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A five-year provincial air quality and deposition monitoring, evaluation and reporting plan (2019-2023)

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Acronyms and Abbreviations

Acronym	Definition
AAAQO	Alberta Ambient Air Quality Objective
ACA	Alberta Capital Airshed
ADMF	Acid Deposition Management Framework
AEP	Alberta Environment and Parks
AER	Alberta Energy Regulator
ALSA	Alberta Land Stewardship Act
AMD	Alberta Air Monitoring Directive
AOSR	Alberta Oil Sands Region
APEI	Air Pollutant Emissions Inventory
AQHI	Air Quality Health Index
AQMF	Air Quality Management Framework
AQMS	Air Quality Management System
CAAQS	Canadian Ambient Air Quality Standards
CAC	Criteria Air Contaminant
CAPMoN	Canadian Air and Precipitation Monitoring Network
CAPS	Cavity Attenuated Phase Shift
CASA	Clean Air Strategic Alliance
CCME	Canadian Council of Ministers of the Environment
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CoE	Condition of the Environment
CRAZ	Calgary Region Airshed Zone
ECCC	Environment and Climate Change Canada
EMSD	Environmental Monitoring and Science Division
FAP	Fort Air Partnership
GAW	Global Atmosphere Watch
GEM-MACH	Global Environmental Multi-Scale Modelling Air Quality and Chemistry
GHG	Greenhouse Gas
GIS	Geographic Information System
H_2S	Hydrogen sulphide
HCHO	Formaldehyde
HNO_3	Nitric acid
HONO	Nitrous acid
LARP	Lower Athabasca Regional Plan
LICA	Lakeland Industry and Community Association
LUF	Land-Use Framework
MAML	Mobile Air Monitoring Laboratory
NADP	National Atmospheric Deposition Program
NAPS	National Air Pollution Surveillance
NH_3	Ammonia

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Acronym	Definition
NMHC	Non-methane hydrocarbons
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NPRI	National Pollutant Release Inventory
O_3	Ozone
OSM	Oil Sands Monitoring
PAC	Polycyclic aromatic compound
PAH	Polycyclic aromatic hydrocarbon
PAML	Portable Air Monitoring Laboratory
PAMS	Photochemical Assessment Monitoring Stations
PAMZ	Parkland Airshed Management Zone
PAN	Peroxyacyl Nitrates
PAS	Palliser Airshed Society
PAZA	Peace Airshed Zone Association
$PM_{2.5}$	Particulate matter with diameter equal to or less than 2.5 micrometres
PM_{10}	Particulate matter with diameter equal to or less than 10 micrometres
ppb	parts per billion
PRAMP	Peace River Area Monitoring Program
PUF	Poly Urethane Foam
QAP	Quality Assurance Plans
SAP	Science Advisory Panel
SO_2	Sulphur dioxide
SOP	Standard Operating Procedures
SSRP	South Saskatchewan Regional Plan
TBD	To be determined
TEMPO	Tropospheric Emissions: Monitoring of Pollution (Earth observation satellite)
THC	Total hydrocarbons
TROPOMI	TROPOspheric Monitoring Instrument (Earth observation satellite)
TRS	Total Reduced Sulphur
TSP	Total Suspended Particulates
µm	Micrometres
U.S. EPA	United States Environmental Protection Agency
VAPS	Versatile Air Pollution Samplers
VOC	Volatile organic compound
WBEA	Wood Buffalo Environmental Association
WCAS	West Central Airshed Society

Alberta's Environmental Science Program

The Chief Scientist has a legislated responsibility for developing and implementing Alberta's environmental science program for monitoring, evaluation and reporting on the condition of the environment in Alberta. The program seeks to meet the environmental information needs of multiple users in order to inform policy and decision-making processes. Two independent advisory panels, the Science Advisory Panel and the Indigenous Wisdom Advisory Panel, periodically review the integrity of the program and provide strategic advice on the respectful braiding of Indigenous Knowledge with conventional scientific knowledge.

Alberta's environmental science program is grounded in the principles of:

- *Openness and Transparency.* Appropriate standards, procedures, and methodologies are employed and findings are reported in an open, honest and accountable manner.
- *Credibility.* Quality in the data and information are upheld through a comprehensive Quality Assurance and Quality Control program that invokes peer review processes when needed.
- *Scientific Integrity.* Standards, professional values, and practices of the scientific community are adopted to produce objective and reproducible investigations.
- *Accessible Monitoring Data and Science.* Scientifically-informed decision making is enabled through the public reporting of monitoring data and scientific findings in a timely, accessible, unaltered and unfettered manner.
- *Respect.* A multiple evidence-based approach is valued to generate an improved understanding of the condition of the environment, achieved through the braiding of multiple knowledge systems, including Indigenous Knowledge, together with science.

Learn more about the condition of Alberta's environment at: environmentalmonitoring.alberta.ca.

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Executive Summary

The Environmental Monitoring and Science Division (EMSD) of Alberta Environment and Parks (AEP) is responsible for monitoring, evaluating and reporting on key environmental indicators and providing open and transparent access to air quality and deposition data. To effectively report on air quality and deposition in the province, a robust and spatially representative monitoring system is necessary.

EMSD has evaluated the existing air and deposition monitoring program from a provincial perspective and has developed a 5-year Air Quality and Deposition Monitoring Plan. The main objectives of this Plan are to: (i) evaluate the core long-term air and deposition networks and to propose improvements to these networks; (ii) identify gaps in the existing network and opportunities to address these through focused studies or complementary monitoring; and (iii) document the air and deposition monitoring, evaluation, and reporting responsibilities of EMSD over the next 5-years.

The core long-term air monitoring network identified in the 5-Year Air Quality and Deposition Monitoring Plan includes stations with continuous analyzers that report their data to the central air data management system (currently called Alberta AirData). A station classification system was developed to evaluate the core long-term air monitoring network using a data-driven approach based on criteria using emissions data, modelled ambient air quality, and population data. Station classification will identify the overall purpose or objective of each monitoring station and helps to assure the parameters monitored are consistent with the objective of the station. This station classification was used to identify possible gaps in monitoring and to recommend changes to the long-term air monitoring network.

Based on the station classification process, it is observed that there is generally adequate air monitoring in large communities (population ≥ 50,000). However, there are significant areas in the province where monitoring gaps exist. These include medium sized communities and small communities that are potentially influenced by a nearby industry. Also, there are large regions of the province, located primarily outside of existing Airshed zone boundaries, which have limited air monitoring. Some of these areas include northwestern Alberta, east of the Edmonton-Calgary corridor and southern Alberta. Based on the station classification criteria, it was determined that there is only one provincial background air monitoring station (Steeper), located in west-central Alberta. The need for additional background monitoring in the province will be assessed by EMSD.

Historically, deposition monitoring in Alberta has been based on monitoring acidifying substances in precipitation that may contribute to wet deposition. However, it is well known that dry deposition contributes to over half of total deposition at many locations in the province. Also, eutrophication is a relevant issue in Alberta, with many Albertan lakes being eutrophic or hypereutrophic (Orihel et al., 2012). However, the extent to which deposition influences eutrophication in these lakes is largely unknown. Significant changes to Alberta's existing wet deposition monitoring network are recommended to improve its relevance and to improve data collection protocols. Some of these changes include: (i) relocating urban deposition monitoring sites to more suitable locations based on receptor sensitivity and modelled deposition; (ii) improving monitoring equipment and monitoring protocols to assure that data collected in Alberta is comparable nationally and internationally; (iii) adding equipment that will allow the inference of dry deposition; (iv) improving reporting of deposition results; and (v) assuring representative monitoring in all ecoregions of the province.

Implementation of traditional monitoring to address existing gaps in the air and deposition monitoring network may not be feasible due to factors such as costs (capital equipment and operations), siting issues (large footprint required) and power requirement (at remote locations). EMSD, in partnership with stakeholders, will be investigating alternative complementary monitoring methods to address monitoring gaps. Some of these include: (i) use of passive, portable and integrated sampling where appropriate, based on the data quality objectives; (ii) use of low-power or no-power portable air monitoring platforms at remote locations; and (iii) use of remote sensing technologies such as satellite air quality data. Also, where appropriate, EMSD will be working with Airshed organizations, industry and the regulator to utilize portable monitoring units that are currently not part of the provincial monitoring network to fill monitoring gaps. Efficient use of these and other complementary monitoring methods or platforms may effectively address many of the existing gaps identified by this Plan.

Shorter-term focused monitoring studies are investigative monitoring conducted to address a specific science question(s) or local air quality issue. A process for systematically planning focused studies on an annual basis is defined in this Plan. The process includes identifying known information needs before the start of the fiscal year so that EMSD can prioritize the information need and work with the requestor to design the appropriate monitoring study that will address the issue. Other focused studies may be initiated through a direct request to EMSD that requires a more immediate response (e.g., emergency response or response to a complaint that requires immediate monitoring). All focused monitoring studies will also have a data evaluation and reporting component ranging from a presentation for the public to a technical report and/or peer-reviewed manuscript.

Significant air quality and deposition issues are issues that are expected to be important over the next five to ten years. Specific significant issues discussed in the Plan include: (i) the appropriate monitoring to address the impact of increased wildfire activity on air quality; (ii) pro-active monitoring and evaluation of air quality to facilitate comparison to the more stringent Canadian Ambient Air Quality Standards (CAAQS) for particulate matter and ozone and the new CAAQS for nitrogen dioxide and sulphur dioxide that will come into effect in 2020; (iii) improved methods for monitoring of nitrogen dioxide that take into account the positive bias known to occur by most monitors currently in use; (iv) assessment of the need for ammonia monitoring in Alberta based on estimated increases in emissions; (v) evaluation and reporting on improvements to air quality due to the phase out of coal-fired power generation; (vi) assessment of ambient levels of formaldehyde, a known carcinogen, in Alberta; and (vii) improvement of monitoring and evaluation methods for addressing odour issues. EMSD will proactively explore these significant issues over the next 5 years, and will consider new monitoring, evaluation and reporting activities.

Data availability and timely reporting is fundamental to the mandate of EMSD. Existing systems allow public access to air quality data in near-real time and quality controlled data within two months of collection. EMSD will support the development of a central data management system that will facilitate electronic storage of all air quality data, collected continuously or using integrated monitoring methods, as required by the Air Monitoring Directive (AMD). This system will contain air quality data collected by industry as required by approvals that was previously not available or accessible. Availability of these data will enable the use of industry regulatory monitoring stations to address current monitoring gaps in the province. Also, Condition of the Environment (CoE) reporting is required by the Chief Scientist of Alberta Environment and Parks. As such, the Chief Scientist will be developing a public reporting schedule for reporting of key indicators related to air quality and deposition.

The Plan identifies close to 60 Implementation Items categorized as ongoing, short-term, medium-term and long-term. These items are reflected throughout the text of the report in the section that they are associated with and also summarized in Section 8 of this report. EMSD will work with subject matter experts, Airshed organizations and other stakeholders to implement these items. EMSD will also provide an annual update on the implementation status of items presented in this Plan.

1 Introduction

Air and deposition monitoring data can provide data to support action(s) to address local, regional, provincial and national air quality issues or priorities. The Government of Alberta's Ministry of Environment and Parks (AEP) is responsible for the monitoring and management of air quality and deposition in the province.

Within the last decade, there have been important changes in how air quality is managed and reported on in Alberta. A national Air Quality Management System (AQMS) was implemented through the Canadian Council of Ministers of the Environment (CCME). The AQMS included the commitment to assess ambient air quality in regions within each province and territory against Canadian Ambient Air Quality Standards (CAAQS). Furthermore, under Alberta's Land-use Framework (LUF) Regional Plans, Air Quality Management Frameworks (AQMFs) were developed and continue to be developed, with specific triggers and limits for key air pollutants. The implementation of these frameworks and management systems requires an adequately designed monitoring network.

Environmental Monitoring and Science Division (EMSD), within AEP, is responsible for ambient air monitoring, evaluation and reporting in the province. The EMSD 5-year Air Quality and Deposition Monitoring Plan (referred to as 5-year Monitoring Plan hereafter) was developed to ensure that an appropriate core long-term monitoring network is in place to report on the condition of ambient air quality and deposition. It should also have the capacity for in depth evaluation and reporting, including the assessment of cumulative effects and linkages between the atmosphere and outcomes on human and ecosystem health.

1.1 Scope of Plan

The EMSD 5-year Monitoring Plan will facilitate the delivery of monitoring, evaluation and reporting that is based on sound science and will provide a framework for activities EMSD will carry out over the next five years. The plan will primarily focus on:

- Core long-term air and deposition monitoring of indicators, which are used to understand the current condition of air quality and trends;
- Complementary monitoring, which allows flexibility in the monitoring network;
- Focused studies, which facilitate in depth investigation(s);
- Significant air and deposition issues, which should be explored to ensure a relevant, current and scientific monitoring network; and
- Data quality, evaluation and reporting priorities.

The 5-year Monitoring Plan will:

- Include the monitoring questions that will form the foundation of the provincial monitoring network;
- Identify core long-term monitoring, associated monitoring objectives and minimum required monitoring;
- Outline a process to consistently initiate and conduct focused studies;
- Describe complementary monitoring that can support long-term monitoring;
- Identify relevant air and deposition issues that are significant;

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- Include recommendations to improve monitoring protocols to assure provincial consistency where necessary; and
- List the major air and deposition monitoring, evaluation and reporting activities that will be completed by EMSD over the next five years.

The plan will not:

- Evaluate the current state of regulatory or fence line monitoring in Alberta;
- Include oil sands monitoring that is not directly related to provincial reporting requirements identified in regional, provincial or national frameworks; or,
- Include monitoring of greenhouse gas (GHG) emissions or ambient GHG concentrations not related to understanding or interpreting air quality.

In addition, this plan will not directly address options for managing emissions when air quality or deposition levels exceed regional, provincial or national benchmarks. However, EMSD may be involved with identifying the origin or sources that may be contributing to these exceedances.

1.2 Air Quality and Deposition Monitoring

Air quality is a measure of the quantity or amount of pollutants in the atmosphere and the degree to which these pollutants can harm human health and/or have negative impacts on the environment. Air pollutants are traditionally measured: (a) with standard reference instrumentation (online continuous monitoring) that has been calibrated to accurately quantify ambient air pollutant levels, or (b) by collecting a sample for laboratory analysis (offline monitoring). Many air pollutants have ambient objectives, guidelines, standards or other benchmarks that are used to determine if air pollutants are having a negative effect on the environment or human health. Other measures of the impact of air quality on the environment can include visibility and odour, which can be assessed using separate thresholds.

Air pollutants emitted directly by industrial or domestic sources can transform while being transported in the atmosphere. The transformation processes lead to secondary pollutants being formed that can be more damaging to human health or the environment than the primary pollutant(s). Understanding the transformation processes and mechanisms for secondary pollutant formation is essential to determining the impacts of air emissions on human health and the environment. Long-term air monitoring in the 5-year Monitoring Plan will focus on the core long-term network of continuous air quality analyzers. These measurements are routinely compared against air quality thresholds from objectives, standards and frameworks to determine whether management of air quality is needed. These data will also be used for reporting on the condition of the environment.

Air pollutants may be removed from the atmosphere and deposited to ecosystems through wet or dry deposition. Wet deposition refers to the removal of atmospheric pollutants via precipitation. Dry deposition refers to the transfer of gases and particles from the atmosphere to surfaces by processes such as gravitational sedimentation or diffusion in the absence of precipitation. Long-term deposition monitoring in this 5-year Monitoring Plan will focus on quantifying the deposition of acidifying substances, base cations and nutrient nitrogen. Event, bulk, passive and denuder sampling have all been used to infer deposition in Alberta. The deposition of air toxics (such as organic compounds and heavy metals), when needed, is investigated through focused study monitoring. Total deposition, in conjunction with established benchmarks such as critical loads can be used to assess the potential impact of atmospheric deposition on ecosystems and help identify where more in depth ecosystem and deposition monitoring needs to occur.

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1.3 Delivery of Air Quality and Deposition Monitoring

Air quality and deposition monitoring in Alberta is delivered through a distributed system, which includes industry, Airshed organizations and the provincial and federal governments (Figure 1). Monitoring conducted by industry consists of regulatory fence line monitoring and is not within the scope of this plan.

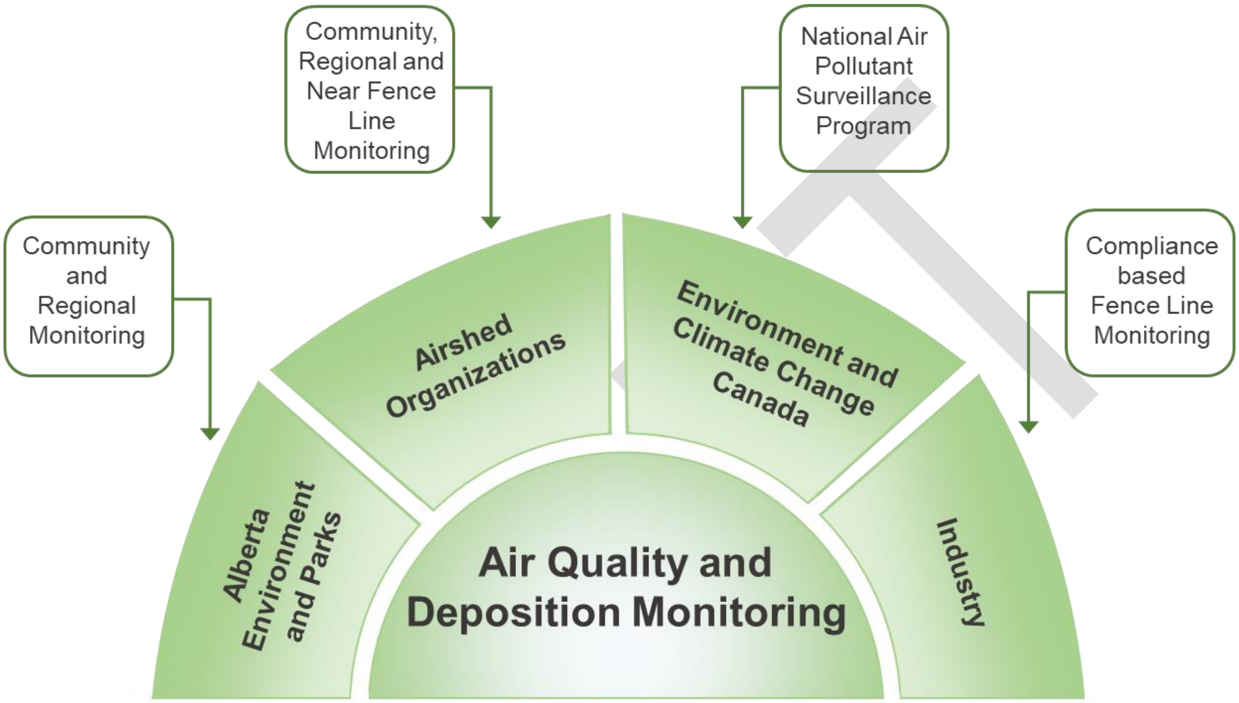

Figure 1: Distributed model for provincial air and deposition monitoring in Alberta

Airsheds in Alberta are multi-stakeholder organizations that use consensus as a decision making tool. There are ten Airshed organizations in the province (Figure 2), nine of which operate an air monitoring network. They are grass-roots organizations primarily located in areas of the province with significant industry or population and, as a result, Airshed organizations have not been established in some areas of the province. Some Airshed organizations are contracted to operate air monitoring stations owned by the Government of Alberta (see Appendix A1 for a complete list).

To assure data consistency and quality across air and deposition monitoring delivered by the distributed system, policies such as the Alberta Air Monitoring Directive (AMD) have been established (Alberta Environment and Parks, 2016a). However, the AMD does not contain minimum performance specifications or sampling schedules for passive, integrated or mobile monitoring conducted in the province and therefore there may be inconsistencies between some datasets.

350 **Figure 2: Location of Alberta Airshed organizations as of January 2018; Airshed organization boundaries are indicated by the shaded areas**

1.4 Historical Context

Two other provincial monitoring plans for ambient air and deposition have previously been developed through the Clean Air Strategic Alliance (CASA) (Clean Air Strategic Alliance, 1995 and Clean Air Strategic Alliance, 2009). The 1995 Ambient Monitoring Strategic Plan focused on establishing permanent core provincial stations and recognized the delivery of monitoring through a distributed model that included Airshed organizations, industry, the provincial government and the federal government. The monitoring was intended to provide a scientifically sound foundation for ambient air quality evaluations in four key areas: human health, ecosystem health, transboundary transport and visibility. The plan also resulted in the development of a publicly accessible data management system for ambient air quality known as the CASA Data Warehouse and later known as Alberta's Ambient Air Quality Data Warehouse.

The 2009 Ambient Air Monitoring Strategy for Alberta was intended to be an evolution of the 1995 Strategic Plan but more responsive to social, economic and environmental changes that had occurred since the 1995 plan was developed. In the early 2000s, the monitoring system needed to be responsive to increasing industrial and population growth, the rapid grassroots formation of new Airshed organizations, the emergence of provincial frameworks that require monitoring, evaluation and reporting, and new policies such as land-use frameworks (LUF) being developed under the Alberta Land Stewardship Act (ALSA). The 2009 Strategy contained recommendations to: (1) identify and address current air monitoring gaps in areas with concerns about human health, acid deposition and smog formation; (2) improve responsiveness to significant air quality issues in Alberta that will result from population and industry growth; (3) address funding and implementation issues that resulted in partial implementation of the 1995 plan; and (4) focus air and deposition monitoring on collecting the appropriate information that is needed for cumulative effects management.

Both the 1995 and 2009 Ambient Air Monitoring Strategies were not implemented fully for a variety of reasons, including the lack of a pragmatic implementation plan. The current 5-year Monitoring Plan, while directed by a similar vision as the two preceding plans, that of providing a scientifically sound provincial network to meet current monitoring objectives, is independent from these plans. A list of Implementation Items for this 5-year plan is contained in Section 8.1. These are categorized as ongoing, short-term, medium-term and long-term. The status of implementation will be assessed annually by EMSD.

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2 Monitoring Questions

The 5-year Monitoring Plan was developed around four monitoring questions. These questions help to define the foundation for air quality and deposition monitoring needed in the province. All monitoring for air quality and deposition should help to address one or more of the following questions:

1. How does ambient air quality and atmospheric deposition in Alberta compare to regional, provincial, and national triggers, limits, objectives and standards indicated in frameworks?

National, provincial and regional frameworks assign thresholds for ambient pollutant concentrations and deposition loadings that determine when management actions are required. These thresholds are designed to allow proactive management decisions that can be made before serious health or environmental effects occur. The 5-year Monitoring Plan defines the monitoring necessary to adequately report against CAAQS, the provincial Acid Deposition Management Framework (ADMF), Alberta Ambient Air Quality Objectives (AAAQO) and regional AQMFs under regional land-use plans. In order to achieve this, the 5-year Monitoring Plan identifies core long-term networks for air (Section 3.1) and deposition (Section 3.2) monitoring. The stations are classified based on monitoring objectives and suggested reporting products are indicated. Furthermore, gaps in the air monitoring and deposition networks are identified and prioritized based on potential monitoring needs.

2. What are the sources, concentrations and atmospheric deposition of air pollutants that could impact human health or ecosystem functions or cause odour?

In order to determine if air quality or deposition are negatively impacting human health or ecosystem functions or causing odours, analysis in addition to core long-term monitoring (Sections 3.1 and 3.2) is often needed. Air quality issues may arise due to both anthropogenic (e.g., stacks in industrial facilities, vehicular exhaust) and natural sources of air emission (e.g., forest fires). Issues may be identified by comparing ambient air quality or deposition to established benchmarks (Question #1), by assessing long-term trends (Question #3), by predicting future air quality (Question #4), by evaluating emissions inventories and projected development, or by observing suspected impacts on human health or ecosystems. Comprehensive understanding of an air quality or deposition issue and cumulative effects may require further investigation through focused studies (Section 4) and collaboration with human health and ecosystem function experts.

In addition to focused study investigations, near real-time reporting and data collection can be used to inform the public and decision makers during episodes of poor air quality. The Air Quality Health Index (AQHI) is recognized in the 5-year Monitoring Plan as a key reporting tool to inform the public about human health risk(s) related to poor air quality. Minimum monitoring requirements for core long-term air monitoring stations (Section 3.1) with population centres are identified to support AQHI reporting. Additionally, wildfire smoke is identified as a significant issue and additional monitoring may be needed to measure particulate matter or other health-related parameters during smoke events (Section 6.1).

3. Have spatial patterns or absolute concentrations of air pollutants and deposition changed over time and how does this relate to factors such as changes in emissions and climate?

Long-term monitoring (Sections 3.1 and 3.2) and appropriate spatial coverage is required to understand how air quality varies across the province. Trend analyses can be used to identify significant air quality issues that require further investigation(s). Furthermore, past air quality can be assessed in the context of other factors, such as known changes in emissions and past meteorological conditions, in order to understand causes of air quality issues. The evaluation of the core long-term air quality and deposition networks through the 5-year Monitoring Plan identifies and prioritizes gaps in monitoring that could be filled to provide a more comprehensive data set of air quality and deposition in the province. Complementary air monitoring (Section 5) described in the plan may also be used to assess spatial and temporal variations of air quality and deposition.

4. How will air quality and its effects on human and ecosystem function change in the future under various emission scenarios?

Future air quality and deposition can be predicted using models with estimates of air emission scenarios. Air emission scenarios could include a range of possibilities. In some scenarios, emissions may decrease in the future due to wide-spread adoption of air management or alternative technologies. In other emission scenarios they may increase if an area of the province undergoes rapid development. Modelling studies are not identified in the 5-year Monitoring Plan. However, modelling studies may be initiated if needed as part of the exploration of focused studies or the significant issues identified in the plan. The air monitoring network (Sections 3, 4, and 5) should be designed so that it can support air modelling studies by providing air monitoring data with sufficient data quality and spatial/temporal sampling to evaluate model performance.

3 Long-term Air and Atmospheric Deposition

Long-term air and deposition monitoring is monitoring that has been or is planned to be in place for longer than five years. Such monitoring makes up the core provincial air and deposition monitoring network (Figure 3) and addresses at least one of the monitoring questions discussed in Section 2. The monitoring instrumentation at each station meets performance requirements, operation protocols, and is audited as outlined in the AMD. This section describes the evaluation of the long-term air and deposition monitoring networks. Existing monitoring stations are classified and assigned monitoring objective(s). A gap analysis is also conducted to prioritize additional monitoring sites that could be added to fill gaps in the monitoring network.

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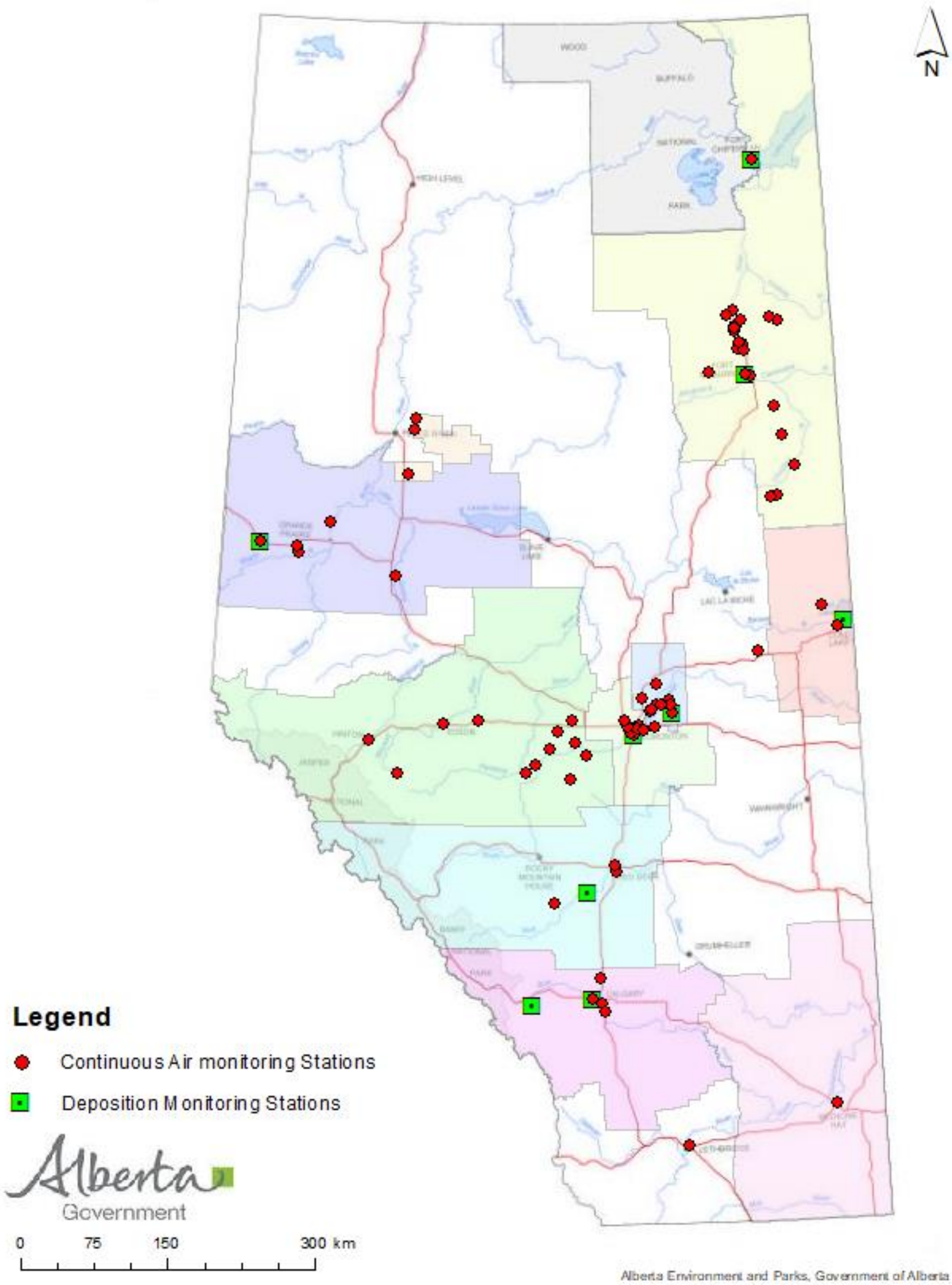

Figure 3: Long-term air and deposition monitoring; Airshed organization boundaries are indicated by the shaded areas

3.1 Evaluation of the Air Quality Monitoring Network

3.1.1 Current Air Quality Monitoring

Currently, the Alberta core long-term air monitoring includes continuous air monitoring. Additional information on air quality is also collected by complementary monitoring (Section 5). A continuous air monitoring station is a monitoring site equipped with continuous analyzers. Continuous analyzers are widely used and well understood, and therefore, the data are used for a variety of purposes, including: (i) reporting for the CAAQS and LUF AQMFs; (ii) analysis of long-term trends for condition of the environment reporting; and (iii) investigation of specific air quality questions as part of focused studies. Therefore, the data collected by the core long-term air monitoring network are used to address Monitoring Questions #1, #2 and #3 of this Plan (Section 2).

As of April 2018, there are 73 continuous stations in the core long-term network: 66 of these stations are operated by Airshed organizations and seven are operated by the provincial government. As illustrated in Figure 3, the current core long-term monitoring stations are clustered in selected areas of the province, typically within Airshed boundaries.

Continuous air monitoring is conducted using on-site calibrated instrumentation. This form of monitoring involves drawing air at a constant rate into an instrument that is designed to measure a specific air pollutant or set of air pollutants. Concentrations of pollutants measured using continuous monitoring instrumentation can be averaged to a desired frequency (e.g., 5-minute or hourly) for storage and dissemination. Air parameters that are routinely measured using continuous monitoring instruments include: mass of fine particulate matter ($PM_{2.5}$; particles smaller than 2.5 µm in diameter), ammonia (NH_3), carbon monoxide (CO), hydrogen sulphide (H_2S), nitric oxide (NO), nitrogen dioxide (NO_2), oxides of nitrogen (NO_X; the sum of NO and NO_2), ozone (O_3), sulphur dioxide (SO_2), total reduced sulphur (TRS), total hydrocarbons (THC), non-methane hydrocarbons (NMHC), and methane (CH_4). Other air parameters such as carbon dioxide (CO_2), some speciated hydrocarbons and some speciated sulphur compounds can also be monitored using continuous monitoring methods, although these are not typically monitored at core long-term continuous stations. Meteorological parameters (e.g., wind speed and direction, relative humidity (RH), and air temperature) are routinely co-located with continuous monitoring instruments. There are various makes and models of continuous monitoring instrumentation with varying detection limits and operating ranges. The AMD outlines the minimal requirements for equipment technical specifications (Alberta Environment and Parks, 2016a).

The data collected using continuous monitoring has a high temporal resolution and are most often used to assess current conditions and trends. Real-time data from some continuous monitoring stations are used to inform the public on current conditions through the AQHI. Air quality data from all core long-term monitoring sites undergo a full quality control and assurance process (Alberta Environment and Parks, 2016a) and can be downloaded by the public at http://airdata.alberta.ca.

In the future, additional monitoring technologies and monitoring sites may be incorporated into the long-term air monitoring network. However, the monitoring technologies must meet data quality requirements for their intended purpose(s).

3.1.2 Station Classification Types

As part of the 5-year Monitoring Plan, all existing long-term air monitoring stations were assigned a station classification. Furthermore, the station classification criteria were used to identify gaps in the network for various station classes. The station classification outlines the purpose of monitoring (i.e., the monitoring objective) and informs the type of monitoring and minimum parameters needed. Additionally, station classification can inform the appropriate use and reporting of data collected at the station. For example, data collected near a large industrial facility (i.e., near fence line) should not be used to infer air quality within a broader region of the province. Although some Airshed organizations have developed localized classification systems for monitoring stations within their jurisdictions, there has not been a single provincial classification system for long-term air monitoring.

Therefore, a station classification system was developed, based on the proximity of a station to air emission sources and communities, as well as the regional air-mass characteristics in the monitoring area. These station classifications and associated primary monitoring objectives are summarized in Table 1 and are described in the subsections below. Suggested reporting uses and parameters to be monitored for each station class are given in Table 2. Note that the parameters listed represent the minimum parameters to be monitored. In order to prevent all monitoring stations from being limited to minimum required monitoring, provincial super sites will be identified where extended suites of compounds are monitored, as discussed in Section 3.1.4.2. In addition to the primary objectives the monitoring network should be designed to support air quality modelling. This includes ensuring monitoring is not restricted to one type of environment and includes representative regional monitoring stations.

Table 1: Monitoring objectives by station classification

Type	Classification	Primary Monitoring Objective
Community	Large Population Centre	To report on indicators[1] and trends in air quality within a large population centre (≥50,000 people), with a focus on human health.
Community	Impacted Community	To report on indicators[1] and trends in air quality within a smaller population centre located near industrial operation(s), with a focus on human health.
Community	Small Community	To report on indicators[1] and trends in air quality within a smaller population centre that is not influenced by industry, with a focus on human health.
Near Industry	Near Fence	To provide data for air quality surveillance and regulatory assurance near an industrial emissions source.
Regional	Background	To report on indicators[1] and trends in air quality at locations that are not influenced by local anthropogenic emissions sources. These data can be used to assess background air quality conditions and to evaluate contributions from long-range/transboundary transport.

[1] Examples of indicators include the Air Quality Health Index and benchmarks reported through the Canadian Ambient Air Quality Standards and Land-use Framework Regional Plans

Type	Classification	Primary Monitoring Objective
Regional	Hot Spot	To report on indicators[1] and trends in air quality at locations that are downwind of large emissions sources, such as urban centres and large industrial areas. These data can be used to assess the cumulative effects of multiple and varied sources.
Regional	Intermediate	To report on indicators[1] and trends in air quality at locations that are regionally representative, but that are not at regional background levels. These data can be used to evaluate the transport and transformation of emitted pollutants.

Table 2: Station classifications, reporting products and minimum list of parameters to be monitored

Classification	Possible Routine Reporting Products	Minimum Parameters to be Monitored
Large Population Centre	AQHI, SOE, CAAQS, LUF	$PM_{2.5}$ mass, NO, NO_2, O_3, wind speed, wind direction, RH, temperature
Impacted Community	AQHI, SOE, CAAQS, LUF	$PM_{2.5}$ mass, NO, NO_2, O_3, wind speed, wind direction, RH, temperature, and pollutants emitted in large quantities by nearby industry (e.g., SO_2, NMHC)
Small Community	AQHI, SOE, CAAQS, LUF	Based on local monitoring need
Near Fence	Industry-specific LUF triggers/limits	As required to satisfy any ambient monitoring requirements in an EPEA approval
Hot Spot	SOE, CAAQS, LUF	Dependent on nearby emissions and other monitoring within the same Hot Spot region
Intermediate	SOE, CAAQS, LUF	Dependent on nearby emissions and other monitoring within the same region
Background	SOE, LUF	To be determined

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3.1.2.1 Community Monitoring: Monitoring within Large Population Centre, Impacted Community, and Small Community

The primary monitoring objective for all community monitoring stations is to report on indicators and trends in air quality, with a focus on human health. The minimum parameters required at community monitoring stations are $PM_{2.5}$, NO_x, and O_3 due to their ubiquity and potential for health effects at relevant ambient concentrations. Furthermore, these parameters are required to report on the AQHI[2], which is used to inform the public about the health risks of current air quality. In addition, specific pollutants that are emitted from nearby industry, such as SO_2, should be measured, if applicable. As part of Monitoring Question #1, these stations should measure parameters that are used for LUF and CAAQS reporting that have anthropogenic sources or precursors in the area. When new stations are deployed, effort should be made to locate community stations such that the data collected is representative of the largest possible geographic area within the community.

Three types of community monitoring station classes are defined: Large Population Centre, Impacted Community, and Small Community. A Large Population Centre (as defined in Section 3.1.4.1) may be affected by many emissions sources, including fossil fuel combustion, the use of motor vehicles and home heating. These stations may also be impacted by industrial emissions. An Impacted Community is a smaller community (as defined in Section 3.1.4.1) that is potentially affected by nearby industrial emissions (as defined in Section 3.1.4.1) and/or is within an area that is affected by cumulative anthropogenic (urban and/or industrial) emissions (Hot Spot areas as defined in Section 3.1.2.3). The Small Community classification is for monitoring within a smaller community (population less than 50,000 people) that is not identified as potentially affected by nearby industrial and/or is not in an area that is affected by cumulative anthropogenic emissions as classified within this 5-year Monitoring Plan (Section 3.1.4). Small Community monitoring may be deployed to meet local monitoring need(s) not identified in the current provincial level evaluation.

3.1.2.2 Near Fence Monitoring

Near Fence monitoring stations are near an industrial facility and are outside of population centres. They are intended to monitor ambient conditions in areas adjacent to industrial operations as part of the regulatory system. Data from these stations are compared against Alberta's Ambient Air Quality Objectives (Monitoring Question 1) and can be used to track changes to ambient air concentrations related to changes in industrial emissions (Monitoring Question 3). Additionally, data from these stations may identify significant air quality issues through LUF reporting (Monitoring Question #1). The parameters monitored at these stations are tailored to the substances emitted at the facility, and the data collected are routinely used for compliance purposes (Section 5.2). Although recognized within the 5-year Monitoring Plan, evaluating near fence compliance monitoring is not within the scope of the plan.

3.1.2.3 Regional Monitoring: Background, Intermediate, and Hot Spot

Regional monitoring is used to characterize and monitor pollutant concentrations in regions with relatively homogenous air masses. Data collected at regional monitoring stations may be used to understand the spatial extent of air quality issues identified in Community monitoring and/or Near Fence monitoring and to

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[2] If data are available at a given station, carbon monoxide, SO_2, total reduced sulphur, and/or hydrogen sulphide can also be included in the calculation of the AQHI.

identify episodes of long-range or transboundary transport. Strategic placement of regional monitoring may also inform air quality experienced by rural and dispersed populations and ecosystems.

Three main classifications for regional monitoring stations were defined: Background, Intermediate, and Hot Spot. The method used to classify areas of the province into these regions is described in Section 3.1.3.3. Background stations are in regions outside of population centres that are not affected by local anthropogenic emissions. Data collected at Background stations may be used as baseline comparisons to monitoring in other areas of the province. Hot Spot stations are located in regions outside of population centres, are not classified as Near Fence monitoring, but are downwind of large emissions sources, such as urban centres or large industrial areas. These stations expected to measure high concentrations of the primary air pollutants. Data collected at Hot Spot stations may be used to study the collective impact of densely distributed emissions sources. Intermediate stations are in regions outside of population centres with concentrations of air pollutants that fall between that measured in Background and Hot Spot regions. Air mass in the intermediate region is expected to have undergone atmospheric transformation as a result monitoring in intermediate regions may help to understand the formation of secondary pollutants. Monitoring in intermediate regions may also be used for baseline comparisons against concentrations measured at stations in the same region that are affected by localized sources. The minimum monitoring requirements for classified Intermediate and Hot Spot stations are dependent on nearby emissions and other monitoring within the same region. Additional work is needed to determine the minimum monitoring for Background stations (Implementation Item 3:9).

3.1.3 Data sets used in the Station Classification and Gap Analysis

In order to classify existing stations and to identify gaps in the monitoring network, datasets of municipal boundaries and population, industry emissions, ambient air pollutant concentrations from an atmospheric chemical model and satellite were used. This section describes these datasets.

3.1.3.1 Municipal Boundaries and Population

The Municipal Census for 2016, obtained from Alberta Municipal Affairs (Government of Alberta, 2017) was used to identify population size and the boundary coordinates of communities. The data set contains census information of 400 communities including 8 Métis and 48 First Nations communities. Census for some urban service areas, such as Fort McMurray and Sherwood Park were not available from Alberta Municipal Affairs and therefore populations from the community's websites were used. For the purpose of this 5-year Monitoring Plan, a population of 500 was assigned for settlements and 50 for localities and hamlets where no census information was available. In the cases where the boundaries of communities were unavailable, typically for small population centres such as hamlets, a 1 km radius from the central location of the community was used to mark the community boundary. Communities were categorized into large and small population centres using criteria that is comparable to the National Air Pollution Surveillance (NAPS) monitoring station classification for population neighbourhoods and appropriate for Alberta.

3.1.3.2 Industrial Emissions

Areas of potential industry impact were identified using emissions data from 2015 National Pollutant Release Inventory (NPRI) (Environment and Climate Change Canada, 2015). A facility was categorized as a "large industry" if the sum of emissions of SO_2, NO_2, volatile organic compounds (VOCs) and particulate matter exceeded 1000 tonnes/year. Particulate matter emissions were determined using the largest of the emissions for $PM_{2.5}$, PM_{10} (particles no bigger than 10 µm in diameter) or total suspended particulate matter. All other facilities that reported to the NPRI were categorized as "small industry". Around each facility, a

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potential impact area with a radius of 10 km was identified for large industry and 5 km for small industry. The area of potential industry impact does not consider factors that affect dispersion of emissions (e.g., facility design, terrain, prevailing winds). The 5 km and 10 km buffers are intended to be a rough estimate for identifying potential areas of impact for the purpose of this 5-year Monitoring Plan. Figure 4A shows an example of a community boundary and the areas impacted by nearby small and large NPRI sources. For each community intercepted by industrial impact area(s), the cumulative emission of all intercepting facilities was associated with the community.

3.1.3.3 Ambient Air Pollutant Concentrations

In addition to industrial emissions within the impact area, a community may also be affected by emissions from an upwind urban centre or industrialized area. In order to assess this, modelled and satellite inferred ambient concentrations of selected pollutants within population centres were used to estimate ambient air quality in communities with no existing monitoring. The Global Environmental Multi-Scale Modelling Air Quality and Chemistry (GEM-MACH) model predicted annual averages of NO_x and SO_2 provided by Environment and Climate Change Canada (ECCC), used an amalgam of the best available emissions information as of the fall of 2013 and meteorology for the period of October 1, 2013 to September 30, 2014. The results were provided with a 2.5 × 2.5 km resolution. Note that GEM-MACH annual average NO_x and SO_2 were compared with surface air monitoring data and were found to be adequately representative of the spatial variation of air quality across Alberta, despite some systematic biases. As indicated in Section 6.3, NH_3 is identified as a significant air quality issue. Ambient NH_3 concentrations estimated using satellite data averaged onto a 15 x 15 km grid for the 2013 North American warm season (April-September) (Kharol et al., 2017), was provided by ECCC. For the 5-year Monitoring Plan, data were re-averaged onto a 30 x 30 km grid in order to remove gaps in the data set. Within communities with no existing monitoring, the area weighted average modelled concentrations of NO_x and SO_2, and satellite NH_3 were calculated for all grid-points that fall within or partially within the community boundary, as shown in Figure 4B for NO_x in Camrose.

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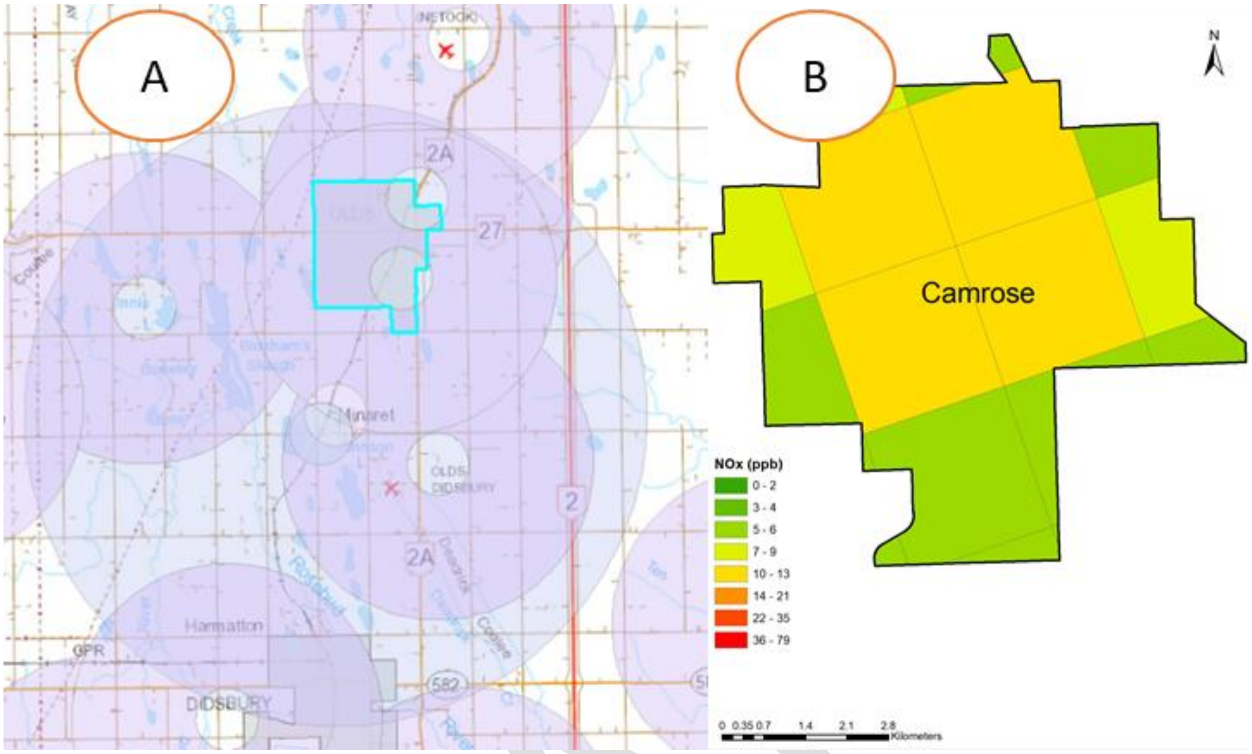

Figure 4: Defining data sets used in station classification and gap analysis; **(A) Potential industry impact areas (purple) for multiple industries, with the municipal boundary of Olds (blue polygon); (B) Modelled annual average of ambient NO_x within the municipal boundary of Camrose**

Additionally, the GEM-MACH model predicted annual average NO_x and SO_2 concentrations were used to partition the province into areas of comparable regional air masses. Five monitoring regions were identified and associated with regional monitoring discussed in Section 3.1.2. First, predicted NO_x and SO_2 concentrations were reclassified into a score of 1 to 10 using the geometric interval classification in a Geographic Information System (ArcGIS). To reduce small scale spatial variability, the resulting scores were smoothed by taking the median value of neighbouring pixels within a rectangle of 10 by 10 cells (25 x 25 km) with the focal statistics tool in ArcGIS. The smoothing process removed the top four scores for SO_2 and the top two scores for NO_x. The smoothed scores of NO_x and SO_2 were combined by taking the higher score of the two pollutants for a particular pixel location. The resulting scores of 1 to 8 were then grouped into five regions: Background (score = 1), Intermediate class I (score = 2, 3), Intermediate class II (score = 4), Intermediate class III (score = 5) and Hot Spot (score = 6, 7 and 8). Figure 5 illustrates the identified regions. This initial identification of air quality regions is conducted using two well parameterized emitted pollutants, SO_2 and NO_x. Future network assessments should include other substances, keeping in mind the limitations of atmospheric models predicted and/or satellite data inferred concentrations.

Implementation Item 3:1 Reassess areas for regional monitoring considering other relevant pollutant concentrations in addition to NO_x and SO_2.

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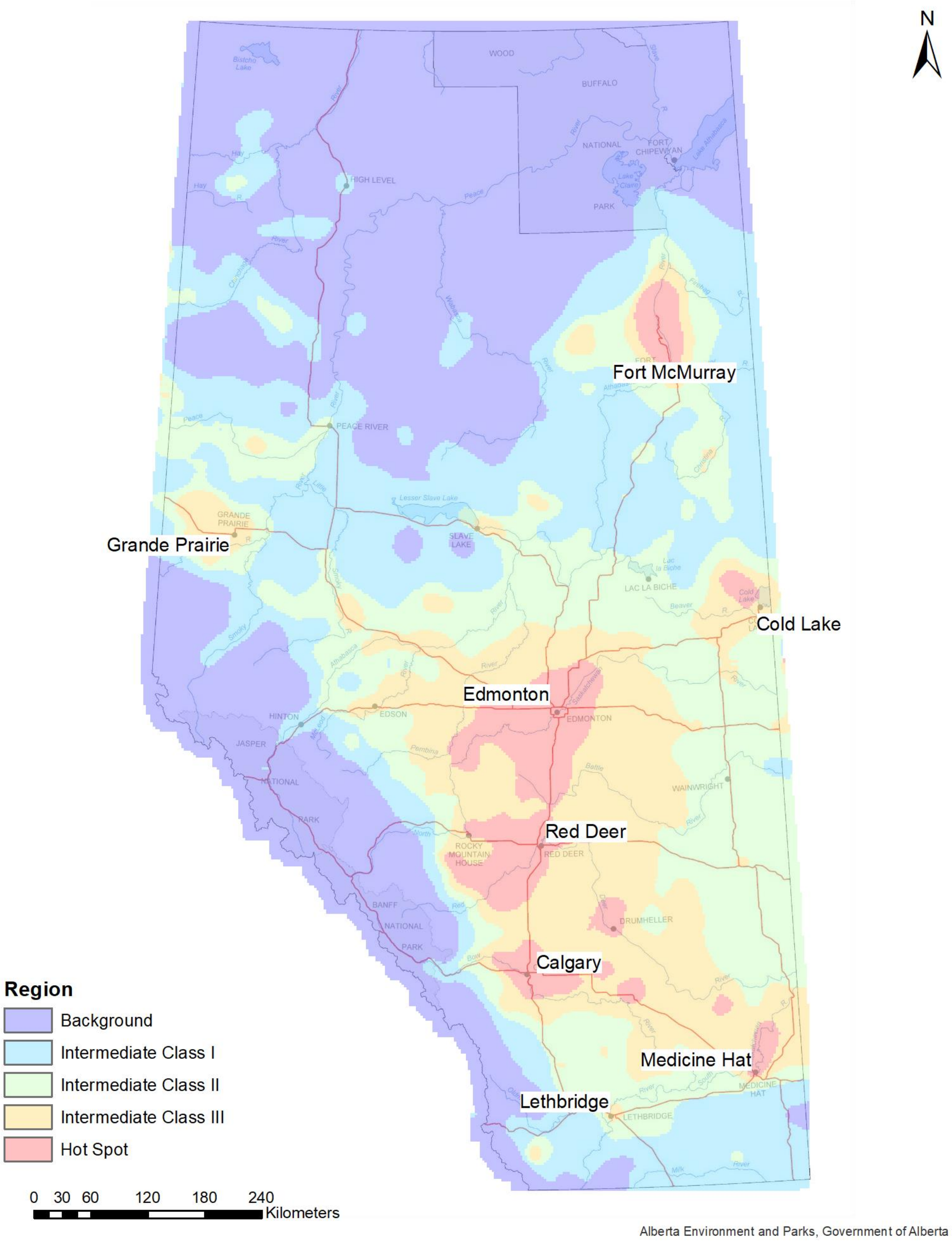

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Figure 5: Regional monitoring areas based on modelled NO_x and SO_2 concentrations

3.1.4 Classification of Existing Air Monitoring Stations

3.1.4.1 Method

Classification of existing stations was performed using two steps. First, data were classified using ArcGIS. Then, the classification results were adjusted based on local knowledge provided by Airshed and station operators. Adjustments were further verified by examining routine reporting products that use data from the stations (Section 7.4.1).

The ArcGIS classification was based on an analysis of the station location relative to population centre(s), emission sources, and model predicted ambient air concentrations. A general overview of the workflow is illustrated in Figure 6. The datasets used to identify population and municipal boundaries, areas of potential industrial impact, and regional air masses are described in Section 3.1.3. Only existing continuous air monitoring stations that report to Alberta's Ambient Air Quality Data Warehouse (http://airdata.alberta.ca) as of January 2018 were included in the classification.

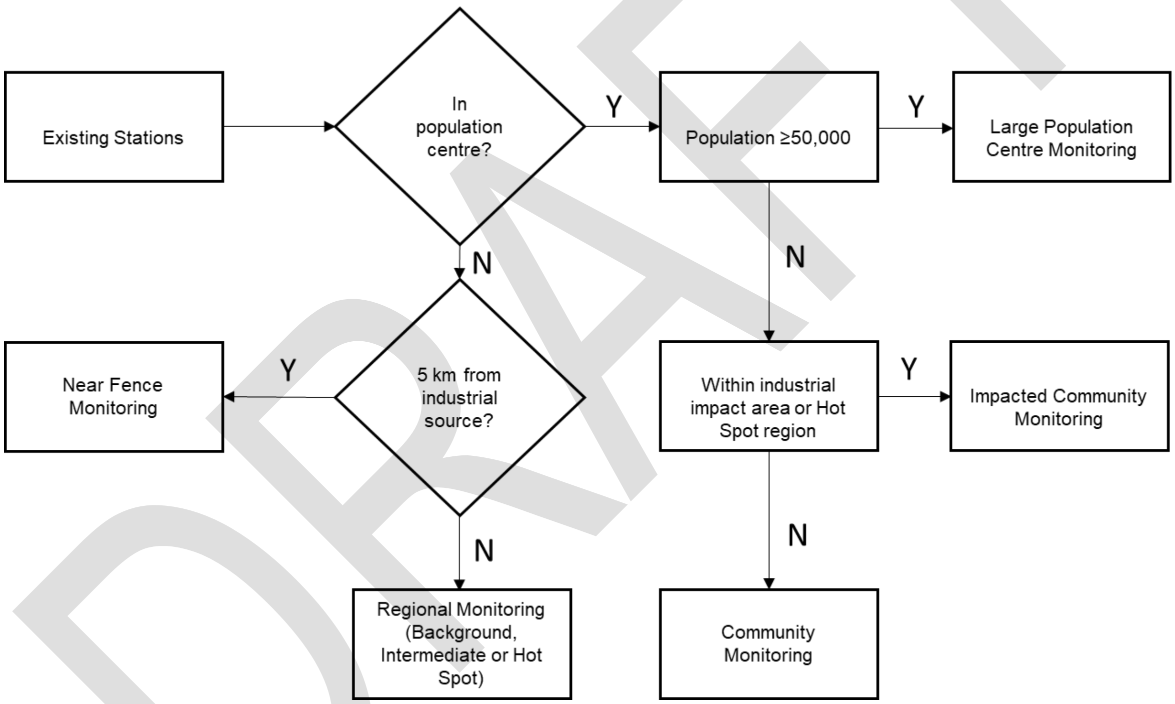

Figure 6: Workflow for station classification

If a station is located within a population centre boundary or within 1 km the boundary, it is classified as Community monitoring. If the population centre has a population of 50,000 or more, the station is sub-classified as monitoring within a Large Population Centre. If the station is located within the boundary of a community with 500 or more people but less than 50,000 people, and the population centre is within an area of potential industrial impact or within a region identified as Hot Spot (as described in Section 3.1.3), the station is sub-classified as a station monitoring within an Impacted Community. If a monitoring station is located within a community with 500 or more people but less than 50,000 people, and the community is not within industrial impact area or regional Hot Spot area, the station is sub-classified as Small Community. Stations that were not within the boundary of a population centre but were within 5 km of an industry that reported emissions to NPRI were identified as Near Fence stations. However, this criterion was later found

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to be insufficient (Section 3.1.4.2) therefore during the adjustment of the station classifications based on input from stakeholders, several Near Fence stations were reclassified. Monitoring that is not located within communities nor located within 5 km of industry reporting to NPRI are classified into one of the regional areas (Background, Hot Spot, or Intermediate) based on the regional boundaries given in Figure 5. Monitoring that is in place for very specific local need and does not fall into the above provincial classification is classified as monitoring primarily for the purpose of addressing local air quality issue. Such stations monitor unique suite of parameters to understand the status of and changes in a very local air quality issue.

3.1.4.2 Classification Results

All stations in the existing network were classified using the methods described above. After the ArcGIS classification was completed, some station classifications were changed based on local knowledge and data collected at the station. For example, the population threshold for a Small Community was too high for some communities in the oil sands area. Some communities, such as Janvier, had a population less than the criterion set for a Small Community (500 people). This station was reclassified from the Intermediate Class to a Small Community based on local input. Other adjustments were related to the 5 km radius used to identify Near Fence monitoring and monitoring within a Hot Spot region. Within the oil sands region, some of the facilities span large areas and the 5 km radius from the latitude and longitude reported to NPRI was not sufficiently large to capture all Near Fence stations. Therefore some stations that were initially classified as Hot Spot or Intermediate Class were reclassified as Near Fence. Outside of the oil sands area all stations that were classified as Near Fence were found to be Small Community or Regional monitoring stations. This suggests that outside the minable oil sands region, a 5 km radius from an industrial facility was not the right criterion to identify monitoring for the purpose of air quality surveillance and regulatory assurance near industrial emissions sources. Monitoring located at the edge of a Hot Spot region (especially west of Edmonton) were reclassified to the Intermediate Class based on data collected at these sites.

Implementation Item 3:2 Revise the criteria used to identify Near Fence monitoring.

The station names as they should be used for EMSD reporting and the station classifications for all existing stations are given in Appendix A1. This classification process is used to assign a monitoring objective to existing stations (Table 1) and should be considered when interpreting and reporting on data.

Implementation Item 3:3 Station names, numbers, and classifications outlined in this plan will be finalized and used consistently in all EMSD reporting.

The number of long-term air quality stations in each class is shown in Figure 7 and the spatial distribution is presented in Figure 8. Most stations are classified as Community Monitoring. There are 20 stations classified as Large Population Centre, 13 Impacted Community stations, and 2 Small Community stations. Often multiple stations are located within a large population centre (see Appendix A1, Table A1).

Approximately 50 additional industry stations will report continuous air monitoring data to Alberta's Ambient Air Quality Data Warehouse in 2019. Further work will be needed to determine how or if these stations fit into the core long-term air monitoring network (see Section 5.4 and Implementation Item 5:5).

Regional Monitoring in Hot Spot areas are located within the Industrial Heartland near Edmonton and north of Fort McMurray (total of 8 Hot Spot stations). The highest number (11) of regional monitoring stations were in the Intermediate regions. One Background station was identified on the lee side of the Rocky Mountains. Data from this station needs to be examined to ensure that data collected and concentrations measured meet the monitoring objective assigned to this station (see Section 3.1.5 and Implementation Item 3:21). Three stations in the Peace oil sands area were classified as Local Issue monitoring. Data

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from these stations are used to better understand fugitive emissions from nearby small upstream oil and gas operations.

For each station in the core long-term network, the existing monitoring will be assessed in the context of the monitoring objectives for the station classification using the minimum parameters to be monitored for each station class provided in Table 2.

Implementation Item 3:4 Examine parameters monitored at current long-term monitoring stations and identify stations that do not meet minimum monitoring criteria for their identified classification.

Furthermore, the minimum monitoring does not capture the full suite of parameters that are useful for understanding air quality in the province. Data collected at super sites may better facilitate source apportionment, investigation of cause or increase our understanding of the formation of secondary pollutants. For example, information on parameters such as hydrocarbons and ammonia are needed to get a full picture of air quality in the province. However, these parameters are not needed at all sites. Therefore, a need to identify potential super site(s) has been identified. These potential super site(s) may be identified among the existing monitoring sites.

Implementation Item 3:5 Identify optimal location(s) and parameter(s) to be monitored at one or more provincial air monitoring super site(s).

The classification process does not identify potential redundancies or gaps in the network. Gaps are addressed in Section 3.1.5. Stations with the same classification that are in close proximity to each other should be tested for potential redundancies. Data collected at these stations as well as any local monitoring needs should be considered when testing for potential redundancies. The redundancy analysis will be informed in part by the results of a provincial hierarchical dissimilarity analysis (Soares, Makar, Aklilu, & Akingunola , 2018).

Implementation Item 3:6 Identify redundancies and extraneous monitoring within the existing air quality network.

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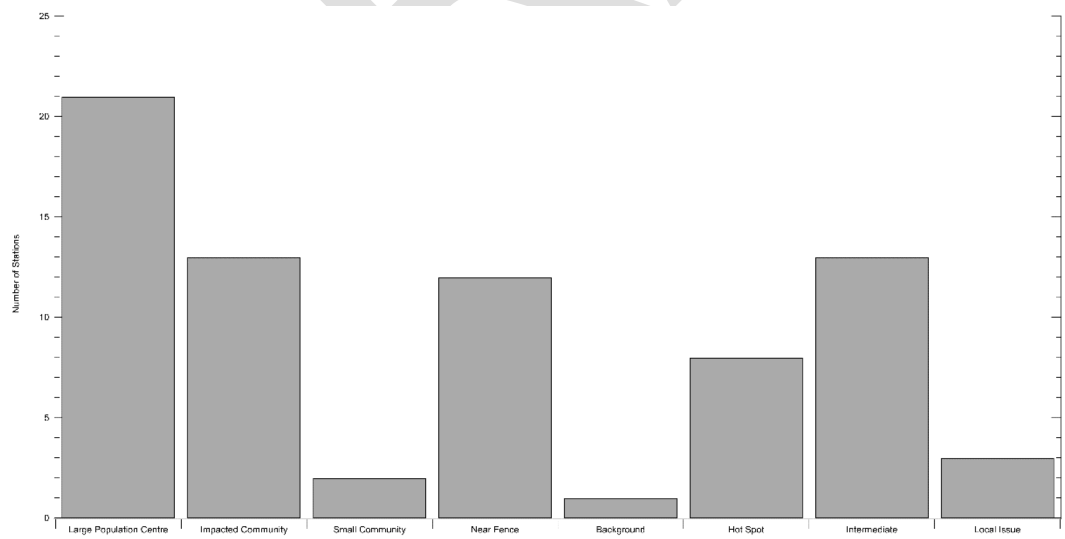

Figure 7: Number of long-term air monitoring stations in each station class; only stations reporting to Alberta's Ambient Air Quality Data Warehouse are included

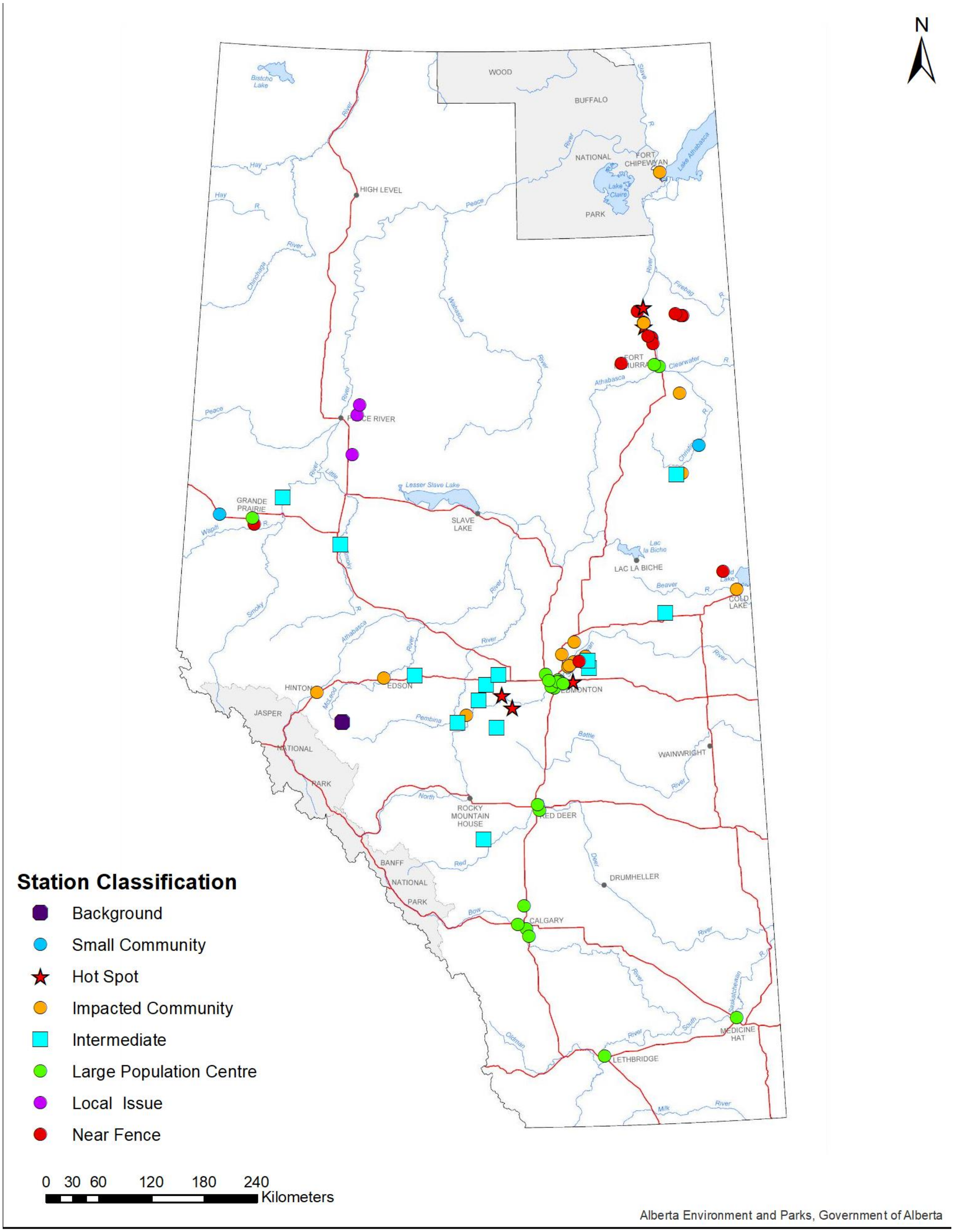

Figure 8: Spatial distribution of classified existing long-term stations

3.1.5 Gap Analysis for Long-term Air Monitoring

The spatial coverage of the current long-term air monitoring is concentrated in central and northeastern Alberta, as is evident in Figure 8. Therefore, analyses were performed to identify gaps in community and regional monitoring.

3.1.5.1 Gap Analysis for Impacted Communities

To identify gaps in community monitoring, an assessment was conducted using the same principles as the station classification process. The workflow to assess potential gaps in community air monitoring is illustrated in Figure 9.

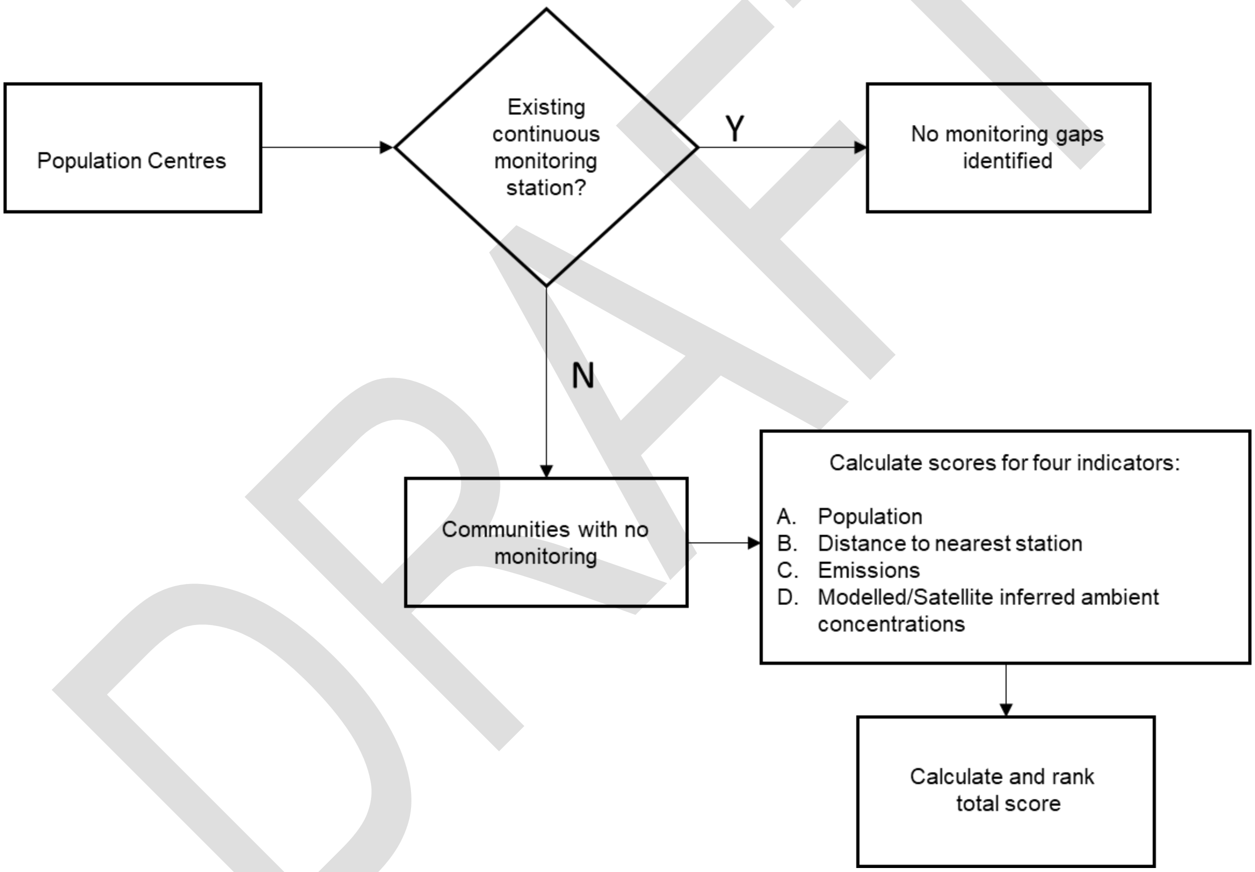

Figure 9: Work flow for community station gap analysis

The assessment was initiated by identifying communities with no existing air monitoring within 1 km of their municipal boundaries and populations greater than or equal to 500 people. For these selected communities, the following indicators were quantified:

- population size within the community;
- distance to the nearest existing monitoring station of any classification;
- industry emissions impacting the community; and

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- modelled and satellite inferred ambient concentrations within the community.

The data used to quantify the indicators are described in Section 3.1.3. The datasets for each indicator were transformed to a common scale (a score) by reclassifying the values on a scale of 1 to 10, using the geometric interval function in GIS. A value of 10 indicates a large need for additional monitoring with respect to that indicator. For example, for the population size indicator, the populations of all communities considered in the gap analysis were reclassified to scores of 1 to 10, where 10 represents the communities with larger population and 1 represents the communities with smaller population. The same approach was used for the distance to nearest existing monitoring station and industry emissions indicators. For the ambient concentrations, scores of 1 to 10 were calculated separately for NO_x, SO_2, and NH_3, using geometric interval classification. The average score for SO_2, NO_x and NH_3 formed the ambient concentration score for each community.

The total score for each community was the sum of scores for population size, distance to nearest station, emissions, and ambient concentration. The total score was used to rank the monitoring need for each community with no monitoring, with the highest total score indicating the community most in need of monitoring.

The top ten impacted communities with no existing monitoring are given in Table 3; a full list is included in Appendix A2. All large population centres (≥ 50,000 people) currently have monitoring stations and therefore no gaps were identified for this sub-classification. The top five identified potential gaps are: (1) Lloydminster, (2) Cochrane, (3) Brooks, (4) Camrose, and (5) Olds and High Level.

Table 3: Ten highest ranked impacted communities in the gap analysis

Rank	Community	Scores for Indicator[3]				Total Score[4]
		A	B	C	D	
1	Lloydminster	9	8	7	5	29.0
2	Cochrane	9	3	8	8.3	28.3
3	Brooks	8	7	6	6.7	27.7
4	Camrose	9	6	6	6.3	27.3
5	Olds	7	4	8	8.0	27.0
5	High Level	5	10	9	3.0	27.0
7	Whitecourt	7	5	8	6.3	26.3
8	Forestburg	2	8	10	6.0	26.0
9	High River	8	4	7	6.3	25.3
10	Leduc	10	3	5	7.0	25.0
10	Drumheller	7	7	6	5.0	25.0

The current evaluation used long-term monitoring sites in Alberta that operate year round. Seasonal or rotational monitoring through the use of portable or temporary monitoring or regulatory monitoring operated by industry may exist in some areas. In other cases, data from air monitoring in a neighboring province may

[3] A. Population size; B. Distance to nearest station; C. Emissions; D. Modelled/Satellite ambient inferred concentrations

[4] Larger scores mean higher priority for monitoring. The maximum possible total score is 40.

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be used to meet the monitoring need for an area in Alberta. Therefore, further investigation is required to determine whether there is existing monitoring in the area that meets the impacted community monitoring objectives or can be adapted to meet monitoring objectives.

Implementation Item 3:7 For the top five gaps in community monitoring, examine if there is existing or planned complementary monitoring that meets the community monitoring objective.

3.1.5.2 Gap Analysis for Regional Monitoring

Potential gaps in Regional Monitoring have been qualitatively identified based on the distribution of existing stations and regional air masses (Figure 10). Most of the existing Regional air monitoring stations are located in the Athabasca minable oil sands area and in the industrial areas to the east and west of Edmonton, which have large and/or diverse emissions.

Currently, there is one Background monitoring station in west-central Alberta. However an additional and/or more appropriate Background monitoring station may be needed in northwestern Alberta. Data collected at the current Background station (Steeper) should be evaluated to assess the adequacy of the current background monitoring in the province. Furthermore, data requirements for sampling frequency, detection limits, and parameters monitored should be determined for the Background station(s).

Implementation Item 3:8 Evaluate the need, possible monitoring sites, and data requirements for additional Background regional monitoring in northwestern Alberta.

There are spatial gaps in Regional Monitoring in southern Alberta and in central Alberta east of the Edmonton-Calgary corridor. Additional monitoring in these areas could include Hot Spot regional monitoring in areas affected by large emission sources and representative Intermediate regional monitoring in areas currently with no monitoring. Further evaluation of regional monitoring needs is required to identify the optimal monitoring network and monitoring platform to be used for regional air quality monitoring. This will include an evaluation of data requirements including sampling frequency, detection limits, and parameters monitored.

Implementation Item 3:9 Evaluate the need, possible monitoring sites, and data requirements for additional Intermediate and Hot Spot regional monitoring in southern and central Alberta.

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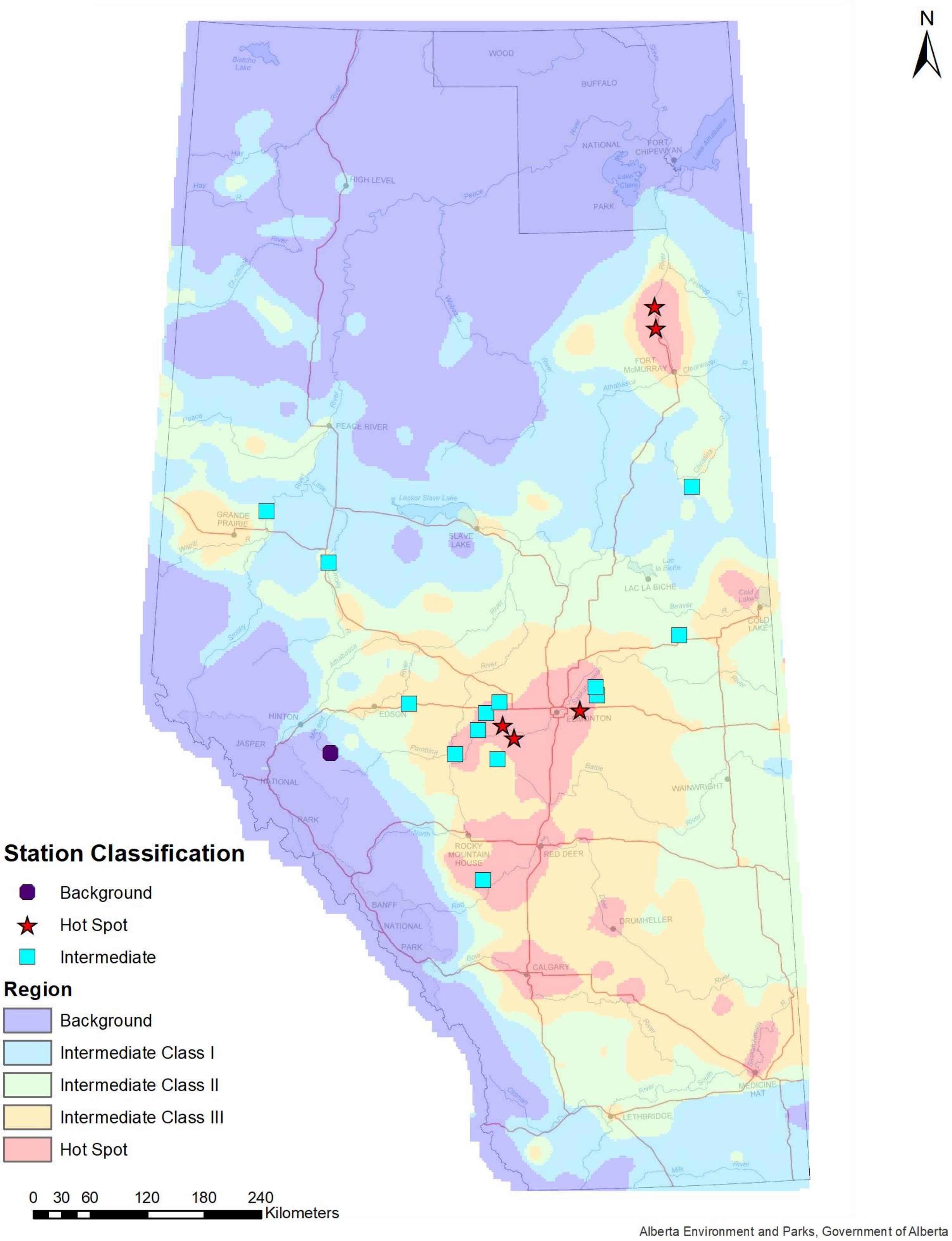

Figure 10: Location of current regional air monitoring. A number of stations initially identified as Hot Spot monitoring west of Edmonton were reclassified as Intermediate monitoring.

3.1.6 Implementing Changes to the Long-term Air Monitoring Network

As indicated in Sections 3.1.4 and 3.1.5, changes to the long-term air monitoring network will be informed by additional work in the following areas:

- Identification of stations with insufficient monitoring for their classification (Implementation Item 3:4);
- Evaluation of monitoring redundancies (Implementation Item 3:6);
- Verification of monitoring gaps (Implementation Item 3:7, Implementation Item 3:8 and Implementation Item 3:9); and
- Determination of the need for super site(s) and background site(s) (Implementation Item 3:5 and Implementation Item 3:8.

In Alberta, long-term air monitoring is delivered through a distributed model, and as such, EMSD will work with partners when assessing for redundant monitoring and verifying monitoring gaps. Potential gaps in impacted communities may further be prioritized in collaboration with Alberta Health and Alberta Health Services using indicators such as size and location of sensitive populations, population growth and forecasted change in land use.

Deployment of new conventional monitoring stations is resource intensive. Where possible, alternative monitoring should be considered, such as the use of existing nearby complementary monitoring, or the reallocation of low priority monitoring. For example:

- An industry monitoring station established for regulatory purposes may be transformed into an Impacted Community monitoring station;
- A redundant monitoring station may be relocated to a higher priority location in the region; or
- A well-situated existing monitoring site may be supplemented with additional monitoring equipment to create a super site.

Implementation Item 3:10 Work within the distributed air monitoring network to identify and reduce redundancies, and reallocate resources to fill gaps and implement super sites, where possible.

Furthermore, a number of jurisdictions and the scientific community are validating various cost effective monitoring platforms, some with promising results (Afshar-Mohajer et al., 2018; Ranjan et al., 2017). Based on the monitoring objective and data requirements, identified monitoring gaps may be filled by portable air monitoring platforms. Portable air monitoring platforms can have a smaller initial investment, lower maintenance costs, less energy consumption, smaller footprint, and easier deployment than traditional air monitoring stations. Portable air monitoring platforms include the Mobile and Portable Air Monitoring Laboratory (MAML and PAML), and the Airpointer, which are equipped with traditional gas analyzers that are used at long-term air monitoring stations. Portable air monitoring platforms can also include small systems that use compact air quality sensors. Portable air monitoring platforms are discussed in additional detail in Section 5.5.

Implementation Item 3:11 Review results from complementary monitoring evaluations and determine whether they can be used to address gaps in the core long-term air quality network.

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3.2 Evaluation of the Atmospheric Deposition Monitoring Network

3.2.1 Current Deposition Monitoring

The objective of the deposition monitoring network is to collect regionally representative samples that can be used to quantify the deposition of acidifying substances, base cations and nutrient nitrogen. Data collected will help address Monitoring Question #1.

Atmospheric deposition can have acute or chronic impacts on ecosystem functions. Wet and dry deposition data collected by the deposition monitoring network, in conjunction with established benchmarks such as critical loads, can be used to assess the potential impact of atmospheric deposition on ecosystems and to identify where more in depth ecosystem and deposition monitoring needs to occur.

The core long-term deposition monitoring will focus on quantifying the deposition of acidifying substances, base cations and nutrient nitrogen. Other important forms of deposition from the atmosphere include potentially toxic gases or particles that are sorbed directly by ecosystem receptors. These toxic substances can include VOCs, polycyclic aromatic compounds (PACs), and metals. Due to the heterogeneous distribution and resource intensive nature of toxic gas and particle monitoring, they may be monitored where needed through one or more focused studies (Section 4).

The current long-term deposition monitoring network consists of nine wet deposition monitoring stations (Figure 3); currently there are no dry deposition monitoring stations in the network. Dry deposition monitoring stations that were once part of the network, were discontinued due to various logistical challenges associated with site access and operation.

Equipment designed to collect samples during precipitation events are used at the wet deposition monitoring stations. These event samples are collected over a period of seven days. Collected samples are shipped to a laboratory where ion chromatography is used to quantify anions and cations in samples. Anions and cations currently analyzed in precipitation samples include ammonium, calcium, chloride, magnesium, nitrate, phosphate, potassium, sodium, sulphate and H^+ (as pH). Major ions provide information on potential acidification due to atmospheric deposition, however atmospheric deposition may also contribute to eutrophication. To assess the contribution of atmospheric deposition to eutrophication networks such as the Great Lakes Precipitation Monitoring Network measure nutrients (total phosphorus and nitrogen) Total phosphorus and total nitrogen include both organic and inorganic nutrients but are not currently included in the list of analytes for the Alberta wet deposition samples. Due to the eutrophic and hypereutrophic status of many lakes in Alberta, it is important to strongly consider measuring these nutrients at existing sites to examine the impact of deposition, if any, on the eutrophication of lakes and other ecosystems. A subset of samples currently collected should be analyzed to determine the contributions of these components to nutrients in precipitation.

Implementation Item 3:12 Determine the feasibility of including total phosphorus and total nitrogen in the list of analytes for Alberta wet deposition samples to facilitate potential eutrophication assessment.

Versatile Air Pollution Samplers (VAPS) were used at historical dry deposition monitoring stations. The VAPS consists of denuder and filter trains that allow simultaneous measurements of relevant gases and particulate matter constituents. Sampling periods were equivalent to that of wet deposition (seven days). The denuder tubes and filter packs were shipped to a laboratory for analysis to quantify chemical species.

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Plans for dry deposition monitoring are discussed in Section 3.2.2 and Implementation Item 3:17. In addition to the core long-term deposition stations, there are complementary deposition monitoring stations through oil sands (Section 5.3) and regulatory monitoring (Section 5.4).

3.2.2 Assessment of Existing Deposition Monitoring Stations

Quantitative and qualitative analyses were conducted to assess the existing deposition monitoring network in Alberta. The general objective of the evaluation is to ensure that monitoring stations are appropriately located to assess the impact of atmospheric deposition on ecosystem functions.

Siting criteria from Global Atmosphere Watch Precipitation Programme (GAW), National Atmospheric Deposition Program (NADP), and Canadian Air and Precipitation Monitoring Network (CAPMoN) informed the evaluation of the current wet deposition stations. Considered criteria includes: land use within 1 km radius of the site, nearby industrial emissions and population density within a 15 km radius.

Emissions data used in the evaluation are described in Section 3.1.3. Cumulative SO_2 and NO_2 emissions within a 50 km radius of deposition monitoring is used to identify remote or potentially highly impacted sites. The census data described in Section 3.1.3 are used to determine population density within 15 km of a monitoring site used to categorize the site as either: isolated, rural or urban. This categorization was performed in accordance with NADP site classification method (NADP, 2011). Alberta Biodiversity Monitoring Institute's land cover GIS data (ABMI, 2010) are used to identify land use near a deposition monitoring station. The land cover data has 12 land classes. The polygon based map has a minimum resolution of 2 hectares. The majority land class within 1 km radius of the deposition monitoring station is used to identify the land class associated with the monitoring station. While year round access to a monitoring station is beneficial, a station location that is too close to a well-used road is likely to have local impact. In an effort to appropriately distribute deposition monitoring throughout the province, the stations location within Alberta Natural Regions (Figure B-1) were also examined. The results are listed in Table 4.

Table 4: Initial assessment of the current wet deposition monitoring stations

Stations	NPRI Emissions within 50km (tonnes/year) (NO_2+SO_2)	Population based Site Classification[5]	Land-use within 1km	Nearest Paved Access (km)	Alberta Natural Region[6]
Beaverlodge	11091	Isolated	Agriculture	0.37	Boreal
Calgary Northwest	16523	Urban	Developed	0.25	--
Cold Lake	13392	Rural	Natural	1.04	Boreal
Dickson Dam	14063	Isolated	Agriculture	0.10	Parkland
Edmonton-McIntyre	37408	Urban	Developed	0.17	--
Elk Island	38133	Isolated	Natural	0.05	Boreal
Fort Chipewyan	147.6	Isolated	Natural	0.21	Canadian Shield

[5] Based on population density within 15 km of the stations; NADP site classification

[6] Indicated for stations that were not identified as urban based on NADP site classification

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Fort McMurray-Patricia McInnes	67236	Urban	Developed	0.019	--
Kananaskis	16151	Rural	Natural	0.35	Rocky Mountain

Three wet deposition stations (Calgary Northwest, Edmonton-McIntyre and Fort McMurray-Patricia McInnes) are located within urban centres. These sites are also located in developed areas and are associated with the highest NO_2 and SO_2 emissions. The samples collected at these stations are not likely to be regionally representative. Thus, urban wet deposition stations do not provide data that can be used to answer the monitoring questions (Section 2).

Implementation Item 3:13 Discontinue wet deposition monitoring stations located in urban and suburban areas.

Similarly, Beaverlodge and Dickson Dam stations although located in isolated areas, are located within agricultural areas. Further evaluation of these stations is needed to determine if samples collected are regionally representative.

Implementation Item 3:14 Examine monitored and modelled data associated with stations located in agricultural areas to assess if these stations meet the provincial deposition monitoring objective.

Three wet deposition stations are located in the Boreal natural region, and one station is located in each of the Canadian Shield, Rocky Mountain and Parkland natural regions. There are no wet deposition monitoring stations in the Grassland and Foothills natural regions. Section 3.2.3 evaluates the extent of highly suitable deposition monitoring areas within each of the natural regions. The results provide an indication of the monitoring gap priority.

Although deposition sites are visited weekly by site operators, in order to ensure quality assurance of the network, an on-site visit by EMSD staff should be conducted frequently (every 3 years) or when there has been a significant change to a station (i.e. addition or removal of sample instrumentations, land use change in local area). Each on-site visit should verify and document the following items:

- condition, calibration and correct operation of instrumentation(s); and
- site conditions (i.e. availability of sheltered work location, reliability of power supply and description of the sample site area).

Implementation Item 3:15 Conduct on-site visit and complete site information form for all of the wet deposition monitoring stations.

In addition to collecting precipitation samples, wet deposition stations should also have an independent measure of precipitation depth, such as a standard precipitation gauge, to accurately determine the precipitation volume for the sample periods and assess the collection efficiency of the precipitation collector. Currently, precipitation depth is calculated using the sample volume and sample collector bucket diameter. The sample volume is measured when received at the laboratory. This method is not independent of sample collection: it does not allow collection efficiency evaluation of the precipitation collector and is susceptible to error if the sample volume is not fully decanted to sample bottle and shipped to the laboratory. Three stations (Beaverlodge, Elk Island, and Kananaskis) have precipitation gauges within 40 to 150 meters from the precipitation collector. Although these distances do not meet the international distance recommendations of 5 to 30 meters (World Meteorological Organization Global Atmosphere Watch, 2004 and NADP, 2014), precipitation depth measured with these nearby gauges can be used to verify the collection efficiency of the sampler at the nearby wet deposition monitoring stations. Precipitation collection

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efficiency for samples collected in 2015 and 2016 ranged from 83% to 94%. A sample with collection efficiency less than 70% would be flagged as having non-standard sampling condition. In order to identify sample completeness and calculate credible wet deposition amounts, each station needs to be equipped with a standard precipitation gauge, which will allow an independent more precise measurement of precipitation depth. Deployment of precipitation gauges should be prioritized based on the availability of nearby gauges.

Implementation Item 3:16 Deploy precipitation gauges to permit sample collection efficiency calculations and reduce uncertainty in determining precipitation depth. Deployment should be prioritized based on the availability of nearby gauges.

Wet deposition forms only a component of the total deposition. Currently, there are no active dry deposition monitoring stations within the core long-term monitoring network. The average annual total precipitation in Alberta (1971 to 2000) varies spatially and ranges from greater than 600 mm per year leeward of the rocky mountains, to less than 400 mm per year in southwestern and northwestern Alberta (Alberta Agriculture and Forestry, 2017). Historically, samples were collected to infer dry deposition at Beaverlodge and Anzac stations. Potential Acid Input from dry deposition ranged from 63% to 88% of total deposition (wet and dry deposition) at the Beaverlodge station (northwestern Alberta) between 2000-2003 (Alberta Environment, 2006). Thus, strategically co-located wet and dry deposition monitoring is needed to assess the impact of total deposition to an ecosystem.

Implementation Item 3:17 Review dry deposition monitoring methods; select and deploy suitable monitoring equipment at select sites.

3.2.3 Location Suitability Mapping and Analysis

In order to identify priority locations for deposition monitoring, spatial analysis tools (GIS) and suitability criteria were used. The use of a suitability analysis to identify desired environmental monitoring areas based on set criteria has been previously demonstrated (Ligmann-Zielinska & Jankowski, 2014; Store & Kangas, 2001). Table 5 summarizes the suitability criteria and input data. The most desirable monitoring locations have low critical loads for acidity, high atmospheric deposition of nitrogen and sulphur, and year round accessibility. The location of nine soil monitoring sites in Alberta, initiated to examine the potential impact from acidic atmospheric deposition, were also included as suitability criteria. To date, a direct linkage between deposition monitoring data and soil property data from these sites have not been made.

Table 5: Suitability analysis criteria

Criteria Type	More Suitable Criteria	Input Data
Receptor Sensitivity	Areas of low critical load	Terrestrial critical load of acidity (Aklilu, Blair, Aherne, & Dinwoodie, 2018)
Atmospheric Deposition	Areas of high deposition for nitrogen and sulphur	2010 modelled annual total deposition of nitrogen and sulphur (Makar, 2013)
Access	Balance between proximity to paved road (access) and distance from potential emission sources	Euclidian distance from all highways and paved roads
Proximity to Emissions	Areas further away from high emission density for sources of nitrogen and sulphur	Emission density of SO_2 and NO_2 from 2015 NPRI point sources

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Soil Monitoring Sites	Proximity to existing soil monitoring sites	Distance from soil sites: < 10 km most desired, 10-25 km desired and > 25 km least desired

The current assessment considers critical loads for acidification over terrestrial ecosystems. Future assessments of the long-term deposition network should also include critical loads for eutrophication, and consider both aquatic and terrestrial ecosystems, if these critical load values have been established for Alberta. Such an assessment should also consider co-location of deposition monitoring with relevant water quality monitoring sites and where possible and appropriate Regional long term air monitoring sites.

Implementation Item 3:18 Future deposition suitability assessments should include critical loads for aquatic ecosystems and for eutrophication, if available, and consider the locations of relevant water quality or Regional long term air monitoring sites.

A composite map of suitability scores for deposition monitoring is generated by combining weighted raster layers representing criteria input data. A layer (map) is created for each of the input data in Table 5. The geographical data may be represented as points (emissions in tonnes/year), lines (road) or polygons (land use). This information is then converted to gridded data in 1 km by 1 km raster files. The gridded data are reclassified to a common scale of 1 to 10, weighted according to the importance of the particular criteria, and combined into a composite map. Figure 11 shows the reclassified input layers, where red indicates the locations that rank high on the suitability scale.

Each map layer input is assigned a weighting factor based on the relative importance of the information in the overall model. The suitability score for an area is calculated using Equation 1.

$$S_i = \sum_{r=1}^{n} W_r \, L_{ir} \qquad \textbf{Equation 1}$$

where S_i is the suitability score for location i, W_r is the weight applied to the criterion, and L_{ir} is the value of criterion r at location i.

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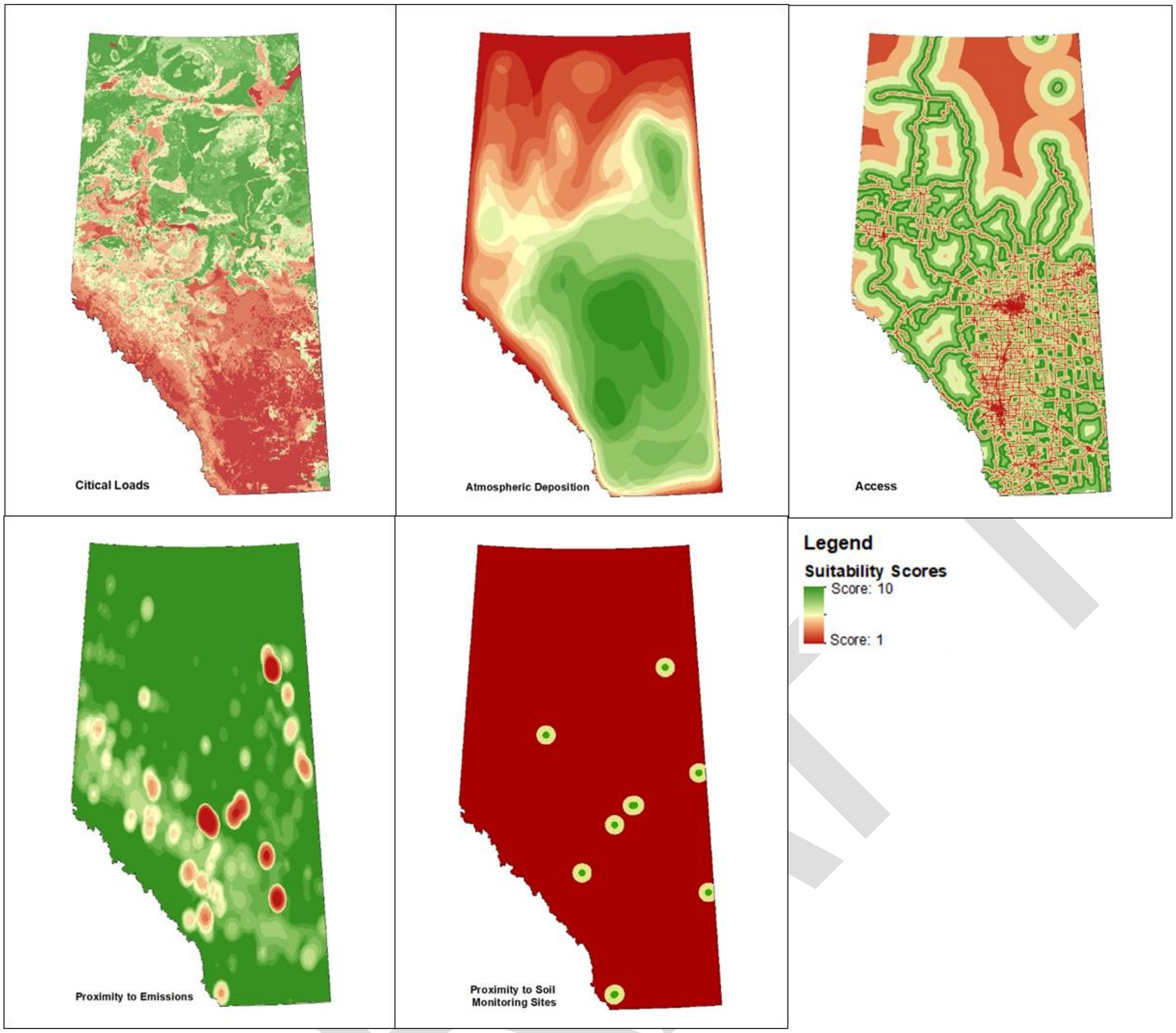

Figure 11: Classification input layer maps

Several scenarios, using different weightings (W_r in Equation 1) were tested as described in Appendix B1. The final scenario (scenario #5) included the following criteria and associated weight (in brackets): critical load for acidity (0.3), nitrogen and sulphur deposition (0.3), access (0.1), emissions (0.1), and soil monitoring sites (0.2). The total weight applied equals to 1. Table 5 provides further information on the suitability criteria.

Areas with similar suitability scores from scenario #5 are grouped into six classes of equal score intervals. Figure 12 shows a map of the results of the suitability analysis (scenario #5). The first class formed the Low Suitability areas, and include areas too close to industrial sources, areas with limited access, and large urban centres. The Deposition Monitoring Hot Spots are areas with the high suitability scores, these areas may have the low critical loads of acidity and/or high deposition. Intermediate Class I and Intermediate Class II include areas with high critical loads and/or low deposition. Intermediate Class III includes relatively low critical loads and/or moderate deposition.

The results of the suitability map were used to evaluate the locations of current monitoring and to identify monitoring gaps. Deposition monitoring to address potential impacts on ecosystems from specific nearby

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industrial sources were not considered and should be prescribed as part of regulatory monitoring (Section 5.2). Deposition monitoring should focus on areas of the province where there is relatively high atmospheric deposition coupled with ecosystems that are sensitive to deposition (within Deposition Monitoring Hot Spot area or Intermediate Class III), and should be well distributed between natural regions. However, the network should also include at least one reference or background site (within Intermediate Class I or II).

The percentage of natural region areas that fall within each classification is listed in Appendix B2. The boreal natural region has the highest percentage of Deposition Monitoring Hot Spot area, and also covers the largest area in the province. The Foothills and Parkland regions contain large Intermediate Class III areas. However there is currently no deposition monitoring in the Foothills regions; appropriate deposition monitoring sites within these regions should be explored. The Grassland region is largely classified as Intermediate Class II.

Implementation Item 3:19 Work with ecosystem and water scientists to identify appropriate deposition monitoring sites within the Grassland and Foothills natural region. Consider redeploying existing monitoring and/or reinitiating historical deposition monitoring sites in these areas.

The existing wet deposition monitoring stations were evaluated in relation to the suitability analysis. The relative area of each suitability class within a 50 km radius from a deposition monitoring location are listed in Appendix B2 .

First, it was verified that stations were outside of Low Suitability areas. This ensures that the collected wet deposition data are regionally representative and are not unduly impacted by nearby industrial air emissions. Stations that were in areas of Low Suitability were also in urban areas as identified in Section 3.2.1.

With the exception of Fort Chipewyan and Kananaskis stations, all other stations outside urban areas had at least 1% of the area as Deposition Monitoring Hot Spot. However, there is no monitoring station located within the large area of Deposition Monitoring Hot Spot between Edmonton and Fort McMurray.

Implementation Item 3:20 Work with ecosystem and water scientists to identify appropriate deposition monitoring sites and design a short term study to evaluate the deposition monitoring gap within the large Deposition Hot Spot area located between Edmonton and Fort McMurray.

Data collected at Fort Chipewyan and Kananaskis station should be compared to background monitoring in neighbouring jurisdictions (for example deposition data from CAPMoN sites in the Wood Buffalo National Park) to ensure it is not significantly impacted by a local source(s).

Implementation Item 3:21 Compare data collected at Fort Chipewyan and Kananaskis deposition stations to background deposition monitoring data in neighboring jurisdictions to ensure the station is not significantly impacted by local sources and thus can act as the provincial background deposition monitoring station.

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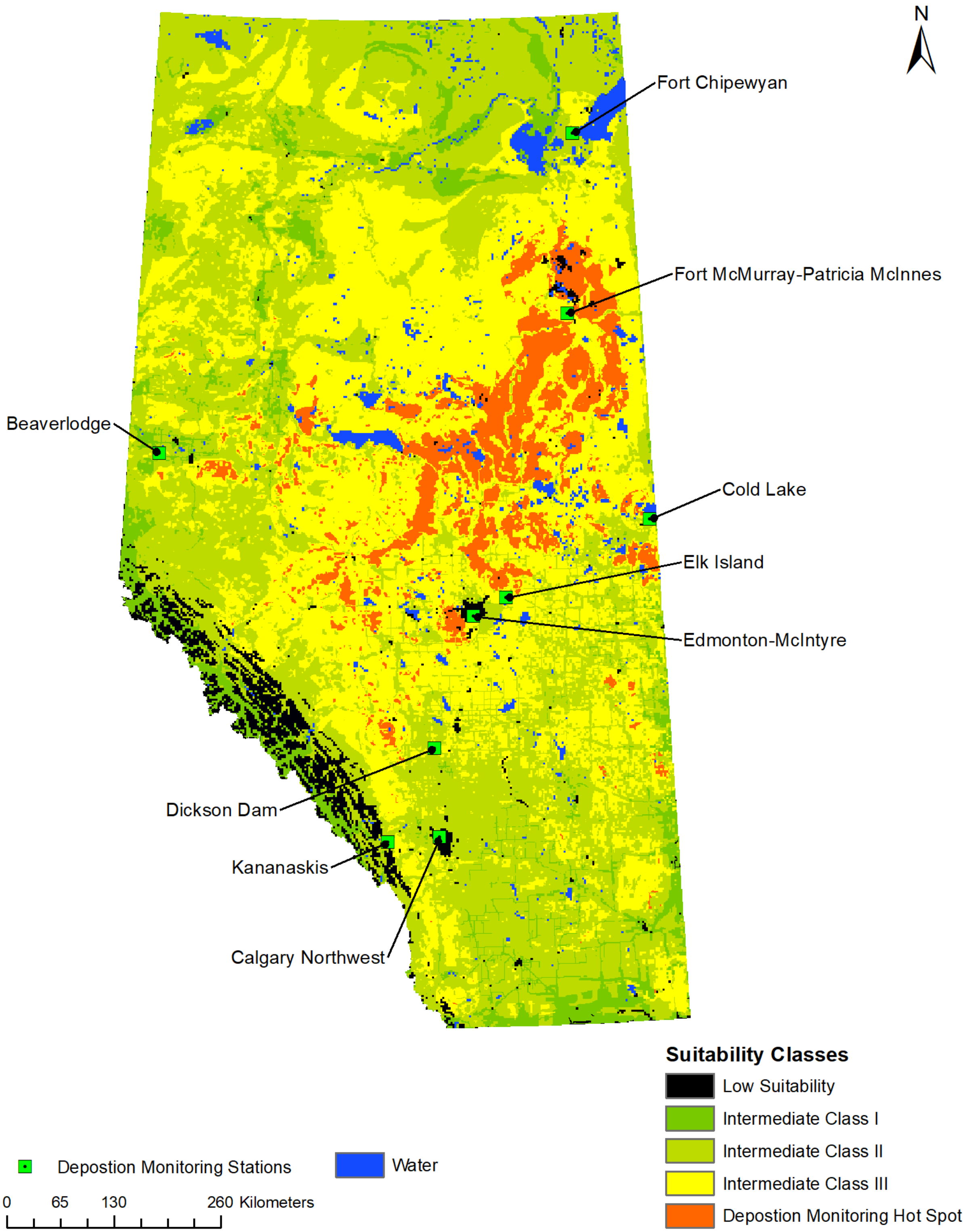

Figure 12: Suitability analysis result (Scenario #5) grouped into five classes based on score similarity

4 Focused Studies

4.1 Purpose

Focused studies are shorter-term monitoring projects (less than five years) designed to answer specific question(s) that cannot be addressed exclusively by analyzing data collected by the existing long-term monitoring program. This section describes the processes by which EMSD-led focused studies can be initiated, and is not intended to describe specific focused studies that are on-going or planned by EMSD. However, some specific focused studies that are planned to be initiated in the next five years appear in the Implementation Schedule (Section 8).

Findings from focused studies can help identify air quality management action(s) and/or guide the improvement of long-term monitoring activities in the study area. Some examples of focused studies include, but are not limited to:

(1) Monitoring to address a question(s) regarding persistent air quality or odour events specific to a community.
(2) Monitoring to identify the cause of an air quality/deposition issue(s) that has been identified by long-term monitoring. For example, investigating the cause of an exceedance of a limit or trigger defined by an air quality management framework.
(3) Evaluating alternative monitoring methods against reference monitoring methods, typically through a co-location study.
(4) Monitoring air quality or deposition to understand regional baseline conditions or the spatial extent of an identified issue. For example, monitoring of fine particulate matter upwind and downwind of a community that is approaching management plan action level under CAAQS.

For the 5-year Monitoring Plan, EMSD has developed a process to identify, prioritize, design, and deploy focused monitoring for air quality and deposition. Appendix C1 is an inventory of air quality monitoring equipment that EMSD typically deploys for focused studies.

Implementation Item 4:1 Focus studies will be identified, designed, and performed using the process described in this plan.

Focused studies that require immediate response, outside of the annual planning cycle, will not follow the process defined in this 5-year Monitoring Plan. This includes response to emergencies, such as unplanned industrial events, wildfires threatening Alberta communities or complaints received by AEP regarding local air quality issues that require immediate response. If a focused study requires immediate monitoring, the Air Monitoring manager evaluates the merit of the request, and responds accordingly. Focused studies under the Oil Sands Monitoring (OSM) program are exempt from this process.

4.2 Identification and Ranking of Information Needs

An information need is a defined gap in knowledge that prevents the understanding of and/or the ability to address an observed or suspected air quality issue. A need can be identified because of questions arising from routine data analysis, significant issues as identified through stakeholder consultation, public complaints, or repeated exceedances of an air quality objective, threshold or limit. Information needs are collected through two streams: “strategic information needs” and “technical information needs”.

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The strategic information needs are developed and prioritized by AEP senior management. Strategic information needs may include advice from the AEP Science Advisory Panel, high level information needs from other divisions of AEP or government departments, external stakeholders, and significant issues identified during evaluation of data from the long-term monitoring network. The process for capturing and ranking strategic information needs is not within the scope of this plan.

Technical information needs are detailed descriptions of specific issues or knowledge gaps. For example, a technical information need for a local air quality issue may describe the location, seasonality, and/or parameters of interest. Government of Alberta staff can submit technical information need descriptions to EMSD using the template in Appendix C2. Information needs from external stakeholders can be submitted through AEP staff who liaise directly with stakeholders. For example, when an Airshed identifies a local air quality issue, the AEP representative on the Airshed technical committee could submit the information need request to EMSD.

Technical information needs that do not require immediate resource deployments are evaluated and prioritized during the EMSD annual planning process. Project plans for the upcoming fiscal year are developed in Q3 (Oct-Dec) and evaluated by EMSD leadership in Q4 (Jan-Mar). An initial screening determines whether the study meets basic criteria for a focused study. The screening questions are:

(1) Does the project have answerable study questions?
(2) Do the study questions fall into at least one of the four monitoring questions? (Section 2)
(3) Is the subject and study area within the mandate of EMSD?
(4) Has the information need already been addressed by previous monitoring, evaluation and reporting?

Technical information needs that pass the initial screening undergo a detailed evaluation. This detailed evaluation will lead to the prioritization of focused studies that will be designed during the next fiscal year. The following list of questions form the core evaluation criteria:

A. Would answering the monitoring/science questions increase our scientific knowledge, provide information for policy development, and/or contribute to an air quality management response?
B. How much staff time and monitoring resources will be needed to answer the monitoring question?
C. Can the information need be addressed using monitoring methods available to EMSD?

4.3 Study Design, Deployment, and Reporting

Focused studies will be designed for strategic and technical information needs that are ranked as high priority. The design phase occurs during the EMSD annual project planning process. The focused study design team, which may include the person who submitted the information need, will determine the type of monitoring, data evaluation, and reporting that are required to fulfill a given information need. A list of currently available monitoring methods and equipment are listed in Appendix C1. Additional monitoring methods that may be eventually used in focused studies are being explored and evaluated (Section 5).

The monitoring method selected for a focused study will depend on the data quality objectives defined for the specific monitoring activity. Understanding data quality objectives, such as the monitoring frequency, detection limit, accuracy, and precision, are necessary to assure that the monitoring activity will address the monitoring question that is articulated at the start of the planning process.

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During the design process, the template in Appendix C3 will be used to document the various design components of the focused study. For studies that are not urgent, this information will be used to formulate and submit an official project plan to EMSD management.

Reporting on the findings of the focused study may be in the form of a summary, full technical report, peer-reviewed publication, and/or presentation slides.

5 Complementary Air Monitoring

This section describes other forms of air quality monitoring that complement the core long-term network and/or might be applicable for focused studies. Complementary air monitoring includes the existing passive monitoring networks, integrated active monitoring, as well as the emerging technologies that are planned to be investigated by EMSD over the next five years. Also, additional monitoring conducted through the OSM program and regulatory monitoring where data is not available electronically through the Alberta Air Data Warehouse, are considered complementary monitoring. In the future, some of these air monitoring networks or platforms may be included in the core long-term monitoring program. It should be noted that the separation of long-term (continuous) air monitoring and complementary air monitoring in this plan is not necessarily reflective of the usefulness or efficacy of any particular method.

5.1 Airshed Passive Sampler Network

Passive air samplers are deployed by Airshed organizations to measure select air pollutant concentrations (e.g., Bari, Curran, & Kindzierski, 2015; Hsu, 2013). At the present time, EMSD does not directly undertake passive monitoring. Passive air samplers can be used to determine spatial variation and dry deposition. They have also been deployed with the purpose of measuring long-term trends; however, as indicated by the analysis in Appendix D, the utility of the existing passive sampler datasets to detect long-term trends for some species is questionable. Nonetheless, passive air samplers are easy to deploy and operate, do not require power, and are less expensive than continuous monitors. Passive air samplers cannot be used to assess shorter-term air quality episodes as they typically provide monthly or bimonthly averages.

Passive air monitoring is an integrated technique. Air pollutants are sorbed onto a filter or other surface through atmospheric diffusion (i.e., a pump is not used to draw air through the sampling medium). After a defined period of time the sample is collected and undergoes laboratory analysis for the pollutant(s) of concern. The mass of a pollutant collected on the filter and the estimated rate of uptake are used to determine the atmospheric concentration of the pollutant. The sampling rate of the gas on the passive sampler depends on meteorological conditions, such as temperature, RH and wind speed. Air parameters routinely measured using passive samplers include NO_2, O_3, SO_2 and H_2S. Passive sampling for ammonia, nitric acid, volatile organic compounds and polycyclic aromatic compounds is also conducted in Alberta. Passive sampling is usually conducted for a longer time period (e.g., one to three months) to help reduce uncertainties in the data and improve detection limits. A detailed description of passive sampler methods is given by Bari et al. (2015) and the references therein.

Figure 13 shows a map of the passive air monitoring sites, which are deployed by Airshed organizations in order to meet local priorities. Therefore, the density of the measurements, species monitored, and monitoring methods vary across the province. For example, the Fort Air Partnership (FAP) is located in an industrial area and its network measures H_2S and SO_2, while the Calgary Region Airshed Zone (CRAZ) is located in and around Calgary so its network historically measured SO_2, NO_2 and O_3. Large portions of the province outside of Airshed boundaries are not covered by passive samplers. Most Airshed organizations use passive samplers manufactured by Maxxam Analytics (Tang, 2001), except FAP uses AGAT samplers

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for SO_2 (AGAT Laboratories Ltd., 2018) and Palliser Airshed Society (PAS) has used three different types of passive samplers since 2007[7]. Most Airshed organizations deploy passive samplers for one month, and therefore measure monthly average concentrations. However, the Wood Buffalo Environmental Association (WBEA) and the Lakeland Industry and Community Association (LICA) have deployed passive samplers for varying time periods from 1 to 2 months.

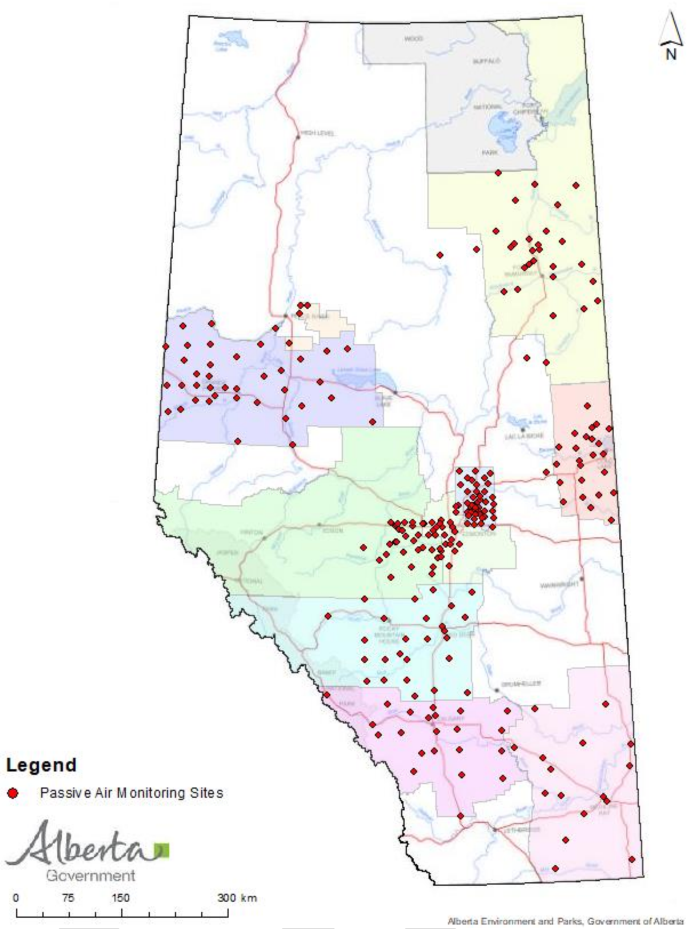

Figure 13: Passive air sampler network; Airshed boundaries are indicated by the shaded areas. Passive monitoring station locations are based on information provided by Airshed organizations to EMSD as of April 2018.

Currently, EMSD is performing assessments of passive monitoring networks within specific Airshed organization boundaries. These assessments are performed at the request of individual Airsheds, and identify redundancies within the networks based on spatial interpolation of measurements and the degree of similarity between measurements. Draft assessments for CRAZ, PAS, the Parkland Airshed Management Zone (PAMZ), and FAP have been completed. An assessment of the LICA network is

[7] PAS used Maxxam samplers for October 2007 to January 2009, AMEC Multigas passive samplers (H Tang et al., 2011) for January 2009 to May 2013, Radiello and Ogawa samplers (Mukerjee et al., 2004) for May 2013 to October 2017, and Maxxam samplers from November 2017 to the present.

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underway and assessments of the Peace Airshed Zone Association (PAZA) and WBEA networks may be completed in the future.

The passive network assessment for CRAZ used the temporal variability and spatial interpolation of annual average concentrations of NO_2, SO_2, and O_3 in the Airshed to provide information supporting the recommendations for the passive network. A reduction in the SO_2 network was recommended since spatially representative SO_2 concentrations of the Airshed could be obtained with fewer passive sites (i.e., sampling redundancies). The number of sites in the NO_2 network was recommended to be reduced in areas monitoring background concentrations and in the City of Calgary. A complete removal of the ozone passives was recommended due to large inconsistencies between co-located passive and continuous measurements. Furthermore, O_3 passive sampler data did not support monitoring objectives.

The PAS passive network assessment used the temporal variability and spatial interpolation of annual average concentration of NO_2, SO_2, and O_3 in the Airshed to provide information supporting the recommendations for the passive network. These recommendations included: i) reduction of NO_2 passive monitoring sites due to sampling redundancies, ii) removal of all O_3 passives from the network for the same reasons as CRAZ, iii) reduction of SO_2 passive monitoring sites due to sampling redundancies, and iv) addition of an anchor site in the southwest corner of the Airshed for NO_2 monitoring.

For the PAMZ passive network assessment, hierarchical cluster analyses were used to group the SO_2 and NO_2 passive sites based on the degree of similarity between the time series of monthly average concentrations. Results from the cluster analysis and spatial interpolation of the concentrations identified redundant sites in the SO_2 and NO_2 monitoring networks, which were recommended to be removed. In addition, it was recommended that a site be added in the western portion of the Airshed to increase the coverage and anchor the network in the west for NO_2 and SO_2 monitoring. The ozone passives were recommended for removal from the network for the same reasons as CRAZ and PAS.

In the FAP passive network assessment, hierarchical cluster analyses were used to group the SO_2 and H_2S passive sites based on the degree of similarity between the time series of monthly average concentrations. Redundancies were identified using the proximity of sites and results of the cluster analysis. Reductions to the SO_2 and H_2S monitoring networks were recommended in areas where sites were identified as statistically similar, while still providing spatially representative monitoring.

Implementation Item 5:1 Finish analysis of passive sampler networks for remaining Airshed organizations (LICA, WBEA, PRAMP and PAZA) and communicate results to the Airshed. Continue to support all Airshed organizations in implementing network recommendations.

5.1.1 Data Quality and Temporal Resolution

This section describes some characteristics of passive sampler measurements that EMSD will consider when reporting on and interpreting passive sampler data for ambient air quality studies. This does not evaluate approaches for use of passive samplers in compliance monitoring. It does not evaluate the passive monitoring technology directly either. The biases and drifts relative to continuous monitoring stations may reflect inconsistencies in sampling protocol or laboratory analysis methods.

Bari et al. (2015) performed a detailed assessment of the Maxxam passive sampler measurements in Alberta. They estimated precision through comparison of duplicate samples and accuracy through comparison between co-located passive and continuous stations. They found that passive sampler measurements of NO_2 and SO_2 did not meet the acceptable level of field performance (±25%) for passive samplers recommended by the United States National Institute of Safety and Health and European Union

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Directive 2008/50/EC. Passive sampler measurements of ozone did meet the (±25%) criteria. They also identified seasonal biases in the passive sampler data.

For environmental reporting, passive sampler data are most often presented as annual averages and used to infer the spatial variation of air quality across a region. EMSD evaluated this approach by comparing annual averages of NO_2, SO_2, and O_3 from co-located passive samplers and permanent air monitoring stations. This analysis used measurements from all available passive samplers, and therefore included comparisons between different brands of passive samplers (e.g., Maxxam, AMEC, etc.). Note that this work applies to annual averages only, and it is possible that alternative data analysis approaches could reduce or change the nature of the identified biases. This work is described in Appendix D. The Pearson correlation coefficient (R) was calculated for co-located annual averages at all station locations and was used to evaluate how well the passive samplers capture the spatial variation of air quality. The mean absolute difference between co-located measurements was used to assess systematic biases between the passive and continuous measurements. Drifts between the passive and continuous stations were also estimated using a Mann-Kendall test with a Sen slope estimator.

The results of this analysis are as follows:

- Passive NO_2 annual averages measure large-scale spatial variation of NO_2 across the province which is comparable to the continuous stations (R = 0.93), but with a large negative bias (mean difference -2.0±0.1 ppb or ~36%). Furthermore, the passive NO_2 bias is drifting and becoming more negative over time at several sites at rates of ~0.2 ppb/year, complicating the ability of passive NO_2 samplers to detect trends.
- Passive SO_2 annual averages capture spatial variation which is comparable to continuous stations (R = 0.95), with a fairly small bias (mean difference 0.12±0.02 ppb)[8], and minimal drift in the bias. However, the majority of co-located annual averages were very low (< 1 ppb) and therefore a comprehensive evaluation was difficult.
- Passive O_3 annual averages differed more from the continuous stations in terms of spatial variation (R = 0.78) than NO_2 and SO_2. The mean bias in ozone was 2.8±0.3 ppb, with systematic biases between stations, with some passive sites measuring higher levels of ozone than continuous stations and other passive sites measuring lower levels of ozone than continuous stations. Therefore, it is difficult to interpret annual average measurements from passive samplers.

The reasons for the observed biases and drifts in time in the historical record of passive sampler measurements have not been determined. Possible causes may include inconsistencies sampler design or in protocols for deployment, laboratory analysis, or uptake calculations. These factors have not been investigated in this work.

The temporal resolution and monitoring method uncertainty of passive sampler data are notable limitations in interpretation and usefulness of the data. Therefore, active sampling measurements are typically preferred over passive sampling data when determining enforcement actions with respect to AAAQO exceedances. The AAAQOs and CAAQS for ozone are based on shorter timescales (1-h and 8-h averages) and therefore cannot be compared against passive sampler data. Furthermore, monthly average ozone

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[8] Note, due to the low levels of SO_2 at most stations, the accuracy looks poor (> 25%) when presented as a percent difference because the denominator is close to zero. Therefore, these results are consistent with the findings of Bari et al. (2015).

may be affected by a combination of natural sources (such as biogenic emissions) and anthropogenic sources (such as vehicle emissions) during different periods of the month and therefore can be very difficult to interpret. Similarly, the AAAQOs for H_2S are also on shorter timescales (1-h and 24-h averages) than what can be reliably measured by passive samplers.

Therefore, while passive sample data can provide useful information on spatial variation of air quality in regions of the province with no continuous monitoring, EMSD will be aware of limitations of passive samplers when including these data in analyses. If a passive dataset is deemed useful for a focused study and/or routine reporting, further analysis may be required to determine the best methods for reporting on and interpreting the results. Furthermore, the Standards, Quality, and Innovation group at EMSD has initiated a co-location study to evaluate and compare various passive air samplers, which will improve our knowledge on the utility and potential applications for these measurements.

5.2 Integrated Monitoring

Much like the long-term monitoring, active integrated monitoring in Alberta is conducted through the distributed model (Section 1.3). Active integrated monitoring in Alberta provides composition information on $PM_{2.5}$, PM_{10}, VOCs, and PAHs. For this technique, air is pumped past a sample medium that collects the pollutants of interest, typically over a period of 24-hours. Samples are then extracted in a laboratory and analyzed to determine atmospheric concentrations. Detailed composition data can help identify possible causes of air quality issues such as elevated $PM_{2.5}$, odour events, and O_3 episodes. Specifically, integrated data can be used for source apportionment to assess the major source sectors that contribute to $PM_{2.5}$, PM_{10}, VOCs and PAHs. In addition, these data provide information on atmospheric processing, transport and deposition, and are useful for evaluating air quality models. However, active integrated monitoring provides fewer samples over a study period than continuous measurements and must be analyzed in a lab before ambient concentrations are available.

In Alberta, active integrated monitoring at several sites is conducted in collaboration with NAPS program. The NAPS program collects these samples at select locations as a 24-hour integrated sample once every three or six days, depending on the compounds monitored. NAPS sites in Alberta, include Edmonton East (VOCs only), Edmonton Central (VOCs only), Edmonton-McIntyre (PM and PAHs), and Calgary Central-Inglewood (VOCs and PM). There is no on-going monitoring of PAHs in Calgary, in addition PM composition monitoring in Calgary is not as comprehensive as that for Edmonton. Consideration should be given to initiating comparable integrated monitoring in Calgary in collaboration with the NAPS program. The NAPS data are publically available at: http://maps-cartes.ec.gc.ca/rnspa-naps/data.aspx.

Implementation Item 5:2 Continue collaborative participation in the NAPS program.

Routine active integrated monitoring is also conducted in the Athabasca Oil Sands Region (AOSR) for $PM_{2.5}$ (4 sites), PM_{10} (7 sites), VOCs (7 sites), and PAHs (4 sites), and in the Cold Lake Oil Sands Region at one location (Cold Lake South station) for VOCs and PAHs. These sites are maintained and operated by WBEA and LICA, respectively, and data are available through Airshed organization websites. When routinely collecting integrated samples, efforts should be made to design the monitoring such that samples are collected in accordance with the NAPS schedule so that a direct comparison to data collected at NAPS sites is possible.

In some areas of the province, non-routine monitoring for VOCs and reduced sulphur compounds is conducted by collecting samples triggered by elevated concentrations of hydrocarbons or sulphur compounds measured by continuous instrumentation. This monitoring is intended to determine the

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composition of air samples during events when elevated concentrations are observed which may cause odours or affect human health.

Integrated monitoring is also a component of focused monitoring studies (Section 4). Such monitoring is use to further explore and investigate air quality concerns. To ensure data quality, and facilitate comparability between integrated monitoring data collected from focused studies and long-term monitoring, establishment, documentation and communication of a best practice for the transport and deployment of integrated samples is needed. Also, the suite of chemicals analyzed during focused studies needs to be appropriate to address the monitoring question(s) determined at the start of the study. In this regard, a guidance document needs to be developed to better inform the design of focused studies that utilize integrated monitoring.

Implementation Item 5:3 Develop or adopt and communicate a standard operating practice for the transport and deployment of integrated samples such as VOCs canisters.

***Implementation Item 5:4 Develop or adopt and communicate a guidance document on how best to select the type of integrated samples and analysis suites to best answer a monitoring question*.**

5.3 Oil Sands Monitoring

The three Oil Sands Regions in Alberta are the Athabasca, Cold Lake, and Peace River regions, and air quality is intensively monitored in these regions by WBEA, LICA, and the Peace River Area Monitoring Program (PRAMP), respectively. Air and deposition monitoring in these regions is planned and implemented by these Airshed organizations through the Oil Sands Monitoring (OSM) program. Since the process for developing and implementing monitoring under OSM is different than for the rest of the province, air and deposition monitoring in the oil sands is considered complementary monitoring in this 5-year Monitoring Plan. However, it should be noted that there is an ongoing network optimization project led by the OSM program to evaluate and optimize air and deposition monitoring in the three oil sands regions, similar to the work conducted in this plan for the rest of the province. The station classifications developed in Section 3.1 are being used in the OSM network optimization project. Near-real time and historical air and deposition monitoring data collected in the oil sands can be found on the websites of the three Airshed organizations that lead and conduct the monitoring (WBEA, LICA, and PRAMP).

5.4 Regulatory Monitoring

The objective of regulatory monitoring is to ensure that a licenced facility or a group of facilities are operating within approval conditions. This form of monitoring may include various types of monitoring platforms to suit the monitoring need. Furthermore, regulatory ambient monitoring may be accompanied by on-site facility source or stack monitoring. The assignment and/or design of regulatory monitoring is not within the scope of this 5-year Monitoring Plan. However, the data collected as part of the regulatory monitoring should be accessible for scientific studies. Figure A-1 illustrates the distribution of regulatory monitoring in the province. Existing regulatory monitoring stations may be incorporated in the long-term air monitoring network, when appropriate, to address the monitoring needs identified within this 5-year Monitoring Plan (Section 3.1.6).

The need for and the type of regulatory ambient air monitoring are identified as part of the industrial approval process, which is separate from the 5-year Monitoring Plan. Factors taken into account include the dispersion modelling assessment, the type of industrial activity (i.e., types and amounts of anticipated

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emissions), neighbouring emission sources, existing monitoring, and/or stakeholders concerns. For example, monitoring may be required in the case where a potential for exceedance of an AAAQO was identified in the application's dispersion modelling assessment. Regulatory monitoring may include continuous analyzers, passive samplers, integrated monitoring and/or other more specialized air monitoring programs, such as deposition monitoring.

While the parameter monitored is identified as part of the approval process, monitoring site placement is proposed by the industrial facility. A review of the proposal may include examination of emission source location(s), meteorological conditions, terrain, modelling results, site accessibility and availability of electrical power. The approved monitoring site must meet AMD (Alberta Environment and Parks, 2016a) requirements, similar to all other ambient air monitoring sites submitting data to AEP.

Data obtained through the regulatory monitoring process is submitted to AEP as part of annual or monthly reporting requirements as outlined in the AMD (Alberta Environment and Parks, 2016a). The data and accompanying report are reviewed by the Operations Division and compared to relevant AAAQOs or noted approval conditions to ensure that emissions do not result in adverse effects. In addition to these reports, any exceedances of AAAQO at regulatory continuous monitoring stations must be reported to the department immediately. Investigations and/or focused studies may be initiated as a result of review of data submitted as part of regulatory monitoring and reporting requirements. Currently regulatory monitoring data are submitted to AEP, and are not readily accessible. In the near future, all reportable industry data will be provided to the central database alongside data collected by the core long-term air quality monitoring network. Auditing frequency, station performance and expected duration and frequency of operation may be used to determine if an industry monitoring site should be incorporated into the core long-term monitoring network.

Implementation Item 5:5 Establish criteria to determine whether regulatory ambient air monitoring stations should be incorporated into the core long-term network.

Regulatory monitoring may be reviewed and/or changed as a result of change(s) in the emission(s) at the facility and/or neighbouring source(s), stakeholder concerns, government policy and/or monitoring technology. A review may also be considered based on monitoring results from the surrounding area. A review of monitoring requirements may also accompany other approval requirements during renewal(s).

5.5 Portable Air Monitoring Platforms

Portable air monitoring platforms house air quality instruments in portable systems. They can house traditional continuous air quality analyzers or smaller instruments such as compact sensors. Compared with traditional air monitoring stations, portable air monitoring platforms can have the following advantages, depending on the platform: smaller initial investment, lower maintenance costs (instruments and personnel), less energy consumption, smaller footprint, and easier deployment. Portable air monitoring platforms are deployed throughout the province by both EMSD and Airshed.

EMSD owns and operates several portable air monitoring platforms that are equipped with traditional air monitoring analyzers:

- One Mobile Air Monitoring Laboratory (MAML) - a 27-foot (8.2 metre) vehicle;
- Two Portable Air Monitoring Laboratories (PAML) - large, but readily moveable, trailers; and
- One Airpointer - smaller and more compact than the MAML and PAML; which has dimensions of approximately 1.2x0.7x0.6 metre.

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EMSD deploys these air monitoring platforms throughout the province as part of focused studies or emergency response. Since these platforms are equipped with traditional analyzers, they should be comparable to standard traditional air quality monitoring stations. The MAML and PAML have been used routinely for several years as part of the province's air monitoring system. The use of the Airpointer as part of the air monitoring system is new to EMSD and therefore needs to be tested for use in the province.

In order to evaluate data quality and develop standard operating procedures for the Airpointer, EMSD deployed an Airpointer to the Elk Island long-term air monitoring station on November 2017 and will collect data until early 2019. The data from the Airpointer will be compared against data from the traditional air monitoring station in order to assess Airpointer performance. The results of this study will inform how the Airpointer can be used in focused studies and/or whether it can fill gaps identified in the core long-term monitoring network. Furthermore, EMSD will review other commercially available portable air monitoring platforms and determine whether additional platforms should be tested.

EMSD is also investigating possible uses for smaller portable air monitoring platforms that use compact air quality sensors. In the context of this monitoring plan, compact air quality sensors are defined as sensors that are smaller than traditional analyzers (i.e., the analyzers currently used in the core long-term network) and that may use technologies such as electrochemical, metal oxide semiconductor, or infrared sensing (Yi et al., 2015). Therefore, portable air monitoring platforms that use compact air quality sensors are usually much smaller than traditional systems and have a smaller footprint.

With continued improvements in air pollutant sensor technology and microelectronics, air quality monitoring with compact sensors is an emerging trend. There are several advantages to compact air monitoring sensors:

- They have low power consumption, which makes solar/battery powered systems feasible.
- They can provide data on a continuous basis, with high time resolution (on the order of minutes or seconds).
- They have small footprints and therefore can easily be transported and deployed.
- Data do not require laboratory analysis and are available in real-time.
- Sensors are available for many parameters, for example ozone, NO_2, CO, certain VOCs, SO_2, and $PM_{2.5}$.
- Sensors are inexpensive compared with traditional analyzers.

As such, compact air sensors could have a range of potential applications, including use in focused studies, expansion of air monitoring networks, and citizen science initiatives. The main drawback is that compact sensors are different from traditional analyzers and therefore data are not directly comparable. Compact sensors often have higher detection limits and lower precision compared with traditional analyzers and they are not currently included in Alberta's Air Monitoring Directive. Therefore, compact sensor data at present cannot be used to assess air quality against standards and thresholds.

EMSD will evaluate portable air monitoring platforms that use compact sensors for measurement of one or more parameters, such as ozone, NO_2, and $PM_{2.5}$. EMSD has reviewed commercially available platforms and has identified several systems (i.e., Vaisala AQT420, Purple Air Model PA-II, Aeroqual AQM65, Aeroqual AQS1, Aeroqual AQY1, etc.) for further testing. Also, EMSD, in partnership with the University of Alberta, is developing a "micro-station" where off-the-shelf micro/compact sensors will be custom-integrated on a shoe-box sized platform. EMSD will test the commercially available portable air monitoring platforms that use compact sensors and EMSD-built micro-station for reliability and comparability with traditional permanent air monitoring stations. EMSD will collaborate other groups (e.g., Airshed organizations, ECCC,

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other provinces) that are testing portable air monitoring platforms in order share results and learn from published and unpublished collocation studies. The systems will be evaluated for detection limits, data quality, capital/maintenance costs, size, instrument reliability, power consumption, data accessibility/security, and network integration compatibility.

Implementation Item 5:6 Review literature for and evaluate the performance of Airpointer and other commercially available portable air monitoring platforms (Vaisala AQT420, Purple Air Model PA-II, Aeroqual AQM65, Aeroqual AQS1, Aeroqual AQY1, etc.), including those equipped with compact sensors, for use in long-term and focused monitoring.

Implementation Item 5:7 Design, build, test and evaluate an integrated portable air monitoring platform equipped with compact sensors ("micro-station").

After the testing phase, EMSD will determine how portable air monitoring platforms using traditional and compact sensors may be used for focused studies and/or to fill gaps in the long-term monitoring network (Section 3.1.6). Examples of possible uses for portable air monitoring platforms may include: (i) AQHI reporting in smaller communities; (ii) monitoring wildfire smoke in rural areas; (iii) citizen science initiatives; (iv) emergency response monitoring; and (v) assessment of the spatial variation of air quality.

5.6 Satellite Remote Sensing

Satellite remote sensing datasets are often free and publicly available and can provide spatial maps of air pollutants over the entire province. Satellite instruments can measure multiple air quality parameters, including NO_2, SO_2, NH_3, some VOCs such as formaldehyde, and aerosol optical depth, which is related to surface particulate matter. These measurements can be used for a variety of purposes, including estimating emissions, supporting decisions around environmental reporting, and assessing spatial variation and temporal trends (Duncan et al., 2014). Satellite instruments also measure parameters that can be useful for interpreting air quality, such as forest fire hot spots and corrected true colour images, which can be used to identify wildfire plumes, for instance.

However, care must be taken when interpreting satellite remote sensing data. The sensitivity of satellite measurements to surface air quality can vary. For example, for NO_2, the satellite measures the amount of NO_2 from the surface up to the tropopause (~15 km) and therefore NO_2 at the surface is not distinguished from NO_2 higher in the troposphere. Furthermore, there are biases in satellite datasets related to sampling (e.g., sparse spatial resolution) and complications in the retrievals that may vary with factors such as the time of year and cloud cover.

Over the coming years, EMSD will investigate possible uses for satellite data in routine reporting. They will compare the spatial variability and temporal trends in satellite datasets with co-located surface air monitoring stations in order to assess the reliability of various satellite datasets. Once this has been determined, routine reporting products from satellite may be produced, such as spatial maps or temporal trends of air quality across the province.

Additionally, satellite data is being used and will continue to be used for other forms of reporting. Some satellite datasets are available in near real-time and are being assessed to determine where and how they may support decisions or complement the existing BlueSky forecast system during air quality episodes, such as wildfires. Furthermore, satellite data are being used in focused studies and could contribute to knowledge about significant issues such as ammonia and formaldehyde. EMSD also uses satellite true colour and forest fire hot spot data as one piece of evidence to help identify episodes influenced by forest fires for the CAAQS.

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Over the next five years, air quality measurements from satellite are expected to improve. The TROPOspheric Monitoring Instrument (TROPOMI) (Veefkind et al., 2012) was launched on October 13 2017 and measures species such as NO_2, formaldehyde, SO_2, CH_4 and CO, with a much higher spatial resolution than previous air quality satellites (up to 7 km × 3.5 km). The first round of TROPOMI air quality measurements are expected to be released publicly in 2018. The Tropospheric Emissions: Monitoring of Pollution (TEMPO) (Zoogman et al., 2014) will also be launched over the next few years. TEMPO is a geostationary satellite centred over the United States and will therefore provide air quality data with good spatial and temporal resolution. EMSD will assess the data from these new satellite instruments as they become available and will determine how it can be used to improve our knowledge of air quality and significant issues in Alberta.

Implementation Item 5:8 Evaluate and report on the usefulness of satellite data to assess spatial and temporal variation of NO_2, SO_2, CO, PM, and/or NH_3 through literature review and data analysis.

5.7 Bulk Deposition Sampling

At long-term deposition monitoring sites, event based weekly precipitation samples are currently collected and monitoring to infer dry deposition is planned. These deposition monitoring methods require power, co-located measurements of meteorology/precipitation depth, and weekly visits from a field technician to collect precipitation samples. As a result, the long-term deposition sites are located in regions that are accessible year-round with a readily available and reliable power supply.

These requirements limit the ability to measure deposition in remote regions. An alternative approach is bulk deposition monitoring, which does not require power and requires fewer visits from field technicians. Bulk deposition monitoring could therefore facilitate co-locating deposition monitoring with relatively remote water quality or ecosystem monitoring sites. The simplest form of bulk deposition sampling is collected using a container that is left uncovered between periods of precipitation. Such samples collect precipitation in addition to an unknown amount of dry deposition, which necessitates careful monitoring design, interpretation, and flagging of the results. EMSD will explore the possibility of using bulk deposition samplers by co-locating a bulk sampler at a long-term monitoring site equipped with a precipitation event sampler and monitoring to infer dry deposition. This investigative study will help to better understand and quantify potential biases in bulk samples and help identify the best use of bulk deposition samplers.

Implementation Item 5:9 Review and select bulk precipitation samplers that could be deployed to remote areas of Alberta. Co-locate selected samplers with event samplers and examine comparability.

5.8 Citizen Science and Community-Based Monitoring

Citizen science and community-based monitoring both involve the engagement of members of the public in designing studies, collecting data, and/or reporting on findings. Community-based monitoring is performed and/or planned by the members of a community with a local information need. Therefore, community-based monitoring projects are on a local scale and address the priorities of the community. Citizen science is a method of data collection which includes volunteers who participate in research and monitoring to help answer scientific questions using the western science knowledge system. Participants can take on a variety of roles, from sample collection, to participation in study design and data analysis. Citizen science projects may be very local in nature (example: collection of air samples near a particular industry) to more global (example: portable air monitors deployed around the world). A Memorandum on

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Citizen Science is under development and will provide EMSD with clear guidance regarding the role and appropriate application of citizen science in monitoring, evaluating and reporting on the condition of the environment in Alberta.

To address monitoring gaps or understand specific community air quality issues, use of citizen science monitoring may be appropriate and provide valuable scientific information. Also, citizens involved in the program gain an improved understanding of environmental monitoring and how the data can be used to inform air quality. In this regard, EMSD will work with stakeholders to build citizen science capacity. This will include the implementation of a pilot project using citizen science methods that will benefit EMSD and stakeholders.

Implementation Item 5:10. Work within the construct of the EMSD Memorandum on Citizen Science to design and implement a pilot citizen science air monitoring study to address an identified monitoring gap.

Community and Indigenous involvement in environmental monitoring is important for the co-production of environmental knowledge that will benefit all parties. During the implementation of the 5-year plan, EMSD will seek opportunities for community and Indigenous involvement in delivering monitoring activities. These opportunities will become more apparent as the work required to implement the proposed monitoring, evaluation and reporting projects are further developed.

6 Significant Issues

The purpose of this section is to identify and briefly discuss significant issues related to air quality and deposition in Alberta. Exploration of significant issues ensures a relevant, current and scientific monitoring network. Reviewing and identifying new significant issues will occur with subsequent iterations of the 5-year Monitoring Plan. Additionally, significant air quality and deposition issues not captured by the plan may be brought forward through the process for initiating focused studies (see Section 4).

A "Significant Issue" is defined here as a topic related to air quality or deposition that is not effectively addressed by current monitoring, evaluation, or reporting activities, and is expected to be important over the next 10 years. The intent is to ensure that EMSD monitoring, evaluation and reporting activities are proactive in addressing air quality and deposition themes that are likely to be a concern in the present and/or near future. For each significant issue, a recommended path forward is suggested.

6.1 Wildfire Smoke

Emissions of air pollutants from wildfires (e.g., $PM_{2.5}$, PM_{10}, CO, NO_x, NH_3, PAHs, and VOCs) can severely degrade air quality on both a local and provincial scale. Numerous reviews have shown that wildfire smoke inhalation causes acute respiratory and cardiovascular effects (e.g., Adetona et al., 2016; Reid et al., 2016), and possibly low birth weight (e.g., Holstius et al., 2012; O'Donnell & Behie, 2013). There is significant evidence that the frequency of wildfires exceeding 5,000 ha in size will increase in the United States due to climate change (Barbero et al., 2015, and references therein). Indeed, the number of wildfires and total acreage burned have increased in Canada between 1961 and 2015 (Landis, et al., 2018). In Alberta, the number of wildfires has steadily increased over the same timeframe; however, the total annual acreage burned has been relatively constant but punctuated by periodic mega-fires which may be occurring more frequently in recent years (Landis et al., 2018).

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The provincial air monitoring network was not specifically designed to forecast, monitor, or evaluate air quality impacts from wildfire smoke. In addition, deployment of air quality monitoring during wildfires often occurs in an *ad hoc* fashion, and can miss the period of largest impact. Although recent studies and reports (Bytnerowicz et al., 2016; Alberta Health, 2017; Landis et al., 2018; Wentworth et al., 2018) have evaluated the air quality impacts from the 2011 Richardson and 2016 Horse River (Fort McMurray) Wildfires, these assessments were done in an *ad hoc* manner. Some studies noted potential improvements to the existing network that would aid in future assessments. Wildfire smoke is considered a significant issue due to the likelihood of increasing frequency and size of wildfires as a result of climate change, as well as the documented air quality impacts of recent wildfires in Alberta.

A focused study could be conducted to document and evaluate the ability of Alberta's air monitoring network to forecast, monitor, communicate, and evaluate wildfire smoke. Forecasting could be used to inform monitoring locations, and additional monitoring could be integrated into the forecasting model to improve predictions. The deliverable would be an external report with recommendations for tractable adjustments/additions to the existing network to improve forecasting, monitoring and evaluation (e.g., implement portable $PM_{2.5}$ monitoring in key locations during the wildfire season, add CO monitors to several sites, routinely use satellite data). It is recognized that the current state of the network may already provide sufficient data for adequate forecasting, monitoring, and evaluating, given that existing monitoring is focused in dense urban areas for most major air pollutants present in wildfire smoke. Focused studies related to wildfire smoke should be conducted in collaboration with stakeholders and experts in this area including Airshed organizations, Alberta Health, the AQHI team and wildfire smoke forecasters.

Implementation Item 6:1 Evaluate current network for monitoring and assessing impacts of wildfire smoke, and suggest network improvements.

6.2 CAAQS for 2020 and 2025

The Canadian Ambient Air Quality Standards (CAAQS) were developed by CCME as part of a national Air Quality Management System. Annual reporting of CAAQS in Alberta is performed by AEP.

In 2020, the existing CAAQS for O_3 and $PM_{2.5}$ will become more stringent and new CAAQS will be introduced for SO_2 and NO_2. Values for the latter will become more stringent in 2025. Table 6 shows the current and future CAAQS, averaging time, and statistical form. An assessment has been completed by the Policy and Planning Division of AEP to proactively determine which CAAQS reporting stations in Alberta may approach or exceed these new and more stringent values.

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Table 6: CAAQS for 2015, 2020, and 2025

Pollutant	Averaging Time	Numerical Value			Statistical Form
		2015	2020	2025	
$PM_{2.5}$ ($\mu g\ m^{-3}$)	24-hour	28	27	TBD[9]	3-year average of the annual 98th percentile of the daily 24-hour average concentrations
	Annual	10.0	8.8	TBD[9]	3-year average of the annual average of all 1-hour concentrations
O_3 (ppb)	8-hour	63	62	TBD[9]	3-year average of the annual 4th highest daily maximum 8-hour average mixing ratios
SO_2 (ppb)	1-hour	N/A	70	65	3-year average of the annual 99th percentile of the daily maximum 1-hour average mixing ratios
	Annual	N/A	5.0	4.0	Average over a single calendar year of all 1-hour average mixing ratios
NO_2 (ppb)	1-hour	N/A	60	42	3-year average of the annual 98th percentile of the daily maximum 1-hour average mixing ratios
	Annual	N/A	17.0	12.0	Average over a single calendar year of all 1-hour average mixing ratios

Further work needs to be done to review and build on the comparisons of current ambient concentrations against future CAAQS, based on the initial evaluation conducted by Policy and Planning. Stations which are projected to approach or exceed 2020 and/or 2025 CAAQS could be further examined to assess whether proactive measures should be taken (e.g., investigating cause through a focused study, deploying additional monitoring, liaising with the Alberta Energy Regulator (AER), developing a preliminary management plan). This may include work to project changes in emissions between now and 2020/2025 to infer whether ambient levels are expected to change in the coming years. This work should be done in collaboration with, and possible led by, AEP Policy and Planning, AEP Operations, AER and Airshed organizations.

Implementation Item 6:2 Identify stations which are most likely to exceed the future CAAQS based on current ambient conditions and, possibly, predicted changes in emissions. Initiate focused study and/or adjust the long-term network based on this evaluation as necessary.

6.3 Ammonia (NH_3) Monitoring

Gaseous NH_3 impacts both air quality (through formation of $PM_{2.5}$) and nitrogen sensitive ecosystems (through deposition and subsequent acidification or eutrophication). For these reasons, NH_3 is listed as one of the seven Criteria Air Contaminants (CAC) by the Government of Canada. NH_3 is the only CAC with reported national emissions that have been increasing since 1990. Figure 14 paints a similar picture for emissions of gaseous CACs in Alberta. There is evidence that deposition of NH_3 is now larger than deposition of oxidized nitrogen (e.g., NO_x, nitric acid HNO_3) across most of the contiguous United States (e.g., Fenn et al., 2018; Li et al., 2016).

[9] TBD = to be determined

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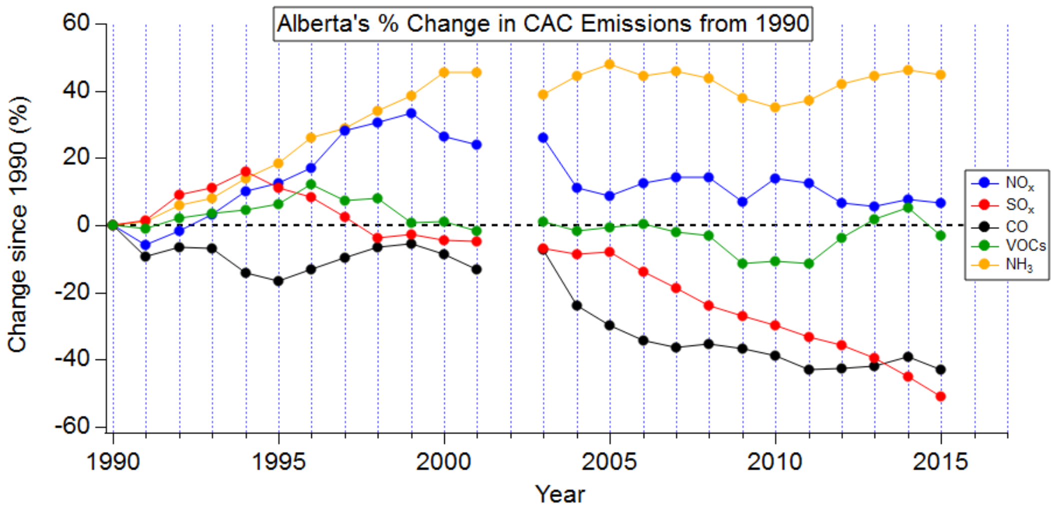

Figure 14: Percent change in Alberta's gaseous CAC emissions since 1990 (reported by the Air Pollutant Emissions Inventory, APEI)

Ambient NH_3 concentrations and deposition measurements in the province are sparse. The current network likely does not provide sufficient data to assess: (i) impacts of NH_3 deposition (and other forms of nitrogen) to national/provincial parks, or (ii) whether reducing NH_3 would limit ammonium nitrate formation and alleviate $PM_{2.5}$ episodes. Although a recent modelling report suggested that wintertime ammonium nitrate formation in the Edmonton region is HNO_3-limited (Nopmongcol et al., 2015). In addition, EMSD's Science Advisory Panel (SAP) noted in June 2017 that "*The agricultural regions of the south did not seem well instrumented. Agriculture is a strong economic and livelihood component of Alberta, and ammonia is an important emission from this sector*." Given the direction from the SAP, increasing/stable NH_3 provincial emissions, possible negative ecosystem effects in park ecosystems, and possible contributions to $PM_{2.5}$ episodes, NH_3 concentration/deposition monitoring is both a significant issue. On-road (vehicular) NH_3 emissions can also be an important contributor to ambient NH_3 concentrations, especially in urban centres (Fenn et al., 2018).

In order to better understand the potential impact of ambient NH_3 on environment receptors in Alberta, a two-year focused study may be conducted to: (i) use satellites, modelling and existing ground-based techniques to better understand spatial patterns of NH_3 concentrations and assess the need for on-the-ground monitoring near and upwind of sensitive ecosystems, (ii) monitor NH_3 and HNO_3 in major urban centres with wintertime $PM_{2.5}$ episodes, and (iii) review existing literature on NH_3 emissions, concentrations and effects in Alberta. The deliverable would be a report interpreting the above monitoring data to assess the potential for negative effects of N-deposition and ammonium nitrate formation due to NH_3, summarizing previous literature, and providing recommendations on the need (or lack thereof) for continued or additional NH_3 monitoring. These studies would be conducted in collaboration with Airshed organizations and Alberta Agriculture and Forestry.

Implementation Item 6:3 Conduct a literature review and design a focused study to monitor NH_3 in cities and near sensitive ecosystems in Alberta.

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6.4 Nitrogen Dioxide (NO_2) Monitoring Methods

NO_2 measurements in the network are currently made using a heated metal catalyst to convert NO_2 to NO. The NO is then detected using chemiluminescence after reaction with excess O_3. Ambient NO is measured in air that bypasses the catalyst, and NO_2 is calculated as the difference between the catalyst-treated and catalyst-free sample streams. Unfortunately, the heated catalyst also converts some difficult-to-predict fraction of other reactive nitrogen species (e.g., HNO_3, HONO, PAN, NH_3). In other words, the NO_2 instruments currently used in the network overestimate NO_2 in a manner that is extremely difficult to compensate for. However, there are commercially-available instruments that measure “true NO_2” (i.e., with no interference from other nitrogen species) using either cavity attenuated phase shift (CAPS) spectroscopy or a photolytic converter. A study by Xu et al. (2013) found that an urban site influenced by fresh emissions suffered from only small NO_2 biases (<10%) using the traditional detection method, whereas a notable NO_2 overestimation was measured at two suburban sites (30-50% overestimation) and one downwind site (130% overestimation).

Overestimations of NO_2 caused by instrument interferences will impact AEP’s ability to properly conduct CAAQS assessments when NO_2 is introduced in 2020. For example, if a CAAQS reporting station has an NO_2 exceedance, it will be difficult to assess whether the exceedance was caused by an interference from other reactive nitrogen species or not. As a result of the interference, the United States Environment Protection Agency’s (U.S. EPA) Photochemical Assessment Monitoring Stations (PAMS) will soon require a “true NO_2” measurement at each site using either CAPS or a photolytic converter (U.S. EPA, 2016). The development and deployment of commercially available “true NO_2” instruments is a significant issue for Alberta’s air monitoring network due to 2020 NO_2 CAAQS requirement and known positive interferences with existing NO_2 monitoring methods.

A two-year focused study could be conducted to evaluate the performance and viability of commercially available “true NO_2” instruments. Such a study could co-locate “true NO_2” instruments at several existing ambient air monitoring sites with different NO_2 regimes (i.e., low, medium, and high) to determine the need, or lack thereof, for measuring “true NO_2” in Alberta’s air monitoring network. The co-location study would also evaluate the logistics and feasibility of operating these monitors throughout the network (e.g., how often calibrations are required, instrument reliability).

The FAP and WBEA Airshed organizations are currently conducting co-location studies for “true NO_2” within their networks. ECCC through the NAPS network, the U.S. EPA, and other jurisdictions outside of Alberta are pursuing this issue and, in some cases, are shifting to “true NO_2” methods. EMSD will continue to work with these organizations to evaluate the data collected and determine if an additional co-location focused study is necessary to assess this issue.

Implementation Item 6:4 Review and evaluate “true NO_2” monitoring methods and collaborate with Alberta Airshed organizations and the National Air Pollution Surveillance community to determine if “true NO_2” monitoring should be adopted in Alberta.

6.5 Phase-Out of Coal Electricity Generation

The GoA has committed to completely phasing out coal-fired power plants by 2030. As a result, the location and magnitude of air emissions from Alberta’s energy sector will significantly change over the next decade. According to the 2015 Air Pollutant Emissions Inventory (APEI), coal-fired power plants contributed 39% and 10% of anthropogenic SO_2 and NO_x emissions in Alberta. In addition, coal-fired power plants are known sources of other environmental contaminants, such as mercury, arsenic, cadmium, lead, manganese, selenium, and polycyclic aromatic hydrocarbons (PAHs). The atmospheric reactions of SO_2 and NO_x have

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the potential to form secondary $PM_{2.5}$, as well as O_3 (from reactions of NO_x and VOCs) downwind of coal-fired power plants. It is important to note that consensus advice was provided to the Deputy Minister of AEP from the Clean Air Strategic Alliance (CASA) in December 2017. The advice proposed standards for NO_x emissions from coal-to-gas conversion.

The shutting down or conversion of the six coal-fired power plants in Alberta has the potential to reduce atmospheric concentrations of pollutants (e.g., SO_2, NO_2, $PM_{2.5}$, O_3, PAHs, mercury, and heavy metals) in the vicinity and downwind of coal-fired power plants over the next decade. The potential improvements to air quality constitute a significant issue that AEP should position itself to monitor, evaluate, and report on.

An air quality modelling project initiated by AEP Operations and PAMZ has already done substantial work on assessing the sources of wintertime $PM_{2.5}$, O_3, NO_x, and SO_2 in central Alberta. Initial results suggest coal-fired power plant emissions have a small (<5%) impact on $PM_{2.5}$, NO_x, and O_3 in downwind areas (i.e., >100 km downwind). However, contributions towards downwind SO_2 concentrations can be up to ~80% closer to the coal-fired power plants. Additional air quality modelling work to be completed in June 2018 will expand the analysis to include all seasons and the entire province. EMSD could use these findings to identify existing stations where the most substantial air quality improvements are predicted to occur and which analysis techniques (e.g., trend statistics, positive matrix factorization) could be used over the next 10 years to quantify any measureable reductions in air pollutants resulting from the phase-out of coal. This work would be conducted in collaboration with AEP Operations, AEP Policy and Planning, Airshed organizations and Alberta Health.

Implementation Item 6:5 Identify stations likely to experience improved air quality due to the phase-out of coal by power plants, and design a focused study to evaluate potential changes in air quality.

6.6 Formaldehyde (HCHO) Monitoring

Formaldehyde (HCHO) is a U.S. EPA hazardous air pollutant due to its toxic effects at moderate concentrations. In addition, it is the most significant carcinogen in outdoor air in the United States, excluding $PM_{2.5}$ and O_3 (Zhu, et al., 2017a). The 1-hour AAAQO for formaldehyde is 53 ppb and, although no annual AAAQO exists, an average lifetime exposure of 0.7 ppb will cause ~13 people out of 1 million to develop lung and nasopharyngeal cancer (US Environmental Protection Agency, 2015). There are many ambient sources of HCHO, including direct emissions from incomplete combustion, composite wood manufacturing, petrochemical activities, oil and gas industries, and lean-burn natural gas engines (Olson & Wilson, 2011; Chang, et al., 2016; Stroud, et al., 2016). However, a significant portion of HCHO is also formed in the atmosphere through photochemical reactions of precursor VOCs. In particular, this secondary source can be difficult to quantify due to the plethora of precursors and reaction pathways that lead to HCHO.

Formaldehyde concentrations in Alberta remain largely uncharacterized, despite the abundance of potential sources of formaldehyde and precursor VOCs. This can be considered a significant issue since the phase-out of coal-fired electricity generators may result in an increase in natural gas combustion. Furthermore, a recent study (Zhu, et al., 2017b) used satellite measurements to find that HCHO vertical column densities across the Cold Lake Oil Sands Region increased by 4% yr^{-1} between 2005 and 2014, consistent with increased crude oil production.

In order to understand the potential impact of HCHO in Alberta, EMSD could perform a literature review to attempt to estimate the spatial and temporal trends in HCHO emissions in Alberta. Annually-averaged ground-level formaldehyde concentrations could also be obtained from satellite measurements as a first

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attempt to assess the potential formaldehyde has to degrade air quality on a provincial scale and to identify/confirm hot spots. These two exercises could be carried out in a 1-year scoping study to determine whether this issue warrants further examination.

Implementation Item 6:6 Conduct a literature review and possible analysis of formaldehyde data in Alberta and other jurisdictions (based on satellite and ambient data) to further scope out the importance of this issue in Alberta.

6.7 Odour Issues

Odour issues occur throughout Alberta, particularly in communities in the vicinity of oil and gas activities (e.g., Fort McKay, Three Creeks). However, many other sources and activities, such as wildfires and agriculture, can cause odour issues as well. Currently, EMSD does not have a long-term monitoring program that specifically monitors for odour. Odour issues have been addressed on an *ad hoc* basis through focused studies, and usually include integrated sampling in an attempt to identify the major odour-causing compounds. However, there are several technical challenges in identifying specific compounds responsible for an odour event. Due to recurring odour complaints, as well as discussions with Alberta Health, odour issues are a significant concern in some parts of the province. It is important for EMSD to be able to proactively address odour issues. In addition, being able to provide a timely and coordinated response to odour complaints is also critical. EMSD could review previous odour complaints, use emission inventories to identify possible odour hot spots, and work with Airshed organizations and Alberta Health to determine regions of the province experiencing, or likely to experience, odour issues. Once identified, EMSD could lead the development of an odour monitoring program (if deemed necessary) for high risk communities across the province, with the main purpose of identifying and mitigating odour events. A necessary precursor to this effort would be a literature review of available technologies, methods, and approaches for monitoring odour.

Implementation Item 6:7 Support the implementation of the provincial odour management policies through monitoring, evaluation and literature review.

6.8 Gaps in AAAQOs

The Alberta Ambient Air Quality Objectives (AAAQOs) are levels against which ambient concentrations can be compared to for assessment of potential impacts to human and ecosystem health. However, there are pollutants for which no AAAQO exists, as well as pollutants for which collection times are longer than the acute AAAQO averaging period. For example, the acute AAAQOs for most volatile organic compounds (VOCs) are 1-hour averaging periods. However, the sampling time for integrated VOC measurements in the province is usually 24-hours, which makes a reliable comparison to AAAQOs impossible.

There are obvious practical reasons for these gaps and discrepancies, such as insufficient health/ecosystem data to develop AAAQOs for a given pollutant, and sample collection logistics. The development and review of AAAQOs is a multi-stakeholder process. The gaps and discrepancies noted above are important to consider, but are not currently within the scope of EMSD. That being said, EMSD can provide scientific guidance or advice, if needed.

6.9 Acute and Emergency Response Monitoring

Largescale difficult-to-predict events, such as wildfires and facility upsets, can necessitate acute and emergency response air quality monitoring. These events can be significant air quality issues throughout the province. However, it is challenging to develop a specific implementation item to improve acute and

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emergency response monitoring, evaluation, and reporting due to the unpredictable and variable nature of these extreme events. EMSD already has instrumentation and platforms that can be rapidly deployed to monitor air quality (e.g., MAML, E-BAMs), as exemplified by the response to the 2016 Horse River Wildfire. Ongoing work to evaluate the suitability of other complementary methods for acute and emergency response monitoring is detailed in Section 5.

6.10 Effects of Complex Mixtures

The effects of complex mixtures on air quality, odours, health, and toxicity are rarely examined. Typically, impacts or effects are assessed on a pollutant-by-pollutant basis (with AQHI being one notable exception). This pollutant-by-pollutant approach does not account for any possible additive, synergistic, or counter-acting effects. This issue has been flagged by Alberta Health as significant. Although EMSD can provide information on monitoring complex air mixtures, it is not well positioned to evaluate how they can impact air quality, odours, health, or toxicity. If such an evaluation is undertaken by another organization (e.g., Alberta Health) or division within AEP, then EMSD can provide scientific guidance and input on monitoring approaches for pollutants of interest.

6.11 Background Air Quality Data

As detailed in Section 3, there is only one long-term air monitoring station in the entire province classified as Background. Information on background air quality (i.e., air quality without the influence of anthropogenic emissions) is crucial for evaluating the impact and cumulative effects of anthropogenic emissions. It is possible to assess background air quality for a period of time at a non-background station if conditions are such that it is not being influenced by anthropogenic emissions. However, background conditions at these stations can be highly variable and this approach is less ideal for stations surrounded by sources (e.g., Large Population Centres). Furthermore, background air quality is unlikely to be spatially equivalent throughout the province.

Therefore, a significant issue in EMSD's current long-term air quality monitoring could be a lack of background air quality data. However, this issue is being considered by Implementation Item 3-10, so a standalone implementation item is not given here. Complementary monitoring methods (Section 5) could also be useful for evaluating background air quality.

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7 Data, Evaluation and Reporting

The mandate of EMSD is to provide open and transparent access to scientific data and report on the condition of Alberta's environment on a provincial and regional scale. Therefore, it is the responsibility of EMSD to ensure that air and deposition data is of high quality, is publicly available, and is evaluated and used to report on environmental condition and cumulative effects.

7.1 Data Collection

7.1.1 Long-term Air Monitoring

For the long-term air monitoring program, a number of systems are in place to ensure that air monitoring instrumentation meet applicable performance specifications and that the data collected are quality-assured and scientifically defensible. These systems are covered in the AMD and include but are not limited to: (i) monitoring siting criteria; (ii) monitoring requirements and equipment specification; (iii) quality-assurance plans (QAP); (iv) standard operating procedures (SOP); (v) routine monthly calibrations; (vi) daily zero and span checks; (vii) manufacturer certification; and (viii) performance audits. The AMD requires the documentation of the minimum training requirement needed for the operation of air monitoring stations but does not require specific competencies as the various monitoring programs require different skills. Currently there is no standardized training requirements for long-term air monitoring operators. Exploring how other jurisdictions standardize training could help inform minimum training requirements and identify possible training and training platform options.

Implementation Item 7:1 Explore operator training requirements in other jurisdictions for potential implementation in Alberta.

7.1.2 Air Quality Assurance Plans

All procedures associated with collecting and reporting on data collected at long-term air monitoring stations are documented in quality assurance plans in accordance with the AMD (Alberta Environment and Parks, 2016a). This includes various standard operating procedures that detail the steps needed to operate, maintain and calibrate instruments. The quality assurance plans for long-term air monitoring stations undergo internal or external audits. Currently, there is not a formal way in which EMSD checks to ensure that the recommendations from the quality assurance plan audits have been implemented. During annual station audits (Section 7.1.3), EMSD auditors should review the quality assurance plan audit reports to ensure that operators have taken corrective actions.

Implementation Item 7:2 EMSD auditors will check that corrective actions associated with quality assurance audits are implemented.

The Monitoring Requirement and Equipment Technical Specification section of the AMD and associated tool box (Alberta Environment and Parks, 2016a), outlines the minimum requirements for air monitoring methods and specifications. Some changes in instrument specifications and operation best practices may not be covered by the minimum requirements outlined in the directive. EMSD should work towards ensuring provincial consistency in instrument specifications, especially where differing practices are known to affect the collected data.

Implementation Item 7:3 Catalogue variable instrument specifications with no required setting identified in the Air Monitoring Directive. For variables that are known to affect the

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data collected, identify the most appropriate setting and ensure that the setting is used for all long-term air monitoring.

Implementation Item 7:4 Compare the station operation requirements within NAPS station operation guidelines with the requirements outlined in the Air Monitoring Directive and document any differences and/or areas of equivalence.

The quality system for a particular monitoring station includes multiple components from station operation to data submission. Collation of performance on all these components will help to highlight stations that require attention. Therefore, a set of performance criteria will be developed and could include measures of data completeness and data quality based on annual screening of data (Section 7.2) and audit results (Section 7.1.3). The outcome of the station performance assessment could be used to improve SOPs or to inform targeted training of personnel at long-term monitoring stations.

Implementation Item 7:5 Develop a process to implement an annual assessment of station performance for long-term air monitoring stations.

7.1.3 Ambient Air Station Audit Program

Qualitative (administrative) and quantitative (performance–based) audits are conducted by EMSD on ambient air monitoring stations and equipment throughout the province. The objective of the program is to ensure that the monitoring of ambient air quality in Alberta is performed in accordance with the requirements of the AMD. These requirements must be met for the data submitted to AEP (also posted publicly) to be considered quality assured. Many stations are tied to AEP or AER industrial approvals, and therefore there is a regulatory aspect to the audits.

Airshed operated monitoring stations, which are part of the core long-term air monitoring network, are audited annually. Industry-operated monitoring stations, are audited approximately once every three years, depending on the availability of audit staff. Audit reports outlining items that need operator attention are sent to the person responsible for station operation and a number of internal AEP staff including the Director of Airshed Sciences, the regional air specialist, the associated industrial approvals and compliance staff and data management. Usually, the station operator will apply the appropriate corrective action to address the non-compliant issue. This may include removal of data submitted to Alberta's Ambient Air Quality Data Warehouse. Audit disputes, should they arise, are resolved using the formal mechanism outlined in the audit section of AMD (Alberta Environment and Parks, 2016a).

Ambient data from industry-operated near fence monitoring stations are required to be submitted to a central database as of January 1, 2019. In order to ensure these data are of comparable quality to those currently submitted into Alberta's Ambient Air Quality Data Warehouse, the audit frequency for industry-operated stations should be increased to once per year.

Implementation Item 7:6 Increase audits of industry operated stations to once per year to ensure that all data submitted into central database is of comparable quality.

7.1.4 Long-term Deposition Network

The requirements for the siting and operation of deposition monitoring networks are outlined in the station siting and precipitation chemistry sections of the AMD. Station performance for wet deposition stations is assessed annually based on field operations. The findings are communicated to the monitoring manager and discussed with the operator, with a focus on improving performance where needed. Interim SOPs for wet deposition monitoring have been communicated with station operators, but need to be formalized. For dry deposition, SOPs will be developed as a part of the deployment of new monitoring.

Implementation Item 7:7 Develop standard operating procedures for wet and dry deposition monitoring program.

7.1.5 Complementary and Focused Study Monitoring

Several portable air monitoring platforms using traditional and compact air monitoring technologies are currently under evaluation by EMSD (Section 5.5). For the platforms that meet monitoring objectives for core long-term monitoring or focused studies, SOPs will be determined. For example, procedures to calibrate the Airpointer are currently under development.

Implementation Item 7:8 Develop standard operating procedures for portable air monitoring platforms prior to their deployment for routine or focused monitoring studies in Alberta.

ESMD deploys integrated monitoring methods for focused studies, including canisters, polyurethane foam (PUF) samplers, and filter samplers. Several data quality issues have been noted in previous studies, including leaks in blanks. Therefore, EMSD will develop SOPs for integrated monitoring deployed in focused studies to improve data quality. Furthermore, EMSD will ensure that integrated samples are analyzed at laboratories with appropriate accreditation for the parameter of focus.

Implementation Item 7:9 Develop standard operating procedures for integrated monitoring methods deployed during focused studies.

Implementation Item 7:10 Ensure that laboratories used to analyze samples collected during focused studies have the appropriate accreditation as recognized by the department.

7.2 Data Quality Control and Assurance

For the long-term air monitoring network, a report commissioned by the Government of Alberta (Alberta Environment, 2012) makes recommendations to improve data quality standards through data verification and validation. Preliminary verification and various levels of data validation conducted on monthly or shorter timelines have been incorporated into the Data Quality Section of the AMD (Alberta Environment and Parks, 2016a) and are currently performed by data providers such as Airshed organizations or third-party firms hired by Airshed organizations. In the future, the new Ambient Air Quality Data Warehouse will be designed to automatically check preliminary verification and data validation on monthly data (Section 7.3.1). The report also recommends an annual data review to provide context and identify suspect data that is not evident on daily or monthly timescales. EMSD generates a number of annual standard reports (Section 7.4); routine annual review prior to the analysis and interpretation of these data will provide additional verification.

Implementation Item 7:11 Develop a set of criteria and process to review air quality data provided to the central data management system annually.

For deposition, laboratory analysis of precipitation samples are reported to EMSD on a monthly basis. These data undergo a number of validation steps as outlined in the precipitation chemistry data handling manual AMD (Alberta Environment and Parks, 2016b).

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Implementation Item 7:12 Ensure the timely preliminary verification and validation of laboratory analysis results from samples collected at long-term deposition monitoring stations.

7.3 Data Availability

7.3.1 Quality Controlled Air Quality and Deposition Data

Ambient air quality data from the long-term network is currently available through a central data management system operated by the Government of Alberta called Alberta's Ambient Air Quality Data Warehouse (airdata.alberta.ca). The system contains data from over 70 long-term and complementary ambient air monitoring stations operated by AEP, Airshed organizations and some industries. Data providers submit quality controlled one-hour average data to the Ambient Air Quality Data Warehouse, usually within one month following the month the data was collected. The system also contains some data from complementary monitoring such as data from passive and integrated monitoring sites.

As of January 1, 2019, electronic submission to a centralized data management system will be required by the AMD for both industrial monitoring data (industrial ambient, source, and others) and the above-mentioned Alberta ambient air quality monitoring data (Alberta Environment and Parks, 2016a). Along with the monitoring data, some reports (e.g., calibration reports) will also to be submitted to the data management system. These new requirements will allow eventual public access to all ambient and industrial air quality data collected by AEP, Airshed organizations and industry. The current Ambient Air Quality Data Warehouse does not have the capacity to accept and store these additional datasets and reports. The system is being operated in an "as is" state pending the development of a replacement ambient air data system.

A system for accepting electronic data from industry is expected to be in place before January 2019 with data provided the month following the month that it is collected. This work is being done in phases to ensure the requirements of the AMD are met. EMSD will support and contribute to this development by providing knowledge of the existing data sets, data submission requirements, required data validation steps, and data user requirements. Furthermore, EMSD will ensure that the data collected in the Ambient Air Quality Data Warehouse includes data and metadata that will be accessible and useful in evaluating data quality (Implementation Item 7:11), station performance (Implementation Item 7:5), and in interpreting measurements (Implementation Item 7:21). EMSD will continue to provide support during the development of the new Ambient Air Quality Data Warehouse and also encourage the requirement that data remains publically accessible. Relevant stakeholders, including Airshed organizations and industry, will also have the opportunity to provide input during the development of the new provincial air data management system and subsequent data access portal.

Implementation Item 7:13 Support and contribute to the development or replacement of the new Ambient Air Quality Data Warehouse. The development of a new Ambient Air Quality Data Warehouse is being led by the Policy and Planning division.

Implementation Item 7:14 Ensure that data necessary for validation and assessment of long-term air monitoring station performance are included in the Ambient Air Quality Data Warehouse.

Traditionally, wet deposition data have been stored internally at EMSD in a variety of file formats. EMSD has developed and populated an in-house database with the historical wet deposition data. EMSD will continue to store new wet deposition data to be collected into this database. This data will also be provided to the new Ambient Air Quality Data Warehouse.

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Implementation Item 7:15 Ensure the timely population of wet deposition data and metadata into precipitation chemistry database.

Currently, deposition and focused study data and associated metadata collected by EMSD are stored on an internal network drive and are available upon request. Occasionally, data from focused studies are published on the department website, but this is not done consistently for all focused studies. Furthermore, the data collected during focused studies are stored internally, but are not housed in an easily searchable database. In the future, the focused study and deposition data should be submitted annually into the Ambient Air Quality Data Warehouse with a public portal that will enable the user to search and retrieve the data.

Implementation Item 7:16 Ensure that all air monitoring and deposition data collected by EMSD (e.g., long-term deposition, focused studies) are housed in the Ambient Air Quality Data Warehouse and are publicly available.

7.3.2 Near-real Time Air Quality Data

Near-real time air quality data collected by AEP, Airshed organizations and some industries is provided to a central web service operated by the Alberta Government. This web service allows the public to access current air quality conditions via several websites and mobile applications developed by internal and external organizations. Data is accessed from this web service for display on websites operated by AEP (airquality.alberta.ca), Environment and Climate Change Canada (ECCC, weather.gc.ca/airquality), the U.S. EPA AirNow (airnow.gov) and individual Airshed organizations. The web service contains one-hour averages of air quality and meteorological parameters and also the calculated Air Quality Health Index (AQHI) updated each hour. Data is generally available within 30 minutes following the measurement hour. The web service and the public communication mechanisms (e.g. websites and apps) help the public to make day-to-day decisions to protect their health when air quality is poor. These data are also used by provincial health services to issue air quality advisories and ECCC to issue special air quality statements.

EMSD is responsible for the implementation of the AQHI protocol, and meets regularly with Alberta Health and ECCC to update the protocol as required. EMSD monitors incoming data to ensure its validity. EMSD also contacts data providers to verify questionable data, notifies Alberta Health and ECCC of invalid data and removes such data from the Alberta near-real time ambient air quality data system.

Implementation Item 7:17 Continue to implement AQHI protocol: verify near-real time data, remove invalid data from near-real time air quality data system, and notify Alberta Health and Environment and Climate Change Canada of invalid data.

In areas affected by wildfire smoke, temporary air quality monitoring is deployed to provide data for decision making and to inform the public. Providing these data to stakeholders in near-real time will facilitate distribution and access.

Implementation Item 7:18 Work towards having portable monitoring data collected during forest fire season or other events available online in near-real time to stakeholders.

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7.4 Evaluation and Reporting

7.4.1 Standard Air Quality Reporting

EMSD will report annually against air quality benchmarks established by Canadian Ambient Air Quality Standards and Land-use Framework air quality management frameworks (e.g. Lower Athabasca Regional Plan, and South Saskatchewan Regional Plan). For these reports, air quality metrics are calculated from the data and compared against established thresholds. Based on these comparisons, management levels are assigned for a given region of the province. These management levels are used by other departments at AEP (Policy and Planning Division, Operations Division) to initiate management plans, where needed. As part of the management plans, there may be a need to investigate cause(s) of exceedances, where EMSD may provide support by designing a focused study, collecting samples and/or analyzing data.

Implementation Item 7:19 Complete and release annual CAAQS reports and Status of Air Quality Reports required by land-use regional plans.

7.4.2 Reporting on Environmental Condition

Reporting on environmental condition is a requirement of the Chief Scientist of Alberta Environment and Parks (EPEA Sec 15.1 (2)(d)(e)). As such, the Chief Scientist is required to develop a public reporting schedule for reporting on the Condition of the Environment (CoE) for all media (air, water, land, biodiversity and climate change). The reporting schedule will establish the cycle or intervals when the public can expect reporting on key environmental indicators.

Indicators for air quality, as well as other media, will be selected to report on the CoE for the province. These indicators will be selected using input from subject matter experts and stakeholders at the appropriate stages of development and will be publicly reported including supporting information such as historical trends and known sources of pollution. A website for environmental condition reporting will be updated annually and indicators may be added or modified as required.

Implementation Item 7:20 Contribute to a website for condition of environment reporting by providing indicators for air quality.

Implementation Item 7:21 Update indicators for air quality annually on the CoE web site.

Environment condition reporting will include indicators for air quality from the long-term air monitoring network. The long-term deposition monitoring network is undergoing a number of improvements (Section 3.2). When these improvements have been made, indicator(s) for deposition will be developed and routinely reported on. This will include information on long-term trends in wet deposition from historical records.

Implementation Item 7:22 Develop indicator(s) for deposition and include in environmental condition reporting.

Implementation Item 7:23 Using historical data collected at wet deposition monitoring stations, evaluate and report on possible long-term trends.

7.4.3 Additional Air Quality and Deposition Reporting

In addition to the routine annual reporting, EMSD performs in depth investigations of specific topics such as validation of emerging technologies, assessments of cumulative effects, investigations of exceedances

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of standards/triggers, and significant issues. EMSD will make the results of these investigations available to stakeholders and the public. Where appropriate, these studies will be published in peer-reviewed scientific journal publications. Other results may be published in investigative, technical, and synthesis reports; for more complex reports, EMSD will seek external peer review. The peer review of scientific journal articles and reports will ensure that the data and evaluation methods are scientifically sound and credible. These scientific reports and articles will be accompanied by knowledge translation pieces (e.g., web stories or fact sheets) in order to make the technical results more accessible to the general public.

The routine analysis of data collected using integrated monitoring for informing air quality management or identifying sources requires clear information needs to ensure the appropriate approach is chosen. EMSD will proactively initiate analysis of these data (if available) when the need arises (e.g., CAAQS exceedance, development of management actions) in close collaboration with the necessary agencies (e.g., AEP Policy, AEP Operations, Airshed Organizations).

Implementation Item 7:24 Analyze and report on previously unpublished historical data collected using complementary and long term air and deposition monitoring. Priority should be given to analysis and reporting that will best inform existing or planned policy.

8 Implementation of the 5-year Monitoring Plan

Throughout the 5-year Monitoring Plan, implementation items have been identified related to monitoring, data, evaluation, and reporting. These implementation items are summarized in the sections below and are sorted according to the timelines that EMSD expects to address them. Items to be accomplished in later years tend to require more resources, are dependent on other projects, and/or are considered to be lower priority. On an annual basis EMSD creates work plans in order to map out the work to be done in the following year. As a part of this planning process, EMSD will review the 5-year Monitoring Plan implementation items and determine the status of the items. New implementation items may be identified and some items may be considered no longer relevant. Through the planning process, EMSD will determine which implementation items should be addressed in the subsequent fiscal year. The resources required and implementation timeframe (start and end date) for specific implementation items will be determined through EMSD's annual project planning process. Some implementation items will require collaboration with partners such as Airshed, AEP, ECCC, or other organizations.

Implementation Item 8:1 Review implementation items annually and assess as complete, ongoing, not started, or no longer relevant. New implementation items may be added to the implementation table. Update Implementation Plan based on this review.

Following the annual implementation review process, EMSD will communicate the status of the 5-year Monitoring Plan implementation with external stakeholders and health and ecosystem subject matter experts at the Government of Alberta. For implementation items which involve direct stakeholder collaboration, stakeholders may be included in the project planning process.

Implementation Item 8:2 Engage with stakeholders and health and ecosystem subject matter experts regarding the status of the 5-year Monitoring Plan implementation annually.

The development of a new 5-year Monitoring Plan will be initiated in September 2022. As a part of the new 5-year Monitoring Plan development, some of the long-term implementation items related to network evaluation methods may be implemented in order to gain improved understanding of the network.

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Furthermore, information gained from the implementation of the current 5-year Monitoring Plan will be used to inform next steps. Implementation items that have not been completed will also be considered for inclusion in the new plan if they are still relevant.

Implementation Item 8:3 Develop the next five-year plan based on information gained and needs identified during implementation of the current plan.

Implementation items outlined in this 5-year Monitoring Plan will be reviewed and updated based on ongoing collaborative input from the science community, stakeholders and policy makers. In this regard, it is recognized that the plan will need to adapt to new information needs and air quality and deposition issues that may arise over the next five years.

8.1 Ongoing implementation items

Ongoing implementation items (Table 7) are items that EMSD is currently working on and will continue to work on routinely over the next five years. These items are often implemented on a cyclical basis, for example, through annual reporting or monthly data submissions. The items may also be implemented as opportunities to modify the monitoring network arise.

Table 7: Ongoing implementation items

Implementation Item #	Description
Implementation Item 3:10	Work within the distributed air monitoring network to identify and reduce redundancies, and reallocate resources to fill gaps and implement super sites, where possible.
Implementation Item 5:2	Continue collaborative participation in the NAPS program.
Implementation Item 7:12	Ensure the timely preliminary verification and validation of laboratory analysis results from samples collected at long-term deposition monitoring stations.
Implementation Item 7:15	Ensure the timely population of wet deposition data and metadata into precipitation chemistry database.
Implementation Item 7:17	Continue to implement AQHI protocol: verify near-real time data, remove invalid data from near-real time air quality data system, and notify Alberta Health and Environment and Climate Change Canada of invalid data.
Implementation Item 7:19	Complete and release annual CAAQS reports and Status of Air Quality Reports required by land-use regional plans.
Implementation Item 7:23	Using historical data collected at wet deposition monitoring stations, evaluate and report on possible long-term trends.
Implementation Item 7:24	Analyze and report on previously unpublished historical data collected using complementary and long term air and deposition monitoring. Priority should be given to analysis and reporting that will best inform existing or planned policy.
Implementation Item 8:1	Review implementation items annually and assess as complete, ongoing, not started, or no longer relevant. New implementation items may be added to the implementation table. Update Implementation Plan based on this review.

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Implementation Item 8:2	Engage with stakeholders and health and ecosystem subject matter experts regarding the status of the 5-year Monitoring Plan implementation annually.

8.2 Short term implementation items

Short term implementation items (Table 8) are items that EMSD has already started to work on or plans to work on within this fiscal year. These implementation items are considered high priority and/or do not take many resources (e.g., working hours or capital budget). They also do not depend on the completion of other implementation items.

Table 8: Short term implementation items

Implementation Item #	Description
Implementation Item 3:3	Station names, numbers, and classifications outlined in this plan will be finalized and used consistently in all EMSD reporting.
Implementation Item 3:4	Examine parameters monitored at current long-term monitoring stations and identify stations that do not meet minimum monitoring criteria for their identified classification.
Implementation Item 3:7	For the top five gaps in community monitoring, examine if there is existing or planned complementary monitoring that meets the community monitoring objective.
Implementation Item 3:13	Discontinue wet deposition monitoring stations located in urban and suburban areas.
Implementation Item 3:16	Deploy precipitation gauges to permit sample collection efficiency calculations and reduce uncertainty in determining precipitation depth. Deployment should be prioritized based on the availability of nearby gauges.
Implementation Item 4:1	Focus studies will be identified, designed, and performed using the process described in this plan.
Implementation Item 5:1	Finish analysis of passive sampler networks for remaining Airshed organizations (LICA, WBEA, PRAMP and PAZA) and communicate results to the Airshed. Continue to support all Airshed organizations in implementing network recommendations.
Implementation Item 5:6	Review literature for and evaluate the performance of Airpointer and other commercially available portable air monitoring platforms (Vaisala AQT420, Purple Air Model PA-II, Aeroqual AQM65, Aeroqual AQS1, Aeroqual AQY1, etc.), including those equipped with compact sensors, for use in long-term and focused monitoring.
Implementation Item 5:7	Design, build, test and evaluate an integrated portable air monitoring platform equipped with compact sensors (“micro-station”).
Implementation Item 5:8	Evaluate and report on the usefulness of satellite data to assess spatial and temporal variation of NO_2, SO_2, CO, PM, and/or NH_3 through literature review and data analysis.
Implementation Item 6:1	Evaluate current network for monitoring and assessing impacts of wildfire smoke, and suggest network improvements.
Implementation Item 6:2	Identify stations which are most likely to exceed the future CAAQS based on current ambient conditions and, possibly, predicted

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Implementation Item #	Description
	changes in emissions. Initiate focused study and/or adjust the long-term network based on this evaluation as necessary.
Implementation Item 6:5	Identify stations likely to experience improved air quality due to the phase-out of coal by power plants, and design a focused study to evaluate potential changes in air quality.
Implementation Item 7:13	Support and contribute to the development or replacement of the new Ambient Air Quality Data Warehouse. The development of a new Ambient Air Quality Data Warehouse is being led by the Policy and Planning division.
Implementation Item 7:14	Ensure that data necessary for validation and assessment of long-term air monitoring station performance are included in the Ambient Air Quality Data Warehouse.
Implementation Item 7:20	Contribute to a website for condition of environment reporting by providing indicators for air quality.

8.3 Medium term implementation items

Medium term implementation items (Table 9) require more resources and may be addressed over the next five years through annual project plans. During the EMSD project planning process, these items will be considered and items deemed higher priority will be included in project plans. The schedule of implementation for some of these items will depend on available resources.

Table 9: Medium term implementation items

Implementation Item #	Description
Implementation Item 3:5	Identify optimal location(s) and parameter(s) to be monitored at one or more provincial air monitoring super site(s).
Implementation Item 3:6	Identify redundancies and extraneous monitoring within the existing air quality network.
Implementation Item 3:8	Evaluate the need, possible monitoring sites, and data requirements for additional Background regional monitoring in northwestern Alberta.
Implementation Item 3:9	Evaluate the need, possible monitoring sites, and data requirements for additional Intermediate and Hot Spot regional monitoring in southern and central Alberta.
Implementation Item 3:11	Review results from complementary monitoring evaluations and determine whether they can be used to address gaps in the core long-term air quality network.
Implementation Item 3:12	Determine the feasibility of including total phosphorus and total nitrogen in the list of analytes for Alberta wet deposition samples to facilitate potential eutrophication assessment.
Implementation Item 3:15	Conduct on-site visit and complete site information form for all of the wet deposition monitoring stations.
Implementation Item 3:17	Review dry deposition monitoring methods; select and deploy suitable monitoring equipment at select sites.

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Implementation Item #	Description
Implementation Item 3:19	identify appropriate deposition monitoring sites within the Grassland and Foothills natural region. Consider redeploying existing monitoring and/or reinitiating historical deposition monitoring sites in these areas.
Implementation Item 3:21	Compare data collected at Fort Chipewyan and Kananaskis deposition stations to background deposition monitoring data in neighboring jurisdictions to ensure the station is not significantly impacted by local sources and thus can act as the provincial background deposition monitoring station.
Implementation Item 5:3	Develop or adopt and communicate a standard operating practice for the transport and deployment of integrated samples such as VOCs canisters.
Implementation Item 5:4	Develop or adopt and communicate a guidance document on how best to select the type of integrated samples and analysis suites to best answer a monitoring question.
Implementation Item 5:5	Establish criteria to determine whether regulatory ambient air monitoring stations should be incorporated into the core long-term network.
Implementation Item 5:9	Review and select bulk precipitation samplers that could be deployed to remote areas of Alberta. Co-locate selected samplers with event samplers and examine comparability.
Implementation Item 5:10	Work within the construct of the EMSD Memorandum on Citizen Science to design and implement a pilot citizen science air monitoring study to address an identified monitoring gap.
Implementation Item 6:3	Conduct a literature review and design a focused study to monitor NH_3 in cities and near sensitive ecosystems in Alberta.
Implementation Item 6:4	Review and evaluate “true NO_2” monitoring methods and collaborate with Alberta Airshed organizations and the National Air Pollution Surveillance community to determine if “true NO_2” monitoring should be adopted in Alberta.
Implementation Item 6:7	Support the implementation of the provincial odour management policies through monitoring, evaluation and literature review.
Implementation Item 7:1	Explore operator training requirements in other jurisdictions for potential implementation in Alberta.
Implementation Item 7:2	EMSD auditors will check that corrective actions associated with quality assurance audits are implemented.
Implementation Item 7:3	Catalogue variable instrument specifications with no required setting identified in the Air Monitoring Directive. For variables that are known to affect the data collected, identify the most appropriate setting and ensure that the setting is used for all long-term air monitoring.
Implementation Item 7:4	Compare the station operation requirements within NAPS station operation guidelines with the requirements outlined in the Air Monitoring Directive and document any differences and/or areas of equivalence.
Implementation Item 7:7	Develop standard operating procedures for wet and dry deposition monitoring program.

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Implementation Item #	Description
Implementation Item 7:8	Develop standard operating procedures for portable air monitoring platforms prior to their deployment for routine or focused monitoring studies in Alberta.
Implementation Item 7:9	Develop standard operating procedures for integrated monitoring methods deployed during focused studies.
Implementation Item 7:10	Ensure that laboratories used to analyze samples collected during focused studies have the appropriate accreditation as recognized by the department.
Implementation Item 7:11	Develop a set of criteria and process to review air quality data provided to the central data management system annually.
Implementation Item 7:16	Ensure that all air monitoring and deposition data collected by EMSD (e.g., long-term deposition, focused studies) are housed in the Ambient Air Quality Data Warehouse and are publicly available.
Implementation Item 7:18	Work towards having portable monitoring data collected during forest fire season or other events available online in near-real time to stakeholders.
Implementation Item 7:21	Update indicators for air quality annually on the CoE web site.
Implementation Item 7:22	Develop indicator(s) for deposition and include in environmental condition reporting.
Implementation Item 7:23	Using historical data collected at wet deposition monitoring stations, evaluate and report on possible long-term trends.

8.4 Long term implementation items

Long-term implementation items (Table 10) may be initiated but are unlikely to be completed within the next five years due to dependencies on other implementation items and available resources. The items related to improved network evaluation methods may be completed when the new 5-year Monitoring Plan is being developed in 2022. Other items may be considered for inclusion in the implementation table of the next 5-year Monitoring Plan.

Table 10: Long term implementation items

Implementation Item #	Description
Implementation Item 3:1	Reassess areas for regional monitoring considering other relevant pollutant concentrations in addition to NOx and SO2.
Implementation Item 3:2	Revise the criteria used to identify Near Fence monitoring.
Implementation Item 3:14	Examine monitored and modelled data associated with stations located in agricultural areas to assess if these stations meet the provincial deposition monitoring objective.
Implementation Item 3:18	Future deposition suitability assessments should include critical loads for aquatic ecosystems and for eutrophication, if available, and consider the locations of relevant water quality or Regional long term air monitoring sites.
Implementation Item 3:20	Work with ecosystem and water scientists to identify appropriate deposition monitoring sites and design a short term study to evaluate

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Implementation Item #	Description
	the deposition monitoring gap within the large Deposition Hot Spot area located between Edmonton and Fort McMurray.
Implementation Item 6:6	Conduct a literature review and possible analysis of formaldehyde data in Alberta and other jurisdictions (based on satellite and ambient data) to further scope out the importance of this issue in Alberta.
Implementation Item 7:5	Develop a process to implement an annual assessment of station performance for long-term air monitoring stations.
Implementation Item 7:6	Increase audits of industry operated stations to once per year to ensure that all data submitted into central database is of comparable quality.
Implementation Item 8:3	Develop the next five-year plan based on information gained and needs identified during implementation of the current plan.

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Appendix A Supplementary Information for Air Quality Monitoring Network

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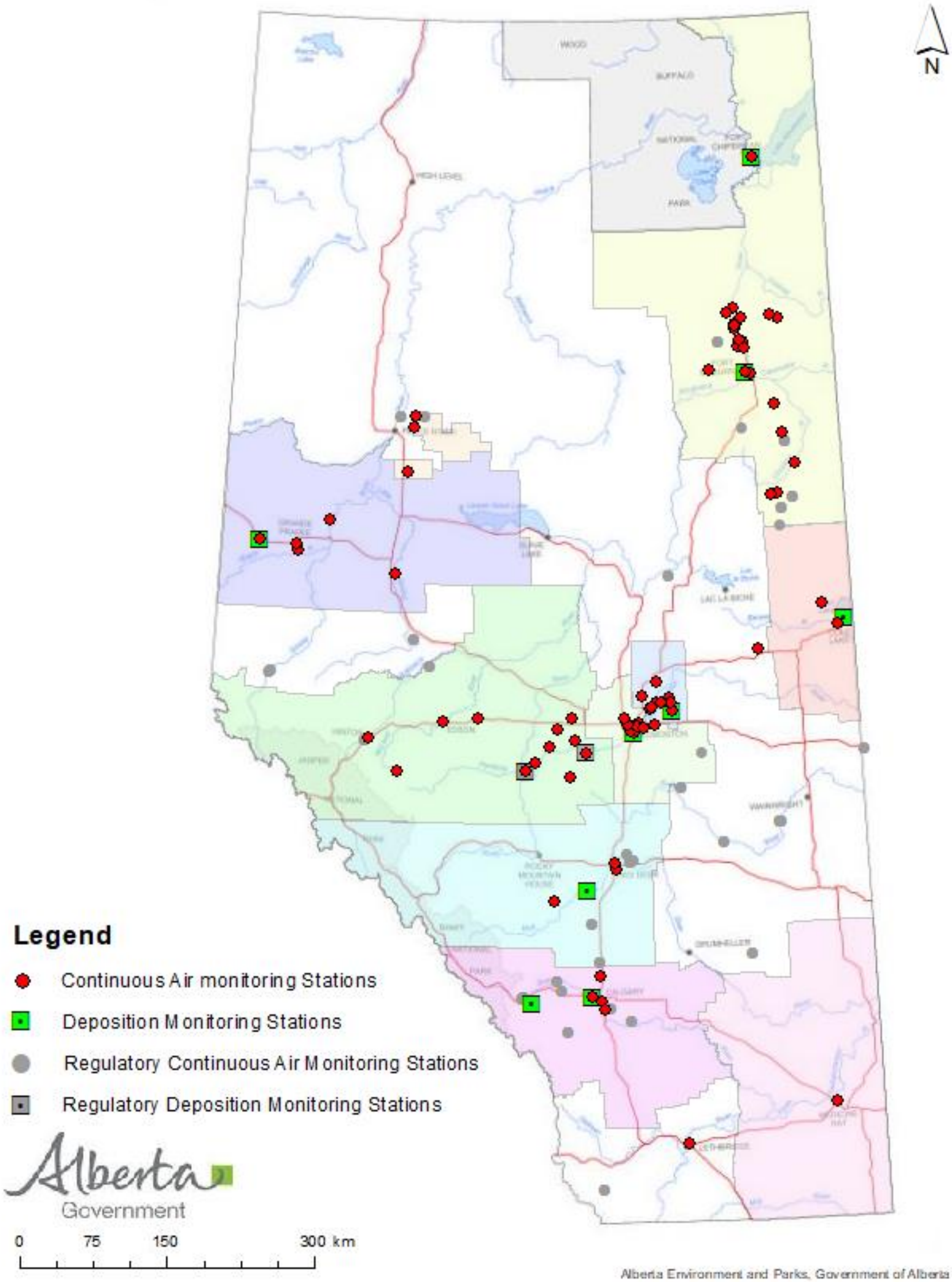

Figure A-1: Air and deposition monitoring in Alberta. Airshed boundaries are indicated by the shaded areas.

Appendix A1 Results of Station Classification

Table A-1 Existing Long-term Air Monitoring Stations Classification

Station Name	Latitude	Longitude	Organizaions	Classification
Airdrie	51.268	-114.038	AEP	Large Population Centre
Anzac	56.449	-111.038	WBEA	Impacted Community
Ardrossan	53.554	-113.144	ACA	Impacted Community
Barge Landing	57.198	-111.600	WBEA	Near Fence
Beaverlodge	55.196	-119.397	PAZA	Small Community
Beverly	53.567	-113.398	ACA	Large Population Centre
Breton	53.090	-114.461	WCAS	Intermediate
Bruderheim 1	53.806	-112.926	FAP	Impacted Community
Buffalo Viewpoint	56.996	-111.593	WBEA	Near Fence
Calgary Central-Inglewood	51.031	-114.009	CRAZ	Large Population Centre
Calgary Northwest	51.079	-114.142	CRAZ	Large Population Centre
Calgary Southeast	50.955	-113.970	CRAZ	Large Population Centre
Caroline	51.947	-114.698	PAMZ	Intermediate
Carrot Creek	53.621	-115.869	WCAS	Intermediate
Cold Lake South	54.414	-110.233	LICA	Impacted Community
Conklin	55.632	-111.079	WBEA	Impacted Community
Crescent Heights	50.049	-110.681	PAS	Large Population Centre
Drayton Valley	53.220	-114.984	WCAS	Impacted Community
Edmonton Central	53.544	-113.499	ACA	Large Population Centre
Edmonton East	53.548	-113.368	ACA	Large Population Centre
Edmonton McIntyre	53.486	-113.465	AEP	Large Population Centre
Edmonton South	53.500	-113.526	ACA	Large Population Centre
Edmonton-Woodcroft	53.564	-113.563	ACA	Large Population Centre
Edson	53.594	-116.396	WCAS	Impacted Community
Elk Island	53.682	-112.868	FAP	Intermediate
Evergreen Park	55.118	-118.765	PAZA	Near Fence
Firebag	57.237	-110.898	WBEA	Near Fence
Fort Chipewyan	58.709	-111.175	WBEA	Impacted Community
Fort Hills	57.349	-111.640	WBEA	Hot Spot
Fort McKay South	57.149	-111.642	WBEA	Hot Spot
Fort McKay-Bertha Ganter	57.189	-111.641	WBEA	Hot Spot
Fort McMurray-Athabasca Valley	56.734	-111.390	WBEA	Large Population Centre
Fort McMurray-Patricia McInnes	56.751	-111.477	WBEA	Large Population Centre
Fort Saskatchewan	53.699	-113.223	FAP	Impacted Community
Genesee	53.302	-114.200	WCAS	Hot Spot

Station Name	Latitude	Longitude	Organizaions	Classification
Gibbons	53.827	-113.327	FAP	Impacted Community
Gold Bar	53.549	-113.415	ACA	Large Population Centre
Henry Pirker	55.177	-118.808	PAZA	Large Population Centre
Hinton	53.427	-117.544	WCAS	Impacted Community
Horizon	57.304	-111.739	WBEA	Near Fence
Janvier	55.903	-110.748	WBEA	Small Community
Lamont County	53.760	-112.880	FAP	Intermediate
Lethbridge	49.716	-112.801	AEP	Large Population Centre
Lower Camp	57.027	-111.501	WBEA	Near Fence
Lower Camp Met Tower	57.033	-111.506	WBEA	Near Fence
Mackay River	56.779	-112.089	WBEA	Near Fence
Mannix	56.968	-111.482	WBEA	Near Fence
Maskwa	54.605	-110.453	LICA	Near Fence
Meadows	53.530	-114.636	WCAS	Intermediate
Mildred Lake	57.050	-111.564	WBEA	Near Fence
Muskeg River	57.249	-111.509	WBEA	Hot Spot
Power	53.633	-114.420	WCAS	Intermediate
Range Road 220	53.752	-113.126	FAP	Impacted Community
Red Deer Lancaster	52.241	-113.765	PAMZ	Large Population Centre
Red Deer Riverside	52.299	-113.794	PAMZ	Large Population Centre
Redwater	53.952	-113.106	FAP	Impacted Community
Reno	55.869	-117.056	PRAMP	Local Issues
Ross Creek	53.716	-113.200	FAP	Impacted Community
Scotford (Temporary)	53.757	-113.029	FAP	Near Fence
Sherwood Park	53.532	-113.321	ACA	Large Population Centre
Smoky Heights	55.403	-118.281	PAZA	Intermediate
St. Albert	53.627	-113.612	ACA	Large Population Centre
St. Lina	54.216	-111.502	LICA	Intermediate
Steeper	53.132	-117.091	WCAS	Background
Stony Mountain	55.621	-111.173	WBEA	Intermediate
Surmont	57.240	-110.936	WBEA	Near Fence
Three Creek #842	56.275	-116.981	PRAMP	Local Issues
Three Creek #986	56.376	-116.941	PRAMP	Local Issues
Tomahawk	53.372	-114.769	WCAS	Intermediate
Valleyview	54.940	-117.215	PAZA	Intermediate
Violet Grove	53.144	-115.126	WCAS	Intermediate
Wagner2	53.424	-114.375	WCAS	Hot Spot
Wapasu	57.259	-111.039	WBEA	Near Fence
Waskow ohci Pimatisiwin	57.184	-111.639	WBEA	Hot Spot

Appendix A2 Results of Gap Analysis for Communities

Table A- 2 Gap analysis score for communities with population ≥ 500 with no existing monitoring stations

Total Score	Regional Monitoring Classification[10]	Communities	A. Population	B. Distance to nearest station	C. Emissions	D. Modelled/Satellite inferred ambient concentration
29.0	Intermediate Class III	Lloydminster	9	8	7	5.0
28.3	Hot Spot	Cochrane	9	3	8	8.3
27.7	Intermediate Class III	Brooks	8	7	6	6.7
27.3	Intermediate Class III	Camrose	9	6	6	6.3
27.0	Hot Spot	Olds	7	4	8	8.0
27.0	Intermediate Class I	High Level	5	10	9	3.0
26.3	Intermediate Class III	Whitecourt	7	5	8	6.3
26.0	Intermediate Class III	Forestburg	2	8	10	6.0
25.3	Intermediate Class II	High River	8	4	7	6.3
25.0	Hot Spot	Leduc	10	3	5	7.0
25.0	Hot Spot	Drumheller	7	7	6	5.0
24.7	Intermediate Class II	Taber	7	5	7	5.7
24.0	Hot Spot	Rocky Mountain House	6	5	7	6.0
24.0	Intermediate Class I	Canmore	8	6	8	2.0
23.7	Hot Spot	Chestermere	9	1	6	7.7
23.7	Intermediate Class III	Didsbury	6	4	8	5.7
23.3	Intermediate Class III	Crossfield	4	2	8	9.3
23.3	Hot Spot	Innisfail	7	3	6	7.3
23.3	Intermediate Class II	Claresholm	5	6	7	5.3
23.3	Intermediate Class III	Stettler	6	6	6	5.3
23.0	Hot Spot	Spruce Grove	10	2	5	6.0

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[10] Regional monitoring areas based on modelled NO_2 and SO_2 concentrations (Figure 5)

Total Score	Regional Monitoring Classification[10]	Communities	A. Population	B. Distance to nearest station	C. Emissions	D. Modelled/Satellite inferred ambient concentration
23.0	Intermediate Class III	Fox Creek	4	6	8	5.0
22.7	Hot Spot	Redcliff	6	1	9	6.7
22.7	Intermediate Class II	Provost	4	9	4	5.7
22.3	Hot Spot	Sylvan Lake	8	2	6	6.3
22.0	Hot Spot	Lacombe	8	2	5	7.0
22.0	Intermediate Class III	Three Hills	5	6	5	6.0
21.7	Hot Spot	Beaumont	9	1	5	6.7
21.7	Hot Spot	Morinville	7	2	6	6.7
21.7	Hot Spot	Strathmore	8	4	3	6.7
21.7	Hot Spot	Ponoka	6	5	5	5.7
21.7	Intermediate Class II	Mannville	2	7	7	5.7
21.7	Hot Spot	Bassano	3	7	6	5.7
21.7	Intermediate Class III	Hanna	4	8	6	3.7
21.7	Intermediate Class III	Slave Lake	6	8	4	3.7
21.3	Intermediate Class III	Carbon	1	6	7	7.3
21.0	Intermediate Class III	Carstairs	5	4	5	7.0
21.0	Intermediate Class I	Wanyandie Flats West Settlement	1	7	8	5.0
21.0	Intermediate Class II	Hardisty	1	8	8	4.0
20.7	Intermediate Class III	Rimbey	4	5	6	5.7
20.7	Intermediate Class II	Vermilion	5	7	4	4.7
20.0	Hot Spot	Devon	6	3	3	8.0
20.0	Hot Spot	Wetaskiwin	8	5	1	6.0
20.0	Intermediate Class II	Pincher Creek	5	6	6	3.0
20.0	Intermediate Class II	Castor	2	8	6	4.0
20.0	Intermediate Class I	Rainbow Lake	2	10	6	2.0
19.7	Intermediate Class III	Okotoks	10	3	1	5.7
19.7	Intermediate Class II	Wainwright	6	8	1	4.7
19.3	Intermediate Class III	Vauxhall	3	6	5	5.3
19.3	Intermediate Class III	Bashaw	2	6	6	5.3

Total Score	Regional Monitoring Classification[10]	Communities	A. Population	B. Distance to nearest station	C. Emissions	D. Modelled/Satellite inferred ambient concentration
19.3	Intermediate Class III	Viking	2	7	6	4.3
18.7	Hot Spot	Calmar	4	3	5	6.7
18.7	Hot Spot	Bowden	3	4	4	7.7
18.7	Intermediate Class III	Killam	2	7	5	4.7
18.3	Hot Spot	Sundre	4	2	7	5.3
18.3	Intermediate Class III	Daysland	2	7	4	5.3
18.0	Intermediate Class II	Fairview	5	1	8	4.0
18.0	Hot Spot	Stony Plain	9	2	1	6.0
18.0	Intermediate Class III	Tofield	4	4	5	5.0
18.0	Intermediate Class II	Bow Island	4	5	5	4.0
17.7	Hot Spot	Wabamun	1	1	10	5.7
17.7	Intermediate Class III	Coalhurst	4	1	7	5.7
17.7	Hot Spot	Penhold	4	2	5	6.7
17.7	Intermediate Class I	High Prairie	4	5	6	2.7
17.3	Intermediate Class II	Turner Valley	4	4	6	3.3
17.3	Intermediate Class III	Morleyville Settlement	1	5	8	3.3
17.3	Intermediate Class III	Irricana	2	4	6	5.3
17.3	Intermediate Class III	Westlock	6	5	1	5.3
17.3	Intermediate Class I	North Zama Settlement	1	10	5	1.3
17.0	Hot Spot	Blackfalds	7	1	2	7.0
17.0	Hot Spot	Thorsby	2	2	6	7.0
17.0	Intermediate Class III	Mundare	2	4	6	5.0
17.0	Hot Spot	Eckville	2	4	5	6.0
17.0	Intermediate Class I	Fort Macleod	5	4	4	4.0
17.0	Intermediate Class III	Vegreville	6	5	1	5.0
17.0	Intermediate Class III	Trochu	2	5	4	6.0
17.0	Intermediate Class II	Vulcan	3	6	2	6.0
17.0	Intermediate Class I	Banff	7	7	1	2.0
17.0	Intermediate Class II	Swan Hills	3	7	5	2.0

Total Score	Regional Monitoring Classification[10]	Communities	A. Population	B. Distance to nearest station	C. Emissions	D. Modelled/Satellite inferred ambient concentration
17.0	Intermediate Class I	Joachim Settlement	1	7	8	1.0
17.0	Intermediate Class II	Consort	1	9	3	4.0
16.7	Intermediate Class III	Bonnyville	6	4	2	4.7
16.7	Intermediate Class II	Elk Point	3	5	4	4.7
16.7	Intermediate Class II	Boyle	2	6	5	3.7
16.3	Intermediate Class III	Legal	2	3	6	5.3
16.3	Intermediate Class III	Delburne	2	4	5	5.3
16.3	Hot Spot	Alix	2	4	5	5.3
16.3	Intermediate Class III	Linden	1	5	5	5.3
16.3	Intermediate Class II	Nanton	4	6	1	5.3
16.0	Hot Spot	Bon Accord	3	1	5	7.0
16.0	Hot Spot	Bentley	2	3	5	6.0
16.0	Hot Spot	Millet	4	5	1	6.0
16.0	Intermediate Class II	Spirit River Settlement	1	5	7	3.0
15.7	Intermediate Class III	Beiseker	1	4	5	5.7
15.7	Intermediate Class III	Barrhead	5	5	1	4.7
15.7	Intermediate Class I	Valleyview	4	2	7	2.7
15.3	Intermediate Class II	Lac La Biche Settlement	1	6	6	2.3
15.3	Intermediate Class III	Sedgewick	2	8	1	4.3
15.0	Intermediate Class II	Coaldale	7	1	1	6.0
15.0	Intermediate Class II	Mariana Settlement	1	6	5	3.0
15.0	Intermediate Class I	Cardston	5	6	1	3.0
15.0	Intermediate Class II	Coronation	2	8	1	4.0
14.7	Intermediate Class II	Kitscoty	2	7	1	4.7
14.7	Intermediate Class II	Grimshaw	4	4	5	1.7
14.3	Intermediate Class III	Onoway	2	2	5	5.3
14.3	Intermediate Class III	Duchess	2	7	1	4.3
14.0	Intermediate Class III	Lamont	3	1	4	6.0
14.0	Intermediate Class I	Manning	2	6	5	1.0

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Total Score	Regional Monitoring Classification[10]	Communities	A. Population	B. Distance to nearest station	C. Emissions	D. Modelled/Satellite inferred ambient concentration
14.0	Background	Grande Cache	5	7	1	1.0
14.0	Intermediate Class II	Oyen	2	8	1	3.0
13.7	Intermediate Class III	Two Hills	3	5	1	4.7
13.7	Intermediate Class II	St. Paul	6	3	1	3.7
13.7	Intermediate Class II	Rycroft	1	5	5	2.7
13.3	Intermediate Class II	Peace River	6	2	2	3.3
13.3	Intermediate Class I	Raymond	5	4	1	3.3
13.3	Intermediate Class III	Mayerthorpe	3	5	1	4.3
13.3	Intermediate Class I	Lesser Slave Lake Settlement	1	6	5	1.3
13.3	Background	Steen River Settlement	1	10	1	1.3
13.0	Background	Boyer Settlement	1	10	1	1.0
13.0	Intermediate Class I	Footner Settlement	1	10	1	1.0
13.0	Background	Tugate Settlement	1	10	1	1.0
12.7	Intermediate Class II	Picture Butte	3	2	3	4.7
12.7	Intermediate Class III	Smoky Lake	2	5	1	4.7
12.7	Intermediate Class I	Magrath	4	4	1	3.7
12.7	Intermediate Class II	Black Diamond	4	4	1	3.7
12.3	Intermediate Class II	Stirling	2	4	3	3.3
12.3	Intermediate Class I	Milk River	2	6	1	3.3
12.3	Intermediate Class III	Acme	1	5	1	5.3
12.3	Intermediate Class II	Stavely	1	6	1	4.3
12.0	Intermediate Class III	Flyingshot Lake Settlement	1	1	7	3.0
12.0	Intermediate Class III	Hythe	2	2	5	3.0
12.0	Background	Fort Vermilion Settlement	1	9	1	1.0
12.0	Background	North Vermilion Settlement	1	9	1	1.0
11.7	Intermediate Class I	Sandy Lake Settlement	1	8	1	1.7
11.7	Intermediate Class I	Wabiskaw Settlement	1	8	1	1.7
11.7	Background	St. Bruno Farm	1	8	1	1.7
11.7	Intermediate Class II	Otauwau Settlement	1	8	1	1.7

Total Score	Regional Monitoring Classification[10]	Communities	A. Population	B. Distance to nearest station	C. Emissions	D. Modelled/Satellite inferred ambient concentration
11.7	Intermediate Class I	Falher	2	2	6	1.7
11.7	Intermediate Class II	Athabasca	1	6	1	3.7
11.7	Intermediate Class II	Athabasca Landing Settlement	1	6	1	3.7
11.7	Intermediate Class II	Marwayne	1	7	1	2.7
11.3	Intermediate Class III	Sexsmith	4	2	3	2.3
11.3	Intermediate Class I	McLennan	2	3	5	1.3
11.3	Intermediate Class I	Wanyandie Flats East Settlement	1	7	1	2.3
11.3	Intermediate Class II	Barnwell	2	4	1	4.3
11.3	Background	Red Earth Settlement	1	7	2	1.3
11.3	Background	Fitzgerald (Smith Landing) Settlement	1	8	1	1.3
11.0	Intermediate Class I	Pelican Settlement	1	7	1	2.0
10.7	Intermediate Class II	Nobleford	2	3	1	4.7
10.7	Intermediate Class III	Lobstick Settlement	1	4	1	4.7
10.7	Intermediate Class III	Clive	1	4	1	4.7
10.7	Intermediate Class I	Foremost	1	6	1	2.7
10.3	Intermediate Class II	Spirit River	2	5	1	2.3
10.3	Intermediate Class III	Victoria Settlement	1	4	1	4.3
10.3	Intermediate Class III	Clyde	1	4	1	4.3
10.3	Background	Atikamisis Lake Settlement	1	7	1	1.3
10.3	Background	Grande Cache Settlement	1	7	1	1.3
10.0	Hot Spot	Caroline	1	2	2	5.0
10.0	Background	Muskeeg-Seepee Settlement	1	7	1	1.0
10.0	Background	Susa Creek Settlement	1	7	1	1.0
10.0	Background	Grande Cache Lake Settlement	1	7	1	1.0
10.0	Background	Victor Lake Settlement	1	7	1	1.0
10.0	Background	Cline Settlement	1	7	1	1.0
9.7	Intermediate Class II	Dunvegan Settlement	1	6	1	1.7
9.3	Hot Spot	Warburg	1	2	1	5.3
9.3	Hot Spot	Spring Lake	1	2	1	5.3

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Total Score	Regional Monitoring Classification[10]	Communities	A. Population	B. Distance to nearest station	C. Emissions	D. Modelled/Satellite inferred ambient concentration
8.7	Intermediate Class III	Alberta Beach	2	1	1	4.7
8.7	Intermediate Class III	Wembley	3	2	2	1.7
8.7	Intermediate Class I	Berwyn	1	5	1	1.7
8.7	Background	Little Buffalo Lake Settlement	1	5	1	1.7
8.3	Intermediate Class II	Peace River Landing Settlement	1	2	2	3.3
8.3	Intermediate Class I	Big Prairie Settlement	1	5	1	1.3
8.3	Intermediate Class I	Heart River and Salt Prairie Settlement	1	5	1	1.3
8.0	Background	Ya-Ha-Tinda Ranch	1	5	1	1.0
7.3	Intermediate Class III	Breton	1	1	1	4.3
7.3	Intermediate Class III	Lac Ste. Anne Settlement	1	1	1	4.3
6.0	Intermediate Class II	Shaftesbury Settlement	1	2	1	2.0

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Appendix B Supplementary Information for Atmospheric Deposition Monitoring Network

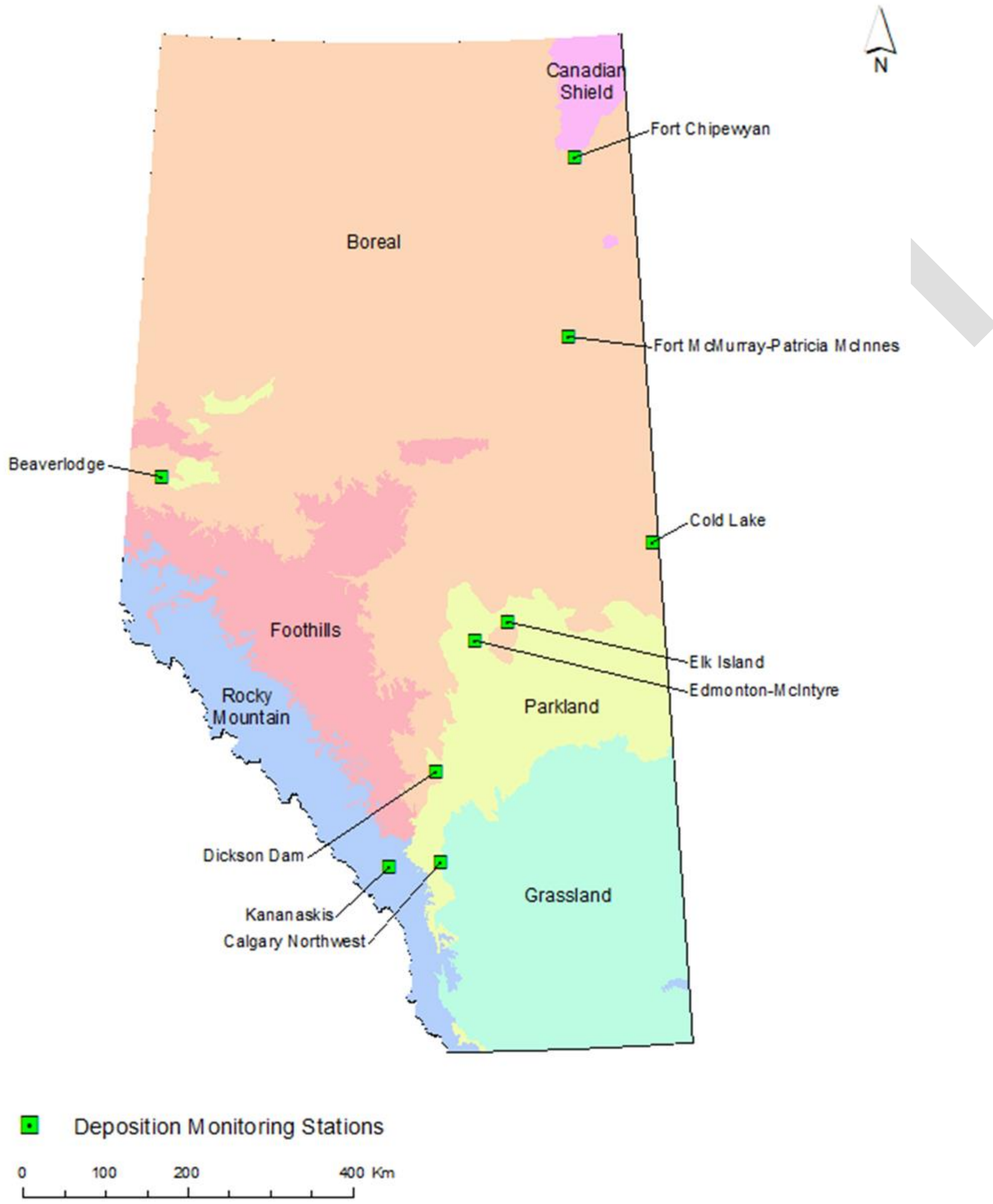

Figure B-1: Alberta natural regions and current wet deposition monitoring stations

Appendix B1 Deposition Monitoring Suitability Evaluation

The various scenarios were examined using different weights for the deposition suitability analysis. Table B-1 summarizes the weights selected for the tests. Scenario 1# included only information on critical loads of acidity and atmospheric deposition of sulphur and nitrogen. The most desirable monitoring locations were in central and northeastern Alberta. The inclusion of access, emissions, and soil monitoring sites (Scenarios 2-5) did not notably change the results at a provincial scale. The final scenario (Scenario #5) included the following criteria and associated weight: critical load for acidity (30%), nitrogen and sulphur deposition (30%), access (10%), emissions (10%), and soil monitoring sites (20%).

Table B-1 Suitability evaluation scenarios and weights applied for base run

Scenario #	Criteria
1	Critical Load (50%), Deposition (50%)
2	Critical Load (40%), Deposition (40%), Access (20%)
3	Critical Load (40%), Deposition (40%), Emissions (20%)
4	Critical Load (35%), Deposition (35%), Access (15%), Emissions (15%)
5	Critical Load (30%), Deposition (30%), Access (10%), Emissions (10%), Soil Monitoring Sites (20%)

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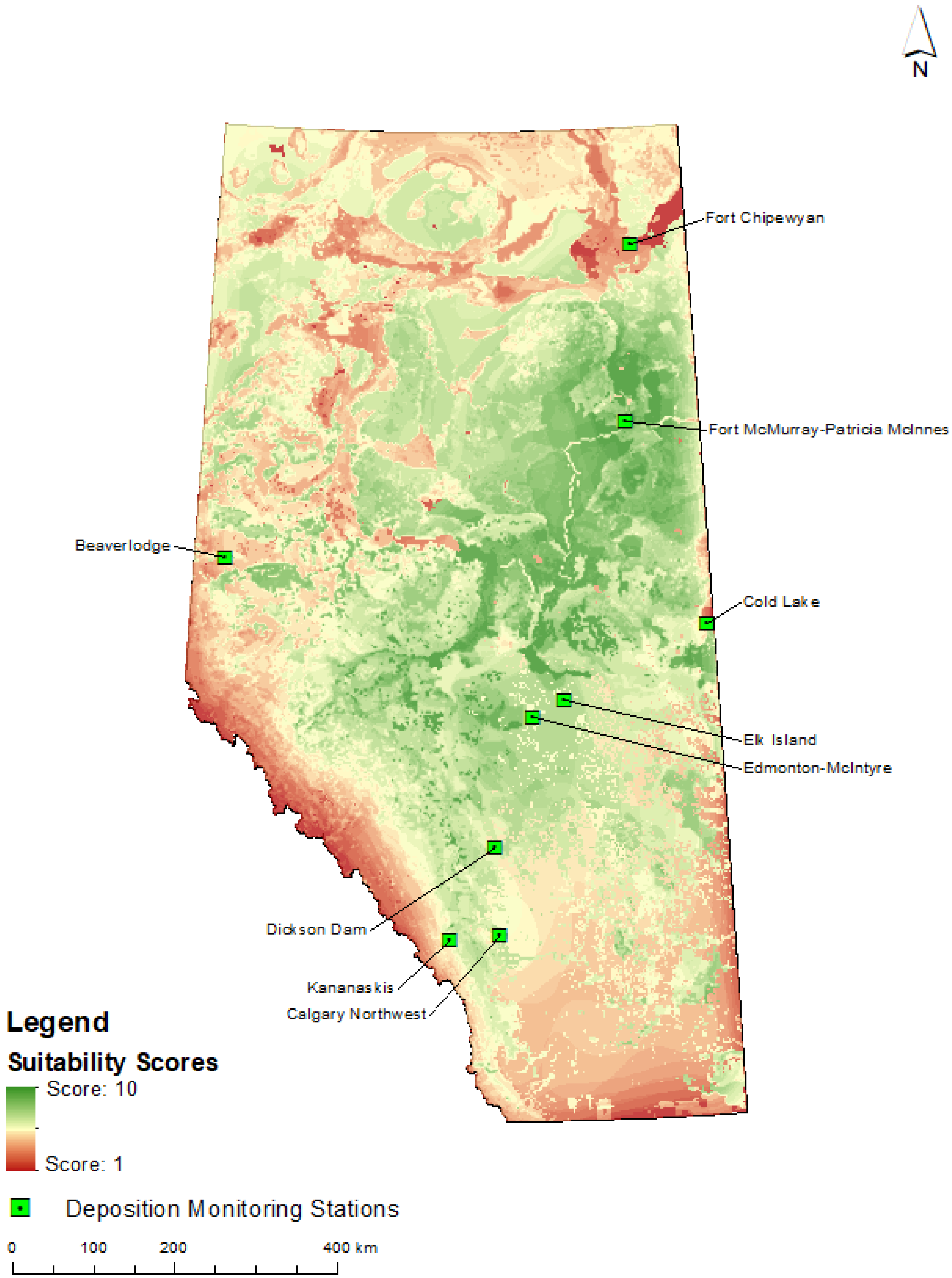

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Figure B-2 Suitability evaluation scenario #1 map

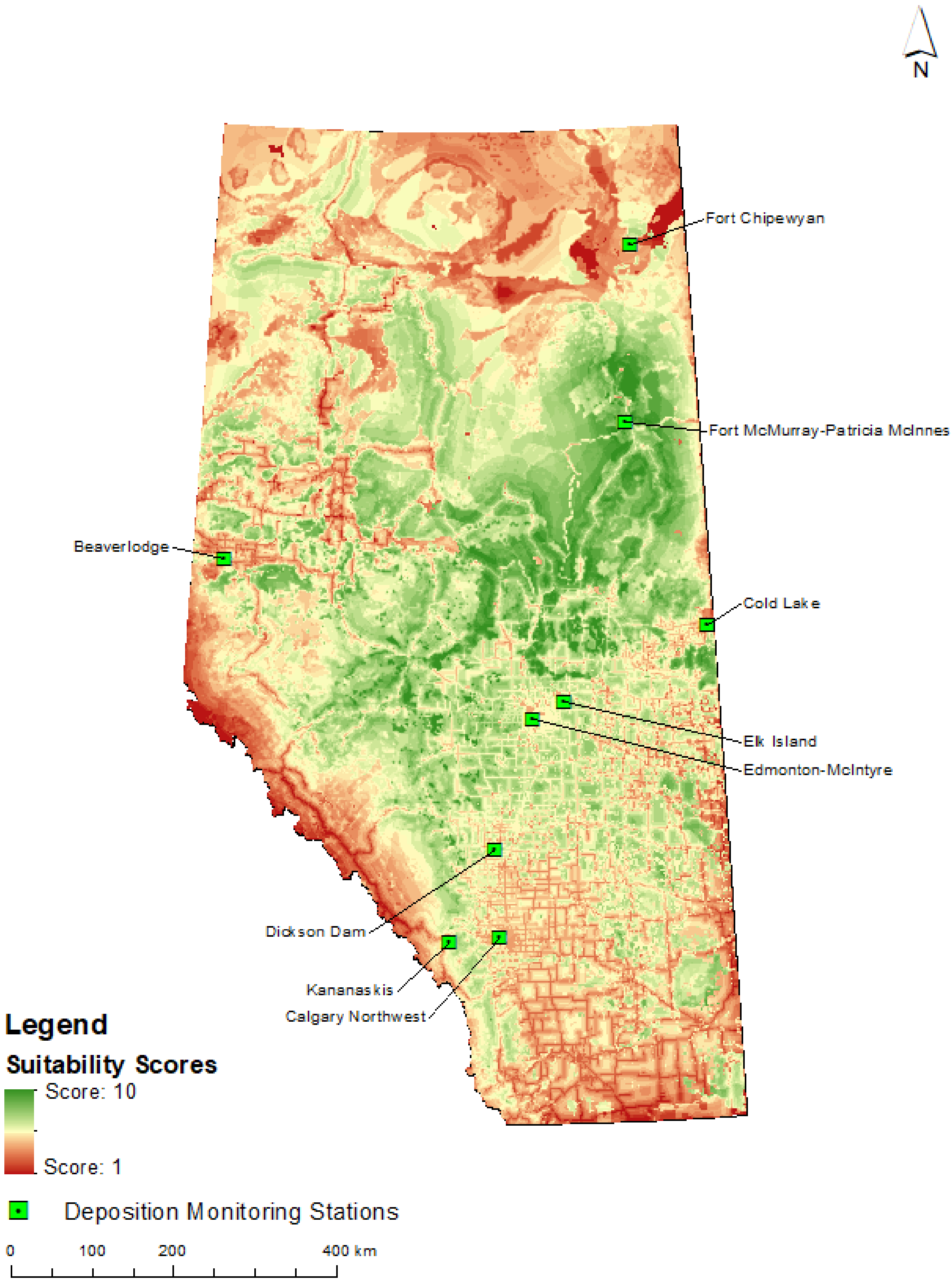
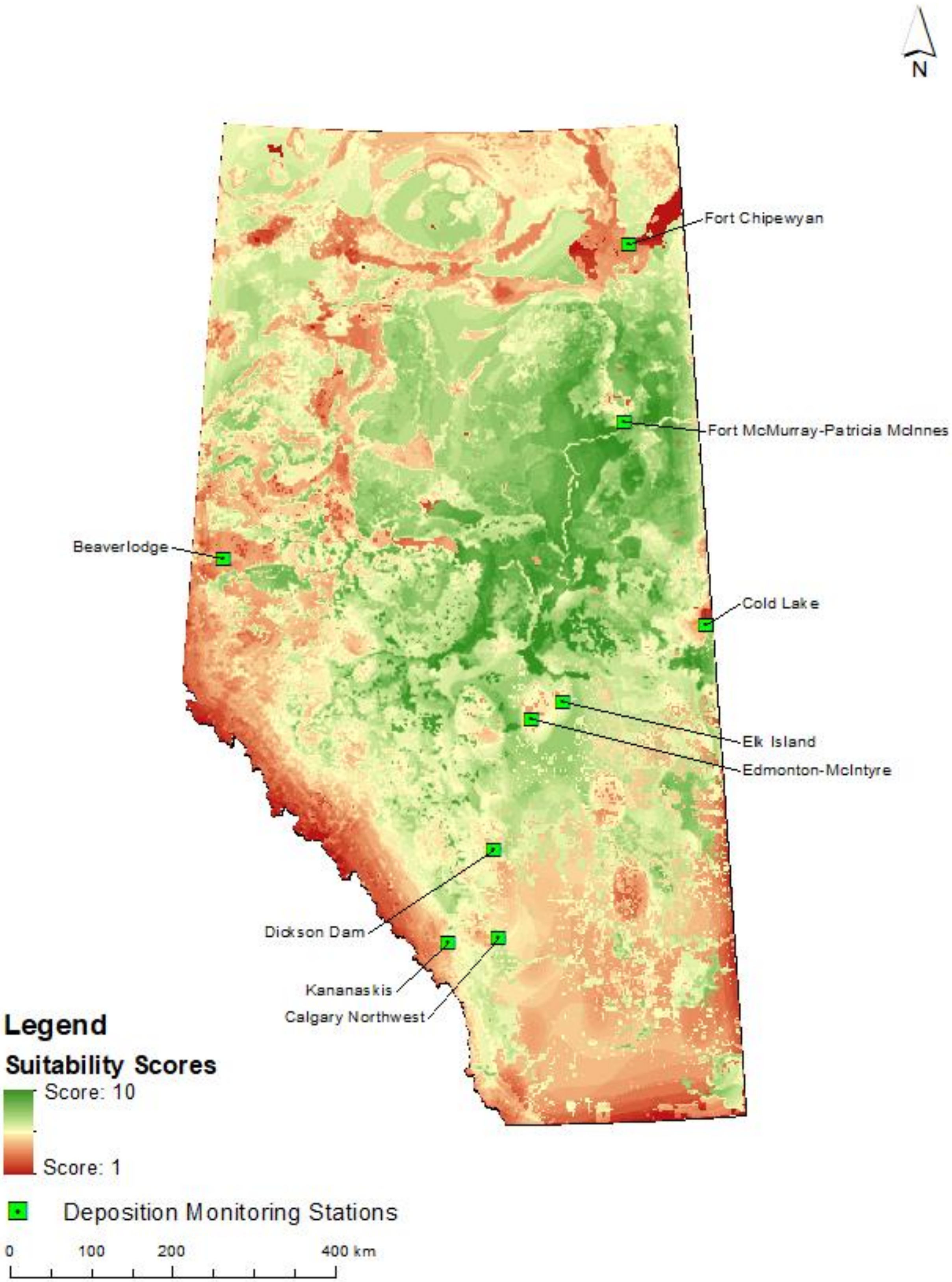


Figure B-3 suitability evaluation scenario #2 map



2285 **Figure B-4 suitability evaluation scenario #3 map**

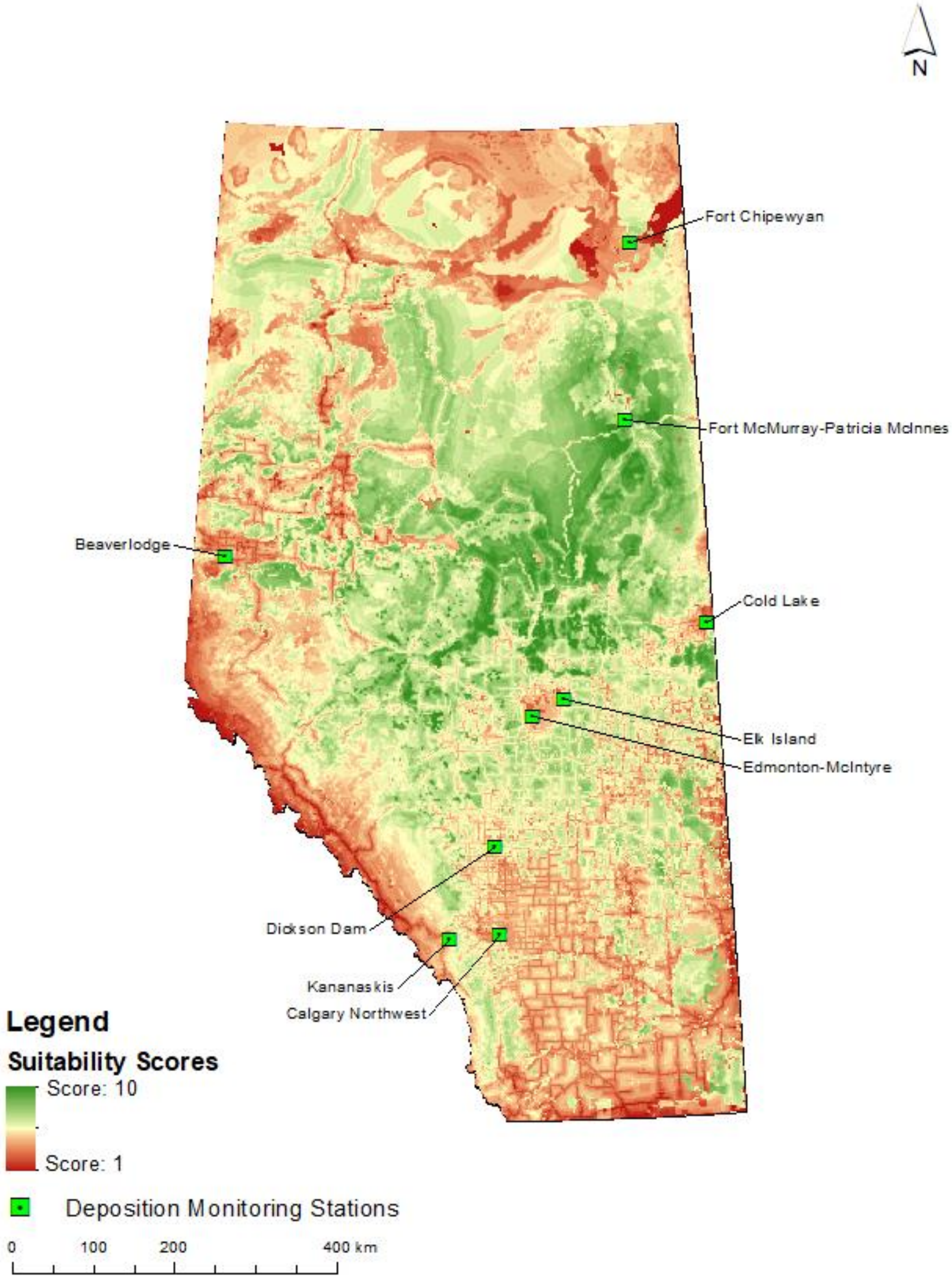


Figure B-5 suitability evaluation scenario #4 map

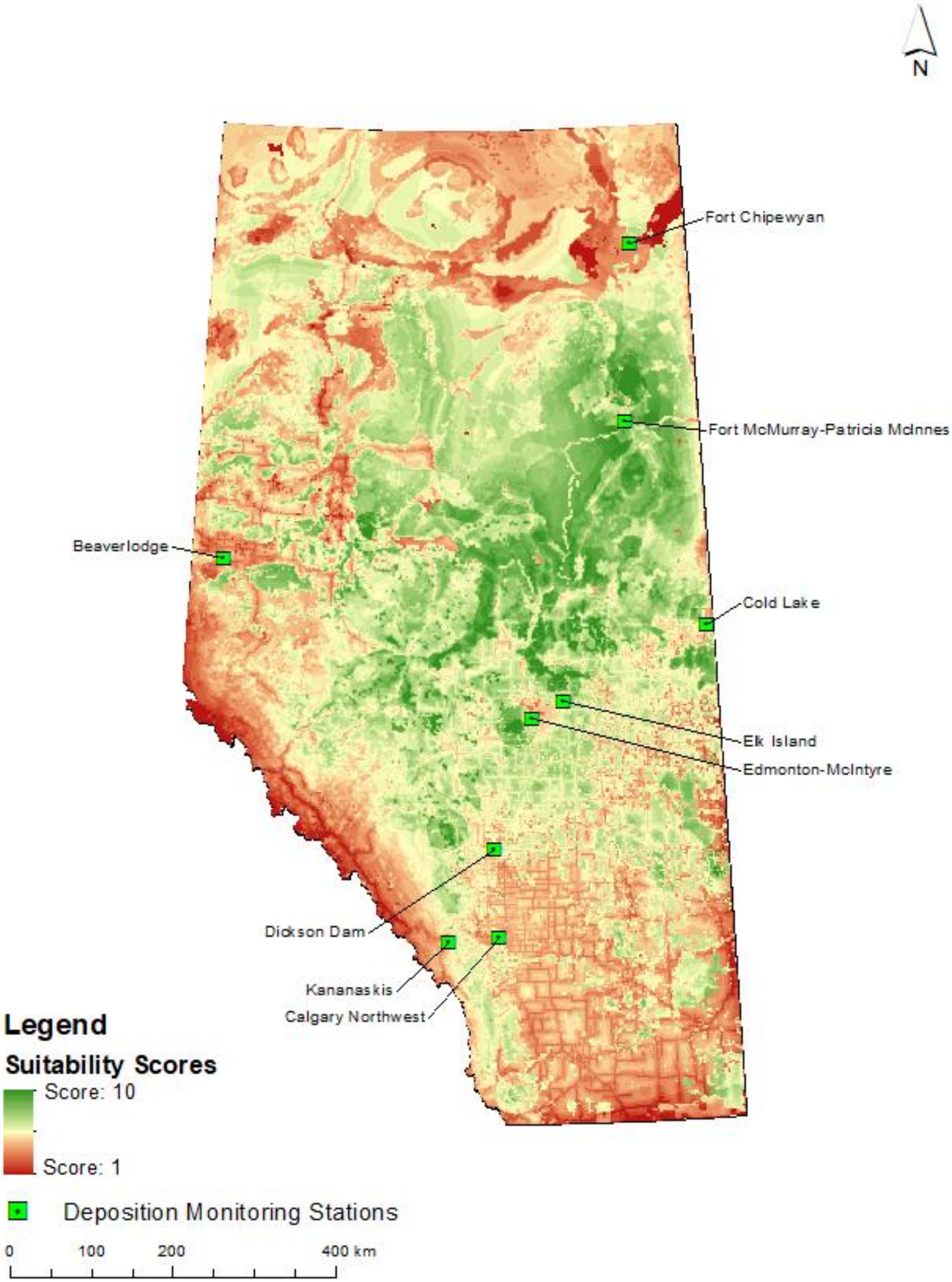


Figure B-6 suitability evaluation scenario #5 map

Appendix B2 Natural Region and Station Classifications

Table B-2 Percentage of suitability class in each natural region

Natural Regions	Total Area (km^2)	Suitability Class	Area (%)
		Low Suitability	0.4%
		Intermediate Class I	4.6%
		Intermediate Class II	35.4%
		Intermediate Class III	44.4%
		Deposition Monitoring Hot Spot	10.8%
Boreal	**380690**	Water	4.4%
		Low Suitability	1.0%
		Intermediate Class I	3.3%
		Intermediate Class II	75.2%
		Intermediate Class III	12.4%
		Deposition Monitoring Hot Spot	0.0%
Canadian Shield	**9673**	Water	8.0%
		Low Suitability	0.3%
		Intermediate Class I	1.7%
		Intermediate Class II	31.5%
		Intermediate Class III	60.5%
		Deposition Monitoring Hot Spot	5.6%
Foothills	**66409**	Water	0.5%
		Low Suitability	1.5%
		Intermediate Class I	13.7%
		Intermediate Class II	62.8%
		Intermediate Class III	20.4%
		Deposition Monitoring Hot Spot	0.4%
Grassland	**95395**	Water	1.3%
		Low Suitability	2.60%
		Intermediate Class I	3.92%
		Intermediate Class II	44.17%
		Intermediate Class III	45.32%
		Deposition Monitoring Hot Spot	0.38%
Parkland	**60712**	Water	1.25%
		Low Suitability	30.7%
		Intermediate Class I	16.2%
		Intermediate Class II	39.7%
Rocky Mountain	**48828**	Intermediate Class III	12.7%

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Natural Regions	Total Area (km^2)	Suitability Class	Area (%)
		Deposition Monitoring Hot Spot	0.0%
		Water	0.7%

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Table B-3 Relative distribution of suitability class within 50 km radius of monitoring stations; only stations outside of urban areas are included

Suitability Class	Beaverlodge	Cold Lake	Dickson Dam	Elk Island	Fort Chipewyan	Kananaskis
Deposition Hot Spot	2%	1%	2%	7%	1%	23%
Intermediate Class I	18%	0%	1%	0%	12%	7%
Intermediate Class II	55%	29%	63%	22%	32%	46%
Intermediate Class III	23%	41%	31%	53%	26%	22%
Low Suitability	1%	18%	1%	14%	0%	0%
Water	2%	11%	2%	4%	29%	1%
Total area (km^2)	*7345*	*4694*	*7841*	*7844*	*7850*	*7433*

Note: Total area considered is the portion of 50 km radius that falls within Alberta

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Appendix C Supplementary Information for Focused Studies

Appendix C1 Focused Study Monitoring

Table C-1 Portable/Mobile monitoring available for focused studies

Monitoring platform	Parameters monitored
Mobile Air Monitoring Laboratory (MAML)	NO_x/NO_2/NO/NH_3, O_3, CO, SO_2, TRS, H_2S, PM_1/ $PM_{2.5}$ / PM_{10}, CH_4/NMHC/THC, PAHs, WS/WD, Temp, RH
Evacuated Canisters	Selected suits of volatile organic compounds
EBAMS	Fine particulate matter mass concentration
Airpointer®	$PM_{2.5}$, NO_x/NO_2/NO, O_3, CO, SO_2/H_2S)
Tisch TE-Wilbur Filter-based FRM	$PM_{2.5}$, PM_{10}, TSP samples for composition analysis
Met-One SuperSASS speciation monitor w/cartridges	$PM_{2.5}$, PM_{10} samples for composition analysis
Portable Air Monitoring Laboratory (PAML)	NO_x/NO_2/NO, O_3, CO, SO_2, H_2S, $PM_{2.5}$, CH_4/NMHC/THC, WS/WD, Temp, RH
Tisch TE-1000 PLUS PUF Sampler	Polycyclic aromatic hydrocarbons
Tisch TE-123 VOC Sampler	Used for regulating canister sample collection

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Appendix C2 Focused Studies Information Needs

Focus Study Information Needs

This template is used by EMSD to collect information needs used to prioritize future focus studies. We aim to respond to your requests within three months. If a study moves on to the project design phase, we will request information that is more detailed and/or involve you in the study design.

Name:

Email:

Phone:

Description of information needs (3-5 sentences):

Please describe the air quality issue or perceived/actual air monitoring gap that you would like to have investigated further. This should not be a prescriptive list of monitoring requirements, but instead should be a brief description of the motivation for this request, as well as the type of information on air quality that is required and the location/area and time period of the issue. See examples below.

Suggested science question(s):

Please suggest science question(s) to be addressed by the focus study such that the information need(s) described above are met. See examples below.

Would you or someone in your work area like to be involved in the study design?

Examples of information needs descriptions

Example #1: Monitoring of pollutant [X] determined that values exceeded that Alberta Ambient Air Quality Objectives at location [Y] repeatedly during time-period [Z]. What is causing these elevated values? How wide-spread is this issue?

Example #2: There have been many complaints from the public about odour in the [X] area. We would like to determine what is causing the odour issues to inform air quality management in the area.

Example #3: We are investigating the health effects of pollutant [X] due to emissions sources [Y]. What is the ambient level of pollutant [X] near the emissions sources and how does it vary with the time of year?

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Appendix C3 Air Monitoring Project Design Template

Air Monitoring Project – Enter name of study

Date: Enter date.

Study Progress Stage	Date
Draft	Enter date.
Final (Prior to starting study)*	Enter date.
Update (Study is in progress)	Enter date.
Monitoring completed	Enter date.
Analysis and report completed	Enter date.

* After review by a staff member from the air science team of EMSD and approved by the air monitoring manager and/or the executive director of EMOB.

Project Background

Identify the study area and the information need(s)

Objective

Objectives of the study and a list of science question(s) to be addressed and/or hypotheses to test.

Project Requested By

Person(s) who requested the project/is responsible for the information need.

Project Team

Science Team Lead: Science team lead.
Monitoring Team Lead: Monitoring team lead.
Air Monitoring Technologist(s): Monitoring technologist(s) responsible for field work/sample collection.
Air Specialist(s)/Scientist(s): Specialist(s)/scientist(s) responsible for data analysis and report generation.

Contacts

Enter contact information of project team

Duration of Study

Identify duration of study, duration of monitoring at each site, etc.

Monitoring Sites

Identify appropriate representative monitoring locations.
Include latitude and longitude of monitoring sites, site map, etc.

Parameters Measured

List/table of appropriate air parameters to be measured in the study.

Monitoring Method

Identify monitoring method, ensuring representativeness and required data for quality control and assurance such as:
(1) SOP and QAP for method
(2) Frequency and duration of monitoring
(3) Blanks and duplicates
(4) Required Calibration
(5) Required field observations or notes to be made by the technologist

Laboratory Analysis (if applicable)

Laboratory analyzing the sample: Identify laboratory analyzing sample.
Compounds to be analyzed: Identify suite of compounds to be analyzed.
Method of analysis and associated detection limit: Identify analysis method and detection limit.

Procedure

Detail procedure to be used in study.

Data Gathering/Validation

Identify data gathering (i.e. one-minute frequency data collection) and QA/QC method.

Data Availability

Indicate anticipated data availability and location of data storage.

Data Analysis and Evaluation Approach

Identify data analysis and evaluation approach, the need to compare to existing long term monitoring and/or other historical monitoring.

Deliverable

Identify the type of report or deliverable needed (i.e. a summary, full technical report, peer-reviewed publication, and/or presentation slides) and the approximate time of delivery.

End of Survey Comments

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Appendix D Comparison of Co-located Passive and Continuous Stations

The goal of this analysis was to determine how well passive sampler annual average data compare with co-located continuous stations in terms of spatial representativeness and trends. Annual averages were selected for the comparison because annual averages are used most-often in regional reporting of passive data. Analyses using monthly average passives or other averaging methods may yield different results. Furthermore, this analysis does not consider possible causes for biases between passive and continuous measurements. Possible reasons of observed differences could include factors such as inconsistencies in protocols for sampler deployment, laboratory analysis, and/or uptake calculations and may not reflect problems with the passive sampler methodology.

Appendix D1 Datasets and Calculation of Annual Averages

The passive samplers with co-located continuous air monitoring stations considered are summarized in Table D-1. Note that co-located passive sampler and continuous measurements were also collected at the Airdrie, Calgary Southwest, and Calgary Central air monitoring stations, but did not meet the completeness criteria for annual average data in any year, and therefore were not included in this study. For this study, annual averages were considered instead of monthly averages because, outside of compliance monitoring/reporting, passive data are most-often reported on as annual averages.

The continuous air monitoring data were acquired from http://airdata.alberta.ca. Annual averages were calculated from the hourly continuous air monitoring data, with the requirement of 75% data completeness for the entire year and 60% data completeness in all four quarters of the year.

Passive sampler data were acquired by email from the Airshed organizations responsible for each passive sampler network. Maxxam PASS samplers (Hongmao Tang, 2001) were used at most of the stations in this study. At the Medicine Hat-Crescent Heights stations, where Maxxam PASS samplers were used from 2003 to January 2009 (and November 2017 to present), AMEC Multigas passive samplers (H Tang, Burns, Yang, & Apon, 2011) were used from January 2009 to May 2013, and Radiello and Ogawa samplers (Mukerjee et al., 2004) were used from May 2013 to November 2017. At the FAP stations (Fort Saskatchewan, Lamont, Scotford 2, Redwater Industrial), SO_2 was measured using AGAT passive samplers (AGAT Laboratories Ltd., 2018).

At most stations, passive samples were collected on approximately a monthly basis. At these stations, annual averages were calculated from the average of the monthly samples, with the completeness requirement that at least 11 months of valid data were collected in a given year. Note that at these stations start and end dates of the measurement period are not provided in the standard file format.

At the LICA stations (Cold Lake South, Maskwa, and St. Lina), the passive sampler data was collected on a monthly basis for 2000 to March 2016. Starting in April 2016, two-month samples were collected. For the two month samples, the annual average was calculated by doubling the two month averages. For example, the average for April-May 2016 was counted twice in the annual average as both April 2016 and May 2016.

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Note that at the LICA stations start and end dates of the measurement period are not provided in the standard file format.

The passive sampler measurements collected by WBEA do not align directly with the beginning/end of each month. Instead, the start and end times of the samples are specified in the data files. These start and end times can overlap between months and even years. Furthermore, averaging periods are variable, with ~30-day averages prior to 2011 and a mixture of ~30-day and ~60-day averages after that, as shown in Figure D-1.

Table D-1: Summary of passive data used in the co-location study

Station Name	Passive Station Airshed - #	Species Measured	Years[11]	Notes
Anzac	WBEA-AMS14	O_3, NO_2, SO_2	2008-2015	WBEA schedule[12]
Beaverlodge	PAZA-12	O_3, NO_2, SO_2	2002-2016	
Caroline	PAMZ-15	O_3, NO_2, SO_2	2000-2016	
Cold Lake South	LICA-22	O_3, NO_2, SO_2,	2007-2016 2009-2016	LICA schedule[13]
Fort Chipewyan	WBEA-AMS8	O_3, NO_2, SO_2	2011-2015	WBEA schedule[12]
Fort McKay – Bertha Ganter	WBEA-AMS1	O_3, NO_2, SO_2	2000-2016	WBEA schedule[12]
Fort McMurray – Patricia McInnes	WBEA-AMS6	O_3, NO_2, SO_2	2000-2015	WBEA schedule[12]
Fort Saskatchewan	FAP-58	O_3, NO_2, SO_2	2009-2012 2015-2016	
Grande Prairie - Henry Pirker	PAZA-43	O_3, NO_2, SO_2	2002-2016	
Lamont	FAP-20	SO_2	2015-2016	
Maskwa	LICA-14	O_3, NO_2, SO_2	2009-2016	LICA schedule[13]
Medicine Hat – Crescent Heights	PAS-19	O_3, NO_2, SO_2	2007-2016	Different samplers[14]
Mildred Lake	WBEA-AMS2	O_3, NO_2, SO_2	2011-2016	WBEA schedule[12]
Red Deer Riverside	PAMZ-65	O_3, NO_2, SO_2	2001-2016	
Redwater Industrial	FAP-64	SO_2	2015-2016	
Scotford 2	FAP-57	SO_2	2008-2016	
Smoky Heights	PAZA-24	O_3, NO_2, SO_2	2002-2016	
St Lina	LICA-32	O_3, NO_2, SO_2	2009-2016	LICA schedule[13]

[11] Not all years listed here meet the completeness criteria

[12] From November 2011 – present, sampling varies from 1-2 months

[13] From April 2015 – present, 2-month average samples

[14] Maxxam PASS samplers: 2003- January 2009; AMEC Multigas passive samplers: January 2009 – May 2013; Radiello and Ogawa samplers: May 2013 – present

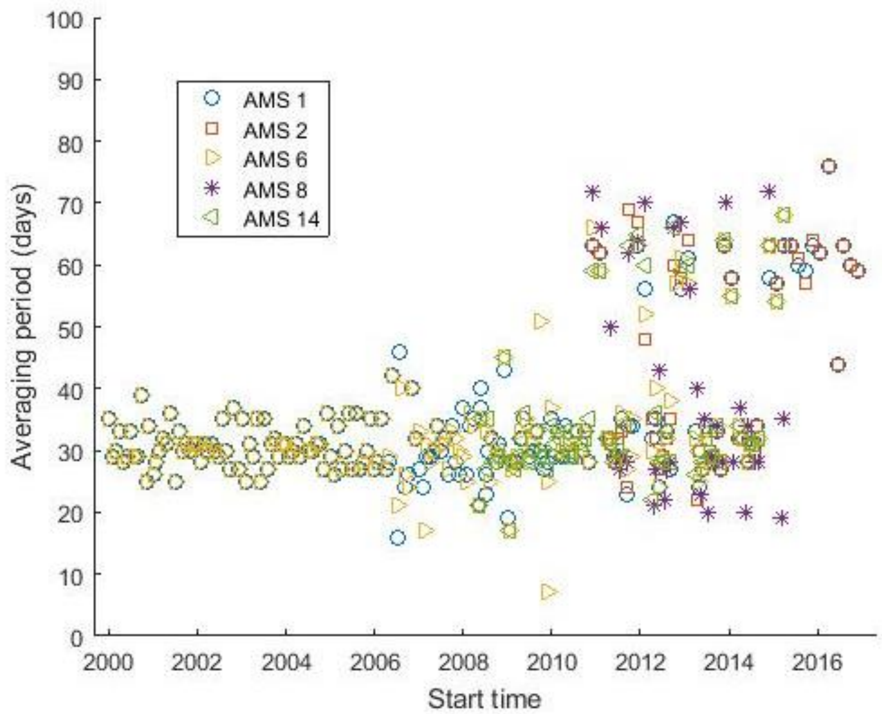


Figure D-1 Averaging period for WBEA passive samplers co-located with continuous monitoring stations

Therefore, the steps illustrated in Figure D-2 for NO_2 at Fort McKay-Bertha Ganter station were taken to resample the WBEA data into annual averages. The original sampling of the passive data (top panel) has variable sampling periods and there are occasionally multiple passive measurements at the same time, due to the duplicate/triplicate samples. These data were then resampled onto a daily measurement grid (middle panel). For each day, all available passive measurements that spanned that day were weighted by (number of days)$^{-1}$ and averaged. Note that the weighting of (number of days)$^{-1}$ gives more weight to measurements averaged over fewer days. No daily value was assigned to a day if no sampling period overlapped with that day. From the daily gridded dataset, monthly averages were calculated (bottom panel), requiring at least 23 days of valid data in the month. Annual averages were then calculated from the monthly averages, using the same method as for the other passive site, with the requirement of at least 11 months of valid data.

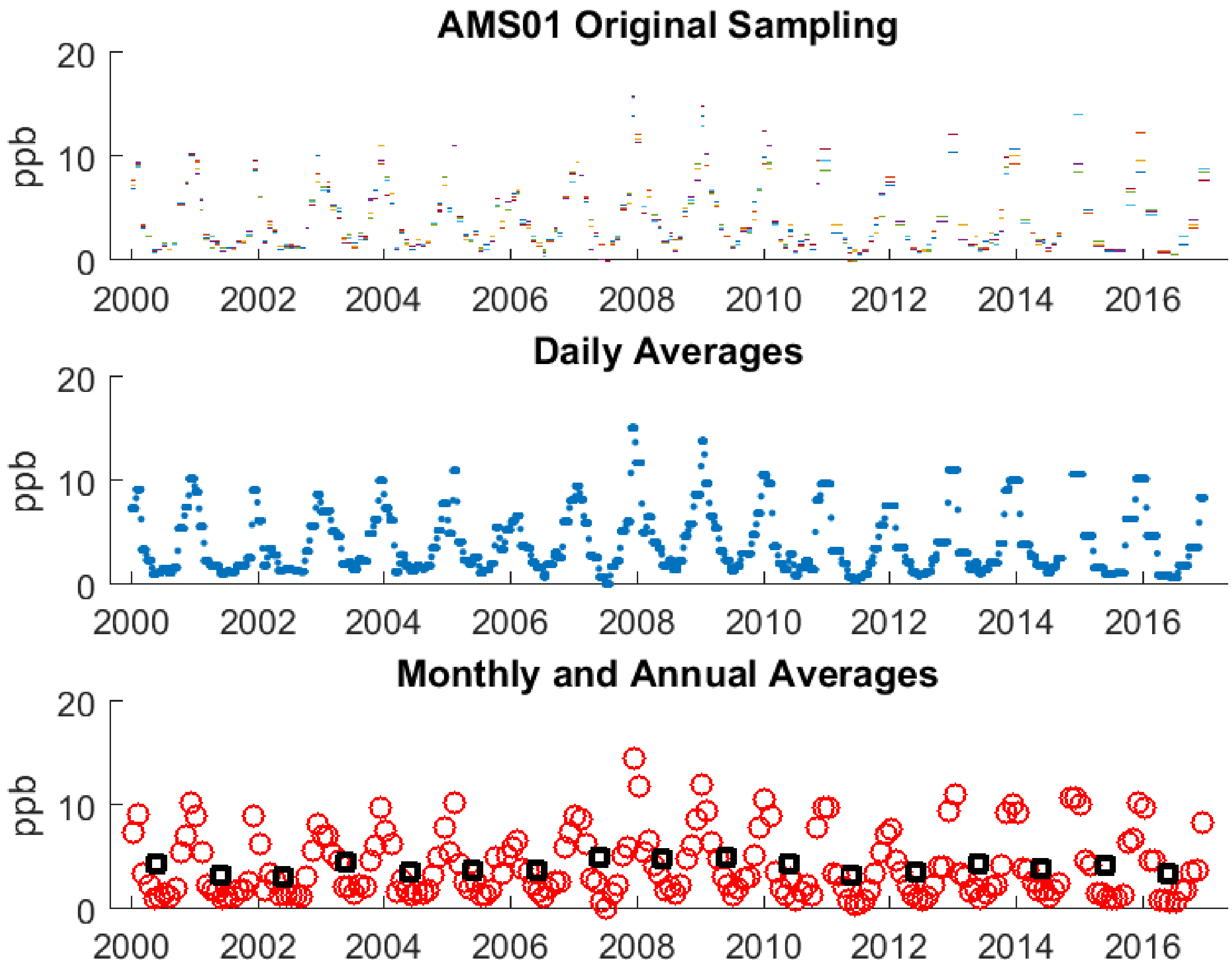


Figure D-2: Example of resampling of WBEA passive data for NO2 at Fort McKay-Bertha Ganter station; (Top panel) Passive measurements original sampling, where the horizontal bars indicate the start and end times of a given measurement. (Middle panel) Resampled daily averages; (Bottom panel) Monthly and annual averages calculated from the resampled data

In order to estimate the bias between the passive sampler and continuous measurements, the mean difference $(passive - continuous)$ and mean percent differences $100\% \times (passive - continuous)/continuous$ were calculated. The uncertainty in the means were estimated from the standard error in the mean, $\sigma/\sqrt{N}$, where σ is the standard deviation and *N* is the number of measurements.

For stations with 10 or more years of co-located annual averages, a drift analysis was performed to assess the stability of the passive sampler measurements in time. First the time series of differences in passive minus continuous annual average was calculated. The Mann Kendall tau-b test was used to determine whether there was a trend in the difference time series. For detected trends, the drift in ppb per year, was calculated using a Sen slope estimator, with a 95% confidence interval. The Mann Kendall and Sen's slope estimator were calculated in MATLAB using the *ktaub* function.

Appendix D2 Results for NO_2

Figure D-3 shows a scatter plot of all co-located continuous and passive annual averages at all stations. The Pearson correlation coefficient of R = 0.93 between the passive and continuous annual averages indicates that the passive samplers are capturing the large-scale spatial variation in NO_2 across the province. However, the passive measurements are biased low compared with the continuous stations with a mean percent difference of (-36 ± 1) %, where the uncertainty is the standard error. This is consistent with the 32% low bias in passive sampler NO_2 calculated by Bari et al. (2015). The observed bias between passive and continuous NO_2 is fairly consistent across all stations sampled.

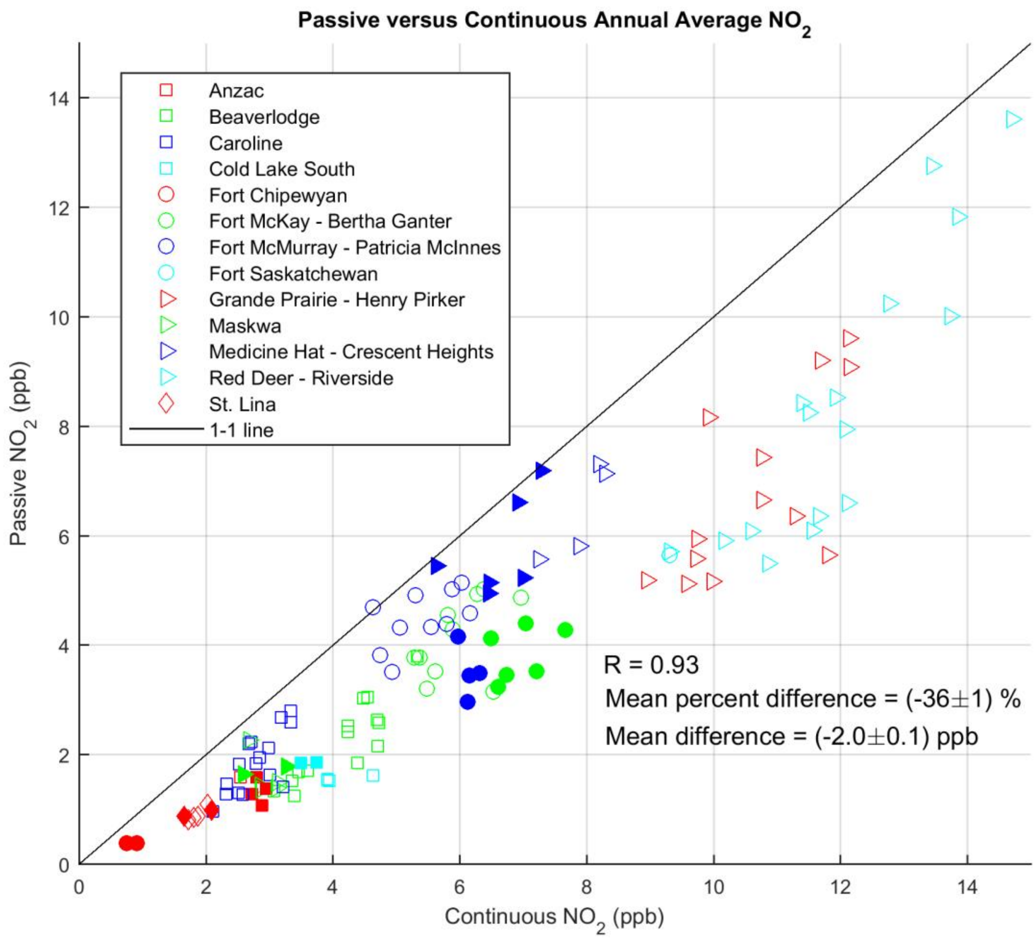


Figure D-3: Scatter plot of passive versus continuous annual average NO_2. The black line indicates 1-1. Open markers indicate measurements collected on a monthly basis with Maxxam passive samplers. Filled markers indicate measurements that were taken with alternate sampling schedules or sampler types

The filled markers indicate alternative sampling schedules or sampling techniques. At the WBEA stations (and Fort Chipewyan, Fort McKay-Bertha Ganter, and Fort McMurray-Patricia McInnes) and LICA stations (Cold Lake South, Maskwa, and St Lina) the filled markers indicate annual averages that include some 2-month averages. At the Medicine Hat-Crescent Heights station, the filled markers indicate years in which

AMEC Multigas passive samplers and Radiello and Ogawa samplers were used. The alternate sampling techniques and schedules are fairly consistent with the other datasets in the scatter plot.

Table D-2 shows a summary of the calculated drifts in time between the passive sampler and continuous measurements for stations with sufficiently long time series. Figure D-4 shows an example of the time series and drift fit at Red Deer-Riverside station. Negative drifts are observed at four out of the seven stations. At these stations, the bias between the passive and continuous data has become larger (more negative) in time. At the Red Deer-Riverside and Grande Prairie – Henry Pirker stations, the stations with the highest annual average NO_2, the magnitude of the drift exceeds 0.2 ppb/year in magnitude. Over 10 years, the passive annual average NO_2 at these stations have drifted by ~20% relative to the continuous data. Therefore, the passive sampler NO_2 data, as it is currently collected, is not sufficiently stable to calculate long-term trends unless the trends are very large (> 20% per decade).

The reason for the negative drifts relative to the continuous stations is unknown. The drifts between the datasets are fairly gradual, as shown for example in Figure D-4, and therefore cannot be attributed to a sudden change in the passive sampler data. The drifts are observed at stations in different Airshed networks, and therefore cannot be attributed to a simple error in data collection or the change from 1 to 2 month sampling averages at some stations. Potential reasons for the drift might include gradual changes in the sampler design or laboratory analysis and/or the uptake calculations and input meteorology.

Table D-2: Drift analysis results for NO_2

Station Name	Drift Detected	Drift Magnitude (ppb/year)	Drift 95% Confidence Intervals (ppb/year)
Beaverlodge	Not significant	--	--
Caroline	Decreasing	-0.06	(-0.09, -0.04)
Fort McKay-Bertha Ganter	Not significant	--	--
Fort McMurray-Patricia McInnes	Decreasing	-0.17	(-0.28, -0.09)
Grande Prairie-Henry Pirker	Decreasing	-0.28	(-0.41, -0.12)
Medicine Hat-Crescent Heights	Not Significant	--	--
Red Deer-Riverside	Decreasing	-0.24	(-0.38, -0.09)

DRAFT

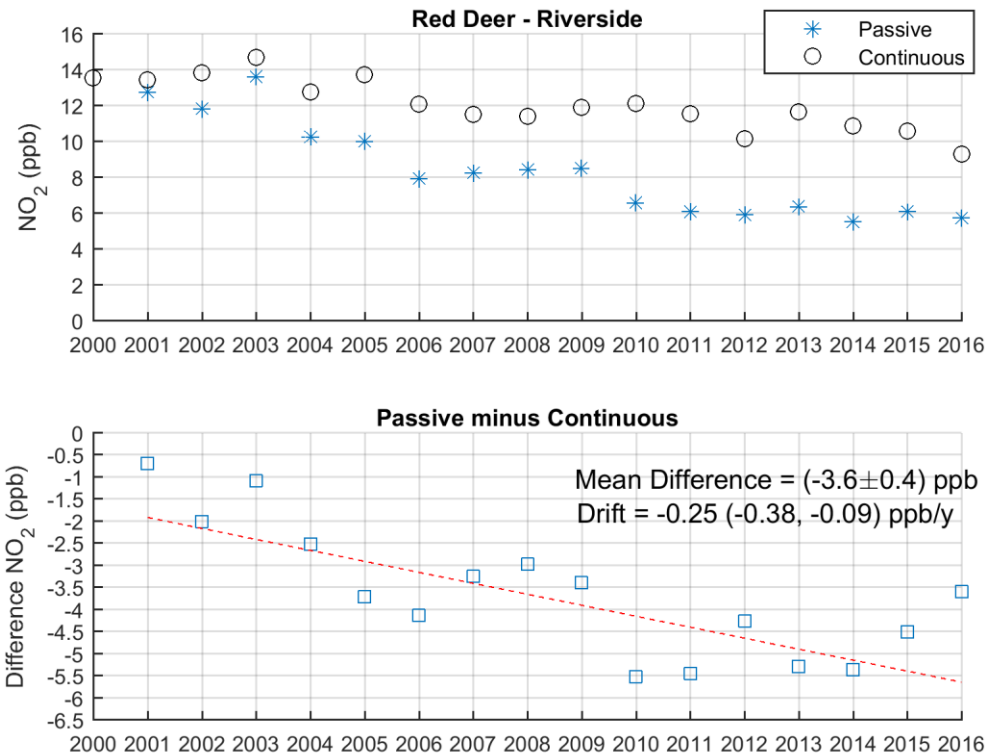


Figure D-4: Example of drift analysis results for NO_2 at Red Deer-Riverside station; (Top) Time series of passive and continuous annual averages; (Bottom) Difference in annual averages with drift fit

Appendix D3 Results for SO_2

Figure D-5 shows a scatter plot of all co-located annual average SO_2 at all stations for continuous versus passive measurements. The Pearson correlation coefficient R = 0.95 between the passive and continuous stations indicates that the passive samplers are capturing the spatial variation of SO_2 annual averages. The majority of these measurements are taken at low levels of SO_2, with 111 out of the total 145 co-located measurements recording annual averages of < 1 ppb at the continuous station. Therefore it is difficult to determine whether there are systematic differences between different stations. Overall, there is a slight mean positive bias in the passive sampler SO_2 of 0.12 ± 0.02 ppb. This is consistent with the median difference of 0.1 ppb for SO_2 found by Bari et al. (2015). When presented as a percent difference, the bias appears to be large (71%) because many of the continuous annual averages in the denominator of the calculation are very close to zero. The mean percent difference is 10 ± 5 % if co-located pairs with annual average SO_2 < 1 ppb at the continuous station are excluded from the calculation.

Table D-3 shows a summary of the drift analysis fit results for SO_2. The drifts are small, with magnitudes <= 0.06 ppb/y at all stations. However, all the stations with sufficiently long time series had annual average SO_2 < 2 ppb and therefore these small drifts may simply be a reflection of the low levels of SO_2 at these stations. An example of the time series and drift fit is shown for Grande Prairie-Henry Pirker station in Figure D-6.

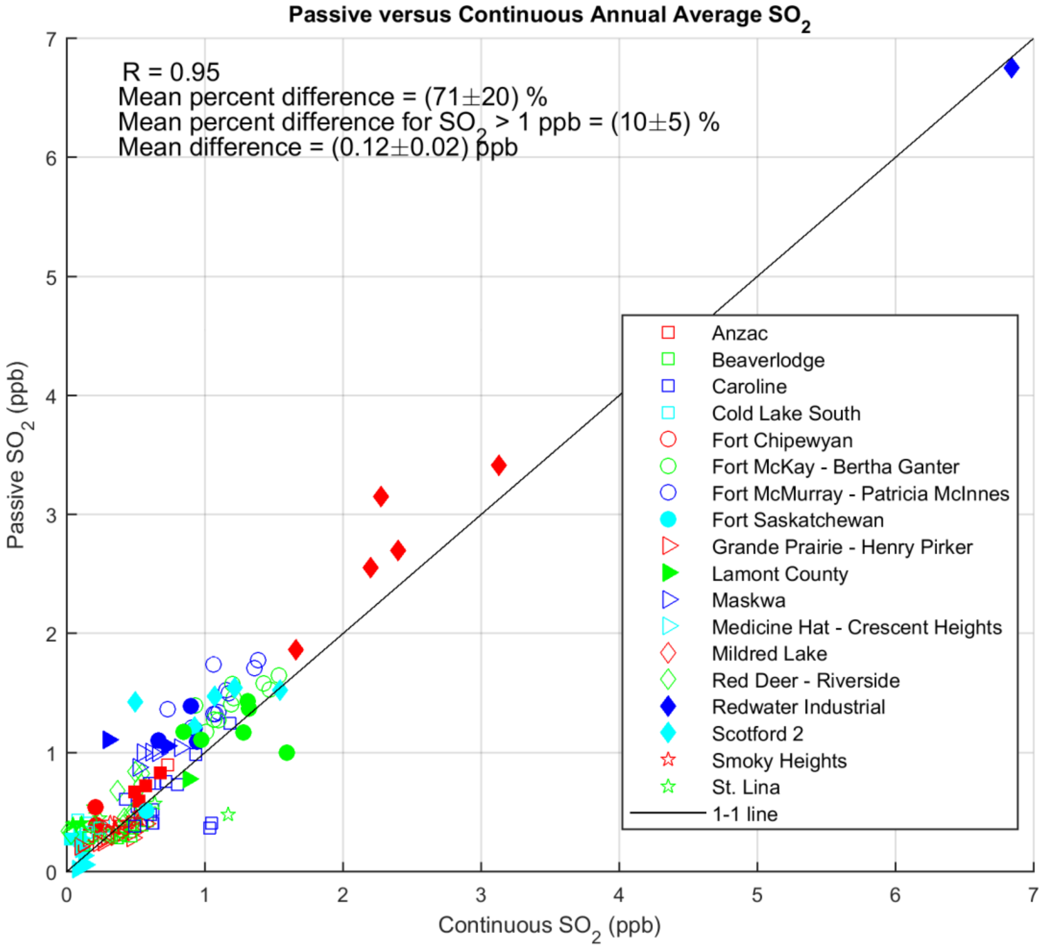


Figure D-5: Scatter plot of passive versus continuous annual average SO_2. Open markers indicate measurements collected on a monthly basis with Maxxam passive samplers. Filled markers indicate measurements that were taken with alternate sampling schedules or sampler types

Table D-3: Drift analysis results for SO_2

Station Name	Drift Detected	Drift Magnitude (ppb/y)	Drift 95% Confidence Intervals (ppb/y)
Beaverlodge	Decreasing	-0.06	(0.09, 0.03)
Caroline	Decreasing	-0.04	(-0.05,-0.02)
Fort McKay – Bertha Ganter	Not significant	--	--
Fort McMurray – Patricia McInnes	Not significant	--	--
Grande Prairie – Henry Pirker	Increasing	0.02	(0.01, 0.03)
Red Deer – Riverside	Not Significant	--	--
Smoky Heights	Increasing	0.02	(0.01,0.03)

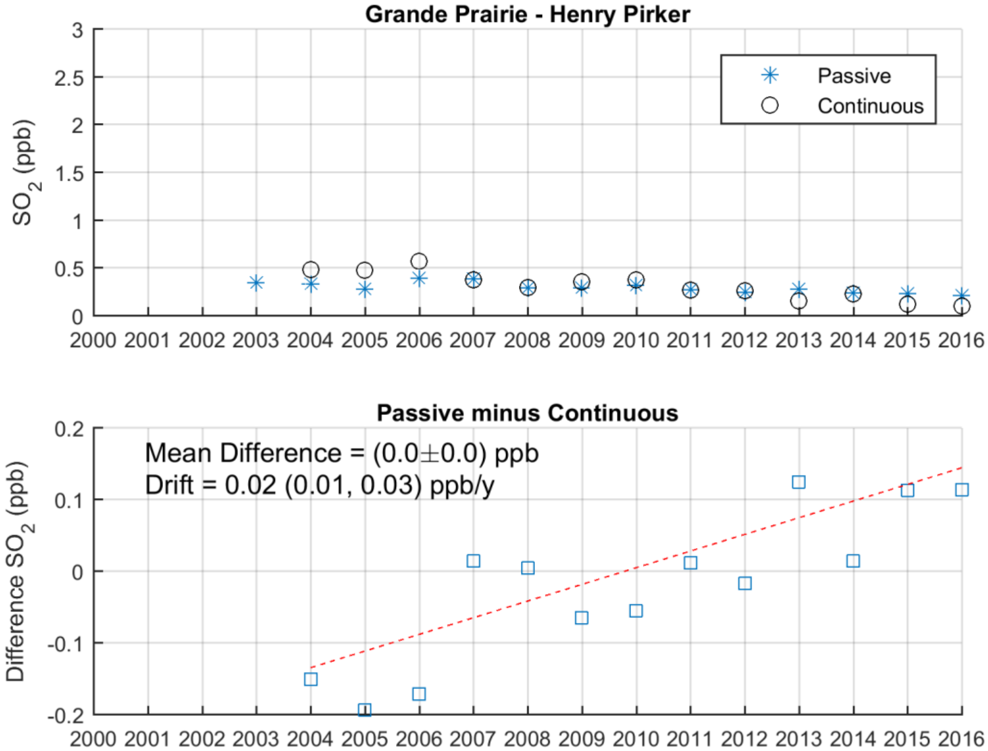
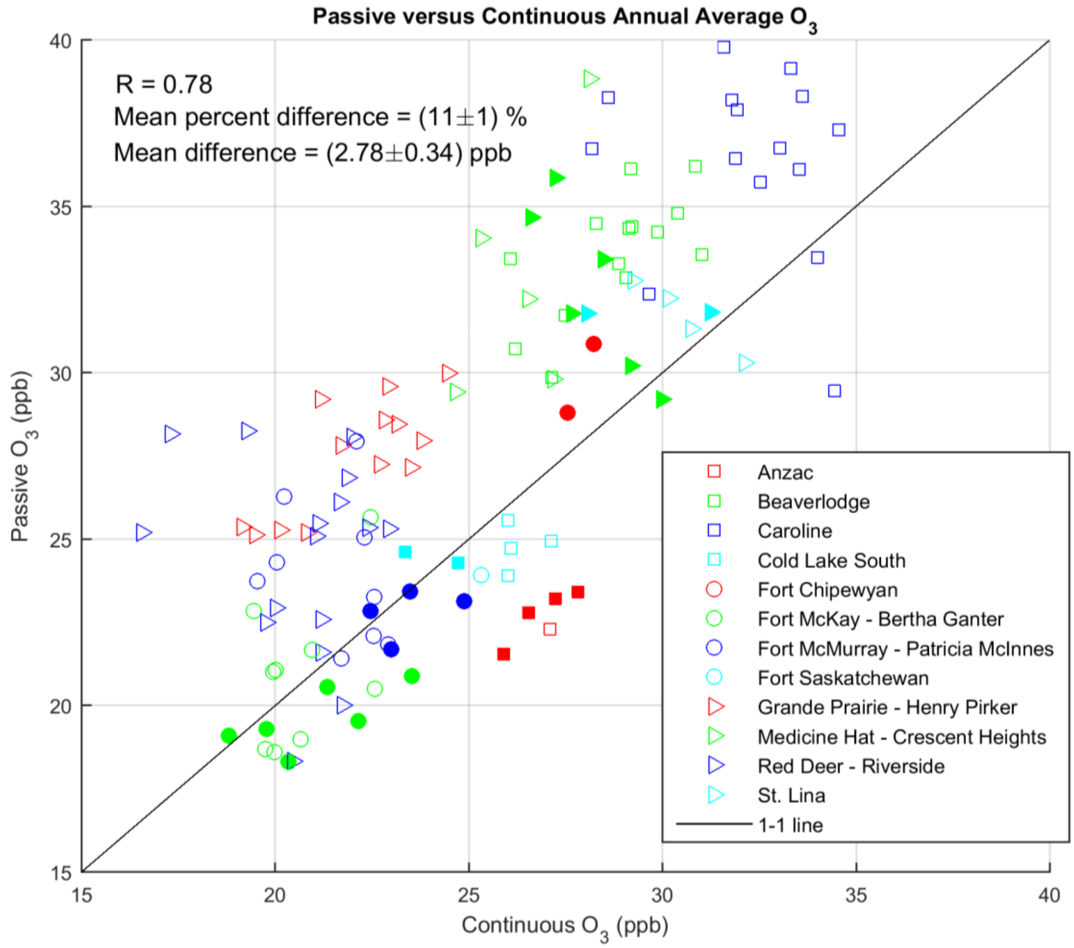


Figure D-6: Example of drift analysis results for SO_2 at Grande Prairie-Henry Pirker Station; (Top) Time series of passive and continuous annual averages; (Bottom) Difference in annual averages with linear fit

Appendix D4 Results for O3

Figure D-7 is a scatter plot of all co-located passive versus continuous annual average O_3, for all stations. The Pearson correlation coefficient of R = 0.78 indicates that there is weaker correlation for O_3 than for NO_2 or SO_2 passive samplers. Furthermore, systematic differences between stations are apparent. For example at Anzac station, passive O_3 annual averages are biased low compared with continuous data, while at Grande Prairie – Henry Pirker station, the passives are biased high compared with the continuous data. The observed biases do not appear to be clustered for stations from a particular Airshed, region of the province, or mean annual average of O_3. The mean percent difference relative to the continuous stations is 11±1 % or 2.8±0.3 ppb. This is consistent with the 12% relative error found by Bari et al. (2015).

As summary of the drift analysis is given in Table D-4. At most stations, no drift was detected. The individual time series at Fort McMurray – Patricia McInnes station is shown in Figure D-8 for example. Although there is variability in the difference between continuous and passive measurements, no trend was detected at this station. At the Red Deer – Riverside station, a positive drift of 0.6 ppb/y was observed. The reason for this drift is unknown.



2470 **Figure D-7: Scatter plot of passive versus continuous annual average O_3. Open markers indicate measurements collected on a monthly basis with Maxxam passive samplers. Filled markers indicate measurements that were taken with alternate sampling schedules or sampler types**

Table D-4: Drift analysis results for O_3

Station Name	Drift Detected	Drift Magnitude (ppb/y)	Drift 95% Confidence Intervals (ppb/y)
Beaverlodge	Not significant	--	--
Caroline	Not significant	--	--
Fort McKay – Bertha Ganter	Not significant	--	--
Fort McMurray – Patricia McInnes	Not significant	--	--
Grande Prairie – Henry Pirker	Not significant	--	--
Medicine Hat – Crescent Heights	Not significant	--	--
Red Deer – Riverside	Increasing	0.6	(0.5, 0.9)

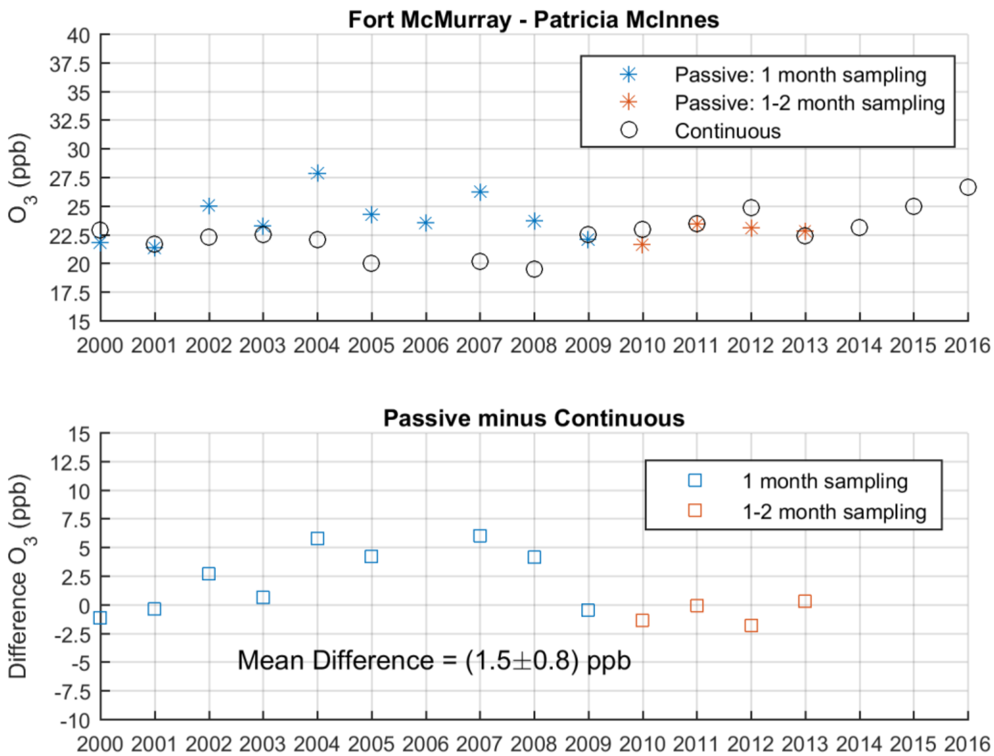


Figure D-8: Example drift analysis results for O_3 at Fort McMurray-Patricia McInnes station; (Top) Time series of passive and continuous annual averages; (Bottom) Difference in annual averages with linear fit

Appendix D5 Discussion

This analysis is an evaluation of the quality of annual average passive sampler measurements for the determination of spatial and temporal variation in air quality. The current analysis uses zero for non-detects in the passive and continuous data; this could be replaced with 2/3 of the detection limit or some other amount. This is most likely to affect comparisons for SO_2 because there are many non-detects in the SO_2 dataset. The passive data may not be as sensitive to peak values occurring during air quality episodes. This could be tested by filtering the continuous data for peak values (e.g., outside 2-sigma in each month) before calculating the annual average from the continuous data. Furthermore, the reasons for differences in annual averages have not been investigated. Future work could include comparisons on other time-scales (e.g., monthly, seasonal) or an evaluation of meteorology and uptake calculations to understand possible reasons for the observed drifts in passive NO_2 and the spatial biases in O_3.