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Integrated Monitoring Plan for the **Oil Sands**

Air Quality Component

Canada

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Executive Summary

The air quality component of the integrated water, air and biodiversity monitoring plan presented here was developed collaboratively by a large group of experts from Environment Canada, Natural Resources Canada, Health Canada, provincial and territorial governments, academia and non-government organizations. The plan underwent an independent expert panel review.

The component is focused on the monitoring needs required to understand air pollutant emissions, their chemical transformation in the atmosphere, long-range transport and subsequent deposition to the local and regional environment. The plan reflects a science-based approach that will ensure delivery of timely, high quality, publicly available data and scientifically interpreted and peer-reviewed results. Air quality is addressed in a comprehensive way, from monitoring at the point of emission through to ambient air and atmospheric deposition monitoring that will enable the evaluation of potential ecosystem and human health impacts. The geographic scope includes the immediate oil sands region, as well as upwind and downwind areas in Alberta, the Northwest Territories, Saskatchewan, and Manitoba reflecting the transboundary nature of air pollution, and the predicted geographical extent of potential ecosystem and human health impacts.

The overarching science questions used to guide the development of the plan are:

1. What is being emitted from the oil sands operations, how much and where?
2. What is the atmospheric fate (transport, transformation, deposition) of oil sands emissions?
3. What are the impacts of oil sands operations on ecosystem (water, biota) and human health? (to be done in collaboration with water, biota and human health experts while providing information on the deposition and exposure due to oil sands emissions)
4. What additional impacts on ecosystem health and human exposure are predicted as a result of anticipated future changes in oil sands development? (to inform regulatory needs)

Increased scope of monitoring of air pollutant emissions from the oil sands region is recommended, including enhanced monitoring of industrial stacks, mobile sources and area sources (including tailings ponds). Improved quantification and characterization of emissions will provide a science-based emission inventory with increased spatial and temporal resolution and including more chemical species, leading to improved understanding of air emissions and their impact on local and regional air quality. Additional measurement techniques to determine air pollutant emissions through satellite remote sensing, and through focused, source-specific, monitoring studies are also recommended. This information is proposed to be publicly available, easily accessible and comprehensive, building upon existing inventory information.

To understand how air pollutant emissions are transformed and transported in the atmosphere and the resulting impact on ecosystem and human health, a multi-component ambient monitoring system is proposed. Fourteen new ambient monitoring stations are proposed, as a complement to existing monitoring sites, to monitor the impact of the oil sands locally and regionally, and to evaluate the transboundary transport of air pollutants across geographical boundaries. The new sites include two 'upwind' stations to monitor air quality that is not influenced by the oil sands region, and two ‘source characterization’ sites in close proximity to oil sands operations. Six of the monitoring sites will also measure the downwind deposition of air pollutants, which is critical to evaluate potential impacts on sensitive ecosystems.

In addition to traditional monitoring techniques, an approach to integrate the information gathered from the ambient and emissions monitoring using air quality models, as well as satellite based information is proposed. This step is critical to interpolate between monitoring sites to areas of the region that will not be sampled through conventional in-situ monitoring, and will give insight into the transport and fate of air pollutants from the oil sands. Information from air quality models can be linked to ecosystem and health based models to provide additional insight into the potential human and ecosystem health impacts from the oil sands.

The air monitoring under this component does not duplicate existing air quality monitoring in Alberta and will support the Air Quality Management System (AQMS) requirements for airshed monitoring and reporting. In recognition that oil sands industrial activities will evolve over time, a long-term multi-decadal perspective is taken, with regular reviews and consultation with stakeholders as needed to assess adequacy and to update if required.

CHAPTER 1. INTRODUCTION

1.1 Why air quality monitoring for the oil sands?

> The atmosphere provides a protective layer for the biosphere through its composition (e.g., protective ozone layer, oxygen and carbon dioxide for respiration, water vapour and rainfall) and its ability to move in response to changes in energy (i.e., weather). Industrial activities can influence the composition of the atmosphere through spatially and/or temporally intensive manipulation of naturally occurring materials. This changed composition of the atmosphere may result in impacts on the ecosystem, as well as on human health. A specific example of such influence of this type of industrial activity is the release of sulphur to air from coal combustion, smelting of ore, etc. resulting in terrestrial and aquatic effects such as loss of fish populations due to acid rain (Environment Canada, 2005). Because of the movement of air masses, pollutants emitted from a specific industrial activity can have an impact on receptors both close to and distant from the point of emission. The information from air monitoring networks is used to make the link between sources of pollution and its impacts and to subsequently inform the development of domestic and international control actions when needed (e.g., Canada-Wide Standards, Canadian Air Quality Management System, Canada-US Air Quality Agreement, UNECE LRTAP), to track the effectiveness of the these regulations when implemented and to provide information to the public on the state of air quality (e.g. Air Quality Health Index).

The oil sands, the world's second-largest oil deposit[1], are a resource of national importance (Figure 1.1). The oil sands operations are an industrial activity that extracts and processes a natural resource (bitumen) and by so doing releases pollutants to the atmosphere (http://www.ec.gc.ca/inrp-npri/). Emission of air pollutants to the atmosphere is a significant by-product of the oil sands industry and due to the rapid evolution of the operations it is a complex issue to understand and address. Current publicly available data are not sufficient to reliably estimate the magnitude and impact of these emissions. Since many of the methods of production of oil from this resource are unique to Canada the scientific environmental measurements needed to understand the air pollution issues raised must be made in the Canadian context. Air monitoring is needed to understand and quantify the emissions from the oil sands operations, to track the spatial extent and temporal variation of the primary pollutants emitted and their transformation products, to quantify their impacts on local and regional air quality and, together with measurements of water quality and biota, to quantify the effect of their deposition. The results from the air monitoring program need to be interpreted and linked across environmental media to relate emissions to cumulative, long-term and acute effects on receptors, both ecosystems and human health. These relationships will form the basis for the regulation of emissions from specific sources as required.

[1] While the Alberta oil sands deposit is the world's second largest reserve, it is third largest in terms of currently estimated recoverable reserve.

The air monitoring recommended here is based on state-of-the-science measurement, data management and data analysis techniques. The results of the air monitoring component plan will provide information to the public on the state of the air in the oil sands region, and to decision-makers to support management of the emissions and their impact on the biosphere in local and downwind environments. The information generated will provide context for additional monitoring addressing specific concerns, such as community-based monitoring. The glossary provides definitions of technical terms used and additional technical supporting information can be found in the Technical Appendices for Air Monitoring which are available by request. In addition to considering the findings of the Federal Oil Sands Advisory Panel, public reports were also examined for criticisms and concerns of air quality monitoring in the oil sands area, as well as for recommendations for future monitoring (Appendix 1A of the Technical Appendices).

The air monitoring component plan was developed collaboratively by the scientists and technical experts in the List of Authors through face-to-face and teleconference meetings followed by an interactive, iterative writing process. The air monitoring component has undergone an independent science peer-review.

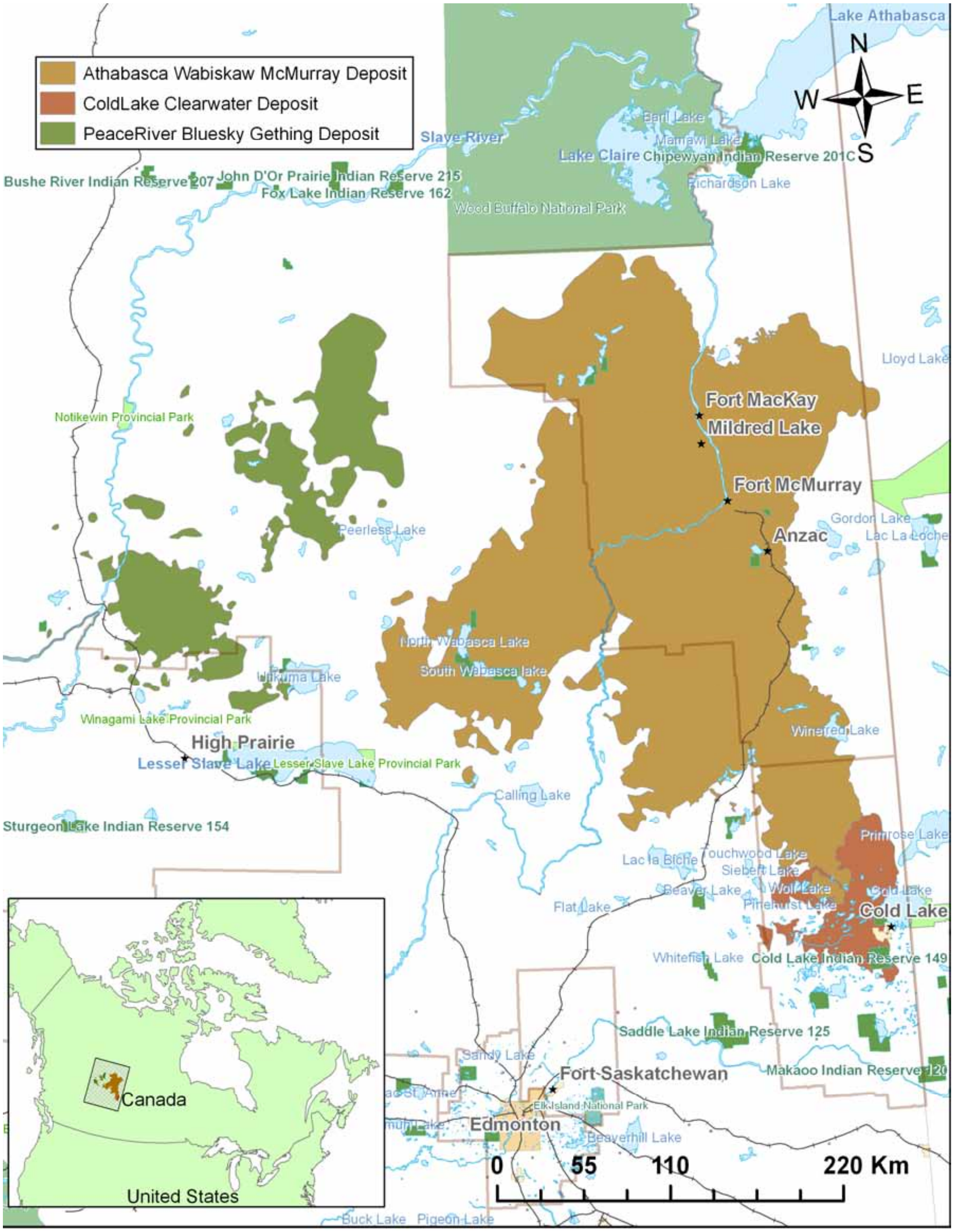

Figure 1.1. Location of oil sands deposits in western Canada. Data for Alberta from the Energy Resources Conservation Board and for Saskatchewan from the Saskatchewan Department of Industry and Resources.

1.2 Existing monitoring in the oil sands region

Air monitoring in Alberta is conducted through airshed associations. These associations are established as non-profit societies under the umbrella of the Clean Air Strategic Alliance (CASA). Each airshed association is independent and is given the tasks of monitoring and reporting air quality data in a specific area in the province (i.e., the airshed zone) where air quality is a prominent issue. Airshed associations are consensus-based and funded by partners in the airshed zone to conduct air quality monitoring by passive and/or continuous methods. The associations active in the oil sands deposits region are the Wood Buffalo Environmental Association (WBEA), the Lakeland Industry & Community Association (LICA) and the Peace Air Shed Zone Association (PASZA). In addition, industries themselves may monitor to meet internal information needs.

WBEA (www.wbea.org), the largest airshed association in Alberta, operates in the Regional Municipality of Wood Buffalo (north-eastern Alberta) with 15 active monitoring stations providing 5-minute, hourly or daily data along a north-south corridor adjacent to the Athabasca River in the oil sands mining and *in-situ* development area, and a background site to the north in Fort Chipewyan. WBEA also operates time-integrated sampling for VOCs and PAHS as well as a network of 27 passive sites, with some passive sites co-located with the active monitoring sites. The passive sites span a larger spatial area than the active sites. In addition to monitoring of ambient air, WBEA conducts focused monitoring on ambient ion chemistry, odour compound speciation, real-world emissions measurements from stacks and mine heavy haulers, measurement of time-integrated flux, and deposition to a network of forest health plots. LICA (www.lica.ca) covers the air zone south of WBEA and uses one active monitoring site and six passives sites, while PASZA (www.pasza.ca) operates five active sites and 47 passive sites in north-western Alberta, surrounding the towns of Grande Prairie and High Prairie. One oil sands upgrader is located outside of the oil sands deposits area in Fort Saskatchewan, the location of refining facilities and other industries. The Fort Air Partnership (FAP; www.fortair.org) monitors air quality in the area of Fort Saskatchewan. As of 2009, FAP operated a network of eight permanent continuous ambient air quality monitoring stations (five of which are compliance stations in the immediate vicinity of petrochemical and refinery facilities) and 57 passive sites.

The locations monitored by these associations are shown in Figure 1.2. Further information on the monitoring being conducted by these regional airshed associations is given in Appendix 1B of the Technical Appendices.

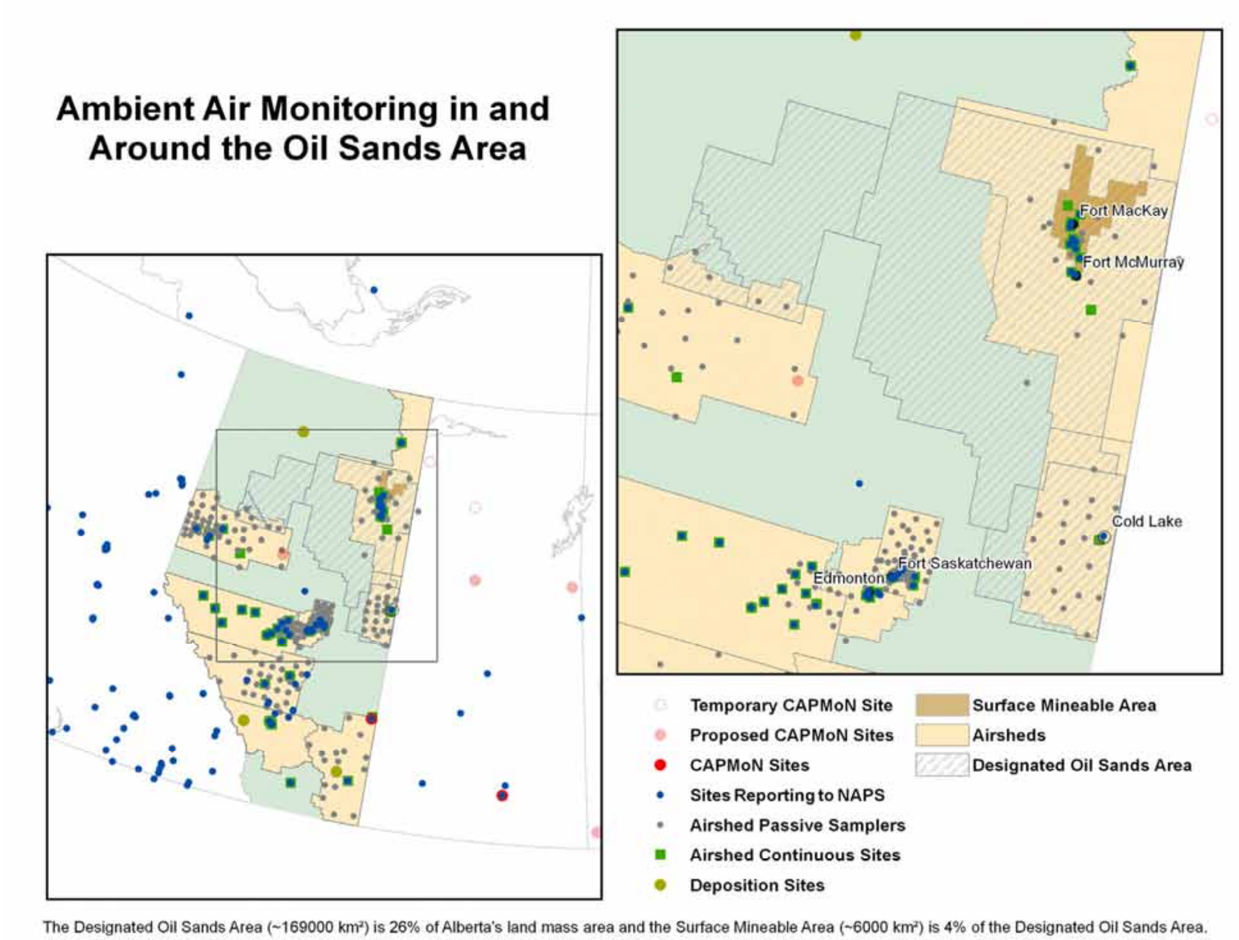

Figure 1.2. Location of current active and passive monitoring sites in the oil sands region and surrounding area. The locations of several proposed sites under the Canadian Air and Precipitation Monitoring Network (CAPMoN) for which the installation process has started are also shown.

Monitoring conducted by the airshed associations is primarily, but not exclusively, for provincial compliance purposes. The public has access to archived airshed data through the CASA data warehouse (www.casadata.org). Real-time hourly monitoring data varies by airshed and includes, where available, hourly O_3, SO_2, NO_2, NO, NO_x, CO, $PM_{2.5}$, SO_2, TRS, H_2S, and THC. Some of the sites operated by the airshed associations report data to the Environment Canada (EC) National Air Pollution Surveillance (NAPS)[2] network which is operated though a federal/provincial/territorial partnership agreement.

Recognizing that the spatial coverage for larger-scale regional monitoring, inter-provincial impacts and impact on federal lands in western Canada is sparse, the Canadian Air and Precipitation Monitoring Network (CAPMoN) has begun an expansion to western provinces, also shown in Figure 1.2.

[2] Based on 2010 data, stations reporting to the NAPS database include 9 WBEA stations, 1 LICA station, 4 PASZA stations and 7 FAP stations.

1.3 Existing air management systems

The Energy Resources Conservation Board (ERCB) is an independent, quasi-judicial agency of the Government of Alberta. The Board adjudicates and regulates matters related to energy within Alberta to ensure that the development, transportation and monitoring of the province's energy resources take place in a manner that is fair, responsible and in the public interest. The Board ensures public interest is safeguarded through its activities in the application and hearing process, regulation, monitoring, and surveillance and enforcement. Under the umbrella of the *Energy Resources Conservation Act and the Oil Sands Conservation Act,* the ERCB is governed by legislation that regulates Alberta's oil sands resources.

Alberta Environment (AENV) has specific regulatory responsibility under the *Environmental Protection and Enhancement Act* (EPEA). Under EPEA, the construction, operation and reclamation of oil sands mines and processing plants require an approval issued by AENV. EPEA has Environmental Impact Assessment (EIA) provisions and the EPEA EIA process is integrated with ERCB processes. If the ERCB finds the proponent's proposal is in the public interest, a proposed project enters the regulatory approvals phase. Section 11 of EPEA provides for cooperation between AENV and Alberta Health and Wellness (AHW) in promoting human health through environmental protection. Alberta manages air quality and acid deposition through specific frameworks with the engagement of stakeholder groups. AENV also has regulatory responsibility under the *Water Act* which may be applicable in the context of deposition of contaminants from air.

Alberta Sustainable Resource Development (ASRD) has specific regulatory responsibility under the *Public Lands Act*. The *Public Lands Act* authorizes specific use of public land through the issuance of surface dispositions such as mineral surface leases, licenses of occupation, surface material dispositions and pipeline disposition. *Public Lands Act* dispositions authorize the use of public land and regulate vegetation removal, aggregate management and conservation and reclamation activities. ASRD also has responsibilities under the *Forests Act*, *Wildlife Act* and *Fisheries (Alberta) Act*.

The Air Quality Management System (AQMS) is being developed by the provincial, territorial and federal governments with stakeholder engagement as mandated by the Canadian Council of Ministers of the Environment (CCME) in October of 2010. The AQMS will include three main interrelated elements: Base-Level Industrial Emissions Requirements (BLIERs), Canadian Ambient Air Quality Standards (CAAQS), and the establishment of local air zones and regional airsheds to support air quality management and reporting. The BLIERS will be performance requirements that will apply to various sources and sectors, which may include the oil sands facilities. It is anticipated that the new, more stringent, CAAQS will replace the existing Canada-wide Standards (CWS) for $PM_{2.5}$ and ozone. CAAQS may be developed for other air pollutants in the future. The CAAQS for $PM_{2.5}$ and ozone and the BLIERs are scheduled to be finalized by the end of 2011, regulations developed in 2012, and the implementation of the AQMS to begin in 2013. Under the AQMS, air zone delineation and management is the responsibility of the provinces and territories.

The regulatory framework under which the Government of Canada also has statutory authorities to protect the environment in the oil sands region includes the following legislation:

- *Canadian Environmental Protection Act, 1999* – enables the monitoring, assessment and regulation of pollutants, including toxic substances, air pollutants and GHGs
- *Fisheries Act* – protects fish-bearing waters and aquatic habitat
- *Species at Risk Act* – protects threatened or endangered species
- *Migratory Birds Convention Act, 1994* – protects migratory birds, their eggs and nests
- *Canadian Environmental Assessment Act* – assesses the impacts of proposed projects
- *National Parks Act* – establishment and maintenance of national parks and reserves

Further description of regulatory requirements related to oil sands emissions to air is in Appendix 1C of the Technical Appendices**.**

CHAPTER 2. OBJECTIVE

The objective of the air monitoring component is to define the air monitoring required to provide the scientific basis for management of emissions from oil sands operations consistent with state-of-the-art practices, including regulation, benchmarking, evaluation of success and revision of practice to ensure that the oil sands are being developed responsibly. The result will be the delivery of timely, high quality, publicly available data and scientifically interpreted and peer-reviewed results, including annual plain language summaries.

> The air monitoring recommended is end-to-end, from point of emission to point of exposure, with scope crossing provincial and territorial boundaries, a science-based approach that is intended to address regulatory requirements and stakeholder issues.
>
> In order to address the identified gaps, the geographic extent for monitoring in the proposed plan will be greater than current efforts, will provide information on the contribution of oil sands emissions to deposition in western Canada and long range transport out of the region and will answer specific scientific and regulatory questions regarding the environmental and health impacts of oil sands emissions.
>
> The approach presented here does not duplicate existing air quality monitoring in Alberta and should support the AQMS monitoring requirements.

The overarching science questions to be addressed are as follows:

1. What is being emitted from the oil sands operations, how much and where?
2. What is the atmospheric fate (transport, transformation, deposition) of oil sands emissions?
3. What are the impacts of oil sands operations on ecosystem (water, biota) and human health? (to be done in collaboration with water, biota and human health experts while providing information on the deposition and exposure due to oil sands emissions)
4. What additional impacts on ecosystem health and human exposure are predicted as a result of anticipated future changes in oil sands development? (to inform regulatory needs)

The authors identified the following key gaps in existing air monitoring regarding the oil sands:

- the lack of background sites, including in areas to undergo future development
- the lack of sufficient data to adequately characterize emissions both from point and diffuse sources
- the lack of air monitoring in areas further downwind of the oil sands activities where there are concerns about the potential effects from the deposition of oil sands contaminants and where there is a need to quantify deposition and potential effects on surface water and landscape due to long-range transport of emissions

- the need for real-time measurements, as opposed to intermittent integrated sampling, for certain air contaminants that could represent acute health and/or environmental hazards
- the need to monitor the rapidly changing extent of development in the oil sands region
- the need to identify and monitor the transformation products of primary emissions
- the lack of co-ordination and consistency in the types of measurements being made and in the databases available to the public and for independent scientific analysis of the data
- the ability to identify and confirm the causes of odour and reduced visibility sufficiently to permit appropriate control measures to be taken

Emissions from the industry result from the bitumen extraction process and from the upgrading process to synthetic crude oil, a refinery feedstock. Industrial chemicals are introduced in the extraction process, and industry either uses utilities producing energy for the extraction and processing or produces energy itself (co-generation). Air monitoring under this component addresses emissions to air from all aspects of oil sands processing in the region containing oil sands deposits, i.e., surface mining, *in-situ* extraction, upgrading and on-site transfer (including naptha/solvent recovery), fugitive release (tailings ponds, re-suspended particulate) and storage of industrial chemicals and byproducts. Air monitoring includes ambient air monitoring of the resulting atmospheric concentrations of oil sands emissions and their transformation products to validate reported emissions, estimate deposition to ecosystems, and inform human exposure risk assessment and monitoring requirements.

In addition to industrial activity in the oil sands production region, some solvent-diluted bitumen is transported by underground pipeline for upgrading in the Strathcona and Sturgeon County region, northeast of the city of Edmonton, a region referred to as the Industrial Heartland and home to over 40 industrial facilities including oil refineries, petrochemical facilities and fertilizer plants. There is currently one oil sands upgrader in operation in the Industrial Heartland; two more facilities have been approved but not yet constructed. Currently, there are challenges in uniquely identifying the impact of emissions from the one operating upgrader. Monitoring data will be used to inform the network requirements for determining the air quality and atmospheric deposition impact of increased upgrading activity in this area. Monitoring of the emissions from refining of oil sands-derived crude is beyond the scope of the current air monitoring plan and will need to be addressed at a later date. The challenge of identifying the effect of refinery operations in already well-industrialized areas will be informed by analysis of data from intensive measurement campaigns conducted earlier elsewhere in Canada (e.g., Halla et al., 2011).

As oil sands development is expected to intensify in the coming decades, urbanization is also expected to occur concurrently. These urban areas will have their own sources of emissions that will have impacts on human and ecosystem health, both on the local and on the regional scale. Hence, in addition to emissions from industrial activity, emissions from this urban development in the oil sands region as well as from natural sources such as forest fires will also be captured.

Exposure of the oil sands labour force while on industry-controlled land, including while on the job and while off duty in the work camps (i.e., residences), monitoring emissions from pipelines being used to move products out from the oil sands production region, monitoring in response to emergencies such as spills and compliance monitoring as determined by the Government of Alberta are outside the scope of what is presented at this time. However, efforts to estimate the contribution of emissions from pipelines and spills should be made to establish bounds and indicate the relative importance of these sources to the environment. While soil quality is also a consideration, soil quality guidelines and the remediation of contaminated sites will not be specifically addressed at this time.

The initial stage of the air monitoring component will address the pollutants or classes of pollutants that are emitted by sources related to oil sands activities and have known ecological and human health effects. These chemicals of concern are summarized in Table 2.1. Other classes of pollutants may need to be added after the emissions are better characterized or if new, emerging chemicals are released as a result of changes in industrial processes.

Table 2.1. Pollutants of known concern from oil sands activities

Pollutant Class	Atmospheric Lifetime	Reasons for proposed monitoring
PACs (PAHs, dibenzothiophenes, other heterocyclics)	hours to months	Toxicity (human, biota)
		Cumulative effects
Metals (including Hg)	hours to months	Toxicity (human, biota)
		Cumulative effects
		Industrial tracers
CACs (O_3,SO_2,$PM_{2.5}$,PM_{10},NO_x,CO)	hours to months	Human and forest health
		Acid deposition and its effects
		Air Quality Standards
		Emissions Regulation
		Atmospheric oxidation capacity
Reduced Sulphur (H_2S, TRS, speciated RS)	hours to days	Toxicity
		Acid deposition and its effects
		Odour
Reduced nitrogen (ammonia, amines)	hours to days	PM and CCN precursor
		Human health (via PM)
		Acid Deposition and its effects
VOCs (speciated)	hours to months	Toxicity (selected VOCs)
		O_3 forming potential
		PM formation and human health effects
PM: mass,size distributions, optical properties, black carbon, organic carbon total, organic carbon species, inorganic species	hours to months	Human Health
		Acid deposition and its effects
		Source apportionment
		Climate effects
Nitrogen, sulphur and oxygen isotopes	hours to decades	Emission source tracers
		Tracers of atmospheric processes

The measurements made will provide a baseline for current emissions, enable prediction of future trends and extend the trends back in time to past conditions. Varied measurement technologies, including remote sensing as illustrated in Figure 2.1, are included to meet the needs of sampling over a range of exposure and deposition environments. The measurements will be integrated with models and satellite data to interpolate in space and time the significance of oil sands emissions to downwind receptors. The end products derived from the air monitoring will focus on quantifying effects on ecosystems and human health from long-term exposure to multiple pollutants, integrated over a time scale of multiple decades, working both back in time through retrospective and historic data sets and into the future through predictive modelling.

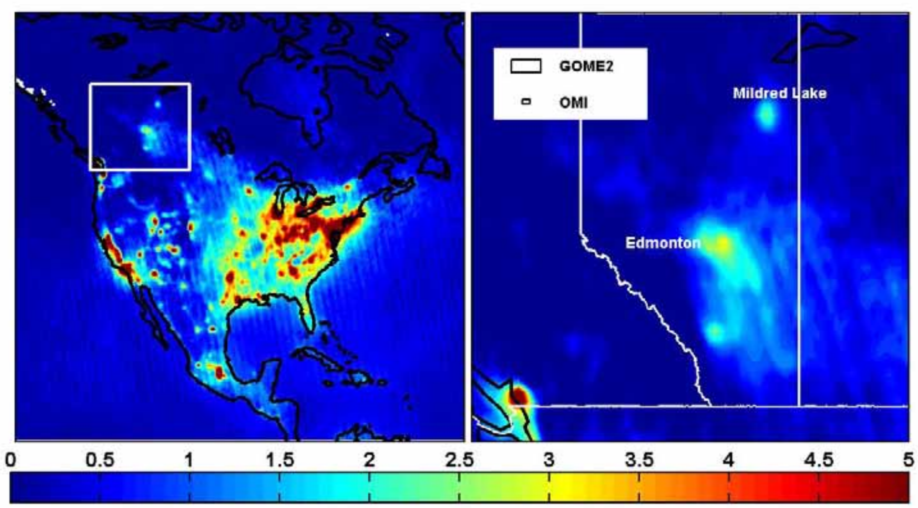

Figure 2.1. NO_2 in the troposphere as determined from the Ozone Monitoring Instrument (OMI) averaged over the year 2008 in units of 10^{15} molecules/cm^2. Since NO_2 is a primary pollutant which transforms quickly to other species in the atmosphere after release, it appears close to source regions. North America is shown in the left panel with detail of the box shown in the right panel. Also shown in the right panel are the horizontal resolution elements of two satellite instruments useful in oil sands monitoring (OMI and the Global Ozone Monitoring Experiment 2, GOME2). The radius of the enhancement around Mildred Lake is approximately 40 km.

Monitoring proposed as part of this plan will include:

- measurements of emissions to air from oil sands industrial point and area sources
- long-term monitoring of air concentrations and atmospheric deposition of significant compounds resulting from these emissions
- assessment of the impact of oil sands emissions on air quality and wet and dry deposition to aquatic and terrestrial ecosystems, including determination of deposition to the ecosystem, input for critical loads calculations, evaluation of transboundary

transport and air concentrations (exposure) at sites without *in-situ* measurements through the application of models and satellite data
- monitoring by satellite and remote sensing to understand the distribution and recent changes in atmospheric concentrations of significant compounds (i.e., NO_2 and SO_2)
- regular assessment of the monitoring network through integrating tools such as air quality models
- short-term surveillance projects to fill knowledge gaps and inform the evolution of the monitoring
- reporting of results to the public together with regular review and updating for relevancy

In recognition that oil sands industrial activities will evolve with time (i.e., intensity, technology) the component plan for air monitoring takes a long-term perspective. Implementation can occur in stages on timelines appropriate to address current and anticipated requirements. Because the data acquired must be transparent and accessible, data management from the point of measurement to the end user is included. Finally, regular review and consultation with stakeholders is needed to assess adequacy and to update as required.

Information generated from this air monitoring should provide data needed for health agencies to undertake air quality assessments. The anticipated risk assessment approach taken would be analogous to the U.S. National Air Toxics Assessment (NATA) or the approach taken when evaluating projects under the *Canadian Environmental Assessment Act*, i.e., ambient air concentrations are compared to Air Quality Standards and/or to reference concentrations when these are available from regulatory agencies. For substances where no such values exist, an analysis would be undertaken from information in the scientific literature to determine the most likely possible adverse outcome, but no quantitative evaluation of risk would be possible. In the most intense exposure settings, not anticipated as being applicable in this case, personal monitoring would be conducted for a panel of individuals in the populations affected by the sources.

It is important to note that by using ambient air data alone, the risk of exposure to any specific substance for an individual or population cannot be fully estimated due to the likelihood of exposure via other routes or environments. To evaluate the health risk for some airborne contaminants, a detailed multi-media assessment would be needed to understand the population health risk in full. Depending on the contaminant, a full health risk assessment would require the air monitoring that is being proposed here together with indoor air monitoring, information on food basket plus country foods and information on drinking water contaminants.

Challenges to be faced for monitoring at ground-level in the oil sands region are due to the large geographical extent, the lack of road access and electrical power, and general issues of logistics due to environment, including the lack of human resources to provide services and health and safety considerations for access to industrial sites. Thus this air monitoring component intends to fill knowledge gaps through state-of-the science measurements of key pollutants, including remote sensing and airborne measurements as needed, from source to long-range transport scales. Results from the monitoring will be externally peer-reviewed and inform the public and decision-makers in and outside of government of potential environmental and health impacts resulting from oil sands emissions, including those due to long range transport across provincial or territorial boundaries.

CHAPTER 3. MONITORING COMPONENT

3.1 Emissions Inventories and Monitoring

A point and area source emissions inventory and database management system adequate to meet the science needs should be in place to collect, manage and review emissions inventory data for air quality in the region. This inventory should encompass all sources in the oil sands development region including industrial and urban. The following questions should be addressed:

1. What is the full suite of chemical compounds that are being emitted from all sources in the oil sands region, both industrial (tailings sand and water re-emissions, coke piles, sulphur piles, stacks, fugitive emissions, vehicles, surface dust and oil sands upgrading) and urban?
2. What are the quantities of oil sands emissions in terms of location of emission, source strength, height, temporal variation and long-term changes?

The actions that are required in order to answer the above questions include:

1. Identification of the potential sources of air emissions associated with oil sands operations
2. Quantification and characterization of the emissions from these sources
3. Identification of emission sources and/or emitted substances that have the potential to have health and/or environmental impacts
4. Improved understanding of the processes that may affect the release of substances of health and/or environmental interest from sources
5. Identify source monitoring program knowledge gaps and possible ways to address these gaps in the future
6. Ensure a comprehensive and publicly accessible database on regional oil sands emissions is in place

3.1.1 Overview

The oil sands region is approximately twice the size of New Brunswick[3], and development of this resource through increased oil sands industrial activities is accompanied by rapidly expanding urban communities. This collective growth is contributing significant air emissions to the region as well as causing possible long range impacts as those emissions and their transformation products are transported downwind. With this in mind, this Chapter outlines the approach to developing a detailed emissions inventory for the region, with the realization that the ideal inventory is not attainable given the scope and diversity of the sources and size of

[3] Environmental Management of Alberta's Oil Sands, Government of Alberta, ISBN : 978-0-7785-7677-8 September 2009

the region and that through the process a prioritization of the investments into this activity will be needed.

In order to implement and manage an integrated air quality management strategy an emissions inventory describing the sources and magnitude of the emissions to air released over a given time for a defined area is needed. An analysis of existing emission data/inventories is needed to determine what data are already available, and what gaps exist. From there, monitoring activities can be proposed to fill these gaps to build a more comprehensive oil sands emission inventory. The sources of oil sands emissions in the inventory will include point sources, typically associated with industrial stacks, area sources including those arising from oil sands tailings ponds and mobile sources, both non-road such as the large mining trucks and on-road vehicles. In this region, existing air emissions inventories include other anthropogenic sources such as non-oil sands industries, quarries, agriculture, transportation, and natural emissions such as from vegetation, soil, and forest fires.

The inventory should be easily accessible, comprehensive, standardized and in the public domain. Such an inventory will enable better air quality management practices in the present, and would enhance future air quality assessments undertaken in the oil sands region. The spatially resolved geographic information system should contain meteorological data together with emission rates and activity data for important sources such as process stacks, mine tailings ponds, and transportation corridors. Emission rate information for these sources would include criteria air contaminants (SO_2, NO_X, PM, CO and total VOCs) while other pollutants (e.g. NH_3 and various air toxics) would be added over time. The objective is to attain the scale needed to characterize irregular events such as on-site fires, downtime of emission control equipment, flare emissions and changes to input fuels. A complete list of the proposed chemicals and proposed monitoring methods is included in Appendix A.

The inventory needed should build upon existing data sources and inventories. There may be a number of ways to fill the identified gaps in emission data (spatial/temporal scale), however this plan will focus on targeted monitoring activities as the main approach. Should other data be needed, the path forward will be to work through existing programs and mechanisms to determine the most appropriate way to meet the identified data needs. These mechanisms can include the environmental assessment process, whereby missing information is requested as part of the process for assessing cumulative effects. As new information is collected, it should be linked to existing data sources and inventories to provide a more holistic picture for those using the data, including government officials and, where the information is public, external data users.

The source and emissions science database should include supporting documentation informing inventory users about the assumptions and sources of the data at a level of much greater detail than practices under required reporting of emissions. This information will allow for improved spatial and temporal understanding of air pollutant emissions, as well as targeted analysis of emission sources and their impact on local and regional air quality.

3.1.2 Current Emissions Inventories

There are currently many examples of fine-scale emission inventories being developed, which can inform the development of a high-resolution and comprehensive inventory.

In Alberta[4], similar to other Canadian provinces and territories, the primary source of emissions inventory data is the National Pollutant Release Inventory (NPRI[5]). The NPRI is a federally legislated, publicly accessible inventory of pollutant releases that is comprised of two key components: data reported by facilities on releases, disposals and recycling of over 300 pollutants, and more comprehensive information on all sources of emissions of certain key air pollutants. Environment Canada administers the NPRI, which collects data from over 9,000 industrial facilities nation-wide that meet specified reporting criteria for NPRI-listed substances. The comprehensive Air Pollutant Emissions Inventory (APEI) component of the NPRI provides emission data from all sources (e.g. motor vehicles, agricultural activities, natural and open sources, etc.) for several common air pollutants by province/territory and for all of Canada.

National Pollutant Release Inventory – Oil Sands Facilities

By the end of 2009, 24 producing oil sands facilities were operating in Canada, all of them located in Northern Alberta. They include five oil sands mines, of which three have on-site upgraders, and 19 thermal *in-situ* facilities. There are currently four oil sands companies with mining operations. All 24 of these facilities reported to the NPRI for 2009.

While most of the emissions from the 24 oil sands operations are reported to the NPRI, emissions from mobile sources (mine fleet) are not captured in the facility-reported data. However, these emissions are included in the NPRI comprehensive emission summaries and trends. Some data gaps remain including the quantification of emissions from the active working face of the mine and other fugitive sources.

Conventional oil extraction facilities are also located within the geographic region of the Alberta oil sands. Twelve of these conventional facilities in Alberta reported to the NPRI for 2009. Beyond the oil sands region of Northern Alberta, one additional oil sands upgrader, located in the Edmonton area, also reported to the NPRI.

The NPRI/APEI data source provides the information foundation for developing a local comprehensive and integrated emissions inventory that would be required for guiding the fine-scale air quality monitoring and modelling that is necessary to characterize the air emissions sources, and their associated impact on air quality in the region. However, the existing NPRI inventory does not provide the multi-pollutant and multi-scale air quality information at the finer spatial and temporal scales that are necessary to achieve the objectives. As a result, it is proposed that an action plan be developed for the development of a more detailed local scale

[4] www.environment.alberta.ca/0969.html
[5] www.ec.gc.ca/inrp-npri/

emissions inventory that is more representative of individual facilities, as well as local sources. The benefits of moving to this level of detail are many, ranging from providing greater insights into local sources that may be impacting monitoring sites to supporting receptor model efforts that help identify and quantify impacts of local sources on human exposure and deposition and helping prioritize efforts to improve air quality. The development of this more detailed, scientifically focussed inventory, while informed by the NPRI, may be independent of the NPRI.

The Province of Alberta is currently using an emissions inventory compiled using a specific industry survey that was distributed in 2010 together with emissions inventories from other cumulative effects projects in the province (i.e., Lower Athabasca Regional Plan[6] and Fort Air Partnership FAP[7] inventory) and NPRI to fill in the gaps. This information is currently being used by the province for modelling and related research activities.

Recognizing the need for more detailed local emissions information, the Alberta government, together with the WBEA, the Cumulative Environmental Management Association[8] (CEMA) and other stakeholders, initiated a number of projects to develop fine-scale emissions inventory information needed for the region. CEMA has conducted a number of regional acid deposition and ozone formation model runs that required detailed regional emissions inventory data for both current and projected future NOx, VOC and SO_2 emissions. Environmental impact assessments required for most new proposed oil sands projects also require estimates of emissions for baseline case (i.e., existing + approved projects), application case (i.e., baseline case + projects submitting applications) and planned development (application case + all other announced projects). However, due to uncertainties regarding emissions from mine fleets, tailings ponds, mines and fugitive plant site emissions, all of these inventories have a high level uncertainty and in most cases include only a few emission parameters.

3.1.3 Emission Factors and Activity Levels

To a large extent, an emissions inventory needs to be based on the application of emission factors, where the basic equation for most sources is:

Emissions = activity data (AD) x emission factor (EF)

The AD should be readily available and directly linked to the source. Production rate or fuel consumption data is a good basis for AD, except for sources that operate intermittently (e.g., bypass stacks), or as alternate (e.g., flares). Alternate source emissions may be significant for local dispersion studies.

[6] www.environment.alberta.ca/03422.html
[7] www.fortair.org/
[8] cemaonline.ca/

There are various tiers of emission factors based on the methods by which they are derived:

- *Tier 1 EFs* represent typical emissions from a similar process, as measured elsewhere (for example the U.S. EPA Compilation of Air Pollutant Emission Factors, or AP-42[9]).

- *Tier 2 EFs* represent typical emissions from similar processes, (e.g., an EF derived from compliance testing of existing oil sands facilities)

- *Tier 3 EFs* go beyond the above and may be based on source concentration monitoring, predictive emission monitoring systems (PEMS[10]), etc.

The scientific emissions inventory should include documentation of the basis for adopting a given AD or EF to enable independent review and to facilitate continuous improvement of the inventory.

Sources that operate intermittently or only when a control equipment is out of service may be characterized via a “potential to emit” EF, as opposed to EFs derived from actual emission tests.

Examples of sources which have already been identified as critical to the scientific emissions inventory and where the emission factor and or activity data have greater uncertainty include:

- stack emissions
    - emission events and upset conditions (e.g., upgrader fire, flare use, emission control bypasses or problems) (parameters include: PAHs, metals, SO_2, NOx, VOCs, RSCs)
    - extraction, in-situ, Gas plant, other
- fugitive emissions
    - tailings ponds (evaporative emissions), open mine faces, mine reclamation, processing plant sites
    - parameters include: VOCs; odour causing compounds, fugitive dust
- mobile sources
    - highway and non-road mining fleet
    - aviation and rail
- community
    - heating, small industrial, other
- natural
    - biogenic, wildfires

[9] www.epa.gov/ttn/chief/ap42/index.html#toc; see glossary

[10] PEMS is an alternate form of continuous monitoring that predicts source emissions indirectly using process parameters instead of measuring them directly. It is mostly used to "monitor" NOx emissions from stationary combustion turbines, by processing, combustion and ambient temperature, gross power output, etc. In the US PEMS are regulated by Performance Specification 16, which determines the equivalency to Continuous Emissions Monitoring (CEMS) on the basis of statistical tests against reference methods

3.1.4 Emissions Uncertainty

It is recommended that all activity data and emission factors used in the scientific emissions inventory be provided with an uncertainty estimate. Emission source uncertainty can be estimated by direct or indirect methods. For example, continuous monitoring is considered to provide the most accurate emission estimate over any test period, and is the cornerstone of the U.S. SO_2 and NO_x emission trading system. A more detailed discussion of emissions uncertainties relating to continuous monitoring and emissions factors (as discussed in section 3.1.3) is found in Appendix 3A of the Technical Appendices.

> Emission inventories are an important pillar in air quality management, and while current inventories support many emission management and regulatory activities, it is recognized that there are a number of inventory shortcomings that could be reduced by application of improved inventory development, analysis and dissemination techniques. One such area is the quantification of the uncertainties that exist around the emissions information, where uncertainty refers to the lack of knowledge regarding the true value of a quantity.

NARSTO, a public / private partnership dedicated to improving management of air quality in North America, concluded that current inventories contain very little information regarding uncertainties of reported emission data. Such information should be highly important to decision makers in their attempts to plan and optimize pollution-management strategies (NARSTO, 2005).

The NARSTO assessment of improving emissions inventories identifies a number of key uncertainty related questions that must be considered in the context of air monitoring:

- How precise are the estimates used for both the emission factors as well as the activity factors?
- What are the key sources of uncertainty in the inventory?
- Is there ongoing research that might fill critical data gaps within the near term?

As an example, Houston, Texas is perhaps a useful analogue for the oil sands facilities since it contains a large complex of refineries and petrochemical industries whose emissions may be somewhat similar to the oil sands facilities (Parrish, 2011, personal communication). Research there shows that inventories continue to underestimate emissions of highly reactive VOCs by an order of magnitude (de Gouw et al., 2009; Mellqvist et al., 2010) after decades of work and major field research efforts. Similarly, emissions from the well-studied on-road U.S. vehicle fleet are poorly estimated by U.S. emission inventories (Parrish et al., 2006). Estimating emissions for the on-road and off-road vehicles in the oil sands region will present much greater challenges. Similar errors must be expected in developing an oil sands inventory through the application of standard methods utilizing activity data and emission factors.

It is important that a realistic assessment of inventory uncertainties derived from standard "bottom-up" methods, and the questions listed above, guide the prioritization of emission characterization.

3.1.5 Improving the Emissions Inventory through Additional Source Monitoring

Data resulting from monitoring of emissions are often not incorporated into air emission inventories. Instead, approved emission rates are used (i.e., the rate at which the facility is permitted to emit). In the absence of approval limits or emissions monitoring data, the general approach is to use emission factors coupled with source operational or activity data to estimate the emissions from various sources. Together these factors limit the value of existing inventories for determining effects of present and future emissions on air quality.

The planned work augments existing regulatory reporting. For example; the reporting requirements for stacks in Canadian regulations (National Pollutant Release Inventory) are based on both the mass emitted and reactivity of the compounds; trace-level compounds, such as PAHs (see Table 3.1, section 3.1.5.1), may therefore not be reported under the regulatory requirements, due to the small amounts of mass of these compounds relative to other volatile organic compounds that are emitted. Similarly, current mine fleet emissions (section 3.1.5.2) are based on projections from US EPA non-road models – measurements of speciated emissions from the oil sands fleet are not part of standard Canadian regulatory reporting requirements. The location of the oil sands off-road vehicles are not reported, nor their typical daily work cycle. Mine fleet emissions chemical speciation (gas and particle-phase), spatial locations, and temporal profiles, are all to be part of the augmented emissions data to be collected here. Regulatory reporting does not include emissions from many area sources in the oil sands, such as tailings ponds (to be undertaken in work outlined in section 3.1.5.3). Quality assurance checks of the reported emissions using space-based instrumentation (section 3.1.5.4) are not required under regulatory reporting; this is an additional source of emissions data to be explored and evaluated. The emissions work to take place will thus extend knowledge of emissions beyond what is required for regulation using the best available scientific methods.

Also of importance is the use of appropriate state-of-the-art field and laboratory techniques or chemicals of interest. For chemicals of significance found in the oil sands region where standard measurement techniques are not available or difficult or expensive to use, research, development, and implementation of appropriate techniques, suitable for a monitoring program, should be a high priority. Of note is the lack of VOC speciation data and lack of information on naphthenic acids.

The following sections provide an overview of the focused monitoring activities that need to be undertaken to address information gaps and deliver the spatially and temporally resolved emissions inventory data required to meet the goals of this regional emissions inventory.

3.1.5.1 Stack Monitoring

Stacks are built for the purpose of attenuating the local impact of significant emissions. Tall (i.e., > 50 m) and large diameter (i.e., > 1 m) stacks must receive special inventory attention. Generally the stack height is determined by the need to meet the ambient standard of a specific criteria air contaminant. Often this contaminant is accompanied by other less well-characterized contaminants. For example, a stack venting solid fuel combustion gases may be well-characterized for SO_2 and particulate matter emissions, but poorly for PAHs/PACs and VOCs. These poorly characterized contaminants are likely to represent the greatest uncertainty in the current compliance testing program for major stacks, and therefore where the focussed monitoring addressed here should place greater effort.

The chemical definition of PAHs relies on their molecular structure, whereas the environmental significance derives from their probable human carcinogenicity. There are various PAH environmental listings, including a 7-PAH, a 15-PAH and a 16-PAH listing. The effort proposed here includes an inventory that quantifies the 18 compounds listed in Table 3.1 and includes alkylated PAHs.

Table 3.1 Recommended Inventory PAH Listing

Compound	Quebec PAH-15	US EPA PAH-16
Acenapthene		+
Acenaptylene		+
Anthracene	*	+
Benzo[*a*]Anthracene	*	+
Benzo[*a*]Pyrene	*	+
Benzo[*b*]Fluoranthene	*	+
Benzo[*e*]Pyrene	*	
Benzo[*g,h,i*]Perylene	*	+
Benzo[*j*]Fluoranthene	*	
Benzo[*k*]Fluoranthene	*	+
Chrysene	*	+
Dibenz[*a,h*]Anthracene	*	+
Fluoranthene	*	+
Fluorene	*	+
Indeno[*1,2,3-cd*]Pyrene	*	+
Napthalene		+
Phenanthrene	*	+
Pyrene	*	+

An open ended characterization of VOCs is recommended as part of the focussed monitoring, consistent with the current NPRI definition of VOC which specifically excludes 48 photochemically unreactive compounds. The stack emissions speciation method outlined in Appendix 3B of the Technical Appendices has been used to quantify VOCs from industrial sources and will satisfy the need to characterize the VOCs in this scientific context.

Ideally, the size distribution of the particulate emissions should be determined, so as to be able to model dry deposition. As a minimum, the determination should be able to estimate $PM_{2.5}$ and the condensable fraction of particulate matter (CPM), both relevant for long-term human health concerns. The original AP-42 methods inaccurately quantify the CPM fraction of $PM_{2.5}$ in sources containing SO_2, particularly in the stacks of recent upgrader expansions[11]. Research on this issue has led to modified test methods[12] which minimize the potential bias due to the oxidation of SO_2 and the interaction with low levels of ammonia. In addition to the detailed speciation efforts described above, continued and expanded emphasis of criteria air contaminant measurements through the use of continuous monitoring would be an important on-going element of the air monitoring component.

[11] Syncrude UE-1 coker expansion, SO_2 controlled by Marsulex ammonia scrubber process.

[12] US EPA methods 201A and 202 (December 2010 revision)

3.1.5.2 Mobile Sources (non-road and highway)

Mobile source emissions, both non-road and highway, are significant contributors to the inventory of air pollutants in the oil sands region. This situation is similar to most areas in Canada where transportation contributes about 52 per cent of all NO_X emissions, 68 per cent of CO, 29 per cent of VOCs[13] and 5 per cent of fine particulate matter ($PM_{2.5}$).

Real world monitoring of mobile sources has increased in recent years through a number of approaches including the development and deployment of specialized on-board emission measurement systems, road side sampling, remote sensing and instrumented chase vehicles. The advantage of these measurements is that the resulting data are more representative of the actual air emissions than those obtained through data derived from regulatory testing which is conducted under very tightly controlled laboratory conditions. However, real world measurements are subject to an increase in variability which needs to be controlled to an acceptable level through advanced planning and project design.

The emission of criteria air contaminants from oil sands mine fleets has been identified as an important source and has commonly been estimated and projected based on the U.S.EPA non-road models[14] and assumptions regarding fleet turnover and the application of new emission limits. There is a high degree of uncertainty associated with such estimates since until recently there has been no mine fleet emission monitoring data available to assess modelling approaches and validity (Chow et al., 2010).

It is recommended that characterization of emissions from mine fleet activities be included, including measurements of emissions under actual operational conditions for the range of vehicle types in use, and of the highway fleet where there are indications that the vehicle mix may be unique. Different fuel mixes used by the various mine fleets must also be accounted for, as emissions will differ from one fuel source to another.

3.1.5.3 Area Emissions

The open mined areas and associated tailings ponds are expanding to accommodate increasing bitumen production, likely resulting in increased total air pollutant emissions from these sources. Little information is available on the air emissions from these sources, either on the chemical speciation of pollutants emitted to air or the magnitude of emissions. Anecdotal evidence suggests that tailings ponds are significant sources to air of reduced sulphur compounds, reduced nitrogen compounds, hydrocarbons and potentially metals. Pond composition changes with age which may also influence emissions.

Area emissions, such as evaporative losses from the tailings ponds or from the oil sand mine extraction faces, which have been estimated through modelling techniques, must be quantified

[13] 2009 NPRI Data, for VOC's does not include natural sources

[14] http://epa.gov/nonroad/

by techniques generally associated with ambient air monitoring as opposed to point source monitoring. These methods rely on upwind-downwind sample collection or direct measurements with point or path sensors, in conjunction with local meteorological measurements to determine the height and width of surface plumes originating in the source area. A path sensor methodology has been evaluated for the measurement of fugitive emissions from a refinery and would appear to have application for certain oil sands type emission sources and substances (Alberta Research Council, 2006). A laser-based method called DIAL (Differential Absorption Light Detection and Ranging) has also been used to measure and map concentrations and mass emissions from facilities.

Area emission measurements need to be repeated over several days and nights of favourable wind speed and direction and in different seasons to determine the variability of the emissions under a variety of meteorological conditions. Validation with known releases of man-made tracers will serve to determine the uncertainty of these emissions measurements. In order to better define the emissions to air from these disperse sources, studies should be undertaken to:

1. identify the emitted compounds,
2. generate flux estimates for these compounds from the surface under different meteorological conditions, and
3. parameterize the relationship between emission flux and atmospheric turbulence to define the fundamental physical process for emissions so that these emissions can be predicted with models on an ongoing basis

A proposed methodology for monitoring tailings ponds emissions is discussed in section 3.2.4.1.

3.1.5.4 Satellite and Remote Monitoring of Emissions

Satellite measurements provide a large-scale, time-integrated view of emissions from the oil sands. The measured quantity is not a concentration but rather vertical column density (VCD), giving the number of molecules over a unit area between the surface and the tropopause. A preliminary analysis shown in Figure 3.1 indicates that statistically significant enhancements in NO_2 and SO_2 VCD over the oil sands region can be measured with current operational satellites. Due to limitations in resolution, the current generation of satellite sensors cannot spatially resolve enhancements associated with individual oil sands operations and it is generally necessary to average many individual measurements together in order to obtain a statistically significant value. For NO_2, this amounts to several days to weeks of measurements while for SO_2, with its weaker signals, months of observations are needed.

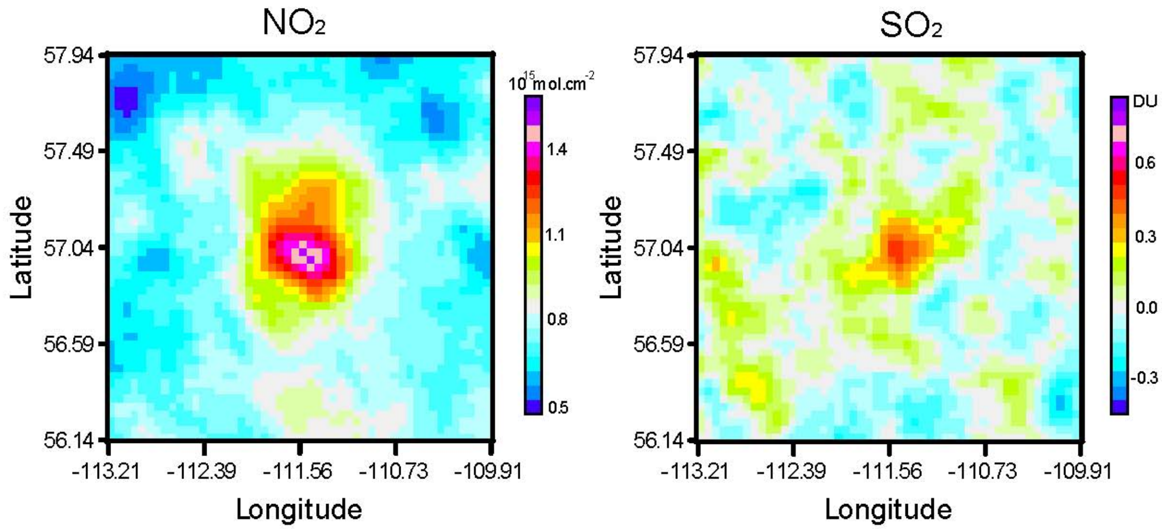

Figure 3.1. NO_2 and SO_2 tropospheric VCDs measured by OMI over Mildred Lake (57°N, 112°W) and averaged over the 2005-2010 period. Each plot spans 200 km in both the N-S and E-W directions. In this figure the units of NO_2 VCD is 10^{15} molecules cm^{-2} and of SO_2 VCD is Dobson Units, DU (1 DU=2.69×10^{16} molecules cm^{-2}, with negative DU due to imperfect removal of ozone in the retrieval).

Satellite observations should be used to estimate the annual, integrated (over the entire area of enhancement) emission rates of NO_x and SO_2 using the top-down method introduced by Martin et al. (2003). Finer time resolution is not possible for SO_2 due to the large number of observations that must be averaged.

Space-based observations of tropospheric NO_2 and SO_2 can also be used to develop a historical record of past emissions. An existing data record (2002-present) that could be useful for oil sands monitoring from space, can give nearly a decade-long time series of NO_2 monthly-means. Satellite data have been used to assess trends in tropospheric NO_2 over continental scales (Richter et al., 2005). Quantifying a trend over the much smaller area of the oil sands, an area comparable to the horizontal resolution of the satellite instruments as shown in Figure 3.1 represents a challenge and an area for future study. The variation in NO_2 VCD can be used to help constrain the change in the emission rate of NO_x over this period. A similar analysis can be performed on the SO_2 data, although it may be necessary to use multi-annual mean values.

Other air quality constituents can be measured from satellites, but it is not clear which ones display an enhanced signal over the oil sands. The most promising candidate that should be investigated is aerosol optical depth.

The area and intensity of emissions will evolve with increased development of the oil sands. Likewise, satellite data and data quality will evolve as current instruments age and new instruments come on-line. Instrument teams periodically release new data products and improved versions of existing products. On this basis, a reassessment every two years should be performed to investigate:

- is there a new data product that is better suited to oil sands monitoring than the one currently being used?
- are there any newly-measured species available that should be included?

In addition to satellite measurements, surface remote sensing measurements can be also applied to inform the quantification of emissions. A mobile Fourier-Transform Spectrometer (FTS) should be used to make local measurements downwind of tailings ponds. The breadth of species that may be measured by these instruments make them ideal for this application. Additional information on satellite and remote sensing monitoring instruments can be found in Appendix 3C of the Technical Appendices.

3.1.5.5 Focused Monitoring to Support Emissions Inventories

Focused monitoring of emissions in the air monitoring component is defined as measurements of emissions either at the source or very near the source so that the specific source is identified. In some cases such as tailings ponds, mines and plant site fugitive emissions, near source emissions monitoring is the best way to get an integrated and representative measure of emissions. Focused monitoring is critical to developing the fine scale inventory that is necessary for understanding and managing the air quality in the oil sands region.

Information to be gathered to support the development of the fine scale inventory can include individual source-specific measurements or long-term monitoring information collected on a scale local to the emissions (section 3.2). These include data for emission inventory validation through determination of ratios of species emitted at/near source locations, such as at the source characterization supersites (Section 3.2.1.1) and in plumes through aerial surveys and intensive ground/airborne studies (Section 3.2.4.2). Direct flux measurements planned over the tailings ponds (Chapter 3.2.4.1) are intended to directly relate the emission fluxes to boundary layer meteorology.

The output from focused measurement campaigns provides the information required to establish source fingerprints and emission rates. When combined with meteorological data, these measurements support the design and implementation of an optimized air quality monitoring network containing a mix of source- and receptor-oriented monitoring stations as well as enhanced general ambient air quality monitoring. More commonly known as source apportionment techniques, these collective tools result in an improved ability to pinpoint individual sources and predict the air quality impacts of continued oil sands growth and urban expansion in the region. The focussed emission monitoring efforts address the need for increased actual multi-pollutant emission measurements for the larger sources as well as those that are not reported in the existing inventories (i.e., those with stack heights below 50 meters). Measurements taken under both warm and cold meteorological conditions and under varying operating conditions will also provide insight to the seasonal and operational variations.

The types of air emissions that should be characterized are dictated by the source that is being studied. Appendix A gives an indication of the air emissions that should be addressed in addition to criteria air contaminants.

The application of source apportionment techniques contributes to the management of air quality by determining the contributions of various pollution sources to a specific receptor location such as a population centre. Common approaches to apportionment include Chemical Mass Balance (CMB) Modelling, Principal Component Analysis (PCA), and Positive Matrix Factorization (PMF). These source apportionment methods, called top-down or receptor-based, avoid the uncertainties associated with bottom-up techniques which depend on potentially inaccurate or limited emission inventory data and meteorological conditions. Having these tools in place and knowing the contributions of the sources within the region permits the optimization of the locations of air monitoring stations and the identification of gaps in the emissions inventory. While these techniques are potentially useful, their application has proven to be problematic with different techniques often giving conflicting conclusions. They should be used with great care, with careful comparisons of results from multiple source apportionment approaches, comparisons with the top-down tests described in the preceding point, and in the context of a careful iterative approach with bottom-up techniques.

The measured point source emission profiles reported in the scientific emissions inventory will require validation using a top-down source apportionment approach. Top-down assessments with ambient monitoring data make it possible to determine how accurately ambient air quality can be described using specific pollutant sources. In populated areas where local air quality needs to be assessed, simple top-down techniques can quickly provide information on the relative importance of different sources of pollution. More elaborate top-down techniques can also be used to provide more certainty in the results and to evaluate results derived via a bottom-up analysis.

Top-down source apportionment techniques also have limitations which must be considered and addressed as much as possible during their implementation. First, the chemicals selected for the top-down apportionment need to be conserved in the atmosphere, with little or no atmospheric chemical transformation between points of emissions and points of measurement at the receptor. Atmospheric mixing and deposition are thus the only processes that will cause variations in the atmospheric concentrations of the compounds. Second, the inventory must have appropriate and distinct source profiles that can reliably match emission sources to ambient air pollution. Sources with similar or same profiles cannot be distinguished from each other using source apportionment techniques. In a region such as the oil sands, where mining operations are located in close proximity, it may be impossible to differentiate the contributions from individual sources. Methods to differentiate sources of emissions with similar chemical composition and to account for secondary products produced from primary emissions must be available for definitive results.

3.1.6 Implementation of Emissions Inventory and Focused Monitoring

An Emissions Inventory Working Group should be established to guide the process of the development of the inventory. A standardized approach for the scientific inventory should be developed and implemented and an inventory compiled of the emission inventories for the region. Near-source monitoring to support emissions inventory requirements (industrial, road-side, ponds, stacks, etc.) should be co-ordinated with on-going and new ambient air monitoring initiatives. A gap analysis of emissions data, emission factors, meteorological information, etc. should be conducted to guide the development of an action plan to validate and refine reported emissions and expand the number of pollutants reported to the emissions inventory. An action plan to address the gaps should be developed and implemented. The action plan should include measurements to validate reported emissions and activity levels from selected priority sources. The current permitting process with respect to emissions estimation, measurement, quality assurance and reporting could be reviewed as a result of this work and revised as needed to better support standardized emissions inventories and air quality management initiatives.

Progress on deriving the emission fields from satellite-derived information can start independently of the co-ordination effort of the working group above due to the unique nature of the source of data.

3.2 Monitoring of Ambient Concentrations and Deposition

Enhanced and improved emission monitoring, as outlined in 3.1, will identify the type and quantity of primary pollutants being released into the atmosphere from different oil sands activities. Relating these air emissions to health and ecosystem impacts in the oil sands region and beyond relies on a well designed ambient air monitoring program that answers the following science-based and policy-relevant questions:

1. What are the spatial and temporal distributions in northern Alberta and Saskatchewan and the NWT of regional-scale air concentrations and wet and dry deposition of compounds including ozone, sulphur oxides, nitrogen oxides, reduced nitrogen, organic pollutants, base cations, and toxic chemicals (including PACs, metals and mercury)?
2. What is the contribution of oil sands emissions to ambient air concentrations and wet and dry deposition fluxes of pollutants in the non-oil sands environment?
3. How do the answers to the above questions change with changing oil sands emissions and changing emissions from other sectors (e.g., non-industrial sources or increasing hemispheric ozone levels)?
4. What proportion of primary pollutants is deposited, converted to secondary pollutants through atmospheric reactions, or transported over long distances? How do the oil sands pollutants and naturally emitted compounds interact to affect the fate of the oil sands pollutants?
5. What are the past, present and future air quality and deposition levels?

A four-component measurement program is needed to address the above questions to the extent scientifically feasible. Ground site monitoring is required to track the status and long term trends of pollutant concentrations and deposition. As well, aerial surveys are required to establish the links between primary pollutants and their atmospheric transformation products to inform monitoring. Modelling and satellite remote sensing, evaluated and validated with the monitoring data from ground-based sites and aerial surveys will be used to fill in monitoring data gaps across the region. Short-term focussed studies are required to address specific knowledge gaps such as emissions from tailings ponds and the sources of odour and degraded visibility.

The ambient air monitoring component is focused on specific scientific objectives that relate to industrial growth, ecosystem health, human health, atmospheric transformation of primary emissions, transboundary and long range transport and deposition. While it is critical to monitor what, where, when, and how pollutants are being emitted from the oil sands, as outlined in 3.1, it is equally important to monitor along the pathways for the emitted pollutants as they transform between the point of emission and the point to which they impact the receptor. The pathways determine the scale and severity of the ecosystem and human impacts of pollutants at the receptors. Air concentrations at ground locations, from source to receptor, are linked through transport and transformation. Transformation occurs on spatial scales that are determined by the time of transport to the receptors, the rate of atmospheric transformation, and the amount of precursors lost to deposition. This dynamic nature needs to be monitored to establish the relationship over time between emissions and impacts.

The strategy of long term ambient air monitoring focuses on the 3-dimensional distribution of primary and secondary pollutant concentrations centred on the oil sands region. At the ground level, monitoring sites at strategically chosen locations focus on the long term trends of pollutant ambient concentration, transformation, and deposition. One possible path forward is to build upon the existing national infrastructure of the Canadian Air and Precipitation Monitoring Network (CAPMoN) and the National Air Pollution Surveillance (NAPS) Network. These networks can be supplemented by additional sites and measurement systems. Balloon-borne sondes launched at several sites can provide regular vertical distributions of selected pollutants and meteorological conditions. Satellite remote sensing and periodic aerial surveys are needed to provide spatial and vertical coverage of selected pollutants for critical linkages to the ground monitoring sites and conditions in unmonitored areas. Finally, as an adaptive strategy for the plan, short term studies are required to address knowledge gaps in air quality issues in the region and provide a basis for initial implementation and then review and renewal of the approach.

3.2.1 Ground-level Ambient Air Monitoring

Fourteen ground-level ambient air monitoring sites were strategically chosen in the oil sands region and further downwind/upwind (in Alberta, Saskatchewan, Northwest Territories, Manitoba) to monitor air quality, deposition, source emissions, long range/transboundary transport, pollutant transformation, and background concentrations (i.e., upwind conditions). The strategy used in the selection process was to define the monitoring questions and objectives to be met and then define the measurements types, measurement methods and the number and locations of sites required to meet these objectives. The 14 sites are classified according to their monitoring objectives and are shown in Figure 3.2 where they appear in 5 different site categories based on their objectives (note that many sites meet more than one objective), namely:

- 6 *Ecosystem/Long Range Transport/Transboundary Transport Sites* for the purpose of quantifying atmospheric wet and dry deposition to sensitive ecosystems and defining the long range transport/transboundary influences of oil sands emissions.
- 3 *Source Characterization Supersites* that will monitor a broad range of chemical species in order to characterize oil sands emissions and their associated effects on air quality within the industrial complex over time. Two of these sites will be permanently located and one will move every few years to newly developing areas of the oil sands complex.
- 3 *Transformation Sites* that will focus on establishing the chemical and physical changes (including deposition) to oil sands primary emissions during their atmospheric lifetimes.
- 2 *Upwind Sites* that will measure the inflow of pollutants to the oil sands area along predominantly prevailing wind directions to establish the ambient background of anthropogenic and natural pollutants.
- 13 *Enhanced Deposition Sites* that are included in the Lower Athabasca Water Quality Monitoring Plan Phase 1 (WQMP) and are described in detail in that Plan (6 of these sites are only *Enhanced Deposition Sites* applicable to the WQMP while the remaining 7 are co-located with air quality monitoring and are the ones further discussed in this air component). These 13 sites are intended to quantify the atmospheric deposition of PACs and metals to water bodies in and around the oil sands area and only a brief description of this aspect of these sites is given in the text below. Readers are referred to the Lower Athabasca Water Quality Monitoring Plan Phase 1 for further details regarding deposition of PACs and metals.

The aforementioned fourteen sites (omitting the six solely *Enhanced Deposition Sites* in the WQMP) are described below in terms of three spatial scales: 1) *source scale* within the oil sands industrial complex, 2) *local scale* within a 50-75 km range coinciding with the largest population in the oil sands region in the case of Fort McMurray, and 3) *regional scale* extending to approximately 1000 km. Monitoring at these scales will allow quantification of the long term changes in pollution levels and deposition, and provide data for validating emissions and satellite remote sensing data products. It is acknowledged that additional sites may be needed over time and that re-location of sites may be necessary to target specific sources as the oil sands industrial activities grow and evolve. As such, the air monitoring component of the plan will be adaptive and evolutionary over the long run, with the proposed fourteen sites acting as a framework for future development and change. To that end, a full scientific evaluation of the adequacy and suitability of the ground-based measurements should be carried out in Year 4 or 5 for the purpose of enacting changes and improvements as necessary.

The air quality and deposition measurements to be made at the fourteen sites will depend upon the nature and objectives of the sites. The expected measurements at the different sites are summarized in Appendix A relative to the measurement objectives and spatial scales. Although many of the measurements focus on air concentrations, atmospheric flux measurements (especially those for nitrogen, sulphur, mineral base cations, metals, organics, and PACs) are important because of their potential effects to ecosystems. These flux measurements are necessary not only for air monitoring but also to fulfil the objectives across the Integrated Monitoring Plan. Wet deposition fluxes will be measured using state-of-the-art wet-only deposition collectors according to the internationally-accepted methods. Dry deposition fluxes will be determined in two ways: (1) at most sites by using the inferential method in which air concentrations are measured and multiplied by appropriate modelled dry deposition velocities and (2) at one site by making direct flux measurements using the most appropriate method available. Once the flux measurement method is established, the inferential and direct measurements will be co-located and compared as a component of the quality assurance program. As well, chemical species will be measured as a function of particle size measurement to improve the estimates of particle dry deposition velocities. The inferential and directly measured dry deposition fluxes will be combined with wet deposition measurements and modelled precipitation amounts to provide estimates of total deposition in the oil sands region. Later stages of the air monitoring component will include an evaluation of the use of throughfall measurements to estimate the wet plus dry flux of conservative chemical species.

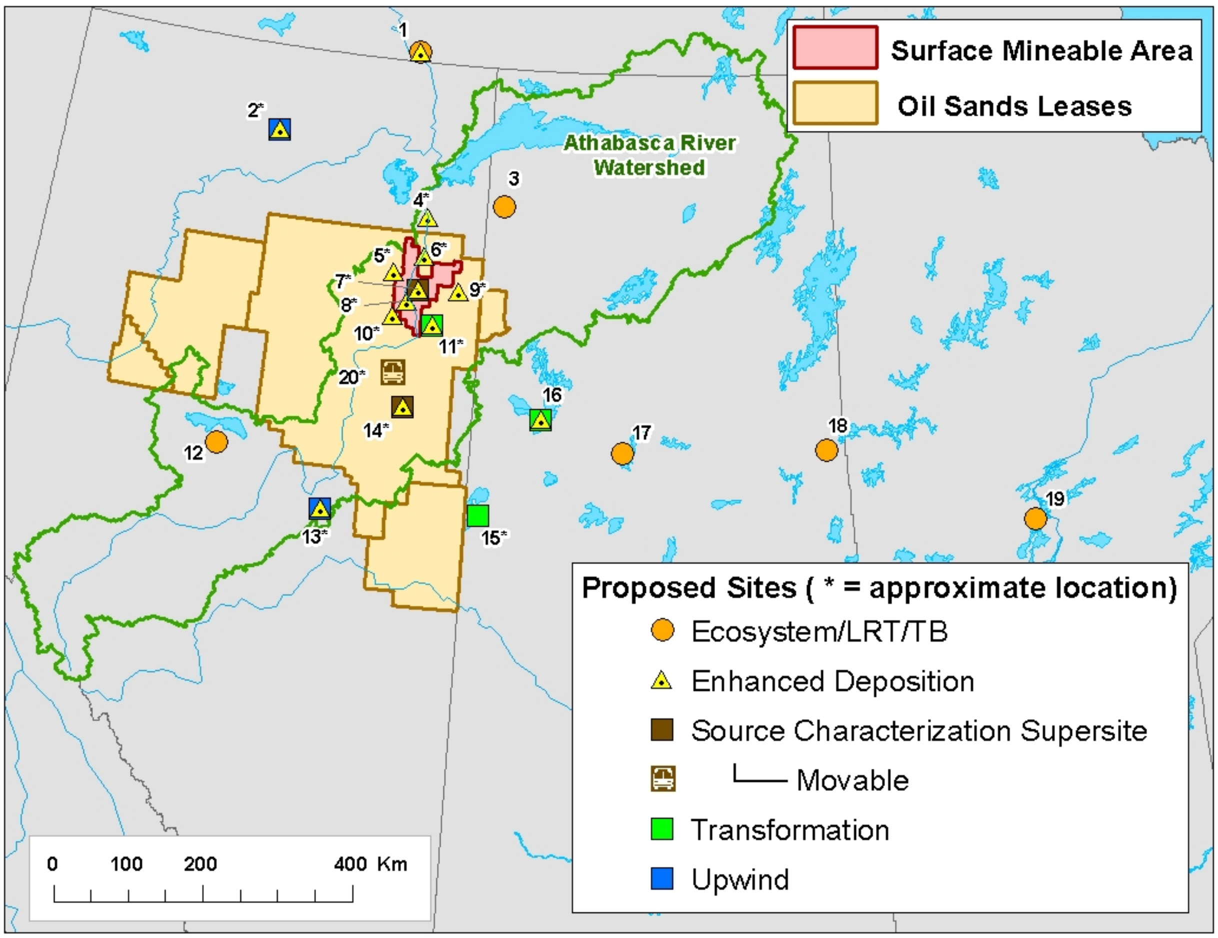

Figure 3.2. Proposed ground-level monitoring sites. The sites numbered 4, 5, 6, 8, 9 and 10 are spatially dense and intended for determining the wet and dry deposition of polycyclic aromatic compounds and metals to the Athabasca River and its tributaries. These 6 sites are identified in and contribute to the Lower Athabasca Water Quality Monitoring Plan Phase 1 (WQMP) and are included here for completeness and integration purposes; no additional measurements are proposed for these sites under the air component. At Sites 1, 2, 7, 11, 13, 14, 16 the measurements defined in the WQMP will be made together with additional measurements. Site 20 is a movable source characterization site for monitoring at hot spots in areas of new industrial development. LRT indicates long range transport; TB indicates transboundary.

3.2.1.1 Source Scale Monitoring

Source scale monitoring will consist of two permanent *Source Characterization Supersites* (#7 and #14 in Figure 3.2) and one movable *Source Characterization Site* (#20) that will be installed in the oil sands industrial area for the purpose of quantifying atmospheric concentrations of oil sands emissions and monitoring the temporal changes in air quality with time (and industrial development). These sites will provide information on the chemical speciation of emissions close to the emission sources and the relative abundance of the various pollutants in air to validate emission data.

Each *Source Characterization Supersite* will be located to represent a different type of industrial/emission activity. One of the permanent *Source Characterization Supersites* will be located in the northern part of the oil sands area to capture the surface mining-related emissions and the other will be located in the southern part to represent the *in-situ*-related emissions (note that 80% of oil sands development is expected to be *in-situ* development). In anticipation of the changing mining activities and landscape over the coming decades, regular evaluation of the siting criteria will be necessary (e.g., every 5 years). The movable *Source Characterization Supersite* will be installed and operated for periods of 2 to 4 years in areas slated for intensive development for the purpose of characterizing the air quality impacts of the new emission sources.

Monitoring at this scale requires measurements of ambient air concentrations of the species listed in Appendix A.

3.2.1.2 Local Scale Monitoring

The *Local* spatial scale (50 – 75 km) represents an atmospheric transport time scale of 2 - 5 hours from the emission source. For fast reacting pollutants (e.g., NO_2), this spatial/time scale is sufficient for changes in atmospheric concentrations to be detected. Furthermore, dispersion of all primary pollutants will cause rapid decreases in their atmospheric concentrations away from the sources. Hence high atmospheric concentrations and deposition of the primary pollutants are constrained to a fairly limited geographic scale. On the 50-75 km scale, monitoring will reveal not only the sharpest gradients for fast reacting/depositing primary pollutants and provide data on secondary pollutants resulting from transformation of the primary pollutants, but also provide information on which pollutants are transported farther from the local scale into the larger regional scale. Hence, long term monitoring on this scale is critical to document the expected largest impacts of oil sands emissions.

Within the 50-75 km range of local scale monitoring, the emissions and associated air concentrations are heterogeneous. The Local *Transformation* site will therefore have the following objectives:

1. To understand the relative effect of oil sands emissions on local air quality and deposition relative to long range transported and natural emissions

2. To understand the chemical and physical processes that affect the impact of atmospheric chemicals, including deposition and ambient concentrations, on local ecosystems and community health
3. To support human health studies by identifying and quantifying the ambient concentrations of chemicals in communities located within and downwind of the oil sands industrial activities

In this context, the local scale monitoring activities will quantify the status and trends of ambient pollutant concentrations and provide insights into the pathways for fast chemical transformations and high deposition close to the emission sources.

Initially, local scale monitoring will involve a single monitoring site known as the local scale *Transformation Site* (#11 in Figure 3.2). Pollutants measured at this site, listed in Appendix A, will be compared with primary pollutants measured at the *Source Characterization Supersites* after consideration of their chemical and physical transformations (including deposition) in the atmosphere. It is important to note that this local *Transformation Site* will be linked closely to the two remaining Transformation Sites (#15 and #16 in Figure 3.2) discussed in Section 3.2.1.3 under Regional Scale Sampling which will focus on the slower reacting and depositing pollutants. Future development of the air monitoring plan will involve the addition of 5 *Enhanced Community Monitoring Sites*, several of which will be located within local scale communities to address the human health objectives outlined above (others may be in more distant communities). It is not possible at this time to identify the location of these sites or the measurements to be made as this must be done at a later date in consultation with Health Canada, the province of Alberta and local populations.

In the case of NO_2 and SO_2, monitoring on the local scale will provide data for satellite NO_2 and SO_2 data product validation and can support routine high resolution dispersion modelling to link observations back to specific emission sources. Moreover, the periodic sonde measurements of O_3 and SO_2 (some minor modifications) and SO_2 when technology development permits, to 5-km altitude at these sites can provide data in the vertical dimension, which are critical for satellite data product and model result evaluation.

3.2.1.3 Regional Scale Monitoring

Atmospheric transport of oil sands emissions beyond the local scale occurs for most of the pollutants or their transformation products, thereby allowing additional time for mixing, transformation and deposition along the transport path. On a time scale of <1 to 3 transport days, corresponding to a range of 75 to 1000 km (wind speed dependent), pollution plumes from the oil sands industrial complex will become more homogenously mixed. At the same time, transformation and deposition will occur for most of the pollutants, with new chemical species being formed, deposited and/or transported out of the region. Interactions of oil sands pollutants with biogenic emissions and other pollution sources (e.g., controlled biomass burning, forest fires) may also occur.

Monitoring of air pollutants at the regional scale will address the following issues:

- *a.* Quantification of the transboundary transport of oil sands emissions across provincial and territorial boundaries
- *b.* Quantification of the atmospheric deposition of oil sands emissions at ecosystems (in particular, sensitive ecosystems) located at long distances from the emission areas
- *c.* Determination of the extent of transformation of primary pollutants and how this affects deposition
- *d.* Determination of atmospheric deposition and concentration impacts on ecosystem health related to the issues of acid deposition, eutrophication, biodiversity, toxic bioaccumulation, and forest health

The specific objectives of the measurements at Regional scale sites are:

1. To quantify, using measurements in combination with chemical transport modelling, the spatial distribution of wet and dry deposition and air concentrations of important chemical species in northwestern Canada, including acidifying species, nutrients such as nitrogen containing compounds, organic pollutants, base cations, metals, PACs, mercury, and new chemicals that may emerge as important.
2. To quantify the atmospheric transport of oil sands primary emissions and secondary pollutants across provincial, territorial and U.S.-Canada boundaries
3. To quantify the contribution of the oil sands sector versus other emission sources (e.g., natural emissions, hemispheric and long distance emissions) to wet and dry deposition in the oil sands area and in the rest of western Canada.
4. To establish the sensitivity and capacity of ecosystems in western Canada to sustain current and future oil sands emissions without deleterious effects (using knowledge of past deposition and in collaboration with ecosystem researchers)
5. To provide measurement data to quantify the main atmospheric transformations (chemical and physical) to which oil sands primary pollutants are subjected in order to improve the measurement- and model-based estimates of atmospheric concentrations and deposition on a regional scale
6. To provide vertical profiles of O_3, SO_2 and potentially NO_2, through sondes when technology permits.

The six *Ecosystem/Long Range Transport/Transboundary Transport Sites* (#1, 3, 12, 17, 18, 19) will be located close to areas of acid-sensitive and nutrient-sensitive terrestrial and aquatic ecosystems (see Figures 3.3 a,b,c) and/or areas of current and long-term exceedances of critical loads (see Figures 3.3 d and e). The six locations will also allow the analysis of deposition status and trends and the quantification of long range transport/transboundary transport of oil sands emissions.

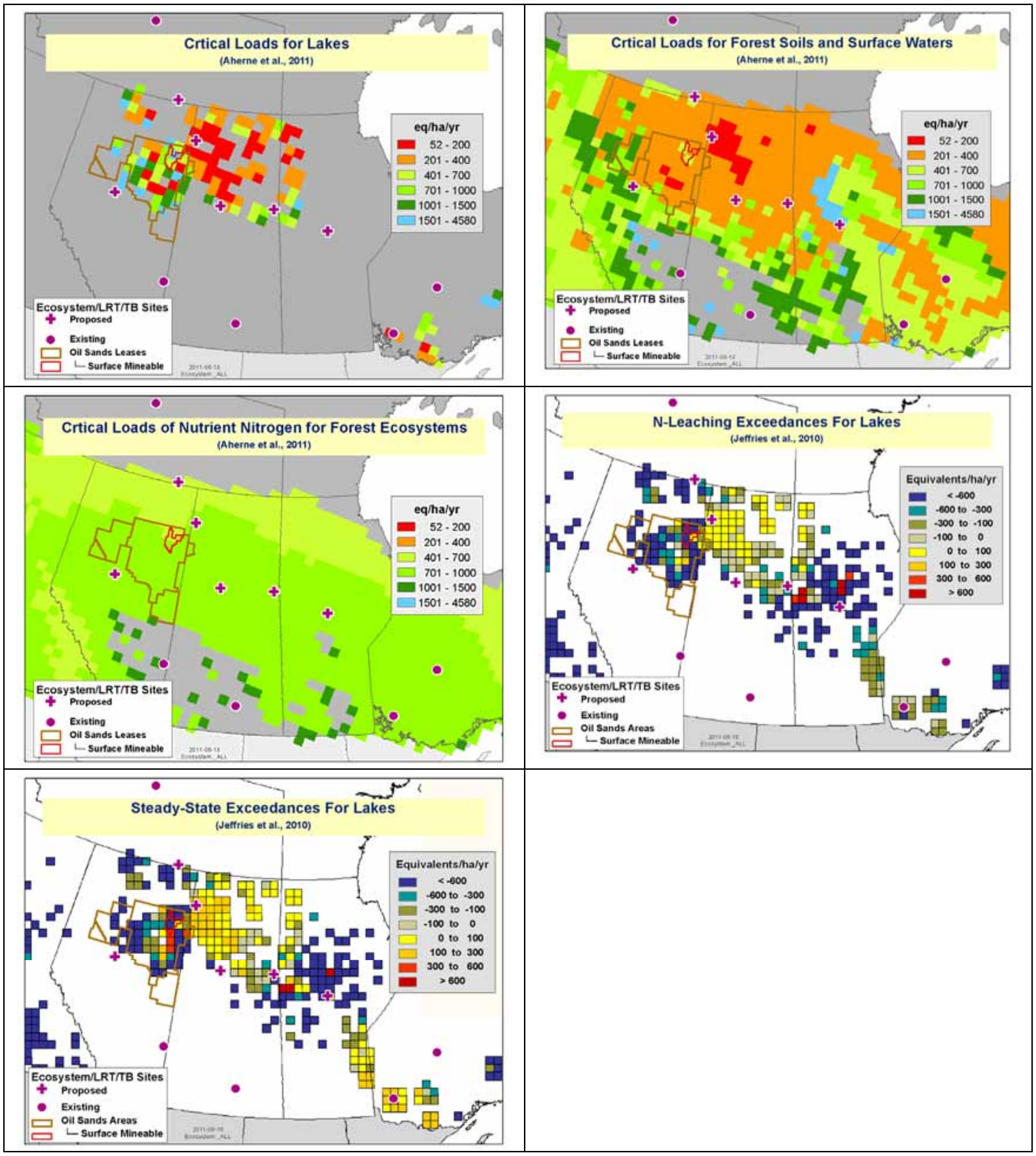

Figure 3.3. Ecosystem effects maps with existing CAPMoN sites (circles) and proposed 6 *Ecosystem/Long Range Transport/Transboundary Transport Sites* (crosses) superimposed. The Oil Sands Leases areas in the maps indicate potential leases. The maps show: (a) critical loads for lakes (Aherne et al., 2011), (b) critical loads for forest soils and surface waters (Aherne et al., 2011), (c) critical loads of nutrient nitrogen for forest ecosystems (Aherne et al., 2011), (d) critical load exceedances for lakes based on nitrogen leaching using the Expert or Steady State Water Chemistry models (Jeffries et al., 2011) and (e) critical load exceedances for lakes without nitrogen leaching using the Expert or Steady State Water Chemistry models (Jeffries et al., 2011).

It is notable that the 6 sites may not be located exactly within the areas of lowest critical loads and/or highest exceedances because of logistical and practical constraints including the lack of site operators, electricity, roads, shipping and security. The final site locations will be strategically placed as close as practicable to the ideal site locations. The measurements from the sites will provide direct measures of deposition in/near the sensitive ecosystems and will anchor the interpolation and modelling products required to provide fine-scale deposition estimates for the calculation of critical loads and critical load exceedances. To keep the air monitoring adaptive and responsive, the need for new sites will be considered in future years based on the results of monitoring and modelling activities that evolve throughout the first years of air monitoring.

Concentrations at the regional scale are expected to be significantly lower in comparison to those seen at the local scale due to dispersion, deposition, and chemical transformation. This condition places greater requirements on analytical capabilities of both online continuous instruments as well as laboratory analytical instruments. Monitoring at the six *Ecosystem/Long Range Transport/Transboundary Transport Sites* will include, to the extent possible, air and precipitation concentration and deposition measurements of sulphur and nitrogen species, base cations, mercury, trace metals, PACs and nitrogen isotopes. The sulphur, nitrogen, and base cation measurements will be carried out daily while the other chemical species will be measured less frequently because of sample size, detection limits and other concerns. Using passive sampling technology, multi-week measurements of NO_2, SO_2, O_3, H_2S, HNO_3, NH_3, gaseous PACs and mercury are recommended at selected fixed sites and a number of surrounding remote sites. While many passive samplers have been validated by comparison with high-volume samplers, denuders and continuous analyzers, application of passive sampling to additional compounds will also be investigated. Within the monitoring program, the passive sampling methodologies will be evaluated and validated against other accepted sampling technologies, in particular by co-locating passive samplers with conventional measurement methods at selected sites. Once validated, the results from the passive samplers will be used to derive the spatial variability of these pollutants and to calculate inferential dry deposition fluxes. As passive samplers would be deployed in locations that are difficult to access and thus sparsely populated, the data collected are for assessing ecosystem impacts, rather than human exposure effects.

Two regional scale *Upwind Sites* (# 2 and #13 in Figure 3.2) will be installed and operated in northern Alberta to allow the quantification of transboundary and long range transport of natural and oil sands emissions. The objective of these sites is to measure the inflow of pollutants to the oil sands region to establish a background. Site 2 will be located northwest of the oil sands and Site 13 will be located southwest of the oil sands area. Measurements at these sites will be the same as the other supersites 7 and 14. Although not identified as such, site #12 can be considered an upwind site in addition to being an *Ecosystem/Long Range Transport/Transboundary Transport* site. It has not been designated as such because it has for some time been planned as an ecosystem-based CAPMoN site.

Two regional scale *Transformation Sites* (#15 and #16 in Figure 3.2) will be installed and operated as complementary to the one local scale *Transformation Site* (#11) to establish the chemical and physical changes (including deposition) to oil sands emissions during their atmospheric lifetimes. These sites will be strategically located downwind of the oil sands mining and drilling areas. For example, Site 15 will be located ~300 km downwind of Fort McMurray under northwesterly flows. Working in tandem with the ecosystem sites, it will be possible to construct the concentration changes and chemical transformation of oil sands primary pollutants along the transport route from the source areas to these receptor locations, and hence obtain the spatial scale of decay in the air concentrations of oil sands pollutants. Under westerly flows, Site 15 will capture the impact of the *in- situ* extraction activities in the Cold Lake region. Measurements at the transformation/deposition sites are listed in Appendix A. These measurements will provide a basis for developing and evaluating the chemical transport model components needed to interpolate between measurement sites.

Another component of the Regional Scale monitoring is the retrospective measurement of long term (i.e., many decades) atmospheric concentration and deposition due to oil sands and other emission sources. This aspect will be assessed through the measurement of nitrogen, sulphur, oxygen and carbon isotopes in air, precipitation and tree ring samples. The tree ring samples will be taken in areas surrounding three of the *Ecosystem/Long Range Transport/Transboundary Transport* monitoring sites (sites yet to be determined) to provide records of air quality, deposition and soil chemistry (past deposition of N and S species) due to changing emissions; air and precipitation sampling for isotopes will take place directly at the air monitoring sites. Separation of the climatic and anthropogenic effects on the tree-ring isotopic series will be done by using a statistical model that links climatic parameters to isotopic responses in trees (e.g., Savard, 2010). Air and precipitation sampling to quantify the isotopic fingerprints of oil sands and other Alberta emissions will take place prior to the tree ring and ambient sampling.

As mentioned previously, the Lower Athabasca Water Quality Monitoring Plan Phase 1 (WQMP) identifies *Enhanced Deposition* sites designed to quantify the wet and dry deposition fluxes of toxic substances to water bodies in and near the oil sands (see Figure 3.2). Seven of the sites will be located within the oil sands area near the Athabasca River (#4, 5, 6, 7, 8, 9 and 10 in Figure 3.2) and the remainder will be located farther away (#1, 2, 11, 13, 14 and 16). The species to be measured in support of the WQMP include PACs and metals in air and precipitation. PACs can be considered as a sentinel for industry development with time.

Finally, three additional regional scale Ecosystem Sites should be implemented and operated at calibrated watershed locations in Alberta, NWT and/or Saskatchewan in a later phase of the Lower Athabasca Water Quality Monitoring Plan. These sites will be selected, installed and operated to continuously monitor surface water chemistry in sensitive watersheds in order to link the water chemistry to atmospheric deposition and oil sands emissions. The locations of the sites will be determined at a later date in consultation with the water monitoring activities.

3.2.2 Monitoring to link the different scales

The predicted rapid changes and the complexity of the oil sands sources coupled with the limited access to surface monitoring locations require that periodic aerial surveys be made of the emitted plumes and their evolution in the atmosphere. Under these conditions, aerial surveys play a role in the long term air quality monitoring, including:

- emission data validation. In addition to measurements at the *Source Characterization Supersites*, aerial surveys provide data for pollutants in the mixed layer. Oil sands emission plumes can be isolated from background air prior to mixing during airborne emissions, and the pollutant concentration ratios will more accurately represent emissions from individual sources.
- filling data gaps, both horizontally and vertically. Aerial measurements can cover a large space in a relatively short time and thus provide an extension of ground-based monitoring. Furthermore, aerial surveys can also conduct vertical profiling at strategically selected locations. If planned in accordance with satellite passes, such a spatial coverage provides data for satellite data product validation.
- connecting boundary layer meteorological conditions to emission plume dispersions to determine the physical processes that affect the transport of oil sands emissions.

In addition to the airborne aerial surveys, high resolution satellite images will be acquired for analysis and compilation of emission activity data for certain industrial activities. For example, images from the Landsat (resolution 30 m) will be used to construct a GIS database for the slow changing mining activities, including changes to the landscape, tailings ponds surface area, sulphur and coke storage, and construction and operation of industrial facilities. Images from the Quickbird satellite (resolution 60 cm or better) will be used to examine the mining truck fleet and to generate oil sands related traffic activity data. The satellite data may be further used for digital elevation modelling (DEM) to obtain the volume of oil sands excavated over set periods of time, yielding new mined surface areas that can be a source of VOC release into the atmosphere. An algorithm needs to be developed to turn aerial photography into a GIS-based emission activity data base, from which more accurate emission inventories can be obtained on a timely basis.

The spatial domain of aerial surveys will include the Athabasca oil sands region, the Cold Lake oil sands region, and the Peace River oil sands region. This spatial domain requires a range of approximately 1000 km per aircraft sortie, depending on flight planning that meets the needs for spatial and vertical distribution of air pollutant concentrations. Two air monitoring missions are recommended for the aerial monitoring and a rudimentary plan for the aerial surveys is contained in Appendix 3D of the Technical Appendices. The detailed planning will draw on the results from the ground monitoring results, such as which pollutants to monitor, which flight tracks to use and the survey intervals. Satellite image data processing can begin with acquisition and collection of images which are either in the public domain or commercially available. A plan for satellite image data processing is also given in Appendix 3D.

3.2.3 Remote Sensing

Remote sensing can fill in areas where there are data gaps, both horizontally and vertically, such as on emission activity data collection for certain industrial activities.

3.2.3.1 Ground-based remote sensing

A network of at least three ground-based remote sensing stations is suggested, close in to industrial activity (site #7; see Figure 3.2), at an upwind site (site #2), and at a downwind (site #16). Additional sites near, but 10-20 km removed from, the centre of the enhancement would be very valuable to help capture gradients across the satellite field of view that may otherwise bias the comparisons (sites #9 and 10).

A standard set of instruments is suggested at each site in order to measure NO_2 and SO_2 VCD, aerosol optical depth, and cloud cover. Beyond its value for monitoring, an aerosol instrument is included in this package as it is important to have simultaneous measurements of aerosol to correctly analyze the NO_2 and SO_2 data (with the MAX-DOAS technique). Likewise, quantifying cloud cover is also important in the QC of ground-based data.

This measurement set includes two NO_2/SO_2 instruments - a Multi-Axial Differential Optical Absorption Spectrometry (MAX-DOAS) instrument and a Pandora spectrometer. Both provide VCDs of NO_2 and SO_2 and thus there is a measure of cross-validation. The Pandora instrument is better suited for measuring SO_2 whereas the MAX-DOAS instrument is the better instrument for NO_2 and can additionally provide some profile information. Note that the MAX-DOAS and Pandora spectrometers are relatively new instruments and only now are being deployed for routine, automated monitoring of NO_2 and SO_2. As such, a development period is required, including one for their retrieval algorithms. It is important, however, to begin collecting spectra as early as possible to begin the time series as the retrieval products can always be improved upon after the fact. A SunPhotometer is the ideal instrument for measuring aerosol. More information on these instruments is given in the Appendix 3C of the Technical Appendices.

The ground-based instruments will need to be calibrated and validated before being deployed in the field, including side-by-side measurements with other, calibrated instruments

3.2.3.2 Airborne remote sensing

Weekly launches of ozone/SO_2-sondes are proposed for site #7. These sonde packages measure ozone and SO_2 profiles at high vertical resolution through the entire troposphere. Sondes designed to measure NO_2 are new (Sluis et al., 2010) and relatively unproven. A study to determine if this technology is mature and reliable enough for use in monitoring should be undertaken for possible future inclusion in the sonde package.

Sondes are a key link between all other types of measurements and the air quality models. They are the primary source of SO_2 profiles and tie together the more comprehensive, but less frequent, profiles from the aircraft intensives. They can also be integrated over altitude, into a VCD, for a direct comparison with satellite and ground-based VCD measurements.

Sonde profiles can additionally be used to evaluate the accuracy of the simulated SO_2 profiles that are used to link the satellite-measured SO_2 VCDs to the estimate of the annual emission rate (see Section 3.1.5.4) and surface concentrations used to calculate deposition (section 3.4.2).

3.2.3.3 Satellite remote sensing

Satellite remote sensing of emissions has been previously described in section 2.5.4. Several satellite instruments have been identified as either useful or potentially useful for oil sands monitoring. Note that of the potentially useful species, only NO_2 and SO_2 are known to have oil sands signals. The other species require further study to assess their usefulness. A list of these instruments and data retrievals can be found in Appendix 3C of the Technical Appendices.

3.2.4 Short Term Studies to Address Priority Knowledge Gaps

There are many important knowledge gaps for air quality monitoring in the oil sands region that require in-depth information collected over shorter periods of time. The oil sands present a completely new mix of air pollutants in a new environment, and short term focused studies designed to identify potential issues will precede, or at least be deployed simultaneously with the more traditional monitoring outlined previously. Oil sands air pollution issues identified at present include:

- Emission quantification from uncharacterized sources in the oil sands, such as tailings ponds (section 3.1.5.3).
- Characterization of the pollutant mix from the oil sands, such as chemical speciation and source identification of odours, chemical speciation of VOCs, PACs, and metals.
- Processes that impact the oil sands pollutants in the atmosphere, such as seasonal changes in boundary layer dynamics, winter chemistry, aerosol chemistry, aqueous-phase chemistry.
- The applicability of existing knowledge on chemical transformation of pollutants to the oil sands region. Under the cold and dark winter versus hot dry summer in the oil sands, the chemical reactions and physical processes (phase partitioning, air-surface exchange, etc) are affected and further impact the atmospheric fate of oil sands emissions.
- The influence of terrain, such as river valleys, and of unique meteorology (e.g., very cold wintertime periods) on local scale movement of pollutants and the resulting exposure of the population.
- Atmospheric visibility impairment, including its cause, processes and source attribution leading to control measures.
- Development of historic deposition to the oil sands region (nitrogen, sulphur and base cations)

Shorter term intensive studies will address these issues. Findings from these studies can have a significant influence on the long term monitoring. For example, they can identify the need for monitoring new chemical compounds or for emission inventory updates. As part of an adaptive air quality monitoring program, the short term studies will form the foundation for review and renewal of the air monitoring component and will identify issues requiring some expansion of emphasis or shifting focus. Given the expense and logistical impracticality of developing extensive monitoring networks at all required scales, a coherent picture of the temporal and spatial pollutant distributions can only come from carefully developed and thoroughly tested models. Thus, in addition to providing basic information needed for the measurements in the air monitoring plan, the short-term studies which follow are designed to also provide continuous updates to the models, as described in section 3.4 and Appendix 3E, and to ensure that the best available science is used in the model forecasts.

Three types of short term studies that can be conducted individually or in combination are needed to target different areas of concern: (1) intensive airborne and ground studies, (2) laboratory studies, and (3) field studies exploring specific processes. These are described in more detail below.

3.2.4.1 Field Studies of Tailings Ponds Emissions

To achieve the goals of quantifying the emissions from tailings ponds, complementary approaches will be deployed using both aircraft and ground mobile platforms as briefly described here.

First, speciation will be made of the VOCs (including sulphur and nitrogen species) in air upwind and downwind of the tailings ponds, to identify the emitted species. One of the VOC species that can be observed directly (to be determined) will be selected as a tracer compound. For this tracer, ground level measurements of integrated concentrations coupled with atmospheric turbulence measurements will be made directly downwind of a selected pond. A lidar wind profiler will provide the information to quantify vertical mixing to a height of 1000 m. The down-wind long-path integrated concentrations, surface fluxes and vertical wind data will be used to determine fluxes through modelling (e.g. backward langrangian stochastic (bLS) modelling as described in Staebler et al., 2009). For chemical compounds from the same source, the fluxes can be estimated based on ratios to the tracer compound. The relationship between air emissions and atmospheric turbulence will be parameterized for use in air quality models. Second, a top-down approach will be implemented through aircraft flights over the ponds, as part of the intensive aircraft studies as outlined in Section 3.2.4.2. These flights will aim to map the three dimensional distributions of the tracer compound, and thus further constrain the fluxes derived from ground level measurements (Staebler et al., 2009). The chemical speciation studies for the ponds for the facilities will be used to provide improved algorithms for simulating the subsequent dispersion of the emitted chemicals (section 3.4).

Other approaches to flux measurements over tailings ponds will be considered where technically feasible, including floating chambers or air vertical gradient measurements at the downwind shore coupled with atmospheric turbulence measurements. Plans for these measurements can be found in section 3.1.

3.2.4.2 Direct measurement of the evolution of pollutants

The routine aerial surveys of oil sands pollutants outlined in Appendix 3D of the Technical Appendices are intended for fixed tracks and profiles over fixed locations to build up a database for the long term trend detection for oil sands pollutants. Instrumentation is limited, targeting only a small number of key pollutants.

Short term intensive studies using more extensively instrumented aircraft and ground platforms are needed to link emissions with the ambient measurements at the monitoring sites by providing the following (see Appendix 3F of the Technical Appendices for a detailed discussion):

- detailed chemical speciation of pollutants, including VOC speciation, PM organic speciation, metals, oxidant levels in order to determine the evolution of these pollutants;
- separation of plumes from individual major sources and ratios of primary pollutants in these plumes for emission validation;
- atmospheric transformation, including interactions among pollutants and background atmospheric constituents, that determines the fates of primary and secondary oil sands pollutants;
- deep vertical profiles (from surface to 6 km altitude) of pollutants and their relationship to meteorology and atmospheric dynamics;
- atmospheric physical and dynamic processes that drives partitioning of pollutants between gas and particles;
- information on the vertical distribution of chemicals, which can be used with satellite data to provide a 3D image of the spatial distribution of pollutants (see Appendix 3C of the Technical Appendices).

The intensive airborne studies will target conditions under which plumes can be followed by the aircraft as they are transported to downwind areas. A comprehensive picture of pollution transport from the oil sands, its spatial scale of decay (due to transformation and deposition), and the evolution of secondary pollutants can be determined by linking the airborne study with monitoring results from Sites 11, 16, and 17.

Data from the intensive studies fill in information gaps in ground monitoring and from aerial surveys and the spatial coverage from the intensive studies reveals the extent of pollution transport. Models and satellite remote sensing are the tools of choice for integrating the ground and airborne monitoring results and it is critical to provide a dataset for evaluating the results from these tools. The knowledge on chemical transformation and on meteorology and atmospheric dynamics, unique to the oil sands regional processes, is necessary for incorporating the processes into models for improved modelling capabilities.

3.2.4.3 Controlled Studies of Pollution Transformation

The oil sands activities are expected to emit large quantities of typical air pollutants (CO, NO_x, SO_2, PM, and a suite of VOCs). However, oil sands emissions are unique compared to typical urban emissions due to the mix of VOCs emitted. Moreover, the specific atmospheric conditions in the oil sands region can be quite diverse depending on season and can be very different from the more temperate conditions under which current chemical kinetic data are typically obtained.

Questions arise as to the chemical transformation pathways under the specific atmospheric conditions in the oil sands region and the atmospheric characteristics of these compounds. Furthermore, it should be noted that products can be more toxic than their parent compounds, and it is critical to assess the rate of formation from the primary pollutants in the oil sands region. In particular, the following questions warrant special attention in the air quality monitoring plan for the oil sands region:

- what is the VOC mix from the oil sands emissions?
- how fast are these compounds converted in the atmosphere, under the specific conditions of the oil sands region? What are their transformation products?
- do they and their products favor partitioning into aerosol particles compared to other Canadian urban settings?

The answers to these questions will help guide the air monitoring component in several ways. First, product identification and quantification will enable potential toxicological studies by health researchers. Second, knowledge of these processes (e.g., reaction mechanisms and rate constants appropriate for oil sands atmospheric conditions) enables and improves the predictive capabilities of models for transport and deposition for the pollutants. Third, the knowledge further allows proper planning for ground based monitoring as emissions and monitoring evolve, such as choosing appropriate locations for monitoring sites that have the spatial/temporal scales to document the pollutants from the oil sands.

Laboratory studies are also needed to generate the knowledge on these processes. Details of proposed laboratory studies are contained in Appendix 3G of the Technical Appendices.

3.2.4.4 Degraded Atmospheric Visibility

Atmospheric visibility over the oil sands region is often degraded.. This degradation is likely due to the optical attenuation of light by atmospheric aerosol particles and some gas phase pollutants, most notably NO_2. Atmospheric aerosol particles have a number of properties that determine their optical characteristics, including the concentrations of particles, particle number size distribution and particle chemical composition, with the latter determining if the particles absorb or scatter light. Relative humidity and temperature also affect the water content of particles and hence their size and scattering properties.

No data exist to link specific emission sources to degraded visibility to permit effective control actions. Short term, focused studies are required to provide the following information:

- atmospheric particle number size distribution, chemical composition as a function of size, hygroscopicity, optical properties (absorption and scattering)
- quantification of source strengths for primary particles, including re-suspension of soil dust, sulphur storage, coke storage, combustion sources, tailings ponds emissions, bitumen separation, and upgrading
- formation of secondary aerosol particulate matter over the oil sands region
- growth properties and ice nucleation properties of particles
- measurement of atmospheric concentrations and vertical profiles of NO_2

These information needs can be addressed through the intensive airborne and ground studies outlined in Section 3.2.4.2, with enhanced airborne and ground based instrumentation for measurements of particle optical properties (scattering versus absorption) and hygroscopic growth properties. With the help of a high resolution model driven by a good scientific emission inventory the sources leading to degraded visibility can be identified.

3.2.4.5 Determination of the Source of Odour

Emissions in the oil sands region are known to result in significant odour issues with residents in several communities. It is not clear what compounds cause the odours, nor the sources that are responsible. Possible chemicals include reduced sulphur compounds, reduced nitrogen compounds, oxygenated hydrocarbon species and complex PACs that contain not only hydrogen and carbon but also sulphur, nitrogen and other elements. Due to the large uncertainty, intensive field studies are needed for ground-based canister sampling for VOCs followed by analysis for speciation, along with on site, real time mass spectrometry instrumentation (including Switchable Reagent Ion – Time of Flight – Mass Spectrometry) for scanning for different volatile compounds in the oil sands region. Chemicals detected will be related to odour occurrence to identify the chemical compounds responsible. During the intensive aircraft studies, the airborne instruments can monitor for the chemicals identified as associated with odour occurrence and potentially produce spatial mapping to track the specific sources.

It is recommended that a ground mobile pilot study be carried out first for the chemical speciation work to identify the compounds responsible, followed by intensive source identification and emission studies to determine the source profiles and emission factors. This study may be part of the intensive ground mobile measurements as proposed in Appendix 3F. If tailings ponds are the main source of the odour causing compounds then the short term studies on odours will be combined with the studies on the tailings ponds emission fluxes as outlined in Section 3.2.4.1. After source profiles of the odour chemical compounds are obtained, laboratory studies will be carried out for atmospheric chemical conversion rates and product identification and yields, inputs critical for models that deal specifically with odour dispersion.

3.2.5 Collaborative Research Efforts

Short term studies such as described here have been instrumental in model development, and often provide opportunities for collaboration between national and international organizations, where other organizations voluntarily contribute their infrastructure, instrumentation, personnel, and modelling facilities, in order to create the databases required for multi-organization model intercomparisons. As part of the short-term studies, such collaborations should be sought with national and international partners, with the resulting data shared between all parties (e.g. Smythe et al., 2009; McKeen et al., 2009; McKeen et al., 2005). Model intercomparisons of this nature will be possible with data from the air monitoring component and are encouraged because they lead to improved scientific understanding and result in decision-making informed by the highest quality scientific information. Results from selected intercomparison studies of regional air quality models can be found in Appendix 3H of the Technical Appendices.

3.3 Results Management and Reporting

A framework is needed for managing the acquired data along the entire process from data acquisition to provision to the end user. This framework is essential not only for making data available to users in a timely manner, but also to fulfill any reporting or regulatory requirements to enable decision-making in the oil sands. A similar high standard of data management principles should be applied to all data sources, including field data, results from laboratory analyses, emissions data, and data from non-standard sources such as satellites and other remote sensing platforms.

3.3.1 Air Monitoring Data Management Framework

It is recognized that the air monitoring component will need a well-designed database for monitoring data and metadata collected from different networks and monitoring efforts. Data management will be based on the following principles:

- Data management will address the full life cycle of data including data acquisition, measurement and laboratory analysis, quality control and quality analysis (QA/QC), dataset validation, storage, preservation, stewardship and public access (the latter being timely, free and adaptable to data user needs).
- Data refers to measurement values, laboratory analysis results and associated metadata; internationally-accepted data exchange standards and metadata standards will be followed.
- Compliance with applicable standards, e.g., ISO, CALA.
- Data stewardship involves the maintenance of a scalable and reliable data management infrastructure that will support long-term access and preservation as well as the provision of effective data support throughout the data life cycle.
- Data will be archived and made accessible in a manner that provides transparency of data quality and appropriate data use by including standard approaches to data quality flagging, detection limit determination and reporting of below detection limit

values, data versioning, identification of chemicals, parameters and metadata, and reporting of quality assurance information.

Development of an overarching framework for data management will include the following initiatives:

- Creation of the necessary standard procedures to achieve the above principles across the different sources of data.
- A multi-agency project to develop a single database for air, water and wildlife oil sands related data. This would involve operators of participating air monitoring networks, agencies collecting and managing other related data, with input from end users.
- Development of a web portal to provide convenient access to all existing and future databases containing oil sands air monitoring data.

The data management plan should build on the solid foundation and principles of the following existing databases with the recognition that specific areas still require improvements:

- the National Atmospheric Chemistry (NAtChem) Database: (www.on.ec.gc.ca/natchem/Login/Login.aspx) which uses the internationally-accepted NARSTO Data Exchange Standard (http://cdiac.ornl.gov/programs/NARSTO/epasupersites.html) and adheres to the data framework principles listed above
- the Canada-Wide Air Quality Database (www.ec.gc.ca/rnspa-naps/default.asp?lang=En&n=24441DC4-1) which stores and provides access to all federal, provincial, territorial and community Criteria Air Contaminants data gathered by the National Air Pollution Surveillance (NAPS) program under the auspices of the Federal-Provincial-Territorial NAPS Memorandum of Understanding.

A substantial amount of the monitoring effort will be both developmental and leading edge in nature. Data from this type of monitoring will likely not be finalized and quality controlled for some time. In light of the fact that data transparency is one of the guiding principles, the data management program should include a data delivery and documentation tool that will identify each measurement being made, its anticipated data delivery schedule (as documented in the Data Quality Objectives for the measurement) and the final dates of delivery. To ensure transparency, unsuccessful measurements should be identified as such. It is expected that this system will also provide timely public access to all scientific and non-scientific publications produced under the oil sands initiative.

3.3.2 Quality Assurance and Quality Control

The air monitoring component builds upon existing monitoring networks and includes new measurements where required. It is essential that uniform procedures be implemented across all existing and future monitoring sites to ensure the reliability of utility of the resulting data sets. As there may be a variety of groups involved in monitoring, a formalized Quality Assurance

Program built upon accepted QA/QC principles for field and laboratory measurements and data management is required. The QA/QC Program will address the five major elements of all quality assurance programs: accuracy (including traceability), precision, completeness, representativeness and comparability.

In general, a robust quality assurance program will:

- be designed to demonstrate that the high quality is maintained over the lifetime of the program
- comply with applicable accepted standards (e.g., ISO, WMO)
- be designed to ensure comparability among participating laboratories and to encompass regular inter-laboratory comparison
- be designed to identify when data are out of line with expected results, and to take appropriate action when this occurs
- include appropriate handling procedures regarding sampling, chain of custody, data validation and reporting, and archiving of data and samples
- involve a QA audit program and evaluations of laboratory performance
- evolve and take on new analytes as analytical methods are developed and previously unknown contaminants are discovered
- include a portfolio of state of the art sampling and analytical instrumentation
- support focused studies for sampling or analytical method development when required

To address these elements, QA/QC methods will include the following:

- A Quality Assurance Committee to coordinate QA/QC activities that relate to inter-agency data accuracy, comparability and compatibility including inter-agency site collocation studies, instrument and laboratory intercomparison studies, standard operating procedures, common traceability, calibration and performance standards, definition of Quality Assurance Objectives and assessment of measurement quality and performance.
- A Quality Assurance Plan will be developed and followed under the ongoing coordination of a quality assurance coordinator.
- Data Quality Objectives (DQOs) that will be developed for the various monitoring methods and measurement quality will be assessed against these objectives. Internationally-accepted DQOs will be adopted wherever available, e.g., The World Meteorological Organization's DQOs for precipitation chemistry measurements (WMO, 2004).
- Individual monitoring networks/measurements/studies will be required to produce Quality Assurance Project Plans and Quality Assurance Project Reports (e.g., Sukloff et al., 2006). The plans and reports will be made available publicly as metadata. An outline of a standard Quality Assurance Project Plan is given in Appendix 3I of the Technical Appendices.
- Individual monitoring networks and projects will be required to implement and follow the field, laboratory and data quality control and quality assurance

procedures outlined in the Quality Assurance Project Plans and to harmonize their standard operating procedures to the extent possible.
- Where possible, raw data will be reported and openly available together with the final quality assured data.

3.3.3 Management of Emissions Inventory Data

Section 3.1.1 described the development of a multi-user, multi-agency, spatially (three dimensional geo-referenced framework) and temporally resolved scientific emissions inventory for the oil sands region, including both industrial and urban sources, designed to encompass all sources in the area, including emissions from natural sources. A comprehensive and standardized emissions inventory is necessary to understand major source contributions and for model integration (as described in section 3.4) to evaluate the impact of current and proposed legislation on local and regional air quality.

Management of the scientific emissions inventory may not be under the same data management structure as the ambient data (e.g. data obtained from instruments or laboratory analysis) but will be based on similar principles of high quality data management. In particular, these will include the following principles for maintenance and updates:

- An annual system performance audit is performed
- Current and future emission profiles are to be well documented to allow users to understand the completeness, assumptions and potential limitations associated with the data.
- QA/QC will be as described in section 3.3.2 but adapted to emissions monitoring data and values based on emissions factors implemented to facilitate completeness and minimize uncertainty in emission estimates.
- The inventories' actual emission sources and conditions will be assessed with respect to sources, pollutant species, temporal and spatial coverage.
- Various usage and means of detection limits (upper bound)
- The concept of validation approaches/cross-check:
    - "Bottom up" – looking at sources to estimate ambient loadings
    - "Top down" – receptor to look at ambient measurements to map sources

3.3.4 Satellite Data

QA/QC of satellite data is based on current best practices as described in Appendix 3C of the Technical Appendices and a QA plan will be developed for non-standard monitoring data. However, the principles of data management and quality control are the same as described in sections 3.3.1 and 3.3.2. QC measures need to be implemented before satellite data are used for monitoring of near-surface air quality. These include processes general to remote sensing techniques, instruments and compounds, while others are specific to one of these considerations.

3.4 Integration

3.4.1 Overview:

"Integration" refers to the process of combining information from the available monitoring data using modelling and satellite data retrieval as tools, to provide the cumulative impact of the oil sands on air quality, atmospheric deposition and ecosystem and human health. This approach allows for significant interpretation and analysis of the current impacts of the oil sands sector, above and beyond what can be provided by the collection and reporting of ambient data alone. It also makes possible scientifically credible predictions of future impacts of oil sands development scenarios. The information products that result from integration provide value because limitations of the individual methods can be overcome, i.e.

- ground-based monitoring data are limited to specific locations; model results depend on the quality of the parameterizations;
- emissions fields and meteorological inputs used; and
- satellite measurements are limited to times when the satellite is overhead and by the accuracy of the models and monitoring measurements used to develop data retrieval algorithms.

The models and satellite retrievals, dependent as they are on the availability of high-quality atmospheric measurements for their development and evaluation, provide an integrated view of the impact of oil sands emissions on ambient air pollutant concentrations and deposition rates, as well as the resulting impacts on human and ecosystem health.

The use of models and satellite information allows for the construction of detailed maps of air pollutant concentrations and deposition which is not possible with a limited number of ground-based monitoring sites alone. The mapped values can be compared with data from ambient monitoring sites and provide information in areas for which monitoring data are not available. The use of models improves the overall understanding of the quality of the emissions data and of the chemical and physical processes that give rise to observed concentrations and deposition at monitoring stations. The application of air quality models using current meteorology and an improved scientific emissions inventory, evaluated with ground-based and aerial monitoring data, will provide a powerful tool for the management of air quality and associated deposition in western Canada. Modelling results have additional applicability to analysis of environmental and human health impacts. Modelling can be applied to identify the sources of past air quality degradation and has the potential to be applied in an air quality management plan in a forecast mode to support preventative action.

For integration purposes, it is recommended that a state-of-the-art, comprehensive air-quality model be used to inform analyses of smog-related pollutants, acid deposition, mercury and PACs. The selected model should include, as needed to appropriately describe the pollutants of concern, gas-phase chemistry, aqueous phase chemistry, inorganic heterogeneous chemistry, particle microphysics (settling, nucleation, condensation, coagulation, activation, below-cloud scavenging), secondary organic aerosol formation, and the dry and wet deposition of gases and particles. The model should be one that is continually upgraded with new science and continuously tested.

3.4.2 Determining the impacts of oil sands on air quality and atmospheric deposition

To fulfil its mandate to provide forecast services for weather and air quality to the public, Environment Canada has developed modelling and service delivery capacity (details can be found in Appendix 3H of the Technical Appendices). The regional air pollution forecast model GEM-MACH (Global Environmental Multiscale – Modelling Air quality and CHemistry), rigorously tested and incorporating foundational science from the peer-reviewed research model A Unified Regional Air quality Modelling System (AURAMS) (see Appendix 3H of the Technical Appendices for details) is in operational use in Canada providing twice daily 48 hour public forecasts at 15 km resolution over North America. Figure 3.4 shows output from the current operational GEM-MACH forecast grid of SO_2 concentrations at the surface. This model is used here to illustrate integration of data leading to improved source management capability.

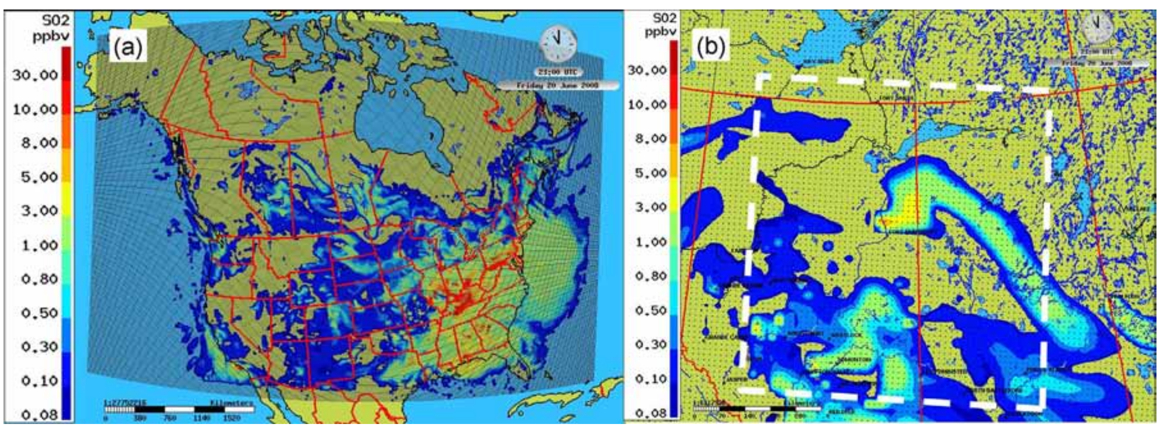

Figure 3.4. Operational GEM-MACH15 forecast grid, and SO_2 concentrations at 23 UT, June 20, 2009. (a): entire model grid; (b) oil sands close-up; regularly spaced dots show operational model grid locations. Dashed white line: boundary of high resolution grid suggested to be run in forecast mode

The simulations and forecast products recommended to be provided are shown in Table 3.2 and described below:

- Forecast type 1 includes the entire domain in Figure 3.4(a), and is currently available as Canada's operational air quality forecast. It is proposed that additional oil sands specific post-processing products be added to this forecast, and be placed in the same publicly accessible archive as the measurement data collected under the monitoring program.
- Forecast type 2 is proposed to be identical to the operational model run, with the key difference that all emissions associated with the oil sands operations be removed so

that the products allow an ongoing estimate of the impact of the oil sands on the concentrations of different pollutants, as well as on ecosystem and human health.

- Forecast type 3, run over a 2.5 km resolution domain, examines the emissions and subsequent transformation in the atmosphere more closely and provides greater local-level accuracy for certain chemical processes (e.g. formation of secondary organic aerosol)

Table 3.2. Proposed model output to support data interpretation. Note that the products defined here are needed to produce annual or seasonal transport estimates, annual or seasonal deposition maps, and other products.

Forecast type	Description	Recommended Additional Products
1	15km resolution, domain as in Figure 3.4a	(a) Time series of all model chemical products at model timestep, and select meteorological variables, at all monitoring site locations (b) Flux curtains: images showing mass flux of key pollutants transported across boundaries (Alberta/Saskatchewan, Alberta/North West Territories, US/Canada), and the total quantity transported across each boundary for SO_2, total $PM_{2.5}$, speciated $PM_{2.5}$, O_3, CO, NOy, NMHC at hourly intervals. (c) Surface concentration maps for the region depicted by Figure 3.4b at hourly intervals. (d) Daily total wet and dry deposition of individual species (required for the calculation of annual critical load exceedances). (e) Surface concentrations of composite species for ecosystem health analyses (total sulphur, nitrate and ammonium). (f) Daily air quality – health metrics (e.g. AQHI, AQI) at all monitoring sites and all population centres within Figure 3.4b white outline domain. (g) 3D concentrations of satellite-specific chemicals (SO_2, NO_2, CO, HCHO, NH_3) at overpass times, for comparison to satellite retrievals when available, hourly intervals during overpass period. (h) Forward trajectories from oil sands emissions sites, and backward trajectories from oil sands monitoring sites. (i) Visibility estimates calculated from the model-predicted particulate matter concentrations.
2	As in type 1, but with all of the anthropogenic emissions from the oil sands removed	Same suite of outputs as forecast type 1 (a-g), with the addition of difference fields showing the impact of the oil sands on the resulting model predictions.
3	As in type 1, modified for 2.5km resolution, domain as in Figure 3.4b	Time series and surface concentration maps, forward and backward trajectories and visibility estimates as in Type 1 above Additional products, as needed, to support emission and ambient monitoring.

Products from the integration include:

- gridded maps of wet and dry deposition used to create annual totals, in turn used to calculate exceedances of critical loads for aquatic and terrestrial ecosystems as well as the contribution to those critical load exceedances associated with the oil sands.
- ongoing quantitative estimates of the contribution of the oil sands emissions to local primary and secondary pollutant levels.
- assessment of the cumulative effects of air pollutants on human health on a census division basis in collaboration with Health Canada using the Air Quality Benefits Assessment Tool (AQBAT), using air quality forecast model output from type 1 and 2 forecasts.
- assessment of short term exposure effects associated with oil sands emissions through the Air Quality Health Index (AQHI) and other index calculations for the proposed model simulations.
- calculation of the cumulative effects of oil sands emissions on ecosystem health, annual critical load exceedance from all three simulations described in Table 3.2. Cumulative effects modelling requires knowledge of past deposition. As above, prediction of future impacts requires knowledge of the past. Ideally, historic deposition from pre-oil sands onwards such as regional maps at 10 year intervals is required or as the most basic alternative, a historic emission sequence
- estimates of trans-boundary fluxes of primary and secondary pollutants associated with the oil sands, including time averages of the effect of the oil sands sector on downwind air quality. Concentration difference fields between the two simulations will be used to estimate the average impact of the oil sands downwind from the emissions site.
- verification of processes of downwind chemical transformation, incorporating improved anthropogenic and biogenic emissions data and improvements to model processes when available.

The use of models with the improved emissions and ambient air monitoring data collected is essential for continuous improvement. The comparison and updating of emissions, ambient monitoring and resulting model output on an ongoing basis will identify knowledge gaps and redundancies and provide a quantitative, scientific basis for critical re-evaluation and renewal of the air monitoring component on a regular basis.

The measurements being conducted will have the additional benefit of providing data for making model improvements specific to the oil sands source sector as described in Appendix 3E of the Technical Appendices. Specific improvements fall under the categories of:

- secondary organic aerosol formation including aqueous-phase formation of sulphate and organic aerosols
- atmospheric dispersion related to sub-grid scale topography
- representation of winter chemistry
- chemical processing during transport
- evaluation of deposition
- modelling of air toxics
- addition of post-processing facilities to allow for model estimates of visibility.

3.4.3 Satellite Data Retrievals

Satellite data products can be applied to two related monitoring applications: estimating the integrated emissions, and estimating average surface concentrations for locations where there are data gaps. In order to do this, output from the model simulations described above would be used to scale the satellite measured tropospheric vertical column density (VCD) with altitude. A discussion of the methods and limitations of this process are given in Appendix 3C of the Technical Appendices.

It is critical to compare satellite and ground-based observations with output from air quality models on an ongoing basis. Although satellite data and model-generated data differ in geographic and temporal scale, temporally- and spatially-integrated model results can be compared to satellite observations for cross-validation. The model also serves as an intermediary in the comparison of spatially sparse in-situ surface data, profiles from sondes or aircraft, ground-based VCD estimates at surface sites, and observations from various satellites made at different spatial resolutions and local times. This blended type of analysis will provide insight into the consistency of the emission inventories with observed emissions and concentrations, and help identify potential anomalous measurements. In addition, contrasting values of model-generated concentrations and VCDs between polluted and background regions will aid in providing a baseline for the satellite data products. A description of the differences between satellite data and model results, and the methods for analyzing the data to ensure comparability are described in greater detail in Appendix 3C of the Technical Appendices.

3.4.4 Critical Loads

The critical loads approach is an established method of integrating atmospheric emissions/deposition to aquatic and forest ecosystem health. The water monitoring component of the Integrated Monitoring Plan includes critical loads activities for aquatic systems; here, the air monitoring includes critical load activities related to forests and forest soils in and around the oil sands area. Both activities rely upon atmospheric deposition fluxes generated by air monitoring. The scientific objective of the monitoring for critical loads for forests is to improve upon first estimates of critical loads and critical load exceedances to forest soils in and around the oil sands area. Soil samples will be collected and analyzed and model calculations for forest sensitivity will be ground-truthed and improved to establish critical loads/exceedance as it relates to both acid deposition and nutrient eutrophication. The deliverable will be a ground-truthed set of maps of forest critical loads and exceedances and an evaluation of the forest resources at risk in and around northern Alberta, northern Saskatchewan and the Northwest Territories. These maps will be merged with the aquatic critical loads/exceedance maps developed as part of the water monitoring component, integrating atmospheric, aquatic and terrestrial activities.

3.5 Next Step

The air monitoring component of the Integrated Monitoring Plan has been defined by scientific experts who are largely air-quality based, with representation from the community and terrestrial, aquatic and human health sciences. As such, it is one component of a scientific starting point for the implementation phase of an integrated plan.

Program Area	**Immediate Initiation**
Emissions Monitoring (point, area and mobile emissions)	Develop and implement a standardized scientific emission inventory approach Develop an Emission Data Management System Plan science-based studies of point, mobile and area emissions including improving, developing and validating the methodology for chemicals of concern, most notably PACs, metals, VOCs
Air Quality and Atmospheric Deposition Monitoring	Complete the installation of sites already underway and enhance the suite of on-site measurements at existing sites Select locations of new monitoring sites and initiate site installation Develop required new measurement methods, standard operating procedures, data acquisition protocols and quality control procedures Refine scope of measurements needed to fill key knowledge gaps; develop a multi-year plan to address the gaps by airborne and ground-based intensive studies
Data Management and Quality Assurance	Develop project implementation plans for a quality assurance program and for air data management and archiving Request project plans from each program area Contribute to the design of the integrated multi-media data management system
Data and Results Integration	Prepare a modelling and data integration implementation plan including assessment of the models appropriate for use in the results integration work Do retrospective analysis of available satellite remote sensing data using available methods to provide emission fields for NO_2 and SO_2 Run existing models using available knowledge of emissions to forecast the impact of near-term oil sands development

CHAPTER 4. REFERENCES

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Appendix A: Proposed new measurements

Activity	Proposed chemicals -Stage 1	Sampling Protocol/Frequency
Emissions Monitoring	PACs, metals,Hg	Integrated
	SO_x, NO_x, BC, CO, H_2S, NH_3, CO_2, $PM_{2.5}$, $PM_{2.5}$ speciated, PM number size distribution	Continuous and or integrated
	Transportation markers(hopanes, steranes, aromatic acids, etc)	Integrated
	Anthropogenic VOC speciation	Integrated
	Biogenic VOCs (terpenes, isoprene)	Integrated
Tailings ponds Emissions	VOCs,H_2S, PACs, BC, $PM_{2.5}$, metals	Integrated or continuous
	Reduced sulphur, reduced nitrogen	Integrated or continuous
Monitoring, Source Scale	gases: CO, SO_2, H_2S, CO_2, NH_3, NO, NO_2, NO_y, O_3, Hg(0), VOCs	continuous
	PM: BC, PM size (5 nm-30 µm), $PM_{2.5}$ mass, PM constituents: OM, NO_3, SO_4, NH_4	continuous
	particle scattering and absorption, radiation, meteorology	continuous
	Precipitation: major ions, PACs, Me	event based
	PM, VOC,OC and Hg speciation, PACs and Me by size, isotopes, OC,EC	integrated
	NO_2, SO_2, O_3, HNO_3, NH_3, PACs, Hg(GEM, RGM, pHg)	passives
Monitoring, Local and Regional Scale	gases: CO, SO_2, H_2S, CO_2, NH_3, NO, NO_2, NO_y, O_3, Hg(0), VOCs	Continuous
	PM: BC, PM size (5 nm-30 µm), $PM_{2.5}$ mass, PM constituents: OM, NO_3, SO_4, NH_4, pHg	Continuous
	particle scattering & absorption , radiation, meteorology	Continuous
	Precipitation: major ions, PACs, Metals	event based
	PM, VOC,OC and Hg speciation, PACs and Me by size, isotopes, OC,EC	Integrated
	NO_2, SO_2, O_3, HNO_3, NH_3, PACs, Hg(GEM, RGM)	Passives
	vertical profiles of$_{O3,}$ SO_2, NO_2	Sondes
	tree rings, snow sampling	Ecosystem Monitoring
Selected sites, local and region scale	LIDAR, DOAS, sondes, particle Hygroscopicity	continuous
	Vertical profiles (O_3,SO_2,NO_2)	intermittent (weekly)
	fluxes (eddy covariance)	continuous
	enhanced VOCs speciation, oxidants and radicals	short term intensives
Mobile, ground level monitoring	gases: CO, SO_2, H_2S, CO_2, NO, NO_2, NO_y, NH_3, O_3, Hg(0), VOCs	continuous and grab sampling
	PM: BC, PM size (5 nm-30 µm), $PM_{2.5}$ mass, PM constituents: OM, NO_3, SO_4, NH_4	continuous
	particle scattering & absorption , radiation, meteorology	continuous
	enhanced VOC speciation, oxidants, photolytic constants	continuous
	Remote sensing: NO_2 (MAX DOAS), aerosol scattering (LIDAR)	continuous
Airborne Intensives	gases: CO, SO_2, H_2S, CO_2, NO, NO_2, NO_y, NH_3, O_3, Hg(0), VOCs	continuous and grab sampling
	PM: BC, PM size (5 nm-30 µm), $PM_{2.5}$ mass, PM constituents: OM, NO_3, SO_4, NH_4	continuous
	particle scattering & absorption , radiation, meteorology	continuous
	enhanced VOC speciation, oxidants, photolytic constants	continuous

Activity	Proposed chemicals -Stage 1	Sampling Protocol/Frequency
	Remote sensing: NO_2 (MAX DOAS), aerosol scattering (LIDAR)	continuous
Aerial Monitoring	Gases: CO,CO_2,NO_2,SO_2,O_3,Hg	continuous
	Particles: BC, particle counts, particle number size distribution	continuous
	Remote sensing: NO_2 (MAX-DOAS), particle absorption and light scattering	when technology matures
	Meteorology: T, RH, P, wind speed, wind direction	continuous
	Positioning: altitude, longitude, latitude	continuous
	Digital aerial photography	continuous
Isotopic characterization at 3 ecosystem monitoring sites	d34S, d15N, d17O,d18O of all S- and N-species	Air, precipitation, tree rings

Legend

major ions : SO_4, NO_3, NH_4, Cl^-, H^+, organics, base cations,

PACs or Polyaromatic Compounds (including normal ring and alkyl-substituted PAHs, normal ring and alkyl-substituted dibenzothiophenes) : Naphthalene, C1-naphthalenes, C2-naphthalenes, C3-naphthalenes, C4-naphthalens, Acenaphthylene, Acenaphthene, Fluorene,2-Methyl-Fluorene, C2-Fluorenes, C3-Fluorenes, C4-Fluorenes,Phenanthrene,Anthracene, C1-Phenanthrenes/Anthracenes,
C2-Phenanthrenes/Anthracenes, C3-Phenanthrenes/Anthracenes, C4-Phenanthrenes/Anthracenes, Fluoranthene, Pyrene, C1-Fluoranthenes/Pyrenes, C2-Fluoranthenes/Pyrenes,
C3-Fluoranthenes/Pyrenes, C4-Fluoranthenes/Pyrenes, Retene, Benzo(a)fluorene, Benzo(b)fluorene, 1-Methyl-Pyrene, Benzo(g,h,i)fluoranthene, Benz(a)anthracene, Chrysene, Triphenylene, C1- Benz(a)Anthracenes/Triphenylenes/Chrysenes, C2-Benz(a)Anthracenes/Triphenylenes/Chrysenes, C3-Benz(a)Anthracenes/Triphenylenes/Chrysenes, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene, Perylene, 3-Me-Cholanthrene,Indeno(1,2,3-cd)pyrene, Dibenz(a,h)anthracene, Benzo(b)chrysene, Benzo(g,h,i)perylene, Anthanthrene, Dibenzothiophene, C1-Dibenzothiophenes, C2-Dibenzothiophenes, C3-Dibenzothiophenes, C4-Dibenzothiophenes

Me (Metals) : Ag, Al, Al, As, Ba, Be, Cd, Ce, Co, Cr, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Ho, La, Li, Lu, Mn, Mo, Nd, Ni, Pb, Pr, Se, Sm, Sn, Sr, Tb, Th, Ti, Tm, U, V, Yb, Zn

isotopes: Pb, Hg, N, O, H, C, S

PM speciation: major ions, metals, isotopes, EC,speciated OC, pHg

VOC speciation: polar, non-polar, oxygenates, reduced sulphur, reduced nitrogen

Glossary of Acronyms and Terms

Term	Definition
Active sampling	The use of a pump for drawing a specified volume of air to be sampled through an adsorbent tube with a specified, usually low air flow rate.
Activity data	Activity data are defined as data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time.
AENV	Alberta Environment
Alkylated PAHs	Polyaromatic hydrocarbons containing a straight carbon side chain. Alkylated PAHs are more abundant, persist for a longer time, and are sometimes more toxic than the parent PAHs.
AP-42	**AP-42, *Compilation of Air Pollutant Emission Factors***, has been published since 1972 as the primary compilation of EPA's emission factor information. It contains emission factors and process information for more than 200 air pollution source categories. A source category is a specific industry sector or group of similar emitting sources. The emission factors have been developed and compiled from source test data, material balance studies, and engineering estimates. The Fifth Edition of AP-42 was published in January 1995. Since then EPA has published supplements and updates to the fifteen chapters available in ***Volume I, Stationary Point and Area Sources***. The latest emissions factors are available below on this website. Source: www.epa.gov/ttnchie1/ap42/
APEI	Air Pollution Emission Inventory
AQ	Air quality
AQBAT	Air Quality Benefits Assessment Tool. A computer simulation tool designed to estimate human health and welfare benefits or damages associated with changes in Canada's ambient air quality.
AQHI / AQI	Air Quality Health Index / Air Quality Index
AQMS	Air Quality Management System, framework proposed for managing air quality in Canada
AURAMS	A Unified Regional Air Quality Modelling System
AURAMS-PAH	An extended version of the original AURAMS model to include simulations for polyaromatic hydrocarbons (phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, and benzo[a]pyrene)
Background concentrations	The global or hemispheric background concentration of a pollutant is a model construct that estimates the atmospheric concentration of a pollutant due to natural sources only. It is a straightforward modelling exercise that uses a variety of source-apportionment, labelling and source-receptor techniques. The relatively long-lived air quality pollutants like ozone, CO, and PM, or the greenhouse gases, are pervasive in the northern hemisphere. Because their lifetimes are longer than the time taken to advect around a latitude circle, it is unlikely that a location can be found that only observes naturally occurring concentrations of these pollutants. Therefore, global or hemispheric background concentrations of long-lived pollutants cannot be observed. The global or hemispheric background concentrations of these species can only be determined by models and these concentrations will always be less than baseline observations which contain natural and anthropogenic contributions. In contrast, for short-lived air quality species like SO_2 or NO_2 it is possible to find some locations in the northern hemisphere unaffected by anthropogenic

Term	Definition
	emissions allowing the direct observation of global or hemispheric background concentrations. However such locations are relatively few and models are still required to estimate the global or hemispheric background concentrations for most places in the northern hemisphere." [Source: Task Force on Hemispheric Transport of Air Pollution (TF HTAP): Hemispheric Transport of Air Pollution 2010 Assessment Report, edited by: Keating, T. J. and Zuber, A., draft, available online at: www.htap.org, 2010.]
Base cations	Elements or ions with a positive charge that can neutralize acids
Baseline concentration	A baseline concentration is an observation made at a site when it is not influenced by recent, locally emitted or produced pollution. These baseline sites are typically situated in locations with minimal and infrequent impact from local sources of anthropogenic pollution. Observations may be made continuously and subsequently sorted, or air samples taken only when meteorological conditions are such that the recorded concentrations are free from the local contamination. Time series of baseline concentrations provide the range and frequency of pollutant concentrations transported to the site from upwind locations. However the requirement that only recently emitted or produced local pollution be excluded means that baseline concentrations may contain traces of local pollutants that were emitted many days earlier and became well-mixed with other air masses. There is no strict definition of "recently" emitted or produced local sources of anthropogenic pollution. [Source: Task Force on Hemispheric Transport of Air Pollution (TF HTAP): Hemispheric Transport of Air Pollution 2010 Assessment Report, edited by: Keating, T. J. and Zuber, A., draft, available online at: www.htap.org, 2010].
Bitumen	Naturally occurring or pyrolytically obtained substances of dark to black colour consisting almost entirely of carbon and hydrogen, with very little oxygen, nitrogen or sulfur.
BLFM-POPS	Boundary Layer Forecast Model for Persistent Organic Pollutants
BLIERs	Base-Level Industrial Emissions Requirements
CAAQS	Canadian Ambient Air Quality Standards
CACs	Criteria Air Contaminants. Emissions of criteria air contaminants contribute to smog, poor air quality and acid rain. CACs include Total Particulate Matter (TPM), Particulate Matter with a diameter less than 10 microns (PM_{10}), Particulate Matter with a diameter less than 2.5 microns ($PM_{2.5}$), Carbon Monoxide (CO), Nitrogen Oxides (NO_x), Sulphur Oxides (SO_x), Volatile Organic Compounds (VOC) and Ammonia (NH_3).
CALA	Canadian Association for Laboratory Accreditation
CanMETOP	Canadian Model for Environmental Transport of Organochlorine Pesticides
CAPMoN	Canadian Air and Precipitation Monitoring Network
CASA	Clean Air Strategic Alliance, a multi-stakeholder partnership composed of representatives of industry, government and non-government organizations committed to a comprehensive air quality management system for Alberta.
CCME	Canadian Council of Ministers of the Environment
CEAA	Canadian Environmental Assessment Act
CEMA	Cumulative Environmental Management Association
CEMS	Continuous emission monitoring systems
CEPA	Canadian Environmental Protection Act
CH_4	Methane
Class 8 Trucks	The Class 8 truck gross vehicle weight rating (GVWR) is anything above 33,000 pounds (14,969 kg).These include all tractor trailer trucks.

Term	Definition
CMAQ	Community Multiscale Air Quality model
CMB	Chemical Mass Balance
CO	Carbon monoxide
Coking	A process for thermally converting the heavy residual bottoms of crude oil entirely to lower-boiling petroleum products and by-product petroleum residue (coke).
CPM	Condensable particulate matter - Particulate matter that forms from condensing gases or vapors
Critical loads	The amount of acid deposition a particular region can receive without being adversely affected
CTM	Chemical transport model
CWAQ	Canada-wide Air Quality database which stores and provides access to all federal, provincial, territorial and community criteria air contaminant data gathered by NAP
CWS	Canada-wide standards
DIAL	Differential Absorption Light detection
EA or EIA	Environmental assessments or Environmental impact assessments
EC	Environment Canada
EC/OC	Elemental carbon / organic carbon
EDMS	Emission Data Management System
EF	Emission factor
EI	Emission inventory
Emission Factor	A representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per megagram of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average).
EPA or US EPA	United States Environmental Protection Agency
FAP	Fort Air Partnership
Fine Particles	Particles with diameter less than or equal to 2.5 µm
FMon	Focused monitoring
Fugitive emissions	Emissions of gases or vapours are those emissions which could not reasonably pass through a stack, chimney, vent or other functionally-equivalent opening, sometimes due to leaks and mostly from industrial activities.
GEM-MACH	Global Environmental Multiscale – Modelling Air quality and Chemistry
GEM-MACH/Hg	A version of GEM-MACH incorporating the mercury chemistry of GRAHM
GHG	Greenhouse gas
GIS	Geographic Information System
GOME	Global ozone monitoring experiment (satellite)
GRAHM	Global/Regional Atmospheric Heavy Metals model
H_2S	Hydrogen sulphide
HCHO	Formaldehyde
Hg	Mercury
HNO_3	Nitric acid
Hygroscopicity	Ability to attract water molecules

Term	Definition
IM/IT	Information management / information technology
In-situ extraction	In-situ or in-place recovery of crude bitumen from the oil sands using mining techniques to extract the bitumen from the sand underground and pump it to the surface.
ISO	International Organization for Standardization
isopleth	An isogram, or line of equal or constant value of a given quantity.
LARP	Lower Athabasca Regional Plan
LICA	Lakeland Industry and Community Association
Lidar	Light detection and ranging - Method for investigating atmospheric behaviour using pulsed light beams (lasers).
LRT	Long-range transport
MAX-DOAS	Multi-Axial Differential Optical Absorption Spectrometry - A technique for the measurement of trace gases in the atmosphere through the use of sky scattered solar radiation.
Mobile Sources	Motor vehicles, engines, and equipment that move, or can be moved, from place to place. Mobile sources include vehicles that operate on roads and highways ("on-road" or "highway" vehicles), as well as nonroad vehicles, engines, and equipment. Examples of mobile sources are cars, trucks, buses, earth-moving equipment, lawn and garden power tools, ships, railroad locomotives, and airplanes.
Naphthenic acid	Any of a group of saturated higher fatty acids derived from the gas-oil fraction of petroleum by extraction with caustic soda solution and subsequent acidification.
NAPS	National Air Pollution Surveillance Network
NARSTO	North American Research Strategy for Tropospheric Ozone. Partnership among government, private industry, and research organizations in Canada, the United States and Mexico that is dedicated to improving the management of air quality in North America www.narsto.org
NatChem	National Atmospheric Chemistry database
NH_3	Ammonia
NMHC	Non-methane hydrocarbons
Nonroad Vehicles, Engines, and Equipment	This category of mobile sources includes nonroad gasoline equipment and vehicles, nonroad diesel equipment and vehicles, aircraft, marine vessels, locomotives, and assorted other engines and vehicles. Subcategories include recreational, construction, industrial, lawn and garden, farming, commercial, logging, and mining equipment and vehicles
NO_x	Nitrogen oxides, the sum of NO and NO_2
NO	Nitric oxide (gaseous)
NO_2	Nitrogen dioxide (gaseous)
NO_3^-	Nitrate (ion)
NOy	Total reactive nitrogen
NPRI	National Pollutant Release Inventory
NWT	Northwest Territories
O_3	Ozone
OMI	Ozone Monitoring Instrument (satellite)
Open source emissions	Sources that emit air contaminants over large geographic areas, primarily in a stationary but non-point source manner, and are diffuse in nature. Examples include dust from farms, construction, and paved and unpaved roads.

Term	Definition
PAC	Polycyclic aromatic compounds
PAH	Polycyclic aromatic hydrocarbon
PAN	Peroxyacyl nitratres
Passive sampling	The collection of airborne gases and vapours at a rate controlled by a physical process such as diffusion through a static air
PASZA	Peace Air Shed Zone Association
PCA	Principal Component Analysis – a statistical method for data analysis
PEMS	Portable Emission Monitoring System
PM	Particulate matter
$PM_{2.5}$	Fine particulate matter with diameter less than or equal to 2.5 µm
PM_{10}	Particulate matter with diameter less than or equal to 10 µm
PMF	Positive Matrix Factorization – a multivariate factor analysis technique used to determine source profiles based on ambient data
QAPP	Quality Assurance Programme Plan
Real-world monitoring (emissions)	The measurement and analysis of emissions under real conditions rather than in a laboratory or pilot plant.
Remote sensing	The collection and analysis of data made by instruments carried in or above the Earth's atmosphere.
RSC	Reduced sulphur compounds
SAGD	Steam assisted gravity drainage – a form of in-situ extraction from the oil sands
SOA	Secondary organic aerosol
SO_2	Sulphur dioxide
SO_4^{2-}	Sulphate
Sonde	An instrument used to obtain weather data during ascent and descent through the atmosphere
Spectrometer / spectrometry	An instrument/technique that disperses radiation to measure radiant intensities at various wavelengths
STEM	Sulfur Transport and dEposition Model - a regional chemical transport model developed at the University of Iowa to provide a theoretical basis to investigate the relationships between the emissions, atmospheric transport, chemical transformation, removal processes, and the resultant distribution of air pollutants and deposition patterns.
SVOC	Secondary volatile organic compounds
Tailings ponds	Areas of mining tailings where the water-borne refuse material is pumped into a pond to allow sedimentation of solid particles from the water.
TB	Transboundary
THC	Total hydrocarbons
Tropopause	The boundary between the troposphere and the stratosphere varying in altitude from approximately 8 kilometres at the poles to approximately 18 kilometres at the equator.
TRS	Total reduced sulphur
UNECE LRTAP	United Nations Economic Commission for Europe Convention on Long-range Transboundary Air Pollution
Upgrader	A facility that upgrades bitumen into synthetic crude oil.
VCD	Vertical column density, a satellite measurement quantity
Vertical mixing	Upward and downward movement of air that occurs as a result of temperature gradients.
VOC	Volatile organic compounds
WBEA	Wood Buffalo Environmental Association
WQMP	Lower Athabasca Water Quality Monitoring Plan

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