives	passive gas-phase PACs	Monthly
Lower Camp	57.03	-111.50	WBEA	Road	20 m away from the Athabasca R	Precipitation (filtered/unfiltered)	PACs, metals	Monthly
						Hi vol air and particles on filters	PACs, metals	24 hr, 1 day in 6
						Air using PUF passives	passive gas-phase PACs	Monthly
Syncrude UE1	57.15	-111.64	WBEA	Road	Forest	Precipitation (filtered/unfiltered)	PACs, metals	Monthly
						Hi vol air and particles on filters	PACs, metals, VOC	24 hr, 1 day in 6
						Air using PUF passives	passive gas-phase PACs	Monthly
EC New Site #1	TBD	TBD	EC	Road?	Athabasca R and Firebag R	Precipitation (filtered/unfiltered)	PACs, metals	Monthly
						Hi vol air and particles on filters	PACs, metals, VOCs	24 hr, 1 day in 6
						Gases and particles	SO2, H2S,NO,NO2,O3,CO, PM sizing	1hr
						Air using PUF passives	passive gas-phase PACs	Monthly
EC New Site #2	TBD	TBD	EC	Heli	South of Wood Buffalo NP	Precipitation (filtered/unfiltered)	PACs, metals	Monthly
						Hi vol air and particles on filters	PACs, metals, VOCs	24 hr, 1 day in 6
						Gases and particles	SO2, TRS,NO,NO2,O3,CO, PM sizing	1hr
						Air using PUF passives	passive gas-phase PACs	Monthly
EC New Site #3	TBD	TBD	EC	Road?	South of Fort McMurray	Precipitation (filtered/unfiltered)	PACs, metals	Monthly
						Hi vol air and particles on filters	PACs, metals, VOCs	24 hr, 1 day in 6
						Gases and particles	SO2, TRS,NO,NO2,O3,CO, PM sizing	1hr
						Air using PUF passives	passive gas-phase PACs	Monthly
EC New Site #4 & #5	TBD	TBD	EC	Heli?	east of the minable area	Precipitation (filtered/unfiltered)	PACs, metals	Monthly
						Hi vol air and particles on filters	PACs, metals, VOCs	24 hr, 1 day in 6
						Gases and particles	SO2, TRS,NO,NO2,O3,CO, PM sizing	1hr
						Air using PUF passives	passive gas-phase PACs	Monthly
EC New Site #6 & #7	TBD	TBD	EC	Heli?	west of the minable area	Precipitation (filtered/unfiltered)	PACs, metals	Monthly
						Hi vol air and particles on filters	PACs, metals, VOCs	24 hr, 1 day in 6
						Gases and particles	SO2, TRS,NO,NO2,O3,CO, PM sizing	1hr
						Air using PUF passives	passive gas-phase PACs	Monthly
EC New Site #8	TBD	TBD	EC	Heli	western edge of the Athabasca river basin	Precipitation (filtered/unfiltered)	PACs, metals	Monthly

Site Name	Lat.	Long.	Operated By	Access	Remarks		Parameters	Sampling Freq
						Hi vol air and particles on filters	PACs, metals, VOCs	24 hr, 1 day in 6
						Gases and particles	SO2, TRS,NO,NO2,O3,CO, PM sizing	1hr
						Air using PUF passives	passive gas-phase PACs	Monthly
EC New Site #9	TBD	TBD	EC	Heli	Alberta/NWT border	Precipitation (filtered/unfiltered)	PACs, metals	Monthly
						Hi vol air and particles on filters	PACs, metals, VOCs	24 hr, 1 day in 6
						Gases and particles	SO2, TRS,NO,NO2,O3,CO, PM sizing	1hr
						Air using PUF passives	passive gas-phase PACs	Monthly
EC New Site #10	TBD	TBD	EC	Heli	Saskatchewan border	Precipitation (filtered/unfiltered)	PACs, metals	Monthly
						Hi vol air and particles on filters	PACs, metals, VOCs	24 hr, 1 day in 6
						Gases and particles	SO2, TRS,NO,NO2,O3,CO, PM sizing	1hr
						Air using PUF passives	passive gas-phase PACs	Monthly
Fort McKay	57.19	-111.64	WBEA	Road	Residential	Air using PUF passives	passive gas-phase PACs	Monthly
Fort McMurray-Patricia McInnes	56.75	-111.48	WBEA	Road	Residential	Air using PUF passives	passive gas-phase PACs	Monthly
Barge Landing	57.20	-111.60	WBEA	Road	Forest	Air using PUF passives	passive gas-phase PACs	Monthly
Anzac	56.45	-111.04	WBEA	Road	Residential	Air using PUF passives	passive gas-phase PACs	Monthly
Aspen High Deposition # 3	56.70	-111.12	WBEA	Heli		Air using PUF passives	passive gas-phase PACs	Monthly
Jack Pine High Deposition # 2	56.91	-111.54	WBEA	Heli		Air using PUF passives	passive gas-phase PACs	Monthly
Jack Pine High Deposition #4	57.12	-111.42	WBEA	Heli		Air using PUF passives	passive gas-phase PACs	Monthly
Jack Pine Low Deposition # 7	57.89	-111.44	WBEA	Heli		Air using PUF passives	passive gas-phase PACs	Monthly
New Site as of May 2007	57.05	-111.41	WBEA	Heli		Air using PUF passives	passive gas-phase PACs	Monthly
Replacement	57.10	-112.08	WBEA	Heli		Air using PUF passives	passive gas-phase PACs	Monthly
Baseline SE near Gordon lake	56.27	-110.45	WBEA	Heli		Air using PUF passives	passive gas-phase PACs	Monthly
Aspen High Deposition # 8	56.83	-111.77	WBEA	Heli		Air using PUF passives	passive gas-phase PACs	Monthly
Jack Pine Low Deposition # 1	56.54	-112.28	WBEA	Heli		Air using PUF passives	passive gas-phase PACs	Monthly

WBEA = site operated by Wood Buffalo Environmental Association
Heli = helicopter access
PUF = polyurethane foam
Hi vol = high volume air sampler (with filter and PUF); >100m^3

APPENDIX A

Additional Site-Specific Details for the Lower Athabasca River and Major Tributary Catchments

1.0 Climate/Hydrology/Sediment

Spatial Resolution -

- the Athabasca mainstem will be a major focus - if however, a change is observed there (large flow volume, enhanced sediment loads, and dilution effects), then it means there has been an impact. Focussed monitoring efforts can then be undertaken to "back track" and, if necessary, expand the monitoring network up tributaries to elucidate source/cause-effect/significance.
- if there are Total Suspended Sediment (TSS) and contaminant temporal observed at tributary mouths indicating enrichment (including enhanced erosion), focussed monitoring activities will be expanded upstream where necessary to delineate source/cause-effect/significance.
- for a mass balance approach, contributions from tributaries (industrial source points, runoff if applicable) incorporated with a mixing model for the Athabasca will be developed.

Temporal Resolution-

- the sampling frequency needs to be adaptable and able to capture significant hydrological events. For example, daily or hourly data might be required in the tributaries to capture small rainfall/runoff generation events and resultant pulses of water and sediment to the Athabasca. Increased sampling frequency may also be required during extreme hydrologic events on the mainstem such as those produced by fast moving (i.e., > 5 m/s) ice-jam surges.
- within the river and adjacent watershed, back-eddy zones, and overbank deposits to flood plains, lakes and delta deposits represent historic reference of sediment and contaminant loads. There are many that are likely to retain relatively undisturbed, chronologically deposited, informative sedimentary records that extend back several centuries to millennia, where careful paleolimnological sampling and analysis could provide essential information on natural background levels (baseline or reference conditions) of sediment and contaminants transported via the rivers and atmosphere, and to quantify trends over time since the onset of industrial activities.

Lower Mainstem River (LMR) Sites:

M0 – Athabasca River at Athabasca

- active (continuous) long-term HYDAT site with discharge records available back to 1913
- active long-term AENV water quality monitoring site

- only existing long-term monitoring site on the Athabasca River that is outside the oil sands development
- provides an upstream boundary condition

M2 – Athabasca River upstream of Fort McMurray

- active long-term AENV water quality monitoring site
- will provide upstream boundary condition for the Athabasca reach in the oil sands development region
- water quality data are available from nearby CCL 1
- site of drinking water intake for Fort McMurray

M3 – Athabasca River downstream of Fort McMurray and confluence with the Clearwater River

- active (continuous) HYDAT station (07DA001) with discharge records back to 1957, and historical sediment data (1967-1972)
- co-located with AENV Contaminant Load Monitoring Site and RAMP ATR-DC sites

M9 – Athabasca River downstream of Firebag River and near Embarras

- Existing EC/Parks Canada long-term monitoring site (Athabasca River at 27th baseline)
- discontinued (seasonal) HYDAT station (07DD001) with discharge records from 1971-1990, and historical sediment data (1971-1984)

Tributary Sites:

CH1 – Christina River (Athabasca sub-tributary near confluence with the Clearwater River)

- large catchment (13,038 km^2) with considerable mean annual flow (46 m^{3}s^{-1})
- no surface mining, but has SAGD and an upgrader
- watershed includes several existing and planned SAGD oil sands developments in the southern portion of the RAMP FSA.
- RAMP WQ site CHR-1 since 2001

CL1 – Clearwater River

- new site at mouth
- major tributary into Athabasca River

PO1 – Poplar Creek

- relatively small catchment (catchment area 420 km^2, mean annual flow 1 m^{3}s^{-1})
- discontinued HYDAT station (07DA007), with discharge records from 1972-1986
- RAMP POC-1, year-round hydrometric and water quality
- Now incorporates the diverted Beaver River basin, has an altered hydrologic situation, and has impoundments and constructed channels, which may result in anomalous sediment transport

ST1 – Steepbank River

- active (seasonal) HYDAT station (07DA006) with discharge records back to 1972, and with historical sediment data (1975-1983)
- relatively small catchment (1,355 km^2; mean annual flow 5 m^3s^{-1})
- co-located with AENV Contaminant Load Monitoring Site CCL 8
- RAMP WQ monitoring ST-1
- impacted by surface mining
- watershed includes mining and SAGD

MU1 – Muskeg River

- active (seasonal) HYDAT station (07DA008) with discharge records back to 1974, and with historical sediment data (1976-1983), RAMP winter monitoring
- relatively small catchment (1,460 km^2; mean annual flow 4 m^3s^{-1})
- highly impacted by surface mining
- considerable information already available throughout the catchment (AENV Muskeg River Watershed Integrated Water Quality Monitoring Program; AENV CLMS; RAMP STR-1)

MA1 – MacKay River

- active (seasonal) HYDAT station (07DB001) with discharge records back to 1972, and with historical sediment data (1975-1983), RAMP winter monitoring
- co-located is AENV CCL-9, RAMP WQ MAR-1
- medium size catchment (5,570 km^2; mean annual flow 13 m^3s^{-1})
- SAGD in its headwaters
- highly relevant to the community of Fort McKay

EL1 – Ells River

- small/medium size catchment (2,400 km^2; mean annual flow 9 m^3s^{-1})
- minimal impact by OS development at present, but will be affected by mining in the near future, and by SAGD in the future
- source of drinking water for the community of Fort McKay
- RAMP WQ and hydrometric monitoring, ELR-1, S14

CA1 – Calumet River

- small/medium size catchment (174 km^2; mean annual flow <1 m^3s^{-1})
- discontinued HYDAT station (07DA014) with records from 1975-1977
- directly affected by mining
- river course planned to be “relocated” (which includes routing of the Tar River into the same nbew channel as the Calumet) as part of OS development, need to establish present conditions and then monitor the effect of stream channel relocation on water and sediment quality/quantity and fluxes
- CNRL conducts open water hydrometric monitoring
- RAMP water quality site CAR-1

FI1 – Firebag River

- active (seasonal) HYDAT station (07DC001) with discharge records back to 1971, and with historical sediment data (1976-1983), RAMP winter monitoring
- medium size catchment (5,683 km^2) with relatively large tributary input (23 m^3s^{-1}) to the Athabasca mainstem
- co-located is an AENV CCl-12, RAMP WQ FIR-1 S27
- tributary outflow just upstream of AENV medium-term WQMS on the Athabasca mainstem
- northern edge of minable deposits
- a river flowing from Saskatchewan whose watershed includes much SAGD

Other Design/Implementation Considerations:

- gauging stations require a stable cross-section so that the bottom-wetted perimeter is not changing and flow measurements are accurate over the long term. For large rivers like the Athabasca River they are generally established at bridges or overhead cableways so that velocity measurements (and water and sediment samples) can be collected at designated verticals. On the Athabasca River, the river bed is mobile and sandy, the river is very wide and fast flowing, and there are no bridges or cableways past Fort McMurray other than the Peter Lougheed Bridge near the Muskeg River confluence, which is not gauged. Float style ADCP that can be moved across the river from a boat to obtain a cross-sectional discharge will be evaluated and used where appropriate.
- dual hydrometric station approaches for determining sub-reach water-level slopes offer a new opportunity for measuring discharge during dynamic ice periods.
- the inability to measure everything everywhere necessitates the need for developing hydrological models with linked routines for sediment erosion, transport and fate. Ideally the model should be able to differentiate between cohesive (silts and clays) and non-cohesive (sand) sediment and their physical dynamics (cohesive flocculation) and contaminant “interactions” (chemical and biological). The model must predict flows under ice and during dynamic ice periods at freeze-up and breakup. Existing and ongoing ice-condition data could tie into this aspect. The incorporation of contaminant erosion, transport and fate, necessitates the need for monitoring/research on the relationship/behaviour of contaminants with sediments (bed and suspended) with particular reference to particle size effects – most contaminants bind with the cohesive sediment fraction (<63 µm) (Horowitz, 1991).

2.0 Surface and Groundwater Water Quality

Spatial Resolution -

Similar to the hydrology/sediment program, tributary monitoring sites were identified to address the following criteria:

- mainstem confluence sites have been positioned not to be influenced by Athabasca backwater and to provide information on the inputs/loadings (water quantity, quality) to the mainstem and to assess their variability over various time-frames (individual storm events, seasonal, annual regimes, inter-annual variability, trends, etc.).
- to provide information on the impact of oil sands development on tributary water quality and contribution/loadings to the Athabasca River. Tributary sites were identified to provide information on highly, moderately and minimally impacted by oil sands development. Tributary catchments minimally impacted by development will be used to further define baseline conditions.
- to include catchments minimally affected by oil sands development, affected by mining, affected by SAGD, and affected by a combination of mining and SAGD activities to provide information on the effect of different oil sands developments/technologies on water and sediment quality to the Athabasca system.
- to improve process-level understanding of contaminant fate, transport and loadings and to develop modelling/predictive capabilities for both gauged/monitored and un-gauged/monitored systems.
- to cover a range of catchment size and runoff regimes.

- a comprehensive assessment of chemical fluxes in groundwater flows should be conducted in and around tailings ponds and end-pit lakes It should and include parallel pond/end-pit lake chemical characterizations to enable interpretation of groundwater data. Connectivity of Athabasca River with deep aquifers (e.g. Muskeg River via relict gravel channels) and important localised seeps will be quantified.
- areas with OSPW identified in groundwater seepage to surface water may require enhanced land-based, multi-level monitoring wells with transects/fences to characterize nature and extent of OSPW in groundwater and other associated effects.
- since spatial resolution issues will be challenging with respect to groundwater, the monitoring program will be adaptive in both space and time, particularly in the early stages of the monitoring. Groundwater quality issues will likely be localized (i.e. require a dense sample spacing to reliably detect effects), quantity focused locations can likely be more regularly and widely spaced. A refined network of monitoring sites will be selected to consider geology, operations and their proximity to receptors (i.e. can phase in facilities farther removed from receptors with knowledge gained from earlier ones), and types of operation (e.g. upgrader, surface mining, SAGD, etc.). Groundwater quality monitoring will be initially surveillance-based, with an emphasis on high resolution sampling for groundwater discharge along streams/rivers.

Temporal Resolution –

- sampling frequency will be adjusted to address hydrological conditions – e.g., higher frequency during high flow, and short intense runoff producing events in order to estimate water/sediment/contaminant fluxes, in response to threshold exceedences, etc.
- a long-term, multi-year time series should be established for a wide range of elements, PAHs and naphthenic acids and other chemicals associated with oil sands production facilities.

Lower Mainstem River (LMR) Sites:

- all sites from M1-M8 are located between major tributary mouths to quantify mass-balance tributary inputs.
- mainstem sites at M2, M3 and M8 are the same as for the hydrometric/sediment monitoring, and are described in section 6.0.

M4 – Athabasca River downstream of Steepbank River and upstream of Muskeg River

- proposed new monitoring site for river reach boundary conditions existing RAMP ATR-MR-E/W

M5 – Athabasca River downstream of Muskeg River and upstream of MacKay River

- proposed new monitoring site for river reach boundary conditions

M6 – Athabasca River downstream of MacKay River and upstream of Ells River

- proposed new monitoring site for river reach boundary conditions

M7 – Athabasca River downstream of Ells River and upstream of Tar River

- proposed new monitoring site for river reach boundary conditions

Tributaries:

Clearwater Catchment-

Three monitoring sites on the Clearwater River – to separate the Clearwater into two reaches to look at the effect of input from the Christina and Hangingstone on the Clearwater.

Proposed tributary sites CH1, CL1, ST1, PO1, MU1, MA1, EL1, CA1 and FI1 are the same as for the proposed hydrometric/sediment monitoring.

CL2 – Clearwater upstream of Hangingstone River

- estimates loadings from
- has active (continuous) HYDAT station (07CD005; monitored by RAMP in winter) with discharge records back to 1976
- AENV CCL-7; RAMP WQ CLR-1

CL3 – Clearwater upstream of Christina River

- monitoring site for river reach boundary conditions
- has active (continuous) HYDAT station (07DC005; monitored by RAMP in winter) with discharge records back to 1976

- RAMP WQ CLR-1

HA1 – Hangingstone River

- catchment area 1066 km^2; mean annual flow (4 m^3s^{-1})
- active (continuous; operated by RAMP in winter) HYDAT station (07CD004) with discharge records back to 1965, and with sediment data (1978-1980)
- RAMP water quality site
- watershed includes SAGD

HO1 – Horse River

- catchment area 2,157 km^2; mean annual flow 9 m^3s^{-1})
- discontinued HYDAT station (07CC001), with discharge records from 1930-1979
- RAMP WQ site HOR-1
- watershed includes SAGD

Muskeg River Catchment-

MU2 – Muskeg R upstream of Canterra Road Crossing

- active (continuous) AENV Hydromet station (AB07DA0610) with records back to 1974
- AENV Muskeg River Study site M2
- MR/RAMP WQ MUR-2 since 2008

MU3 – Muskeg River downstream of Alsands Drain

- RAMP MUR-3, but with no information

MU4 – Muskeg River upstream of Jackpine Creek

- to estimate cumulative loadings between Jackpine Creek and North Muskeg Creek
- AENV Muskeg River Study site M3
- active (continuous) AENV Hdromet station (AB07DA0595)
- Ramp WQ site MUR-4

MU5 – Muskeg River upstream of of Muskeg Creek and downstream of Stanley Creek

- to estimate cumulative loadings from Muskeg River below Stanley Creek
- AENV Muskeg River Study site M4
- active AENV Hdromet station (AB07DA2750)
- Ramp WQ site MUR-5
- baseline information (1998-2003); impacted since 2004

MU6 – Muskeg River downstream of Wapasu Creek

- to estimate cumulative loadings from Muskeg River and Wapasu Creek drainage
- AENV Muskeg River Study site M4.5
- AENV WQ since 2008
- active (continuous) AENV Hydromet station (AB07DA2754)

MU7 – Muskeg River upstream of Wapasu Creek

- to estimate cumulative loadings between from Kuskeg watershed
- AENV Muskeg River Study site M6
- active (continuous) AENV Hydromet station (AB07DA0440)
- linked to RAMP WQ site MUR-6)
- baseline information (1998-2007), impacted from 2008

JA1 – Mouth of Jackpine Creek

- to estimate cumulative loadings from Muskeg watershed
- AENV Muskeg River Study site T3.1
- active (continuous) AENV Hydromet station (AB07DA0600)
- WQ, sediment and Hydromet since 2008)

JA1 – Mouth of Jackpine Creek

- to estimate cumulative loadings from Muskeg watershed
- AENV Muskeg River Study site T3.1
- active (continuous) AENV Hydromet station (AB07DA0600)
- WQ, sediment and Hydromet data since 2008)

JA2 – Upper Jackpine Creek

- new site to estimate cumulative loadings from upper Jackpine Creek, possibly a baseline site

NM1 – Mouth of North Muskeg Creek

- to capture North Muskeg Creel cumulative loadings
- AENV Muskeg River Site T5
- active (continuous) AENV Hydromet (AB07DA2775)
- WQ and hydromet since 2008

PE1 – Mouth of Wapasu Creek

- new site to estimate cumulative loadings

KL1 – Kearl Lake

- baseline lake
- AENV Muskeg River Study site KL-1
- active (continuous) AENV Hydromet station (AB07DA2210) with water levels since 1998
- RAMP WQ site KEL-1

Mackay River Catchment -

MA2 – MacKay River above Oil Sands development

- baseline site upstream of oil sands development projects. Possible ox-bow lakes for paelo study.
- RAMP WQ site MAR-2 since 2002

Dover River Catchment -

DO1 – Upper Dover River Catchment

- new site to capture reference/baseline conditions upstream of oil sands development
- RAMP WQ (TAR-2; S34) since 2004

Ells River Catchment -

EL2 – Upper Ells River catchment

- to provide baseline information upstream of oil sands projects
- AENV CCL-11
- RAMP WQ (ELR-2; S14A) since 2000

Tar/Calumet/Firebag and Unnamed Creek Catchments -

TA1 – Upper Tar River Catchment

- to provide baseline information upstream of oil sands projects
- RAMP WQ (TAR-2; S34) since 2004

CA2 – Calumet River upstream of oil sands development

- to provide baseline information
- RAMP/CNLR WQ site (CAR-1)
- baseline WQ (2002-2004); impacted since 2005

FI2 – Firebag River upstream of Oil Sands Development

- to provide baseline information
- RAMP WQ site FIR-2 since 2002

UN1 – Unnamed Creek near mouth

- new site to provide baseline information

Other Design/Implementation Considerations

- there is a need to continue quantifying the range and chemical variability of pond and tailings dyke pore waters (i.e. seepage pathway sources). Any areas with oil sands process water (OSPW) identified in groundwater seepage to surface water may require land-based multi-level monitoring wells with transects/fences to characterize nature and extent of OSPW in groundwater and other associated effects.
- sediment coring of lakes and appropriate fluvial depositional areas in the region (e.g., Oxbows) and comparison of lithogenic vs. atmospheric inputs should be conducted (if they can be distinguished by chemical fingerprinting).
- modelling of groundwater/surface interactions will be required as an “interpretive lens” to adapt groundwater monitoring/surveillance as the monitoring program and our understanding matures (e.g. avoid pitfall of collecting data without interpretation framework) and couple with surface water.

- the extent of delivery of atmospherically deposited contaminants from the terrestrial environment to the tributaries and Lower Athabasca main stem needs to be studied in detail in selected small watersheds with an eventual objective of calibrating models. With scale up of the oil sands development over the next 10 years the atmospheric component could become much more important but the extent of delivery to the aquatic environment will be in doubt without further research.
- from a chemical residue perspective, more that needs to be done on the "discovery" side of the issue using new technologies such as the LC - ultra high resolution mass spectrometry. There is no reason to be limited to naphthenic acids. If new chemicals associated with oil sands process waters (OSPW) are found in the river itself by large volume sampling and identification techniques can be found they could be added in later assuming there are archived samples.
- knowledge of the chemicals used by industry in their processes, including the composition of the feed stock, would be invaluable information to the monitoring program. The establishment of a chemical database for all tailings ponds and end pit lakes in the region (existing and planned) would be useful for interpreting possible leakage past containment structures.
- there are analytical challenges for naphthenic acids (see Section 7). It is safe to say that this is where development of a standardized method using new technologies such as the LC-ultra high resolution mass spectrometery is critical (i.e. not just for "fingerprinting" but also for quantitative determination of selected components within the fingerprint). There is also a need for a suitable oil sands naphthenic acid or acid extractable organic reference standard for use in toxicity studies and as an analytical reference. This will require identification of a suitable, stable reference source water and extraction methodology.
- Knowledge gaps exist with regard to PACs. Data exist for parent PACs and C1-C4 analogues, but not much data exist on N-containing, S-containing and photo-oxidized products of all of the above. All should be do-able with current and emerging technologies.
- the establishment of standardized operating procedures for sample collection, handling, analysis, reporting and archiving for all water quality parameters. Protocols exist both federally and provincially for many routinely collected water quality parameters (e.g. dissolved organic carbon), however protocols for other methods exist in research laboratories only (e.g. C1-C4 PACs, naphthenics and other acid extractables) and require additional validation for full implementation
- establishment of background/reference conditions given short data records in the region. Paleo information (sediment cores), as described above, is one method for looking at long-term trends in contaminant types and levels.
- compilation of existing water quality (including discharge) data (e.g. compliance monitoring, RAMP, with appropriate screening protocols for QA/QC.
- significant resources will be needed for data QA/QC, management, analysis and reporting out.

3.0 Aerial Deposition Monitoring – Additional Considerations Regarding Challenges, Constraints and Dependencies

- The fate of pollutants deposited on terrestrial (soil and vegetation) surfaces in rain and snow melt and by dry deposition with subsequent wash-off by precipitation (as opposed to directly on water/ice) and the extent of delivery to water is difficult to quantify. This will be studied in more detail in the catchment scale studies outlined in Sections 7 & 8.
- Modelling of dry deposition is integral to the monitoring program. Atmospheric deposition is controlled by the physical and chemical properties of the species under consideration and by the meteorology. The quantification of atmospheric deposition over local and regional scales requires the use of models that input meteorology, the physical-chemical properties and the measured atmospheric concentrations and output the dry, wet and total deposition fields. The modelling can be improved with satellite observations of snow cover, major pollutants, etc.
- The passive samplers capture efficiently the gas-phase contaminants and only a small and unknown fraction of the particle-bound compounds; by co-locating the active samplers with the passive samplers and collecting a larger set of measurements, the capture rate of particle pound contaminants will be quantified.
- Sites will require locally-clean (i.e. no nearby combustion source) electrical power and competent operators. They must be located in areas protected from human interference. The time line to install new sites in this remote region is 2 to 4 years. Passive sampling sites should be coordinated with other sampling programs to save access costs and increase data value.
- The extent of delivery of atmospherically deposited contaminants from the terrestrial environment to the tributaries and main stem needs to be studied in detail in selected small watersheds with an eventual objective of calibrating models. With scale-up of the OS development over the next 10 years the atmospheric component could become much more important; however, the extent of delivery to the aquatic environment will remain uncertain without further research. Sediment coring of lakes in the region and comparison of lithogenic vs. atmospheric inputs (if they can be distinguished) would also help with this.
- Improving the emission inventories is highly desirable. Ideally, a mass balance analysis could be conducted.
- Samples collected should be shared with fingerprinting and co-relation analyses across media. Common tracers of oil sands emissions should be used where possible.
- We can build on the existing network experience. However, the sampling for the purpose of calculating deposition in the near-field (i.e. within 200 km) of the oil sands industrial activity is not "routine monitoring". The results of the Surveillance Study are needed to define monitoring sites, sampling duration and sampling frequency. This development process is underway.
- Knowledge of the chemicals used by industry in their processes, including the composition of the feed stock, would be invaluable in the monitoring study. The

atmospheric processing of the emissions should be studied and the analyte lists tailored to the important species.

- For determination of deposition, gas and particle phases need to be measured in air and precipitation needs to be collected. Microphysical measurements needed; chemistry as a function of particles size. Snow pack sampling each year.
- For best determination of deposition, event-based precipitation collection and continuous measurement at high resolution of air components is needed. Detection level will determine minimum times for sampling; cost will limit time resolution. A combination of active and passive sampling will be developed.
- Sampling for the purpose of calculation of total deposition (wet + dry) of the parameters of interest here on a seasonal or annual basis for the Athabasca basin using state-of-the-art methods has not been undertaken to date in this region.
- After being emitted some of the contaminants may undergo transformation in various environments (air, water, sediment); a first step will be to determine the significance of these degradation processes and further study the main degradation products. Based on this analysis, the more toxic degradation products should be added and routinely monitored along with the primary emitted contaminants.
- Continued research and development of tools to improve results and information gained from monitoring measurements should be supported. Priority areas include:
    - Assessing relationships between the toxic substances of interest for water quality and the more abundant emissions that can be tracked by satellite imagery will be sought. If these relationships can be established for specific sources in the industry, then satellite imagery can be applied to further populate the input to the models for better estimation of atmospheric deposition.
    - Validation and use of meteorological models and satellite imagery to determine precipitation amounts in the basin.
    - Reporting on the emissions of the different processes, including tailings ponds.
    - Determination of appropriate physical-chemical parameters for chemical species for which they are not available.
    - Transport and deposition modelling (e.g., unified regional air quality modelling systems (AURAMS)

APPENDIX B

Core Water Quality Variables

Group	Water quality variable	
Conventional variables	Colour	Total dissolved solids (TDS)
	Dissolved organic carbon (DOC)	Total hardness
	pH	Total organic carbon
	Specific conductance	Total suspended solids
	Total alkalinity	
Major ions	Bicarbonate	Potassium
	Calcium	Sodium
	Carbonate	Sulphate
	Chloride	Sulphide
	Magnesium	
Nutrients	Nitrate + nitrite	Phosphorus – total
	Ammonia nitrogen	Phosphorus – dissolved
	Total Kjeldahl nitrogen	
Organics	Total organic (naphthenic) acids	Total recoverable hydrocarbons
	Total phenolics	

Group	Water quality variable		
Total, dissol., Speciated Metals	Aluminum (Al)	Chromium (Cr)	Selenium (se)
	Antimony (Sb)	Cobalt (Co)	Silver (Ag)
	Arsenic (As)	Copper (Cu)	Strontium (Sr)
	Barium (Ba)	Iron (Fe)	Thallium (Tl)
	Beryllium (Be)	Lead (Pb)	Thorium (Th)
	Bismuth (Bi)	Lithium (Li)	Tin (Sn)
	Boron (B)	Manganese (Mn)	Titanium (Ti)
	Cadmium (Cd)	Mercury (Hg)[1]	Uranium (U)
	Calcium (Ca)	Molybdenum (Mo)	Vanadium (V)
	Chlorine (Cl)	Nickel (Ni)	Zinc (Zn)

Group	Water quality variable	
Target PAHs	Acenaphthylene	Dibenzo(a,h)anthracene
	Anthracene	Dibenzothiophene
	Benzo(a)anthracene/chrysene	Fluroanthene
	Benzo(b&k)fluoranthene	Fluroence
	Benzo(a)pyrene	Indeno(c,d-123)pyrene
	Benzo(g,h,i)perylene	Naphthalene
	Biphenyl	Phenanthrene
		Pyrene

[1] Since 202, total mercury (Hg) has been measured to ultra-trace levels (i.e., method detections limit of 0.000012 mg/L, or 1.2 mg/L).

WQ Parameters (Cont'd.)

Group	Water quality variable
Alkylated PAHs	C1-substituted acenaphthene
	C1-substituted benzo(a)anthracene/chrysene
	C2-substituted benzo(a)anthracene/chrysene
	C1-substituted biphenyl
	C2-substituted biphenyl
	C1-substituted benzo(b or k)fluoranthene/methyl benzo(a)pyrene
	C2-substituted benzo(b or k)fluoranthene/benzo(a)pyrene
	C1-substituted dibenzothiophene
	C2-substituted dibenzothiophene
	C3-substituted dibenzothiophene
	C4-substituted dibenzothiophene
	C1-substituted fluoranthene/pyrene
	C1-substituted fluorene
	C2-substituted fluorene
	C1-substituted naphthalenes
	C2-substituted naphthalenes
	C3-substituted naphthalenes
	C4-substituted naphthalenes
	C1-substituted phenanthrene/anthracene
	C2-substituted phenanthrene/anthracene
	C3-substituted phenanthrene/anthracene
	C4-substituted phenanthrene/anthracene
	1-methyl-7-isopropyl-phenanthrene (retene)

Sediment Quality Variables

Group	Sediment quality variable	
Physical variables	Percent sand	Percent Clay
	Percent silt	Moisture
Carbon Content	Total inorganic carbon	
	Total organic carbon	
	Total carbon	
Total and Speciated Metals	Aluminum	Manganese
	Arsenic	Mercury
	Barium	Molybdenum
	Beryllium	Nickel
	Boron	Potassium
	Cadmium	Selenium
	Calcium	Silver
	Chromium	Sodium
	Cobalt	Strontium
	Iron	Uranium
	Lead	Vanadium
	Magnesium	Zinc
Organics	AEP Tier 1 total hydrocarbons[1]	
	Total recoverable hydrocarbons[1]	
	Total volatile hydrocarbons (C5-C10) [1]	
	Total extractable hydrocarbons (C11-C30) [1]	
	CCME 4-fraction total hydrocarbons: [1]	
	BTEX (Benzene, Toluene, Ethylene, Xylene) [1]	
	F1 (C6-C10)[1]	
	F2(C10-C16)[1]	
	F3(C16-C34)[1]	
	F4(C-34-C50)[1]	
Parent PAHs	Acenaphthene	Dibenzo(a,h)anthracene
	Acenaphthylene	Dibenzothiophene
	Anthracene	Fluoranthene
	Benzo(a)anthracene/chrysene	Fluorene
	Benzo(a)pyrene	Indeno(c,d-123)pyrene
	Benzofluoranthenes	Naphthalene
	Benzo(g,h,i)perylene	Phenanthrene
	Biphenyl	Pyrene

[1] CCME 4-fraction test added in 2004; AEP Tier-1 variables (i.e., TVH, THE, TRH) eliminated in 2005
[2] 10-day *L. variegatus* test eliminated in 2004

Sediment Quality (Cont'd.)

Group	Sediment quality variable
Alkylated PAHs	C1-substituted acenaphthene
	C1-substituted benzo(a)anthracene/chrysene
	C2-substituted benzo(a)anthracene/chrysene
	C1-substituted biphenyl
	C2-substituted biphenyl
	C1-substituted benzofluoranthene/benzo(a)pyrene
	C2-substituted benzofluoranthene/benzo(a)pyrene
	C1-substituted dibenzothiophene
	C2-substituted dibenzothiophene
	C3-substituted dibenzothiophene
	C4-substituted dibenzothiophene
	C1-substituted fluoranthene/pyrene
	C2-substituted fluoranthene/pyrene
	C3-substituted fluoranthene/pyrene
	C1-substituted fluorene
	C2-substituted fluorene
	C3-substituted fluorene
	C1-substituted naphthalenes
	C2-substituted naphthalenes
	C3-substituted naphthalenes
	C4-substituted naphthalenes
	C1-substituted phenanthrene/anthracene
	C2-substituted phenanthrene/anthracene
	C3-substituted phenanthrene/anthracene
	C4-substituted phenanthrene/anthracene
	1-methyl-7-isopropyl-phenanthrene (retene)

[1] CCME 4-fraction test added in 2004; AEP Tier-1 variables (i.e., TVH, THE, TRH) eliminated in 2005

[2] 10-day *L. variegatus* test eliminated in 2004

APPENDIX C

Summary of Current Atmospheric Monitoring Stations/Programs in the Oil sands Region

Remote Sites (Helicopter access only)		CASA Google Earth		Converted Coordinates		Passive samplers Gas Phase PACs	Active Integrated Samplers PACs, metals, precipitation	NAPS Site Designated or nondesignated	WBEA passive samplers	WBEA Met	WBEA Reduced CAC	WBEA Extended CAC
210	Baseline SE Near Corner Gordon Lake	56.271783	-110.446267	56°16'18.42"N	110°26'46.56"W	Y			Y			
JPL1	Jack Pine Low Deposition 1	56.539583	-112.275483	56°32'22.5"N	112°16'31.74"W	Y			Y			
AH7	WBEA map AH7, CASA Map AH8	56.829817	-111.767833	56°49'47.34"N	111°46'4.2"W	Y			Y			
AH8-R	Replacement	57.101883	-112.075417	57°6'6.78"N	112°4'31.5"W	Y			Y			
JPL7	Jack Pine Low Deposition 7	57.890250	-111.435217	57°53'24.9"N	111°26'6.78"W	Y			Y			
JPH4	Jack Pine High Deposition 4	57.119843	-111.424330	57°7'11.43"N	111°25'27.59"W	Y			Y			
JP 212	New Site as of May 2007	57.053933	-111.408867	57°3'14.16"N	111°24'31.92"W	Y			Y			
JPH2	Jack Pine High Deposition 2	56.909617	-111.540717	56°54'34.62"N	111°32'26.58"W	Y			Y			
AH3	Aspen High Deposition 3	56.696417	-111.122283	56°41'47.1"N	111°7'20.22"W	Y			Y			
Continuous Sites (road access)												
AMS1	Fort McKay	57.189406	-111.640504	57°11'21.86"N	111°38'25.81"W	Y			Y	1 height		Y
AMS 4	Buffalo Viewpoint	56.996700	-111.592600	56°59'48.12"N	111°35'33.36"W	Y			Y	1height	Y	
AMS 5	Mannix	56.968800	-111.482000	56°58'7.68"N	111°28'55.2"W	Y	Y		Y	multiple heights	Y	
AMS 6	Patricia McInnes	56.751386	-111.476596	56°45'4.99"N	111°28'35.75"W	Y			Y	1 height		Y
AMS9	Barge Landing	57.1982	-111.5996	57°11'53.52"N	111°35'58.56"W	Y	Y		Y	1 height	Y	
AMS 11	Lower Camp	57.026869	-111.500749	57°1'36.73"N	111°30'2.7"W	Y			Y	1 height	Y	
AMS13	Syncrude UE-1	57.149200	-111.642400	57°8'57.12"N	111°38'32.64"W	Y	Y	D	Y	1 height		Y
AMS 14	Anzac	56.448889	-111.038056	56°26'56"N	111°2'17"W	Y			Y	1height		Y
Weather Sites climate ID												
3064528	Mildreed Lake Airport			57°2'28.00"N	111°33'32.00"W							
3062700	Fort McMurray AWOS			56°39'12.00"N	111°13'24.00"W							

Notes:

PACs	PAHs+ tiophenes
NAPS, D or ND	Designated or nondesignated NAPS sites
WBEA met	meteorological parameters (temperature, Wind speed, Wind Direction)at various heights
WBEA passive samplers	SO2, O3, NO2, NH3,HNO3
WBEA Reduced CAC	WBEA reduced list for Criteria Air Contaminants :SO2 ,Total Hydrocarbons, H2S or THS
WBEA extended CAC	WBEA extended list for Criteria Air Contaminants (O3, NO,Nox, SO2, PM2.5, THC,H2S orTRS
Weather sites	meteorological parameters (temperature, Wind speed, Wind Direction) + rates of precip
PAHs	PAHs, Naphthalene,Acenaphthylene,Acenaphthene,Fluorene,Anthracene,Phenanthrene,Fluoranthene,Pyrene,Benzo[a]anthracene,Benzo[b]fluoranthene,Benzo[a]pyrene,Indeno(1,2,3-cd)pyrene,Dibenzo[a,h]anthracene,Benzo[g,h,i]pe C1-, C2-, C3- and C4-substituted PAHs
Tiophenes	Dibenzothiophene and C1, C2, C3 and C4-substituted dibenzothiophene
Metals	
ICP-MS	Aluminum,Silicon,Phosphorus,Sulfur,Chlorine,Potassium,Calcium,Titanium,Vanadium,Chromium,Manganese,Iron,Zinc,Selenium,Bromine,Rubidium,Strontium,Yttrium,Niobium,Molybdenum,Lead,Magnesium*,Aluminium*,Sca Cobalt*,Nickel*,Copper*,Gallium*,Germanium*,Arsenic*,Silver*,Cadmium*,Indium*,Tin*,Antimony*,Tellurium*,Iodine*,Cesium*,Lanthanum * ,Cerium*,,Antimony,Arsenic,Barium,Beryllium,Cadmium,Chromium,C
ED-XRF quantitative	Aluminum,Silicon,Phosphorus,Sulfur,Chlorine,Potassium,Calcium,Titanium,Vanadium,Chromium,Manganese,Iron,Zinc,Selenium,Bromine,Rubidium,Strontium,Yttrium,Niobium,Molybdenum
ED-XRF semi-quantitative	Sodium*,Magnesium*,Aluminium*,Scandium*,Cobalt*,Nickel*,Copper*,Gallium*,Germanium*,Arsenic*,Silver*,Cadmium*,Indium*,Tin*,Antimony*,Tellurium*,Iodine*,Cesium*,Lanthanum * ,Cer

The sampling frequencies for all the samplers are:

PACs/metals – 24 hr integrated sample, midnight to midnight, 1day in 6
Precip samples – monthly samples, event based
WBEA monitors – 1 hour
Weather sites – 1hour
Passive samplers (gaseous PACs +WBEA): 1 or 2 months based on helicopter schedule and weather conditions

www.ec.gc.ca

Additional information can be obtained at:

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Inquiry Centre
351 St. Joseph Boulevard
Place Vincent Massey, 8th Floor
Gatineau QC K1A 0H3
Telephone: 1-800-668-6767 (in Canada only) or 819-997-2800
Fax: 819-994-1412
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