Lower Athabasca Region

Status of Management Response for Environmental Management Frameworks, as of October 2019

Environment and Parks, Government of Alberta

October 2020

Lower Athabasca Region Status of Management Response for Environmental Management Frameworks, as of October 2019

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Executive Summary

Air Quality

As part of the Integrated Resource Management System, this report communicates the status of the Government of Alberta's management response to air quality trigger exceedances for Nitrogen Dioxide (NO_2) and Sulphur Dioxide (SO_2) in the Lower Athabasca Region since 2012. This fulfills commitments made to Albertans in the Lower Athabasca Region Air Quality Management Framework for Nitrogen Dioxide (NO_2) and Sulphur Dioxide (SO_2) (AESRD, 2012a).

In 2018, 22 air monitoring stations measuring nitrogen dioxide (NO_2) and 26 stations measuring sulphur dioxide (SO_2) were considered. Christina Lake and Jackfish 2/3 began measuring SO_2 and NO_2 in May and September 2018, respectively, and Barge Landing station started measuring SO_2 and NO_2 in November 2018. These three stations did not meet the data completeness criteria for inclusion in the 2018 report.

Key results from 2018 include:

- No limits were exceeded for air quality indicators.
- The following triggers were exceeded in 2018:
    - Sulphur Dioxide:
        - » Lower Camp station exceeded the Level 3 trigger for the upper range of ambient concentrations of SO_2
        - » Muskeg River, Mildred Lake, Mannix and Buffalo Viewpoint stations exceeded the Level 2 trigger for the upper range of ambient concentrations of SO_2
    - Nitrogen Dioxide:
        - » Fort Hills and Muskeg River stations exceeded the Level 2 trigger for both the annual average and upper range concentrations of NO_2
        - » Fort McKay–Bertha Ganter, Fort McKay South and Horizon stations exceeded the trigger for Level 2 for the upper range of ambient concentrations of NO_2.

The following management activities have been undertaken in this reporting period as a response to exceedances in previous years:

- Development of an improved trend assessment methodology and tool to be used for the analysis of short-term trends (available online at https://open.alberta.ca/publications/9781460136379).
- Reporting of non-point source emissions in the Lower Athabasca Region (LAR) by the Clean Air Strategic Alliance.

- Recommended improvements to the monitoring network program resulting from a third party review are currently under consideration by Alberta Environment and Parks (AEP).

The following detailed investigations are recommended to better understand other potential sources of NO_2 and SO_2 in the Lower Athabasca Region:

- Collect new information to assess the contribution of industrial flaring to SO_2 levels at Lower Camp station.

- Determine the degree to which SO_2 is emitted by coke piles during smouldering or burning and the potential of coke piles to contribute to SO_2 levels at the Lower Camp station.

Surface Water Quality

The status of the management response to surface water quality is reported annually in this series. This report supplements the status of the ambient condition of surface water quality by providing information about the progress of management efforts under the framework. The purpose and scope of each part of the workflow are summarized in the framework (AESRD, 2012b) and in Figure 5.

This report discusses the response to parameters whose indicators crossed thresholds in 2018, as well as the progress within current investigations into undesirable trends observed previously in this reporting series.

Key information and updates from the Lower Athabasca River water quality assessment for 2018 are listed below.

Verification (indicator) summary:

- No water quality indicators crossed a limit.
- Triggers were crossed for two indicators:
    - Potassium (mean trigger)
    - Dissolved uranium (mean and peak trigger)
- Peak dissolved uranium concentrations remained below water quality guidelines

Summary of Investigation:

Investigations are the part of the framework workflow designed to locate sources and assess if current management plans are sufficient to address the water quality issues. No new investigations were initiated in 2018. However, investigations continue for parameters that have undesirable trends in the region: chloride, dissolved iron, dissolved lithium, total nitrogen, potassium, sulphate, and dissolved uranium.

Trend analyses were performed at several sites in the Athabasca Basin. Results were mapped and used to identify potential source areas.

- Source areas occur both upstream of, and within the Lower Athabasca Region (LAR)
- There are data gaps for some jurisdictions and tributaries. Additional data could provide the resolution necessary to differentiate between geographical areas, such as:
    - the Clearwater River and the oil sands region
    - the Athabasca River upstream of the Athabasca town site
    - the Pembina River
    - the Municipalities of Hinton and Whitecourt, and
    - the McLeod River (sometimes)

Mapped trend results identified areas where additional resolution is necessary. In some cases, the necessary data may be available outside of the provincial long- and medium-term monitoring networks

- Additional sources of ambient data exist, but access may require logistic and operational support
- Additional monitoring may be required if data is needed but unavailable.

Management Recommendations:

The following management recommendations will address dependencies and knowledge gaps discovered during investigations:

- Continue LARP water quality investigations:
    - Explore seasonal patterns within areas where undesirable trends exist
    - Verify areas of interest using flow volume estimates and flow-adjustment where feasible
- Capture and integrate water quality data from available sources such as:
    - The Oil Sands Monitoring Program
    - Reported third party municipal and industrial effluent data
- Utilize alternative statistical approaches where trend analysis is not feasible
- Compile information to identify potential mitigation options
    - Compile landuse information within likely source areas

- Identify relevant jurisdictions and management plans within the areas contributing to trends
- Plan and conduct the monitoring necessary to differentiate relevant jurisdictions, watersheds, and the relevant management plans
  - Approaches could include:
    - » Open-water synoptic (longitudinal) surveys of water quality in the Athabasca River
    - » Expand the medium- or long-term water quality monitoring network within the Athabasca Basin
    - » Additional water quantity monitoring or modelling as needed.

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1.0 Introduction to Air Quality

Under the Lower Athabasca Regional Plan (GoA, 2012), a management response is initiated when the Minister of Environment and Parks determines that an indicator trigger or limit, as identified in the Lower Athabasca Region Air Quality Management Framework (LAR AQMF) (AESRD, 2012a) has been exceeded. Alberta Environment and Parks (AEP) is the lead coordinator in undertaking the management response and works with other government branches and regulators (e.g. Alberta Energy Regulator) and external parties, as required, to develop and implement management actions.

The management response is a seven-step process that is undertaken, in full or in part, when an ambient air quality trigger is crossed or a limit is exceeded. A full description of the management system can be found in the LAR AQMF.

Part of the management response is determining the need for management action. Presently, nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) levels are reported annually through the Lower Athabasca Region Status of Air Quality report. When a new condition report becomes available, the previous management response is evaluated for its effectiveness and updated based on the new information.

The management response for air quality considers a variety of factors including but not limited to the type and location of the monitoring station, averaging time (i.e. hourly, 24-hour or annual) and the ambient air quality trigger or limit that was exceeded. In addition, the management response can also include investigation into the cause of an exceedance, notification of the identified sources and affected First Nations, Métis communities and stakeholders, and the identification of management actions to prevent a re-occurrence.

The LAR AQMF and all previous status of ambient air quality and status of management response reports can be found on the Environment and Parks website (www.alberta.ca/lower-athabasca-regional-planning.aspx). Previous management response reports are listed in Appendix D.

2.0 Summary of Ambient Levels Assigned

Alberta Environment and Parks conducts an annual assessment of ambient air quality data gathered from continuous ambient air monitoring stations in the Lower Athabasca region. Data are downloaded from Alberta's ambient air quality data warehouse and checked for accuracy and completeness. Once these data have been verified, the air quality metrics are used to assess ambient conditions relative to triggers and limits. Verification and preliminary assessment of the 2018 data are reported in the 2018 Status of Air Quality, Lower Athabasca Region, Alberta (Thi, 2020).

In 2018, the data from 22 air monitoring stations measuring nitrogen dioxide (NO_2) and 26 stations measuring sulphur dioxide (SO_2) were used for the report. Christina Lake and Jackfish 2/3 and Barge Landing stations started measuring NO_2 and SO_2 in 2018 but did not fulfill the data completeness criteria and were not included in the report. In 2018, no rare or natural circumstances were identified as potential contributors to trigger exceedances.

2.1 Verification and Preliminary Assessment

2.1.1 Nitrogen Dioxide (NO_2)

ANNUAL AVERAGE OF NO_2 CONCENTRATIONS

In 2018, the annual average concentrations of NO_2 within the Lower Athabasca Region remained at management Level 1 with the exception of the Fort Hills and Muskeg River stations (Figure 1). This is the first year for reporting on the Fort Hills station. The Muskeg River station has been at Level 2 since 2012. No specific investigations are warranted at this time as this station was decommissioned in October 2018 because of the Muskeg River mine expansion.

THE UPPER RANGE OF HOURLY NO_2 CONCENTRATIONS

The upper range of hourly ambient concentrations of NO_2 exceeded the trigger into Level 2 at Fort Hills in 2018, its first reporting year (Figure 2). NO_2 concentrations have remained at Level 2 since 2017 at Fort McKay–Bertha Ganter, Fort McKay South and Horizon stations. Muskeg River station has remained at Level 2 since 2012. The upper range of hourly NO_2 dropped from Level 2 in 2017 to Level 1 in 2018 at Fort McMurray-Athabasca Valley station. Level 2 exceedances at all of these stations warrant further investigation.

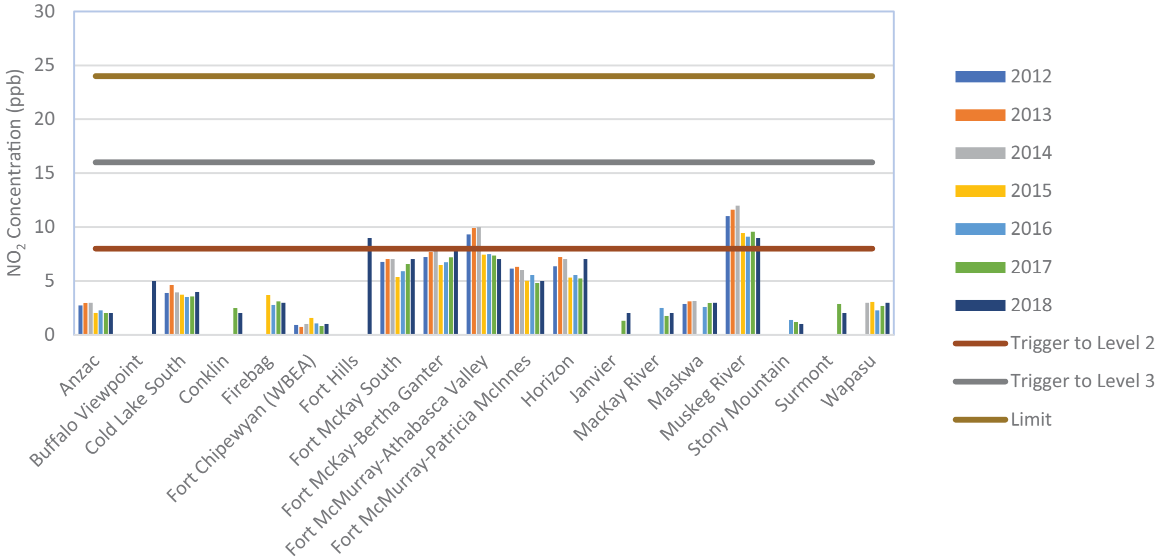


Figure 1. Annual average of the hourly data for Nitrogen Dioxide for 2012-2018 in the Lower Athabasca Region.

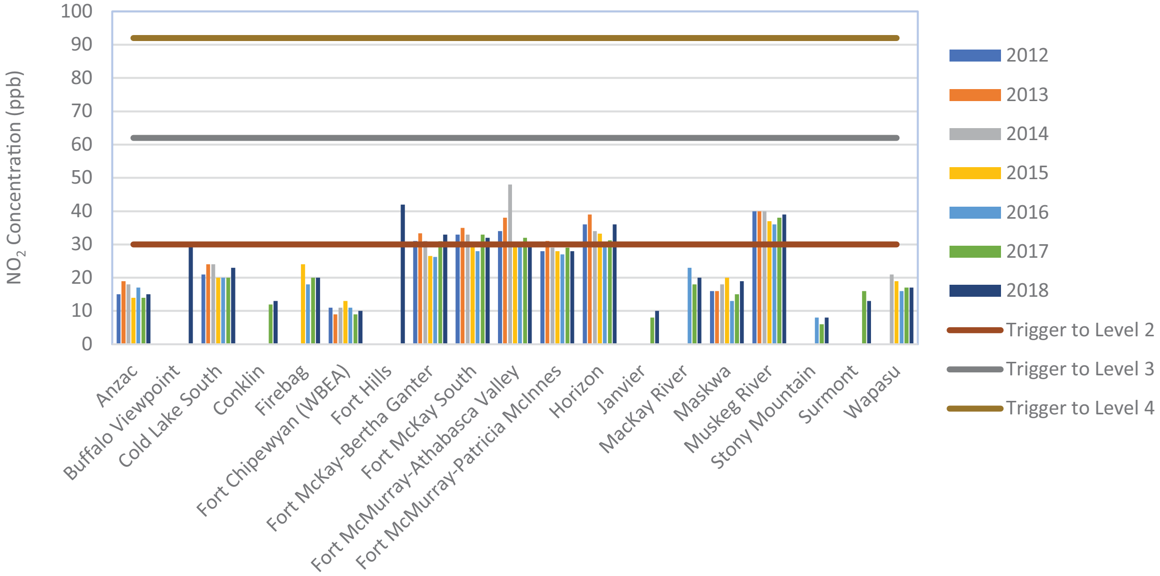


Figure 2. Upper range of the hourly data for Nitrogen Dioxide for 2012-2018 in Lower Athabasca Region

2.1.2 Sulphur Dioxide (SO_2)

The Joint Oil Sands Monitoring Emissions report (ECCC and AEP, 2016) indicates that industrial point sources in the Athabasca Oil Sands Region (AOSR) are major contributors of SO_2 in that area. Despite a reduction in total SO_2 emissions in the region, a number of trigger crossings were identified at air monitoring stations nearer to the oil processing facilities in 2017.

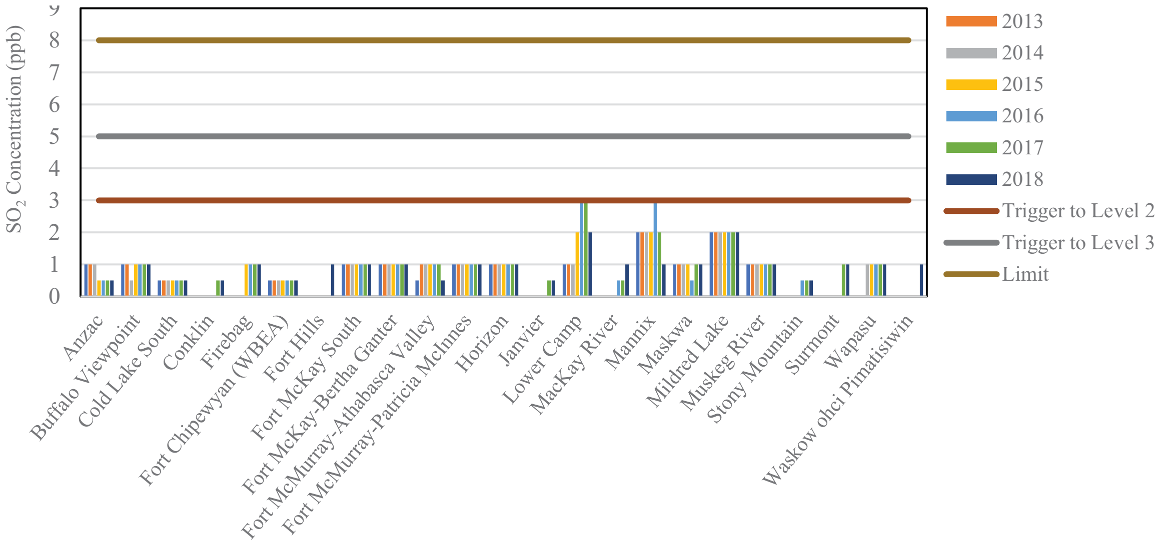


Figure 3. Annual average of the hourly data* for Sulphur Dioxide for 2012-2018 in Lower Athabasca Region.

*Sites with annual averages that round to zero are shown as 0.5 ppb to distinguish them from sites that did not meet completeness requirements.

ANNUAL AVERAGE OF SO_2 CONCENTRATIONS

In 2018, the annual average ambient concentrations of SO_2 at all air monitoring stations remained below the trigger to management Level 2 (3 ppb) (Figure 3). No investigations assessing annual average SO_2 concentrations are required at this time.

UPPER RANGE OF HOURLY SO_2 CONCENTRATIONS

In 2018, only Lower Camp station had an upper range ambient SO_2 concentration above the trigger into Level 3. This is a reduction from Level 4 exceedances observed in 2016 and 2017.

The upper range for ambient concentrations of SO_2 exceeded the trigger for Level 2 at Buffalo Viewpoint, Mannix, Mildred Lake and Muskeg River stations. This is a reduction at the Mildred Lake and Mannix stations as they were above the trigger for Level 3 from 2012-2017 (with the exception that Mildred Lake was at the Level 2 trigger in 2013).

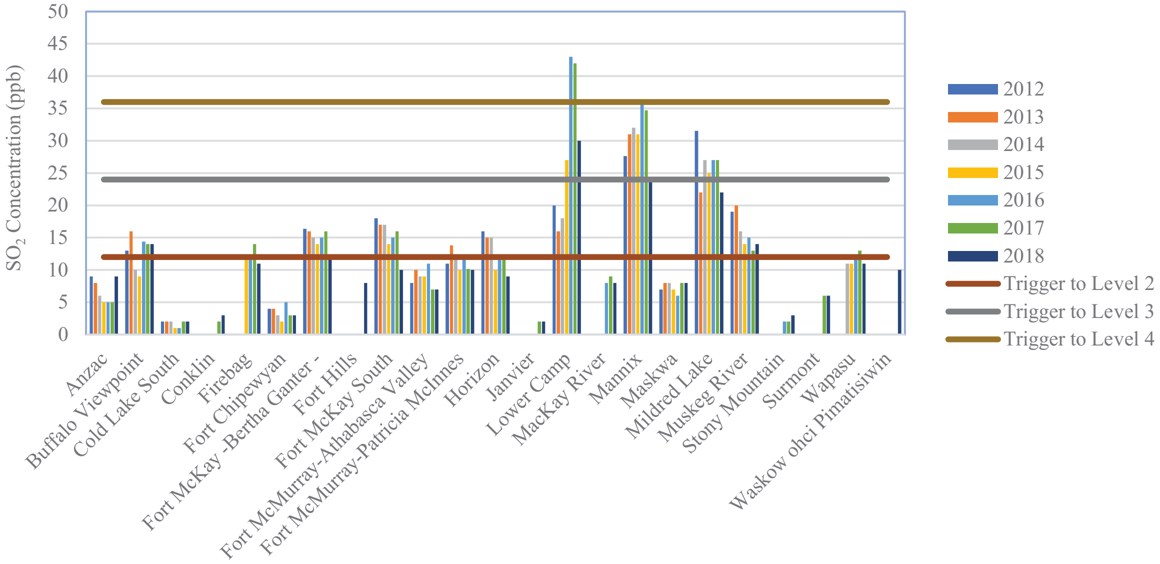


Figure 4. Upper range of the 99th percentile hourly data for Sulphur Dioxide for 2012-2018 in Lower Athabasca Region

These industrial air monitoring stations where Level 2 exceedances occurred are located in the heart of the oil sands operations. Extensive mining, upgrading and processing occur in the area along with large stacks emitting SO_2. Emissions from these stacks typically travel and disperse greatly before reaching ground level. Therefore, the elevated SO_2 episodes at these stations could be related to continuous emission sources or intermittent flaring. Detailed investigations are required to understand the relationship of SO_2 episodes with flaring.

2.2 Minister’s Determination

The Minister’s Determination confirmed that no annual average limits were exceeded for any air quality indicators for January 1 to December 31, 2018 in the Lower Athabasca Region, or since the implementation of the framework. However, exceedances of air quality triggers occurred at several monitoring stations, resulting in the assignment of air quality levels as described above and in the 2018 Status of Air Quality, Lower Athabasca Region, Alberta (Thi, 2020) (Table 1).

Table 1: Ambient levels assigned to air quality monitoring stations in the Lower Athabasca Region for 2012-2018 based on triggers and limits established in the framework.

Station Name	Nitrogen Dioxide (NO_2)												Sulphur Dioxide (SO_2)											
	Annual Average						Upper Range						Annual Average						Upper Range					
	2013	2014	2015	2016	2017	2018	2013	2014	2015	2016	2017	2018	2013	2014	2015	2016	2017	2018	2013	2014	2015	2016	2017	2018
Anzac	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Barge Landing	▨	▨	▨	▨	▨	-	▨	▨	▨	▨	▨	-	▨	▨	▨	▨	▨	-	▨	▨	▨	▨	▨	-
Buffalo Viewpoint	▨	▨	▨	▨	-	1	▨	▨	▨	▨	-	1	1	1	1	1	-	*1*	2	1	1	2	2	2
*Christina Lake	▨	▨	▨	▨	▨	-	▨	▨	▨	▨	▨	-	▨	▨	▨	▨	▨	-	▨	▨	▨	▨	▨	-
Cold Lake South	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Conklin	▨	▨	▨	-	1	1	▨	▨	▨	-	1	1	▨	▨	▨	-	1	1	▨	▨	▨	-	1	1
Firebag	▨	▨	1	1	1	1	▨	▨	1	1	1	1	▨	▨	1	1	1	1	▨	▨	1	1	2	1
Fort Chipewyan	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Fort Hills	▨	▨	▨	▨	-	2	▨	▨	▨	▨	-	2	▨	▨	▨	▨	-	1	▨	▨	▨	▨	-	1
Fort McKay - Bertha Ganter	1	1	1	1	1	1	2	2	1	1	2	2	1	1	1	1	1		2	2	2	2	2	
Fort McKay South	1	1	1	1	1	1	2	2	1	1	2	2	1	1	1	1	1	1	2	2	2	2	2	1
Fort McMurray – Athabasca Valley	2	2	1	1	1	1	2	2	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
Fort McMurray - Patricia McInnes	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	**1**	1
Horizon	1	1	1	1	1	1	2	2	2	1	2	2	1	1	1	1	1	1	2	2	1	1	**1**	1
*Jackfish 2/3	▨	▨	▨	▨	▨	-	▨	▨	▨	▨	▨	-	▨	▨	▨	▨	▨	-	▨	▨	▨	▨	▨	-
Janvier	▨	▨	▨	▨	1	1	▨	▨	▨	▨	1	1	▨	▨	▨	▨	1	1	▨	▨	▨	▨	1	1
Lower Camp	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	1	1	1	1	1	1	2	2	3	4	4	3
MacKay River	▨	▨	▨	1	1	1	▨	▨	▨	1	1	1	▨	▨	▨	1	1	1	▨	▨	▨	1	1	1
Mannix	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	1	1	1	1	1	1	3	3	3	3	3	2
Maskwa	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mildred Lake	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	1	1	1	1	1	1	2	3	3	3	3	2
Muskeg River	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	2	2	2	2	2	2
Stony Mountain	▨	▨	▨	1	1	1	▨	▨	▨	1	1	1	▨	▨	▨	1	1	1	▨	▨	▨	1	1	1
Surmont	▨	▨	▨	▨	1	1	▨	▨	▨	▨	1	1	▨	▨	▨	▨	1	1	▨	▨	▨	▨	1	1
Wapasu	▨	1	1	1	1	1	▨	1	1	1	1	1	▨	1	1	1	1	1	▨	1	1	1	2	1
Waskow ohchi Pimatisiwin	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	-	1	▨	▨	▨	▨	-	1

* Barge Landing, Christina Lake and Jackfish 2/3 were operational in 2018 but did not meet the criteria of 75 percent data completeness in order to be included in reporting and analysis.

▨ Parameter was not measured at this location and period.

3.0 Status of Management Response for Air Quality

The management response is a set of steps that is taken, in full or in part, when an ambient air quality trigger or limit is exceeded. The management response undertaken is determined based on the trigger exceeded, the source(s), factor(s) affecting an indicator, the issue identified, and the management intent associated with each trigger crossed or limit exceeded. A full description of the management system is found in the LAR AQMF (AESRD, 2012a). The status of the management response is reported on regularly and may be supported by supplementary technical reports.

In circumstances where a station exceeds a trigger and is assigned management actions one year, then falls to a lower level the following year, management actions are typically still carried out but may be adjusted in response to the change in status.

3.1 Investigation Results

The purpose of the investigation stage is to determine the likely factors influencing the performance of an indicator and to inform decisions about management actions. The scale of the investigation depends on the management level, as well as, the complexity of the issue identified. Input from the public, Indigenous Peoples, industry, non-governmental groups, government at multiple levels and regulatory agencies may contribute to understanding regional issues and exploring options to address the ambient concentrations. Analysis of ambient concentrations, trends, and the identification of potential emission sources leading to elevated ambient concentrations are ongoing. A summary of the work in progress is described in Tables 2 and 3.

3.1.1 Nitrogen Dioxide (NO_2)

Nitrogen dioxide occurs naturally in the environment as a result of forest fires, atmospheric lightning discharges and biogenic oxidation of nitrogen containing compounds present in soil. Anthropogenic emissions of nitrogen dioxide are mainly the result of combustion processes, such as the combustion of fuel for vehicles or the combustion of coal, oil and natural gas for industrial processes (HSDB, 2005). Anthropogenic emissions are mostly in the form of nitric oxide with some (less than 10%) nitrogen dioxide, which are typically considered together as oxides of nitrogen (NO_x) (AE, 2007). In Alberta, industrial sources (both point and non-point) are the major contributors of NO_x emissions, representing 70% of total anthropogenic emissions followed by transportations, representing 28% of anthropogenic emissions (CASA, 2018).

3.1.2 Sulphur Dioxide (SO_2)

The Joint Oil Sands Monitoring Emissions report (ECCC and AEP, 2016) indicates that industrial point sources in the Athabasca Oil Sands Region (AOSR) are the major contributors of SO_2. In 2018, the Upper Range of hourly SO_2 triggers showed decreasing patterns of the trigger levels at Lower Camp, Mildred Lake and Mannix stations.

As part of the 2017 management response, AEP contracted a third party to investigate the trigger exceedances at Lower Camp, Mildred Lake and Mannix stations. The investigation reviewed detailed SO_2 emission inventory data from 2010-2016 from all oil sands operations, based on Continuous Emission Monitoring System (CEMS) hourly data, and ground level ambient monitoring systems.

The results of the investigation are summarized below with a more detailed description of the results included in Appendix A.

SO_2 emissions inventory data discrepancies

The third-party investigation found discrepancies in the SO_2 emission inventory data from Syncrude and CNRL reported to Alberta Environment and Parks and Environment and Climate Change Canada (ECCC) for the period of 2010-2016 (AEP, 2018b). The National Pollution Release Inventory (NPRI) now includes a correction factor for the Continuous Emission Monitoring System (CEMS) data for 2014-2015 at Syncrude that corrected for stratified stack flow.

During the 2010-2017 study period the investigation found:

- Exceedances of the 1-hour Alberta Ambient Air Quality Objective for SO_2 (172 ppb) occurred at Lower Camp station one time, Mannix four times and Horizon two times.
- The most abundant SO_2 sources during the study period were:
  - 2015-2017
    - Secondary inorganic aerosol (55%)
    - Oil sands processing & stack emissions (14%)
    - Haul road dust (7%)
    - Oil sands mixed fugitives (6%)
    - Aged air mass and biogenic (14%)
  - 2010-2014
    - Secondary organic aerosol (63%)
    - Mixed industrial & biogenic (19%)
    - Mixed oil sands, stack emissions, fugitive dust-related (5%)

  - Cu-rich related (6%)
  - Haul road dust (4%)

- The air mass back trajectory analysis found logical relationships to an hourly SO_2 concentration maxima condition and long-range transport of potential emission sources within 80 – 100 km away from Lower Camp station.

Alberta Environment and Parks conducted additional analysis for SO_2 trigger exceedances at Lower Camp station, using 1-hour average air monitoring and meteorological data collected at Lower Camp station for 2010-2018. Pollution roses and diurnal variation were plotted using the openair package in R, and histograms were plotted in MATLAB. This investigation found:

- Diurnal variation of SO_2 during 2010-2014 shows a higher value in the middle of the day that may be associated with stack sources and vertical mixing of SO_2, which is transported from stacks to the surface air monitoring station.
- Positive correlations observed between SO_2 and H_2S when $H_2S/SO_2 < 0.05$ during 2010-2013 and ~0.5–0.15 during 2015-2018.
- Changes in SO_2 sources in Athabasca Oil Sands Region (AOSR) starting around 2015 resulted in more episodes associated with winds from the southwest of Lower Camp station during 2015-2017. Additional investigations are planned to understand this change.

Details of this investigation are provided in Appendix B.

Proposed next steps of the investigation

Currently, Alberta Environment and Parks is engaging with industry by sharing the ongoing status of our investigations to support their internal investigations into potential SO_2 sources that may be responsible for the exceedances at the Lower Camp station.

Moving forward, additional investigations are required to improve the general and specific understanding of potential sources of NO_2 and SO_2 in the Athabasca Oil Sands Region (AOSR).

Analyzing additional datasets is required to narrow down potential sources using:

i) Satellite data of NO_2 and SO_2 over Athabasca Oil Sands Region (AOSR)

ii) Industry emission data reports, and

iii) Air monitoring and meteorological data at other stations in Lower Athabasca Region.

Alberta Environment and Parks intends to work together with Environment and Climate Change Canada (ECCC) and other research teams who use NASA satellite data for any updates of potential source information of NO_2 and SO_2 over the AOSR.

Table 2 identifies proposed next steps to improve understanding of the SO_2 exceedances in the region, specifically at Lower Camp station.

Table 2. Status of Proposed Investigations

Investigation Task	Status
Collect additional information on industry flaring to determine any possible influence on the SO_2 upper level measurements at Lower Camp	Ongoing
Collect information to determine if petroleum coke piles are emitting SO_2 and if they may be a contributing factor to SO_2 results	Ongoing
Analysis of meteorological data for the Athabasca River valley area that may influence SO_2 hourly concentrations at Lower Camp station	Ongoing
Collecting updates of potential source information of NO_2 and SO_2 over AOSR from Environment and Climate Change Canada (ECCC) and other research teams who use NASA satellite data	Proposed

Investigating the possible influence of industry flaring on the upper range of SO_2 emissions at Lower Camp and other neighbouring stations

Contributions from flaring remain a significant portion of total SO_2 emissions in the Lower Athabasca Region as shown in annual emission reports of Suncor Millennium, Suncor Firebag, Syncrude Mildred Lake and CNRL Horizon (AEP, 2018b). It is important to understand if SO_2 contributions due to flaring are trending upward, and the influence this has on the upper range of hourly SO_2 concentrations at air monitoring stations.

Investigating fugitive emissions from petroleum coke as a potential contributing factor to ambient level of SO_2 at Lower Athabasca Region

A recent fire incident (Alberta Environmental and Dangerous Goods Emergencies Incident Number 340937, 2018) at the Mildred Lake petroleum coke pile (Suncor site) occurred with a wind direction that suggests possible connection to elevated SO_2 at the Mildred Lake and Lower Camp stations. Petroleum coke in this area contains 6-7% sulphur (Suncor, 2018) and is commonly stored on site often within ~1 km of the Lower Camp station. It is possible that if temperatures are high enough as a result of smouldering or fire, the sulphur within the petroleum coke piles may be released as SO_2. Engagement with industry is ongoing to better understand this possibility.

Analysis of meteorological data for the Athabasca River valley area that may influence SO_2 hourly concentrations at Lower Camp station

Due to the location of Lower Camp station along the Athabasca River, there is a possibility that valley breezes formed during the day result in SO_2 peaks at this station. Receptor modeling could be used to analyze 5-minute or shorter time-span SO_2 concentrations with meteorological data (wind speed, wind direction) from nearby sources for a better understanding of the upper range of hourly values. A study is currently ongoing by Alberta Environment and Parks.

3.2 Identification of Management Actions

Achieving the air quality objectives identified within the Lower Athabasca Regional Plan requires a proactive and future-based approach. Management actions support, rather than replace existing policies and regulations. These actions range from policy or regulatory initiatives to reduce emissions, to voluntary actions, and raising awareness and education on air quality.

Management actions may include activities that contribute to the gathering of baseline information, improving scientific understanding and knowledge, learning from other jurisdictions and identifying initiatives that are already committed to, underway or new ones that can lead to air quality improvement. Management actions and their impacts often require long time periods to take effect, and are commonly dependent on collaborative efforts to be successful.

No new management actions have been identified to respond to SO_2 exceedances in 2018 as ongoing initiatives being developed or already in place will help to understand SO_2 emission patterns and any future needs for additional management actions in the Lower Athabasca Region.

As part of the commitment to stakeholder engagement under the Lower Athabasca Regional Plan, AEP started holding multi-stakeholder workshops and engagement in 2017 to share information on the proposed management response and solicit input on what Alberta Environment and Parks is proposing and to discuss additional potential management responses. Alberta Environment and Parks plans to continue with these in the future.

3.3 Oversight and Delivery of Management Actions

Investigations of SO_2 emission in Athabasca Oil Sands Region

The previous management response report (AEP, 2020a) recommended investigations of SO_2 emissions in the Athabasca Oil Sands Region. A number of actions were underway at that time as identified by previous years' reports. Table 3 provides the status of delivery of those management actions.

Table 3. Status of the delivery of investigation tasks including ongoing initiatives as of October 2019

Investigation Tasks	Lead	Status	Notes
Investigation of SO_2 level and sources in Athabasca Oil Sands Region	AEP Operations	Complete	Results summarized in this report (section 3.1.2).
Develop improved trend assessment methodology	AEP EMSD	Complete	Available at: https://open.alberta.ca/publications/9781460136379
Assess and improve monitoring network	AEP Policy	Ongoing	Under review by AEP.

Investigations of SO_2 emissions in Athabasca Oil Sands Region

Detailed investigations were conducted to establish a better understanding of current emissions and to identify local and potential distant sources of ambient SO_2 in the Athabasca Oil Sands Region. The results are summarized in section 3.1.2 and a more complete synopsis is included in Appendix A. Results of this report will be used to inform future management actions.

Develop Improved Trend Assessment Methodology

The 2012 management response report recommended developing a tool suitable for calculating both short-term and long-term trends of SO_2 and NO_2 concentrations in the Lower Athabasca Region. Alberta Environment and Parks developed a tool, which is available at https://open.alberta.ca/publications/9781460136379, and is being tested internally.

Assess and Improve Monitoring Network

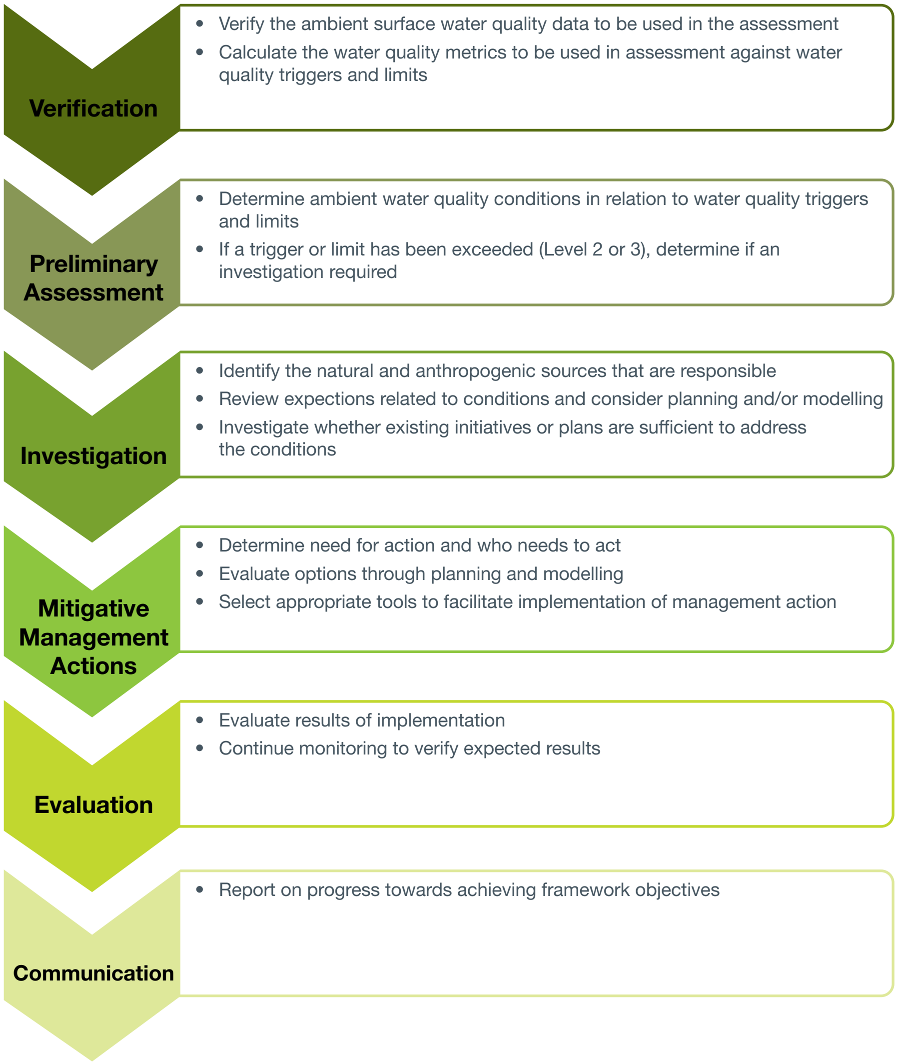
A project was initiated to provide recommendations on adjustments to the monitoring network to improve characterization and understanding of ambient air quality in the Athabasca Oil Sands Region. The report is currently at the final stage of review.

4.0 Air Quality Next Steps

Alberta Environment and Parks (AEP) will continue to oversee the delivery of previously identified management actions while initiating investigations required to understand NO_2 and SO_2 exceedances, particularly at the stations triggering into Level 3 and above. AEP will continue to work with partners to complete the proposed and outstanding investigation tasks (see Section 3.1.2). AEP will also work with specific stakeholders and Indigenous Peoples to inform the investigation and management actions stages of the management response, to assist in improving the current environmental management system for point and non-point source emissions and inform them of the air quality status and management responses underway. Progress updates on the work outlined in this report will be communicated to the public in future Status of the Management Response reports.

5.0 Introduction to Surface Water Quality

Under the Lower Athabasca Region Surface Water Quality Management Framework for the Lower Athabasca River (the framework) (AESRD, 2012b), crossing a trigger or limit initiates a management response process. Undesirable trends in water quality within the region can also result in a management response. The response is re-evaluated each year and updated as new information becomes available. The framework provides a fuller description of the management system. Figure 5 provides an overview of the steps outlined in the framework.



Verification

- Verify the ambient surface water quality data to be used in the assessment
- Calculate the water quality metrics to be used in assessment against water quality triggers and limits

Preliminary Assessment

- Determine ambient water quality conditions in relation to water quality triggers and limits
- If a trigger or limit has been exceeded (Level 2 or 3), determine if an investigation required

Investigation

- Identify the natural and anthropogenic sources that are responsible
- Review expections related to conditions and consider planning and/or modelling
- Investigate whether existing initiatives or plans are sufficient to address the conditions

Mitigative Management Actions

- Determine need for action and who needs to act
- Evaluate options through planning and modelling
- Select appropriate tools to facilitate implementation of management action

Evaluation

- Evaluate results of implementation
- Continue monitoring to verify expected results

Communication

- Report on progress towards achieving framework objectives

Figure 5: The Management Response workflow as originally published in the Surface Water Quality Management Framework for the Lower Athabasca River (AESRD, 2012b)

This report summarizes the status of the management response to previously reported trigger crossings, focusing on ongoing investigations. A management response consists of up to six steps, undertaken as needed (Figure 5). Initial steps include verification and a preliminary assessment. Verification (Step 1) determines trigger or limit crossings. A preliminary assessment (Step 2) evaluates the need for an investigation. At the time of this writing, verification and preliminary assessments are up to date for all the trigger crossings. All indicators that crossed a trigger in 2018 relate to parameters already under investigation. Therefore, there are no preliminary assessments included in this report. However, the procedures applied for preliminary assessments are routinely updated as a component of ongoing investigations (Step 3). These results are reported in section 7.3.

If necessary, investigations follow a preliminary assessment. Investigations strive to identify the source of changes in water quality. Precise delineation of a source could lead to refined mitigation efforts. Therefore, investigations can enhance mitigation by producing actionable information.

Evaluating the effectiveness of any actions that are taken is the next step in the process (Step 5). Management actions and recommendations for 2018 are outlined in Section 8 of this report. Communication progress in all stages of the workflow (Step 6) is ongoing via this and other reports.

Environment and Parks is the lead coordinator in undertaking the management response and will work with other government organizations (e.g. Alberta Energy Regulator) and external parties when appropriate.

5.1 Monitoring of the regulatory site

Triggers and limits identified in the framework apply at a site referred to as 'Old Fort'. 'Old Fort' lies along the main stem of the Athabasca River within the Peace-Athabasca Delta. 'Old Fort' sites are upstream of Lake Athabasca and downstream of all oil sands development (Figure 6). 'Old Fort' refers to a combination of two monitoring sites: Old Fort and Devil's Elbow. Devil's Elbow site is approximately 20 km downstream of Old Fort, past the confluence of the Richardson River.

Historically, open water samples were collected at the Old Fort and under-ice samples from the Devil's Elbow. In 2018, collection of all samples occurred at Old Fort. Appendix C shows the location of historical sampling. Figures in this document, where possible, differentiate between observations collected at Old Fort and Devil's Elbow.

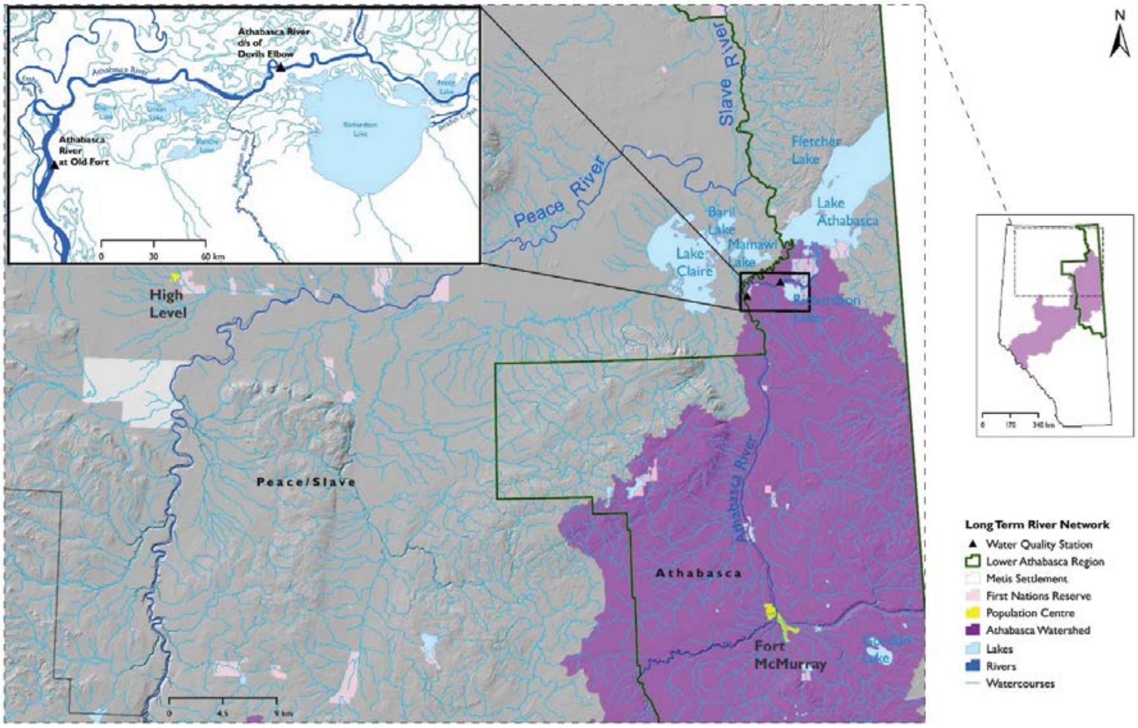


Figure 6: Map of the Athabasca River Basin and locations of the AEP Long-term River Network Water Quality Stations on the Lower Athabasca River

6.0 Summary of Trigger Crossings and Status of Management Response

Surface water quality in the Lower Athabasca Region (LAR) has crossed no limits to date. However, trigger crossings have occurred each year since the framework came into effect in 2012; some leading to investigations. All parameters under investigation had increasing trends at ‘Old Fort’. Past and current trigger crossings are summarized in Table 4, as are the current management responses. In 2018, the average potassium and dissolved uranium indicators crossed a trigger; as did the peak dissolved uranium indicator. Indicators for dissolved uranium, dissolved lithium, potassium and sulphate cross triggers most frequently.

Table 4: History of mean (M) and peak (P) trigger crossings for which there is a current management response.

Parameter	2012	2013	2014	2015	2016	2017	2018	Current Status
Potassium			M			M	M	Under investigation
Sulphate			M	M	P			Under investigation
Iron (dissolved)		M						Under investigation
Nitrogen (total)	M	M						Under investigation
Uranium (dissolved)	M/P	M/P	P	M/P	M/P	M/P	M/P	Under investigation
Lithium (dissolved)	P				M/P	M/P		Under investigation
Chloride								Under investigation
Cobalt (dissolved)			P		P			Closed (2016)
Aluminum (dissolved)		P						Closed (2016)
Lithium (total)		P						Closed (2016)
Strontium (dissolved)				M				Closed (2016)

This is the sixth Status of Management Response Report for the LAR. There are currently seven parameters under investigation. More details of past preliminary assessments are available in the reports listed in Appendix D. As of this writing, these reports are available at the following URL: https://www.alberta.ca/lower-athabasca-regional-planning.aspx.

7.0 Status of Management Response for Surface Water Quality

The following section describes actions taken since the previous management response report.

7.1 Verification

Verification happens each year as new data become available (Figure 5). Indicators are summarized and compared to the triggers and limits provided in the framework. Indicators test if annual values differ from normal historical conditions. If differences in average and peak values are significant, a trigger or limit crossing occurs. For all framework parameters other than Calcium (Ca^+) and Magnesium (Mg^+), crossings imply an increase. Annual verification details are published in other reports (AESRD 2014b; AEMERA 2015; AEP 2016b, c; 2018b; 2019). In 2018, dissolved uranium indicators crossed triggers for mean and peak concentrations. The average concentration indicator for potassium also crossed a trigger (AEP, 2020b).

7.2 Preliminary Assessment

Preliminary assessments establish if trigger crossings are part of a broader trend. Beyond that, the preliminary assessments test whether a trend may be connected to changes in the rate of flow (hydrology); however, the current scope of the framework doesn't extend to manage water quantity issues. Flow-adjustments are used to account for the influence of hydrology. For more information pertaining to the rationale and application of this approach, see Appendices E and F.

Undesirable trends in water quality warrant further investigation. To establish that a trend exists, both unadjusted and (where possible) flow-adjusted data are analyzed. If an increasing trend exists in unadjusted data, but not in flow-adjusted data, trends are explainable by climate or hydrology. Therefore the issue relates to water quantity and does not provide a rationale for water quality investigations. In contrast, hydrology may also make trends difficult to see. In these cases, flow-adjustment may reveal trends otherwise not observable in the data. Therefore, an increasing trend in flow-adjusted values is not explained by climate or hydrology. This provides a rationale in support of a water quality investigation.

Lastly, the absence of any increasing trends (flow-adjusted or otherwise) could suggest that a trigger crossing likely resulted from short-lived variability. This does not establish that an issue exists. Therefore, investigations are usually only pursued when trends are present and not explained by the rate of flow. Ongoing investigations into all parameters related to 2018 trigger crossings are already underway (Table 4). Previous preliminary assessments established the need to investigate. However, investigations will regularly update these analyses to re-affirm their supporting rationale. Outcomes from these analyses are presented in Section 7.3.

7.3 Investigation Plan

This year, Environment and Parks compiled datasets and performed Seasonal Kendall (Hirsch et al., 1982; Hirsch & Slack, 1984) trend analyses (SK). These analyses spanned the Athabasca basin and supported ongoing investigations. Investigations attempt to identify the causes that degrade surface water quality. Knowing where and at what times of year changes occur offers clues about the sources.

Investigations used the provincial surface water quality monitoring network data. SK trend analysis assessed changes month by month and annually. The monthly (season) specific trends give information about what times of year trends are developing. Overlapping geography and timing of trends indicate where and when trends develop.

In section 7.3.8, the results of the trend tests were combined with maps of contributing areas to rank areas of interest for further investigation. More details on the analysis and categorization for mapping are available in Appendices G and H. The locations of trends will be used to identify areas in need of management.

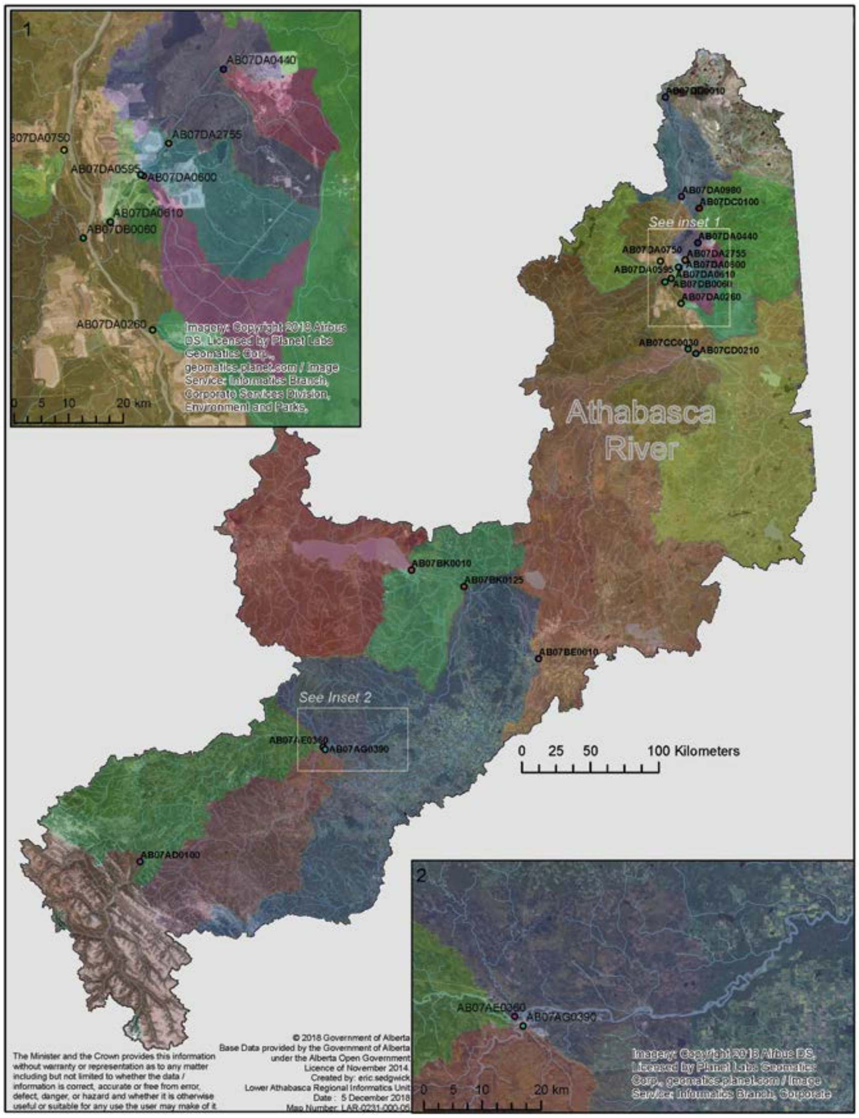


Figure 7: Map of the Athabasca River Basin surface water quality monitoring stations and contributing areas used in investigations

7.3.1 Chloride

Chloride is currently under investigation despite not exceeding any limits or triggers (Table 4). The framework limit for chloride is set at 100 mg/L and the peak trigger is set at 45 mg/L. In 2018, the maximum value (28 mg/L) equaled 62.2% of the peak trigger and 28% of the limit. The 2018 measurements ranged within historical values (prior to 2010) and the interim period from 2010 to 2017.

Changes in flow volumes obscured a trend in chloride. No significant rise in unadjusted concentrations occurred. The trend analysis for chloride showed a decreasing trend in unadjusted concentration that was not statistically significant at ‘Old Fort’ (Figure 8). In contrast, flow-adjustment showed a significant increasing trend. Flow-adjustment indicated increases at a rate of 0.598 mg/L per year relative to the volume of flow. Therefore, the investigation into chloride will continue.

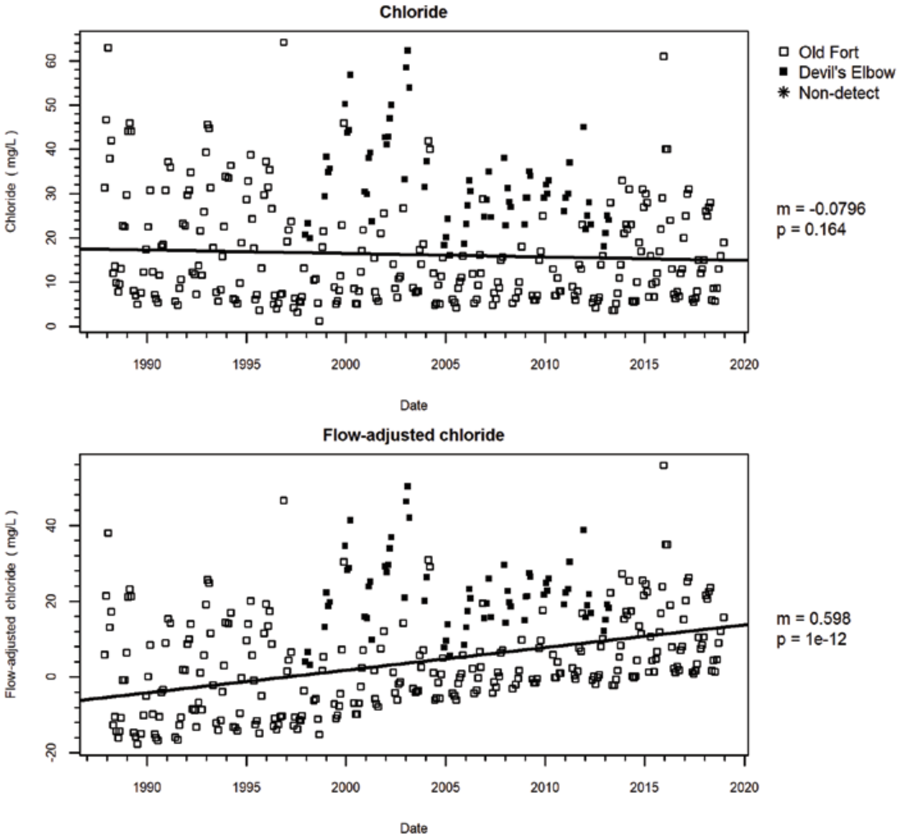


Figure 8: Time series plots of unadjusted concentrations (top) and flow-adjusted concentrations (bottom) of chloride from the Athabasca River at ‘Old Fort’.
Trend lines represent Akritas-Theil-Sen line.

7.3.2 Dissolved Iron

In 2018, dissolved iron did not cross the peak trigger set at 372 µg/L. The maximum value (172 µg/L) equaled 46.2% of the peak trigger value. The 2018 measurements ranged within historical values (before 2010) and the interim period from 2010 and 2017.

The trend in dissolved iron was seemingly obscured by changes in flow volumes. No significant increase could be observed from unadjusted concentrations (Figure 9). The trend analysis for dissolved iron showed an increasing trend in unadjusted concentration that was not statistically significant at ‘Old Fort’. In contrast, flow-adjusted measurements showed a significant increasing trend. Trends indicated that concentrations were, on average, increasing at a rate of 4.01 µg/L per year relative to the volume of flow. Therefore, dissolved iron will continue to be investigated.

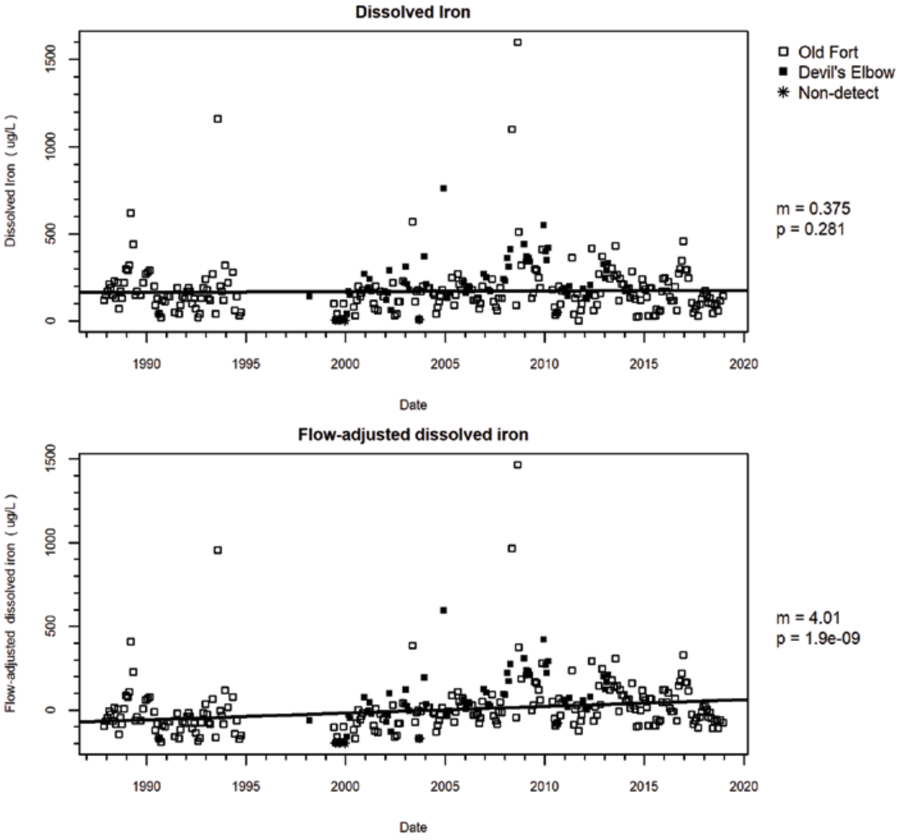


Figure 9: Time series plots of unadjusted concentrations (top) and flow-adjusted concentrations (bottom) of dissolved iron from the Athabasca River at ‘Old Fort’.
Trend lines represent Akritas-Theil-Sen line.

7.3.3 Dissolved Lithium

In 2018, dissolve lithium did not cross the peak trigger value set at 9 µg/L. The maximum value (8.96 µg/L) equaled to 99.6% of the peak trigger value. The 2018 measurements ranged within historical values (before 2010) and the interim period from 2010 and 2017.

Dissolved lithium showed a statistically significant increasing trend at ‘Old Fort’. A trend in dissolved lithium showed increases at a rate of 0.0872 µg/L per year over the period analyzed (Figure 10). The trend was also significant when adjusted for flow. After flow-adjustment, concentrations increased at a rate of 0.37 µg/L per year. Therefore, dissolved lithium will continue to be investigated.

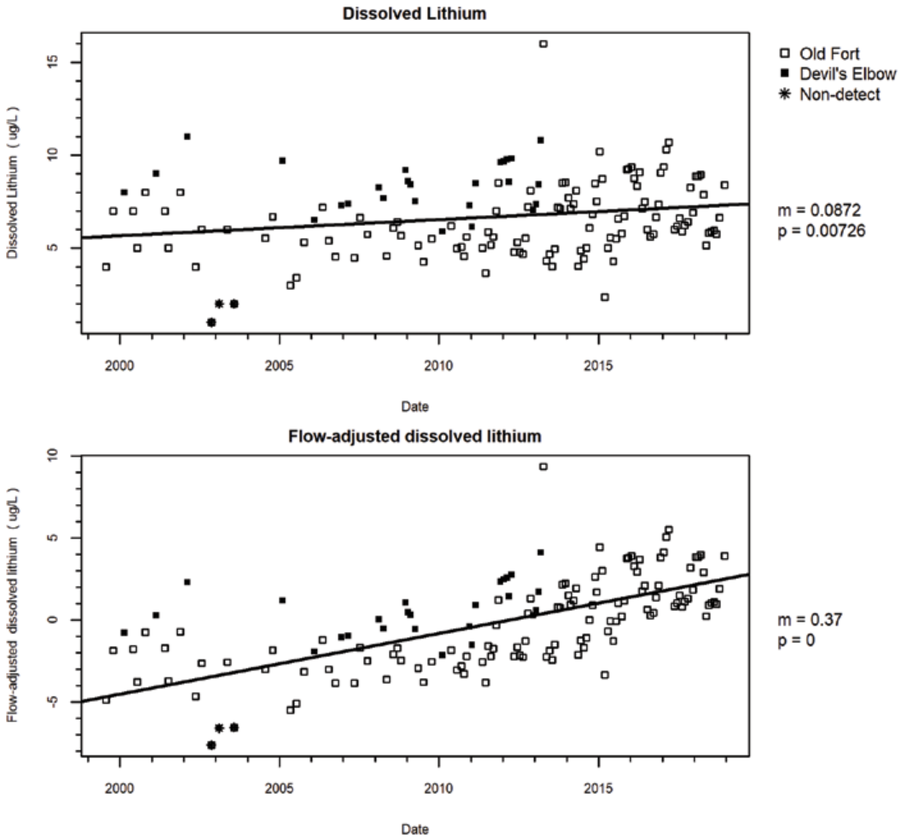


Figure 10: Time series plots of unadjusted concentrations (top) and flow-adjusted concentrations (bottom) of dissolved lithium from the Athabasca River at ‘Old Fort’.
Trend lines represent Akritas-Theil-Sen line.

7.3.4 Total Nitrogen

Total nitrogen is a measure that is calculated from the sum of total Kjeldahl nitrogen (TKN), nitrate (NO_3), and nitrite (NO_2). In addition to total nitrogen, the investigation analyzed its components. Trend analysis results for each nitrogen subcomponent are detailed in Appendix I. These analyses help to understand the drivers of total nitrogen at 'Old Fort'.

In 2018, no values crossed the peak total nitrogen trigger set at 1.041 mg/L. A maximum value of 1 mg/L equaled 96% of the peak trigger value. The 2018 measurements ranged within historical values (before 2010) and the interim period from 2010 to 2017. The dataset for total nitrogen spanned from 1987 to 2018.

The trend analysis for total nitrogen showed a statistically significant increasing trend at 'Old Fort'. Total nitrogen increased at a rate of 0.00484 mg/L per year over the period analyzed (Figure 11). The smallest values observed each year for total nitrogen were higher after 2008. Changes in flow-concentration relationships over time prevented the development of an adjustment model for this parameter. Therefore, flow is unable to explain the trend observed. Consideration of other factors is needed and investigation into total nitrogen will continue. While the slope of the trend line is small, evidence in Appendix I implies that the composition of total nitrogen has changed.

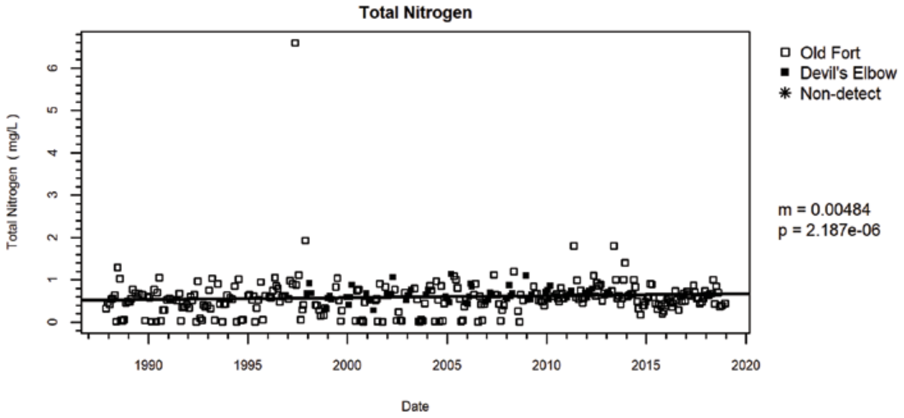


Figure 11: Time series plot of unadjusted concentrations of total nitrogen from the Athabasca River at 'Old Fort'.
Trend lines represent Akritas-Theil-Sen line.

7.3.5 Potassium

In 2018, one value crossed the peak trigger value set at 2100 µg/L. The maximum value (2200 µg/L) equaled 105% of the peak trigger value. All 2018 measurements ranged within historical (before 2010) and interim (2010-2017) values.

The trend analysis for potassium showed a statistically significant increasing trend at ‘Old Fort’ (Figure 12). The concentration of potassium increased at a rate of 9.27 µg/L per year over this period. Concentrations increased at a rate of 35.1 µg/L per year relative to the volume of flow.

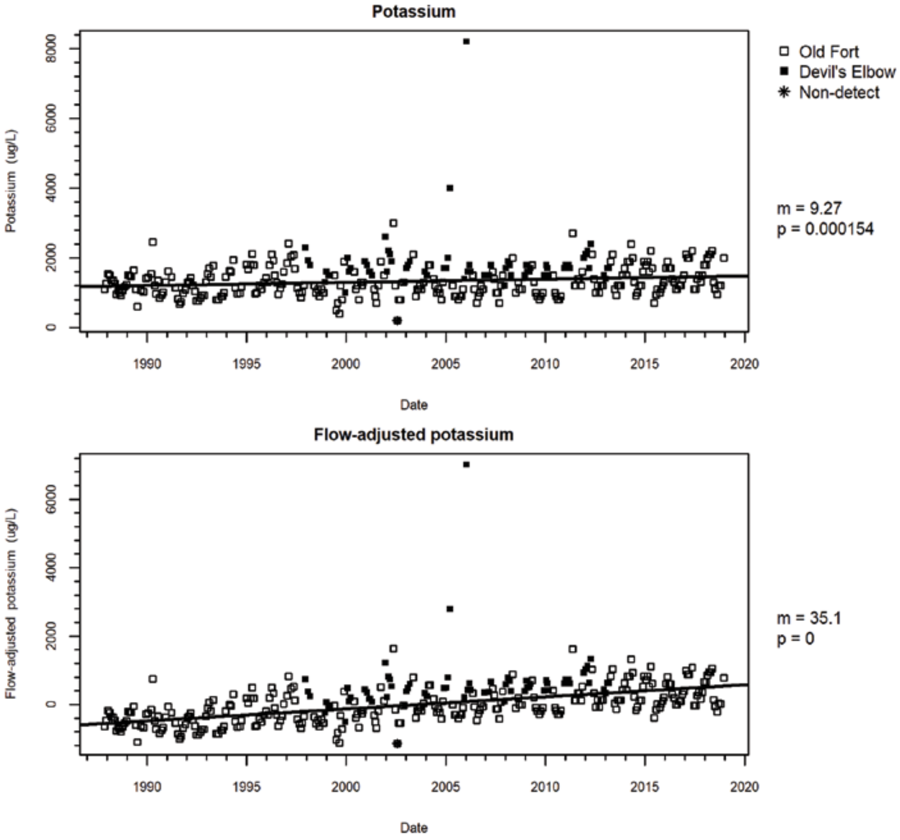


Figure 12: Time series plots of unadjusted concentrations (top) and flow-adjusted concentrations (bottom) of potassium from the Athabasca River at ‘Old Fort’. Trend lines represent Akritas-Theil-Sen line.

7.3.6 Sulphate

In 2018, no measurements crossed either the limit or the peak trigger value, which is set at 41.4 mg/L. The maximum concentration (36 mg/L) equaled 87% of the peak trigger and 7.2% of the limit values. 2018 measurements all ranged within historical (before 2010) and interim values (2010-2017).

Trend analysis for sulphate showed a statistically significant increasing trend at ‘Old Fort’ (Figure 13). Sulphate increased at a rate of 0.261 mg/L per year. The trend was also significant when adjusted for flow. Concentrations increased at a rate of 1.14 mg/L per year relative to the volume of flow.

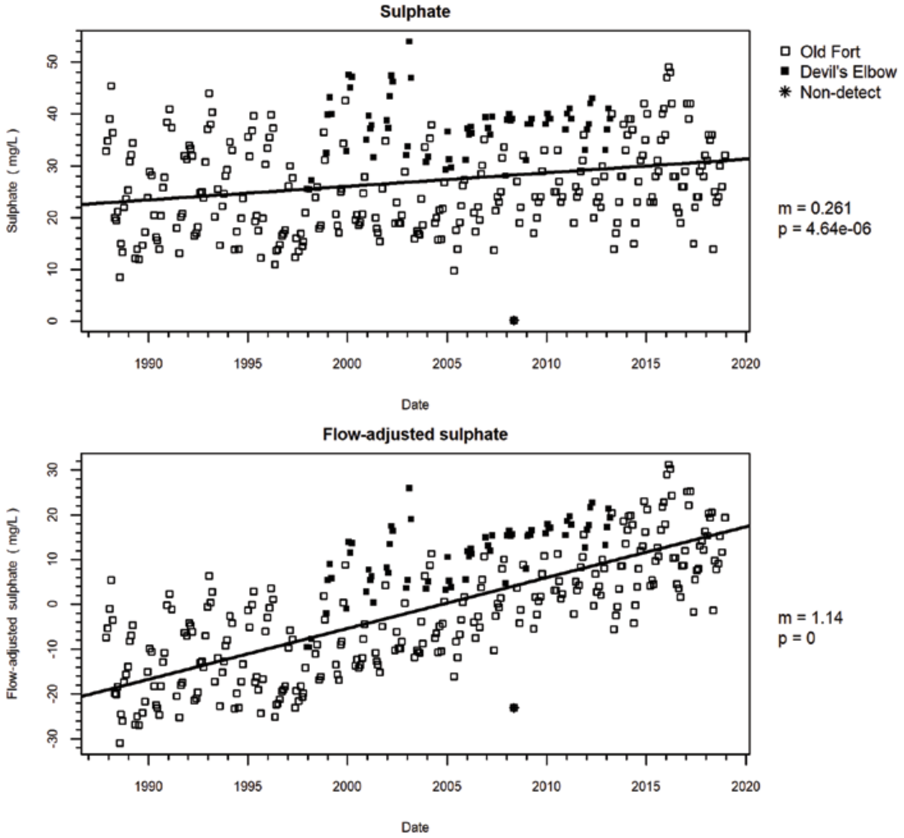


Figure 13: Time series plots of unadjusted concentrations (top) and flow-adjusted concentrations (bottom) of sulphate from the Athabasca River at ‘Old Fort’.
Trend lines represent Akritas-Theil-Sen line.

7.3.7 Dissolved Uranium

In 2018, eight values were above the peak trigger set at 0.381 µg/L. The maximum value (0.426 µg/L) equaled 111.8% of the peak trigger. The 2018 measurements all ranged within historical (before 2010) and interim (2010-2017) values.

The trend analysis for dissolved uranium showed a statistically significant increasing trend at 'Old Fort' (Figure 14). The concentration increased at a rate of 0.00746 µg/L per year over this period. Changes in flow-concentration relationships over time prevented the development of an adjustment model for this parameter. Therefore, flow is unable to explain the trend observed. Consideration of other factors is needed and investigation into dissolved uranium will continue.

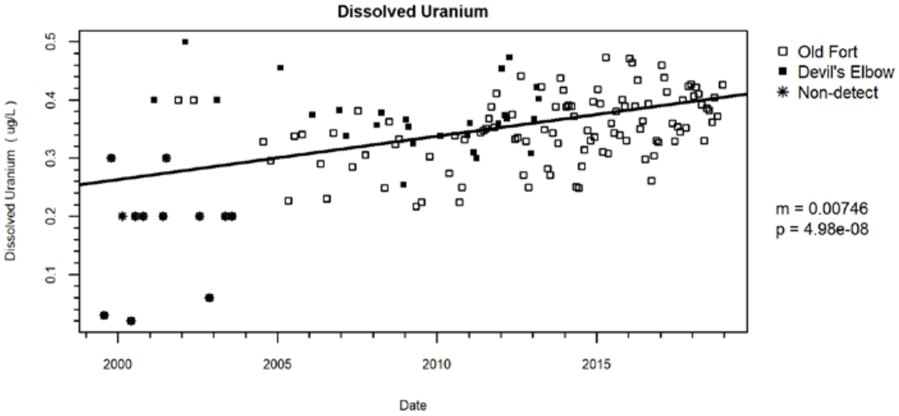


Figure 14: Time series plot of unadjusted concentrations of dissolved uranium from the Athabasca River at 'Old Fort'.
Trend lines represent Akritas-Theil-Sen line.

7.3.8 Seasonal Kendall Analysis

Knowing where and when deteriorating water quality occurs within the Athabasca River basin can inform the investigation and management of water quality issues. Isolating specific reaches that require management changes will make these efforts more precise and efficient. Knowing when an issue is developing can help to narrow the range of possibilities with respect to the related activities.

Seasonal Kendall (SK) analysis is a trend test that compares data across years to narrow down the time of year that a trend is developing (Figure 15).

SK trend results are presented in Figure 15. The grey areas represent missing results where data did not meet the criteria analysis (Appendix E). Mapped results indicate the direction and significance for the trend. Monitoring station codes and their related contributing areas are depicted in Figure 7.

Historical provincial water quality monitoring program records did not meet the criteria for performing a seasonal Kendall trend analysis for any of the parameters at the following monitoring stations:

- AB07AE0360 (downstream of Hinton)
- AB07AC0210 (Clearwater River)
- AB07DA0750 (Ells River)
- AB07DC0100 (Firebag River)

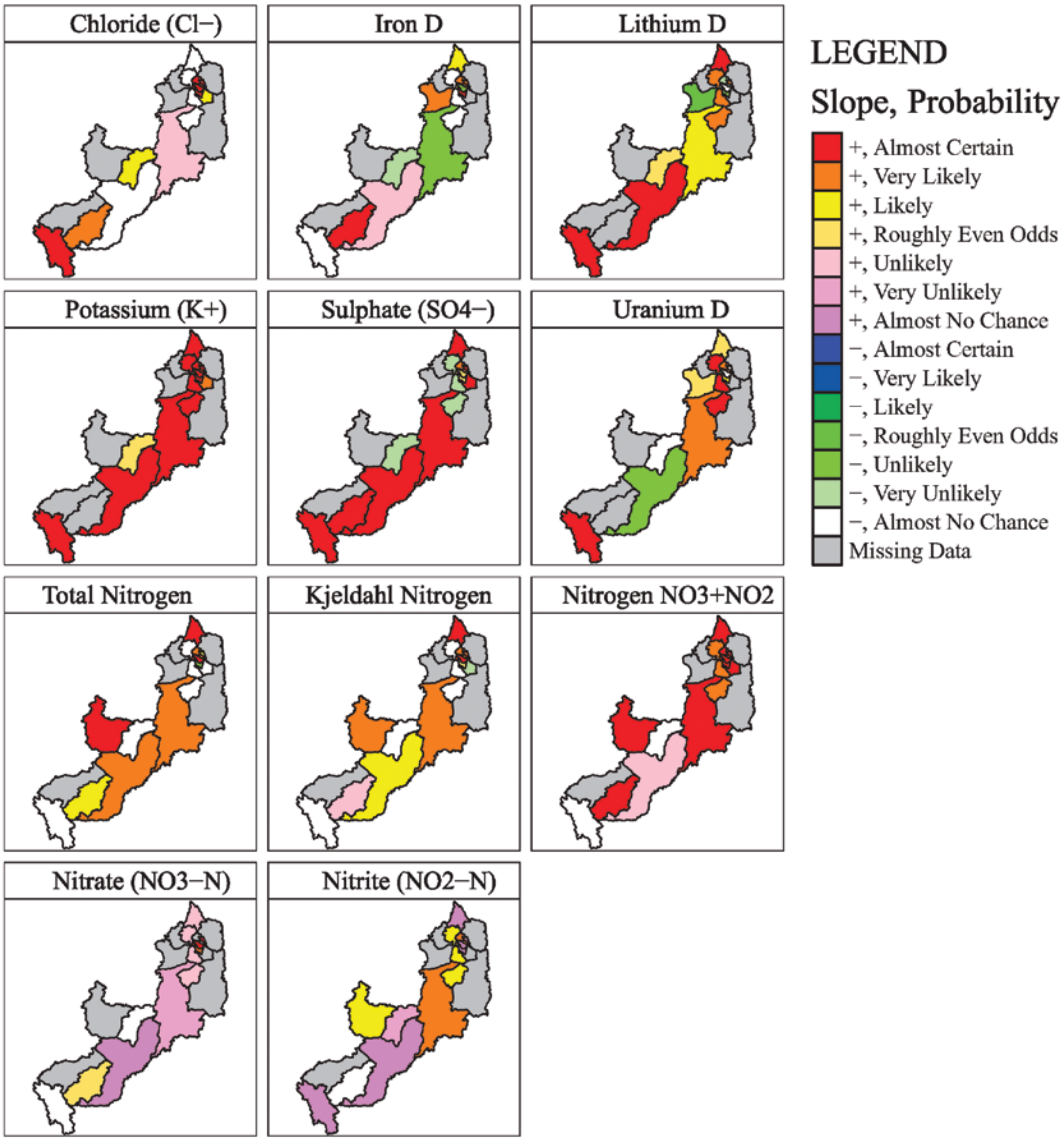


Figure 15: Categorized maps of trend direction and probability for annual results of Seasonal Kendall trend analysis in the Athabasca River basin.

Probabilities were derived from trend slope p-values and relate to expressions of probability detailed in Appendix H. Geographic units correspond to contributing areas described in section 7.3 and illustrated in Figure 7.

Datasets collected downstream from Hinton made it difficult to evaluate water quality trends in the town and surrounding areas apart from those of Whitecourt. This also applies to an area extending from the Jasper National Park boundary to just upstream of Athabasca (town). This reach encompassed notable jurisdictions that include Hinton, Whitecourt, and the Pembina River watershed, among others.

Likewise, datasets collected in the Clearwater River are not sufficient to differentiate the influence of a major tributary. The Clearwater River originates in Saskatchewan, and receives drainage from the Christina River basin. Influences upstream of the Firebag include the Athabasca River, Christina River, and the headwaters in northern Saskatchewan.

The capability to isolate specific reaches will require collation of historical data, and possibly additional monitoring. In the area near Fort McMurray, it is unclear whether the observed effects originate in the oilsands region, the Clearwater or Christina Rivers, or outside Alberta. Therefore, the influence of the Clearwater basin is a confounding factor in explaining the potential impacts of land use along the main stem Athabasca in LAR.

Opportunities for mitigation may exist in the McLeod basin. Chloride, dissolved iron, sulphate, and nitrogen exhibited increasing trends there. Increases in lithium and potassium trends could not be ruled out. The influence of the McLeod River on the Athabasca River was explained for some parameters, but not others. For unconstrained parameters, the influence of the McLeod River could not be separated from the Athabasca main stem.

The Lesser Slave River did not appear to contribute to increasing concentrations of dissolved iron, sulphate, dissolved uranium, or nitrogen (Figure 11) in the Athabasca River. However, trends in nitrogen appear to be developing in Lesser Slave Lake watershed.

These assessments of tributary influence in the Lower Athabasca River are not exhaustive. Historical monitoring programs have not always been consistent between these tributaries. The influences of each tributary could not be resolved from the provincial water quality monitoring data. The data collected from tributaries near oilsands mines do not appear to be contributing to trends in dissolved lithium. However, tributaries in the oilsands region exhibited increases in chloride, dissolved iron and uranium, potassium, sulphate, and nitrogen.

Recall that increasing flow-adjusted concentrations at ‘Old Fort’ were observed for all parameters under investigation. The geography of trends in water quality offers clues about where dilution or loading is likely occurring. Most parameters showed increasing trends in concentration in areas upstream of the LAR. Therefore, factors contributing to trends observed in the LAR are not limited to the region itself and effective mitigation will require cooperative efforts with upstream jurisdictions.

7.4 Management Recommendations

From the ongoing investigations, the following recommendations were developed. These recommendations provide potential strategies to fill knowledge gaps, advance investigations, and develop mitigation efforts.

Continue LARP water quality investigations:

- Explore seasonal patterns within areas where undesirable trends exist
- Verify areas of interest using flow volume estimates and flow-adjustment where feasible
- Capture and integrate water quality data from available sources such as:
    - The Oil Sands Monitoring Program
    - Reported third party municipal and industrial effluent data
- Utilize alternative statistical approaches where trend analysis is not feasible
- Compile information to identify potential mitigation options
    - Compile landuse information within likely source areas
    - Identify relevant jurisdictions and management plans within the areas contributing to trends.

Plan and conduct the monitoring necessary to differentiate relevant jurisdictions, watersheds, and the relevant management plans. Approaches could include:

- Open-water synoptic (longitudinal) surveys of water quality in the Athabasca River
- Expand the medium- or long-term water quality monitoring network within the Athabasca Basin
- Additional water quantity monitoring or modelling as needed.

8.0 Next Steps

As of February, 2020 the status of the management response is as follows:

- Investigations into the following parameters will continue:
    - chloride
    - dissolved iron
    - dissolved lithium
    - total nitrogen
    - potassium
    - sulphate
    - dissolved uranium
- Where data was insufficient to conduct SK trend analyses, paired difference tests will be applied (where possible) to determine trajectories.
- Interpretation of season-specific SK trend analysis results will proceed.

8.1 Indicators under investigation

Chloride, dissolved iron, dissolved lithium, potassium, sulphate, dissolved uranium, and total nitrogen are currently under investigation. As constituent parameters of total nitrogen, total Kjeldahl nitrogen, nitrate plus nitrite, nitrate, and nitrite will also be investigated under that authority. The next step in the investigations will focus on delineating the season-specific spatial extent of trajectories in water quality and identifying activities on the landscape within those areas of interest.

8.2 Indicators for which management response was closed

There were no trigger crossings for which the management response was closed.

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Appendices

Appendix A: Summary of a Contract investigating SO_2 in the LAR

A third-party investigation commissioned by Alberta Environment and Parks found discrepancies in the SO_2 emission inventory data from Syncrude and CNRL reported to Alberta Environment and Parks and Environment and Climate Change Canada for the period of 2010-2016. The National Pollution Release Inventory (NPRI) now includes a correction factor for the Continuous Emission Monitoring System (CEMS) data for 2014-2015 at Syncrude that corrected for stratified stack flow.

During the 2010-2017 study period, the investigation found:

- Exceedances of 1-hour Alberta Ambient Air Quality Objective of SO_2 (172 ppb) at Lower Camp station one time, Mannix four times and Horizon two times.
- Positive Matrix-factorization (PMF) model identified the most abundant SO_2 sources during
    - 2015-2017:
        - Secondary inorganic aerosol (55%)
        - Oil sands processing & stack emissions (14%)
        - Haul road dust (7%)
        - Oil sands mixed fugitives (6%), and
        - Aged air mass and biogenic (14%)
    - 2010-2014:
        - Secondary organic aerosol (63%)
        - Mixed industrial & biogenic (19%)
        - Mixed oil sands, stack emissions, fugitive dust-related (5%)
        - Cu-rich related (6%), and
        - Haul road dust (4%)

- A potential distant source regions, suggested by Hybrid Single Range Particle Lagrangian Integrated Trajectory (HYSPLIT) analysis for SO_2 concentration maxima, specifically >8-10 hour travel time (>80-100 km) away from Lower Camp station, is likely not meaningful in terms of making a dominant contribution to an hourly maxima condition. The air mass back trajectory analysis found logical relationships to an hourly SO_2 concentration maxima condition and long-range transport of potential emission sources within 80 – 100 km away from Lower Camp station.

Emission Inventory for 2010-2016

The investigation found discrepancies between the SO_2 emission inventory data from oil sands plants reported to Alberta Environment and Parks and what was reported to Environment and Climate Change Canada (ECCC) for the period of 2010-2016. Specifically, emissions higher than reported to ECCC were observed at Syncrude Mildred Lake in 2014 (10%) and at CNRL Horizon in 2016 (19%). Also, emission quantities lower than reported to ECCC were observed at CNRL Horizon in 2010 (29%) and 2011 (19%).

In 2018, NPRI developed a correction factor for the CEMS data for 2014-2015 at Syncrude that adjusted for stratified stack flow, (located at: https://pollution-waste.canada.ca/national-release-inventory/archives/index.cfm?do=substance_details&lang=En&opt_npri_id=0000002274&opt_cas_number=7446-09-5&opt_report_year=2014).

Episode analysis for SO_2

Episode analysis was completed for SO_2 from 2010-2017 for Lower Camp, Mannix, Millennium Mine, Fort McKay South and Horizon stations. Hourly exceedances were assessed against the Alberta Ambient Air Quality Objective (AAAQO) (172 $\mu g/m^3$) and other benchmarks such as the Canadian Ambient Air Quality Standard (CAAQS) for 2020 (70 $\mu g/m^3$), National Ambient Air Quality Standards (NAAQS) (75 $\mu g/m^3$) and >100 ppb (used for regulatory impact analysis) at selected industrial air monitoring stations. This analysis was based on ambient air monitoring and meteorological data for the years 2010-2017.

Episode analysis results found one hourly exceedance under the AAAQOs at Lower Camp station, four at Mannix and two at Horizon station. Several elevated SO_2 levels (> 100 ppb but < 172 ppb) were documented at the following stations in the oil sands region (number of occurrences in brackets): Lower Camp station (22), Mannix (26), Mildred Lake (9), Buffalo Viewpoint (6), and Horizon (2).

To understand the probable local sources of SO_2 for different hourly episodes, the report uses the conditional bivariate probability function (CBPF) tool that includes a conditional probability function (CPF) with the addition of wind speed measured at 10 m as another variable. This approach can provide information on the nature of local emission sources and potentially identify the location of contributions from different source types through their wind speed dependence. The use of this approach allows for the identification of sources with the greatest potential influence, and associated with SO_2 concentration exceedances (> 172 ppb) and /or elevated levels (> 70 ppb).

Lower Camp station was selected for episode analysis because the upper range of hourly concentration of SO_2 was at Level 4 for 2016 and 2017 and because sources of SO_2 remain unclear and could be related to continuous emission sources or intermittent flaring. CBPF plots were generated on monthly and weekly timescales for different SO_2 episode periods at Lower Camp station during 2016-2017. Lower Camp station is located between Syncrude to the West and Suncor to the East and South, both of which perform extensive mining, upgrading and processing. The notable SO_2 sources of tall stacks are found to the West (Syncrude) and Southeast (Suncor) sides of Lower Camp station from where emissions typically travel and disperse greatly before reaching the ground level.

The CBPF plots for the higher SO_2 peaks that occurred during April 24-30, 2015 suggest that dominant sources were to the southwest for the exceedance on April 27, 2015 (Figure A1). There are no known SO_2 sources in those areas. It is suggested that further detailed investigations of shorter-term averaged SO_2, and local meteorological data at Lower Camp station may help identify this source. Investigation of the possibility that neighboring petroleum coke deposits may be an emission source was also recommended.

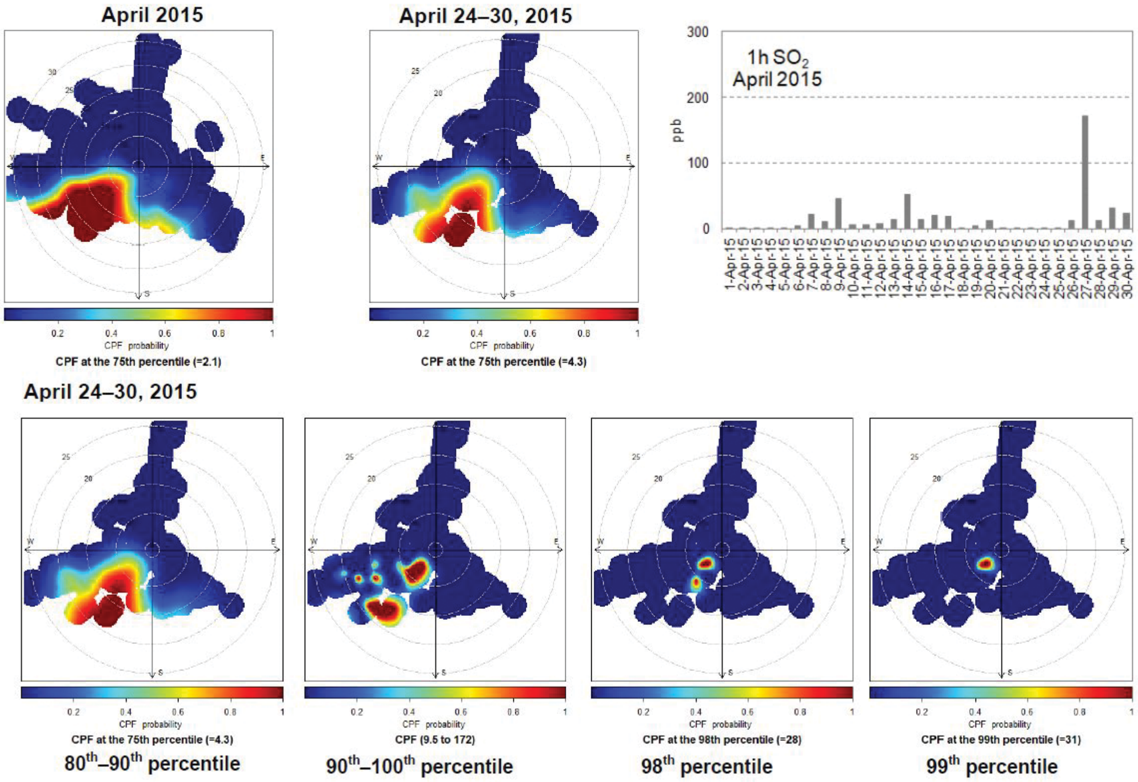


Figure A1: CBPF plots of SO_2 during April 2015 and episode week (April 24-30, 2015) at Lower Camp station

CBPF plots during August 8-14, 2017 revealed a probable influence from the southeast; Suncor facilities in this locale (Figure A2) are likely a dominant source of the elevated levels of SO_2 that originated during this episode period.

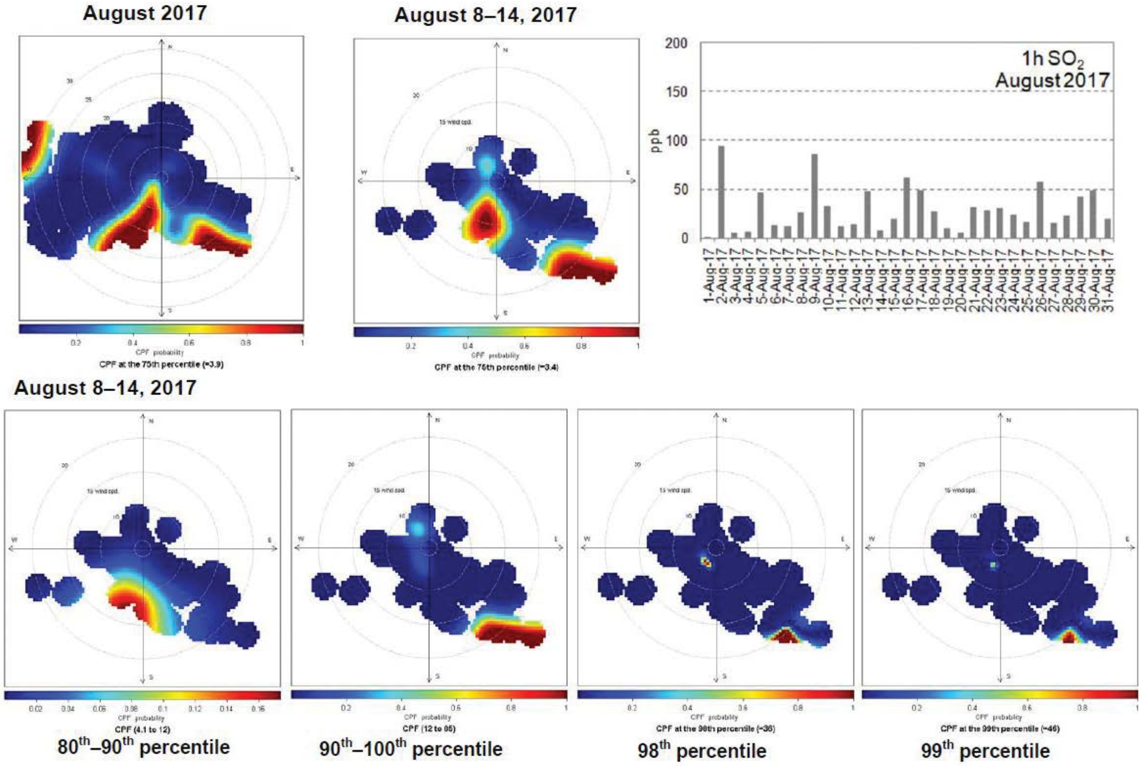


Figure A2: CBPF plots of SO_2 during August 2017 and episode week (August 8–14, 2017) at Lower Camp station

CBPF plots during April 24-30, 2016 revealed a northwest/west source, pointing to probable influence from Syncrude facilities (Figure A3) as a cause of elevated levels of SO_2 during this episode week.

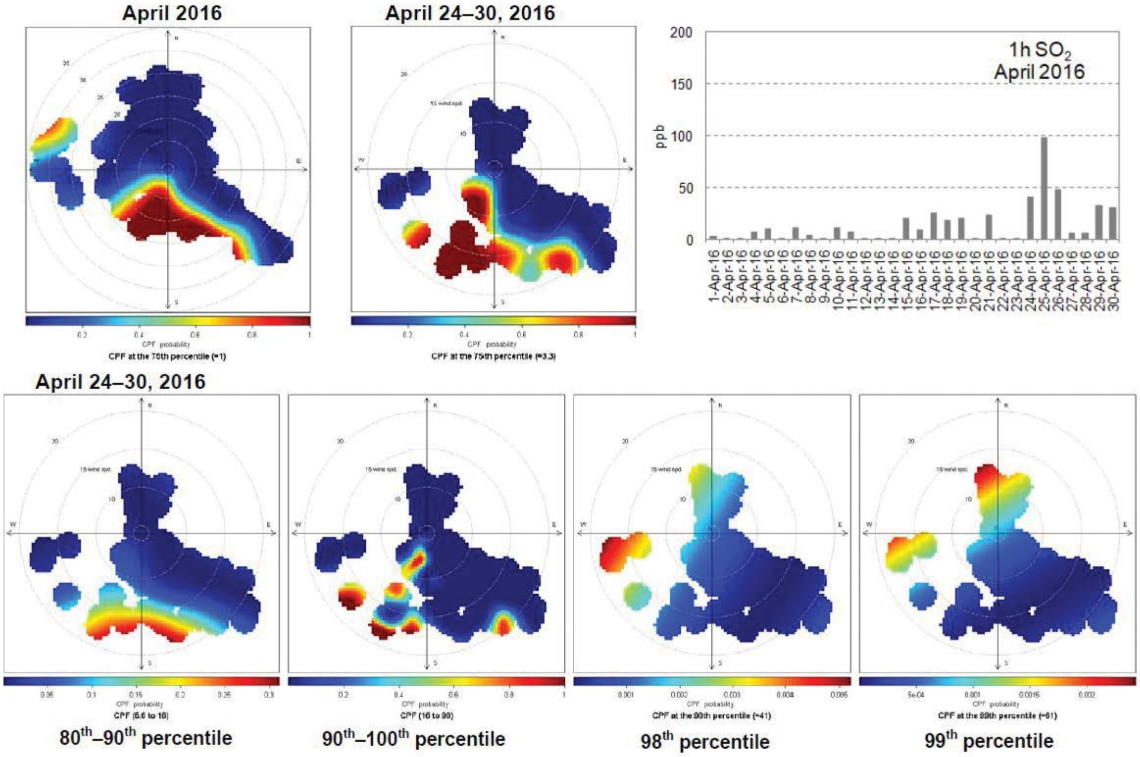


Figure A3: CBPF plots of SO_2 during April 2016 and episode week (April 24-30) at Lower Camp station

Identification of ambient SO_2 sources in the Athabasca Oil Sands Region

The investigation used the current version of the US Environmental Protection Agency positive matrix factorization (PMF) model (version 5) to identify and apportion the contribution of potential ambient air pollution sources in the Lower Athabasca Region. Receptor modeling for PM_{10} concentrations was carried out, followed by PMF receptor model-defined sources for which SO_2 was a statistically strong predictor (AEP, 2018b).

Due to the lack of particulate matter (PM_{10}) and volatile organic compound (VOC) speciation data at the Lower Camp industrial air monitoring station (AMS), the source apportionment model was applied to air monitoring stations surrounding Lower Camp station. Data for PM_{10} components (metal and ion species), gaseous pollutants and VOC species for the Wood Buffalo Environmental Association industrial monitoring stations (Millennium Mine, Fort McKay South and Horizon) were used for this model analysis.

Two separate time periods (2010-2014 and 2015-2017) were modeled due to differences in data quality for each period. For the study period 2015–2017, more than 45 species out of 55 were detected in more than 80% of the samples at the monitoring stations. For the study period 2010–2014 only about 20 species out of 30 were detected in more than 50% of the samples. A combined site approach was used for PMF analysis with an underlying assumption that air monitoring stations can be influenced from similar types of oil sands related sources with varying strength. This approach allows utilization of a large input dataset from three industrial monitoring stations (Millennium Mine, Fort McKay South and CNRL Horizon located within 34 km surrounding Lower Camp air monitoring station) in PMF model.

Because organic carbon (OC) and elemental carbon (EC) were not available in PM$_{10}$ speciation data at the industrial monitoring sites, 'missing mass' was included as an additional component in the PMF model input after Larson et. al. (2006) to account for unanalyzed components in PM$_{10}$ mass (Bari and Kindzierski, 2017).

For the 2015–2017 period, an 11-factor solution was chosen to best represent PM$_{10}$ sources at oil sands industrial air monitoring stations. SO$_2$ was found to be the most abundant species in the secondary inorganic aerosol factor explaining 55% of the variation in the base model run followed by oil sands processed material and stack emissions (14%), aged air mass and biogenic sources (14%), haul road dust (7%) and oil sands mixed fugitives (6%).

This study also showed oil sands processed material and stack emissions (3.71 μg/m^3, 23%) and haul road dust (3.21 μg/m^3, 20%) as two dominant sources contributing to PM$_{10}$ mass in the oil sands region (Figure A4).

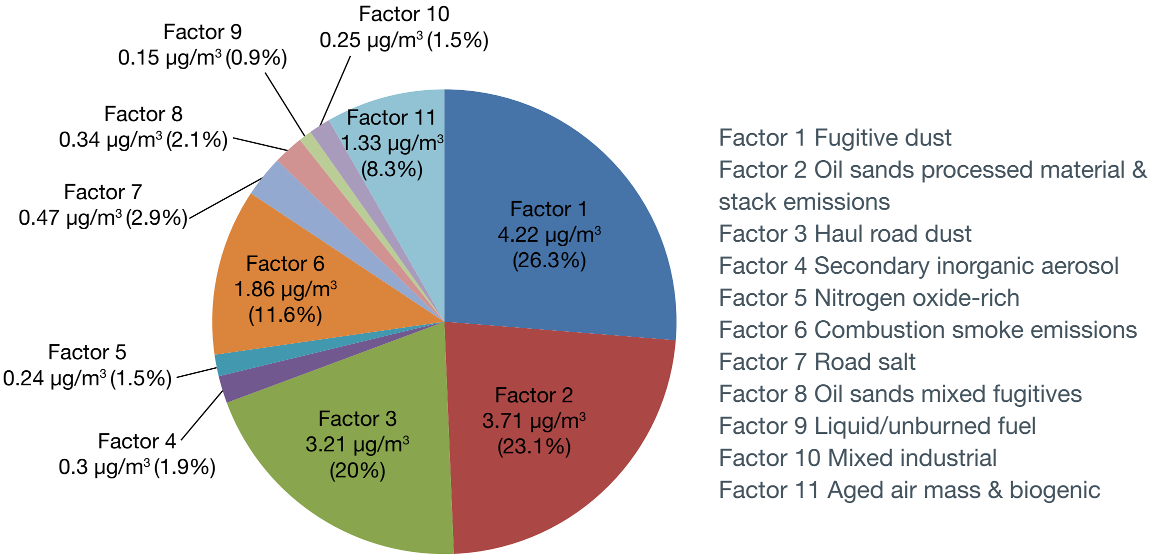


Figure A4: Average source contributions to PM$_{10}$ concentrations for 2015–2017.

Modelling results for the 2010–2014 period shows that SO_2 was the most abundant species in the secondary inorganic aerosol factor explaining 63% of the variation followed by mixed industrial & biogenic (19%), mixed oil sands, stack emissions & fugitive dust (5%), a copper-rich factor (6%) and haul road dust (4%). Like the 2015–2017 period, mixed oil sands, stack emissions & fugitive dust (8.1 µg/m3, 39%) and haul road dust (6.31 µg/m3, 30%) were also found as predominant sources in the oil sands region in 2010–2014.

Influence of long-range transport of potential emission sources

To explore the influence of any potential long-range sources, backward trajectory analysis was conducted using National Oceanic and Atmospheric Administration (NOAA) Hybrid Single Range Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler and Rolph, 2003). Backward trajectory analysis combined with the concentrated-weighted trajectory (CWT) method was applied using PMF-derived source contributions of different factors identified at the high SO_2 episode days at Lower Camp station.

The investigation found that there is little likelihood of distance emission sources, specifically those >8–10 h travel time (>80–100 km) away, making a significant contribution to an hourly SO_2 concentration maxima condition at Lower Camp station. Whereas, the distance emission sources are more likely to make a contribution to the average SO_2 concentration condition (i.e., 2 ppb) or even within a factor of 20 of the average condition (i.e., less than 40 ppb). The investigation suggested that a greater influence on hourly SO_2 concentration maxima is likely to be emission sources well within an 8–10 h travel time.

Appendix B: Alberta Environment and Parks Investigation into SO_2

SO_2 trigger exceedances at Lower Camp station were investigated, using 1-hour average air monitoring and meteorological data collected at Lower Camp station for 2010-2018. Pollution roses and diurnal variation were plotted using the openair package in R, and histograms were plotted in MATLAB.

This investigation found:

- Diurnal variation of SO_2 during 2010-2014 shows a higher value in the middle of the day that may be associated with stack sources and vertical mixing of SO_2, which is transported from stacks to the surface air monitoring station.
- Positive correlations observed between SO_2 and H_2S when $H_2S/SO_2 < 0.05$ during 2010-2013 and ~ 0.5–0.15 during 2015-2018.
- Changes in SO_2 sources in Athabasca Oil Sands Region (AOSR) starting around 2015 resulted in more episodes associated with winds from the southwest of Lower Camp station during 2015-2017. Additional investigations are planned to understand this change.

The air monitoring data at Lower Camp station indicate that there is an abrupt change in peak SO_2 episodes starting around 2015, with more episodes observed for winds from the southwest and occurring at the same time as elevated levels of hydrogen sulphide (H_2S). Around 2015, the diurnal variation of SO_2 also changed, with higher levels of SO_2 throughout the day, and less of a defined peak midday.

Pollution roses

Pollution roses for SO_2 with hourly averages exceeding 12.0 ppb at Lower Camp station for 2010-2018 are shown in Figure B1. Before 2015, there are fewer peak values of SO_2, associated primarily with winds from the west/west-northwest and from the southeast/south-southwest, which is consistent with stack emissions of SO_2 from the Syncrude and Suncor upgraders. For 2015-2018, there are more peak values of SO_2 for a broader range of wind directions. These include a large number of episodes associated with winds from the southwest. This suggests that there has been a change in SO_2 sources in the area, starting around 2015, which has caused more episodes to occur for winds from the southwest of Lower Camp station.

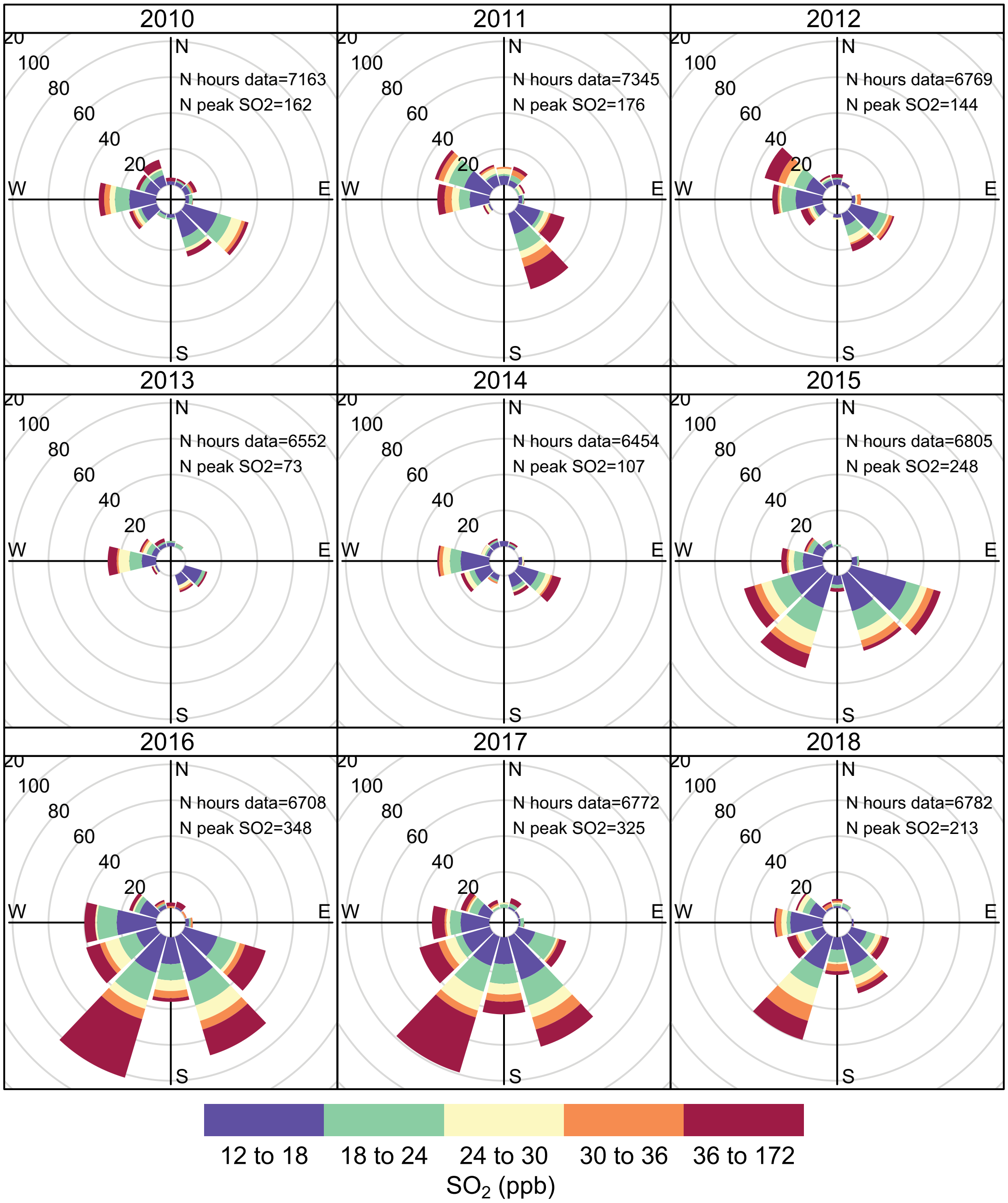


Figure B1: Pollution roses for peak values of SO_2 (hourly average >12 ppb; blue: 12 ~18 ppb, green: 18 ~24 ppb, yellow: 24 ~30 ppb, orange: 30 ~36 ppb, pink: 36 ~ 172 ppb) at Lower Camp station, expressed as number of hours of data (concentric rings) for wind speeds exceeding 4 km/h.

Diurnal variation

The diurnal variation of SO_2 for 2010-2018 is shown in Figure B2. From 2010-2014, there is a clear peak in mean SO_2 in the middle of the day, when there is more vertical mixing in the atmosphere. The diurnal variation is therefore consistent with suspected emissions from stack sources, which require vertical mixing for SO_2 to be transported downward from the stack to the station. For 2015-2018, the diurnal variation is different, with higher mean levels of SO_2 for all hours of the day. Furthermore, the diurnal variation is less clearly defined in 2015-2018, with the highest levels of SO_2 starting midday, but extending into the evening hours. It might be due to divergence between emission and concentration trends during 2015-2018 when higher discharge heights have led to higher plumes, which need deeper and more vigorous convection, which occurs mostly in the midafternoon, to bring them down to ground level (Shie et al; 2013).

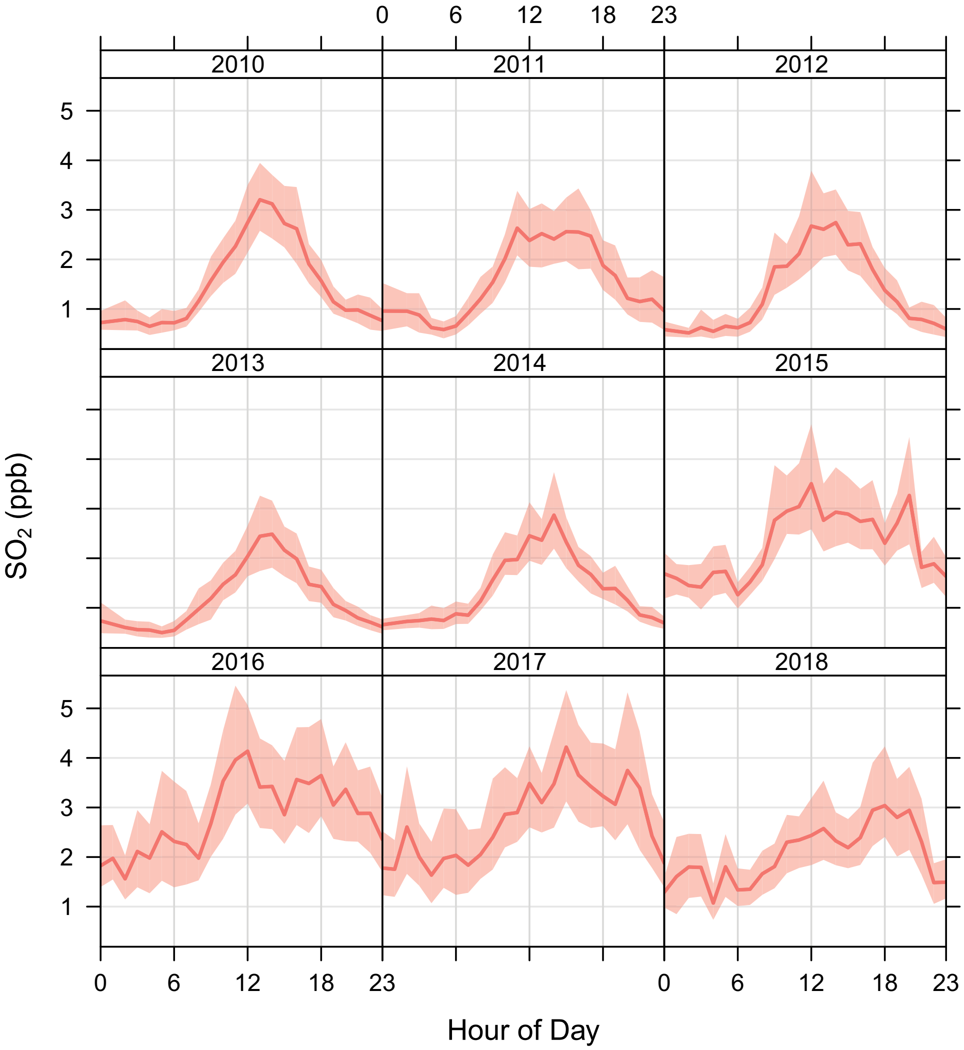
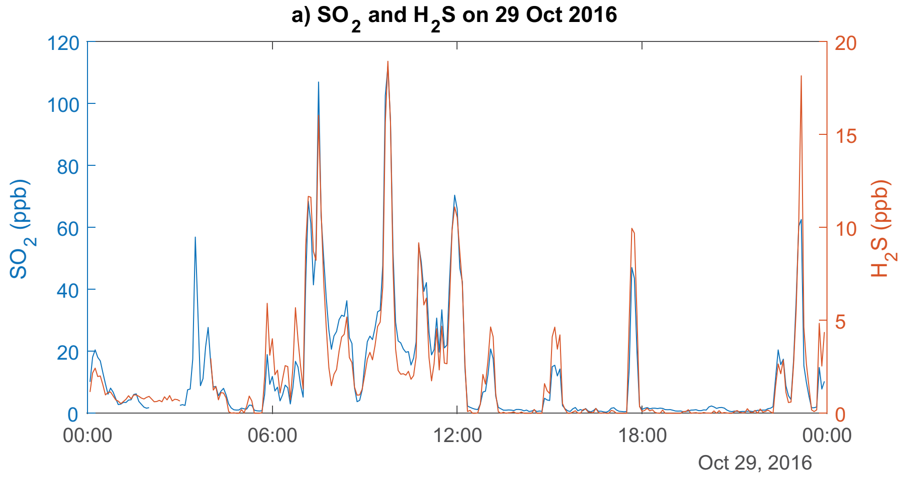
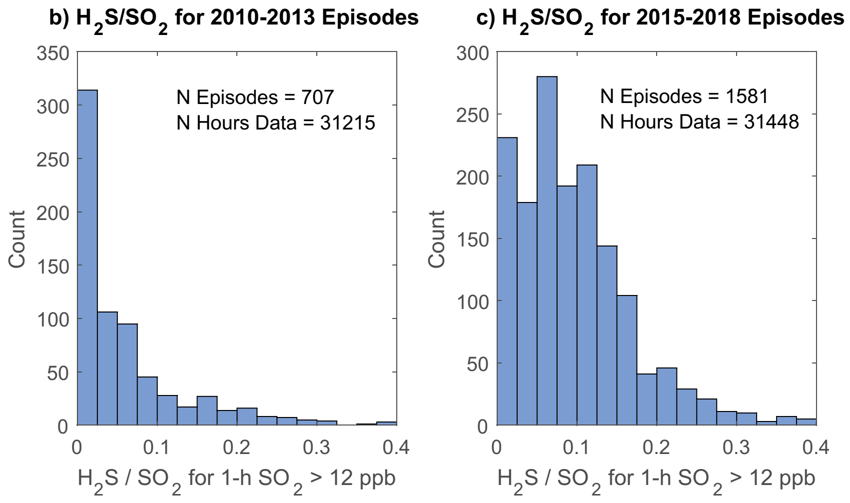


Figure B2: Diurnal variation of SO_2 at Lower Camp station
The red line is the annual mean and the shaded area is the 95% confidence interval, calculated through bootstrap resampling.

Relationship between SO_2 and H_2S

The relationship between SO_2 and H_2S at Lower Camp station is shown in Figure B3. The top panel shows an example of H_2S and SO_2 during a peak SO_2 episode at Lower Camp station on 29 October 2016, using 5-minute averaged data obtained from https://wbea.org/historical-monitoring-data/. Levels of H_2S and SO_2 track closely to one another. Similar correlation is observed for many episodes at Lower Camp station in recent years. The bottom panels show histograms of the fraction of H_2S/SO_2 during peak SO_2 episodes (> 12 ppb). In 2010-2013, most SO_2 episodes occurred when levels of H_2S were low, with the fraction of $H_2S/SO_2 < 0.05$. This is consistent with stack sources from oil sands operations that typically emit little H_2S. In recent years (2015-2018), there are many more SO_2 episodes, most of which have a higher fraction of H_2S ($H_2S/SO_2 \sim 0.05$-0.15).


a) SO_2 and H_2S on 29 Oct 2016


b) H_2S/SO_2 for 2010-2013 Episodes

c) H_2S/SO_2 for 2015-2018 Episodes

Figure B3. Relationship between H_2S and SO_2 at Lower Camp station
(a) Example of time series of 5-minute averaged SO_2 (blue, left y-axis) and H_2S (orange, right y-axis) for SO_2 episode at Lower Camp station on 29 October 2016. Histograms of H_2S/SO_2 fraction for 1-hour average data, for peak SO_2 episodes (> 12 ppb) for (b) 2010-2013 and (c) 2015-2018.

Appendix C: Location and timing of sampling of the 'Old Fort' site

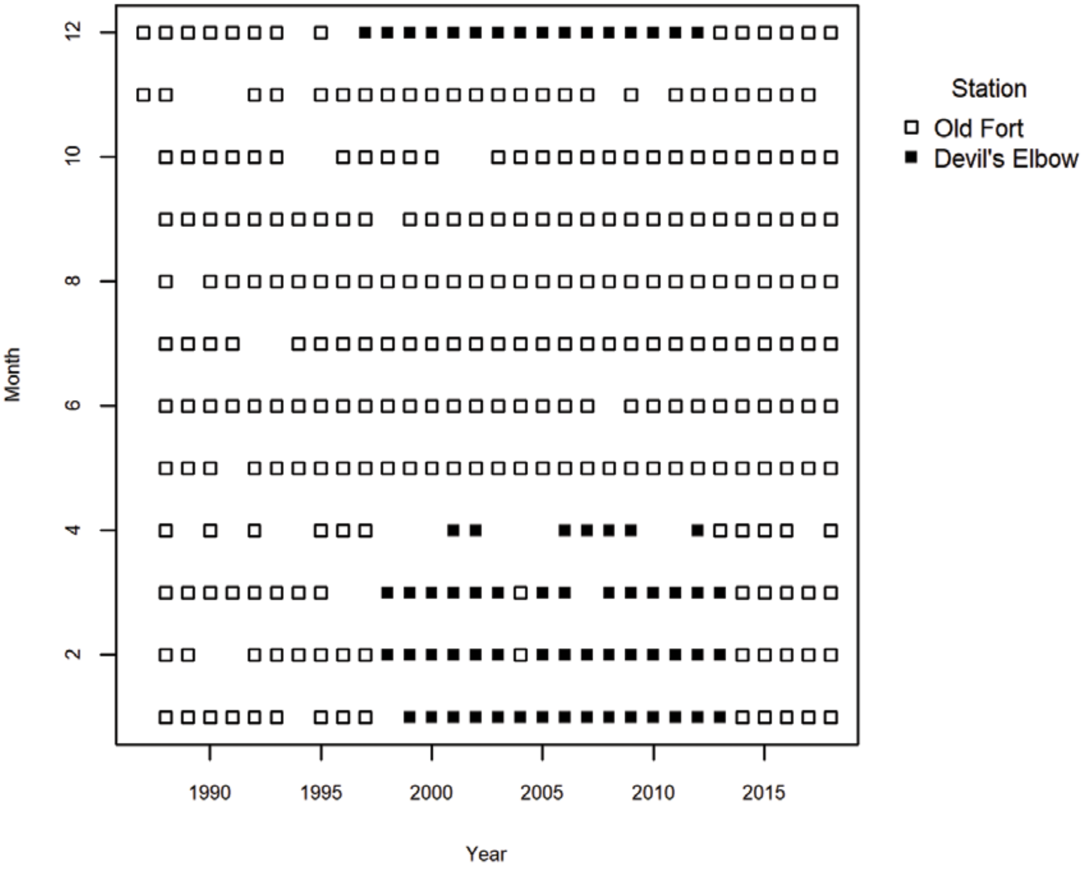


Figure C1: Locations and timing of sampling events at Old Fort and Devil's Elbow

Appendix D: Primary sources for historical management response information

Data Year	Status
2012	Status of Management Response Report: Air and Surface Water Quality as of March 2014 (AESRD, 2014a)
2013	Status of Management Response Report: Air and Surface Water Quality as of May 2015 (AEP, 2016a)
2014	Status of Management Response Report: Air and Surface Water Quality as of May 2015 (AEP, 2016a)
2015	Status of Management Response Report: Air and Surface Water Quality as of December 2016 (AEP, 2017)
2016	Status of Management Response Report: Air and Surface Water Quality as of October 2017 (AEP, 2018a)
2017	Status of Management Response for Environmental Management Frameworks, as of October 2018 (AEP, 2020a)

Appendix E: Methods and rationale for performing flow-adjustment

Streamflow integrates the influences of weather and hydrological conditions in a basin. As such, streamflow measurements (and/or estimates) provide a way to constrain these influences when evaluating water quality measurements in time series. Flow-adjustment amplifies variability related to other factors by reducing the components of variance related to weather and hydrology. Thus, changes in the relationship between flow and concentration over time result from changes in export from the landscape (e.g. Smith et al., 1982).

For instance, as a thought experiment, imagine that water quantity and quality are monitored immediately upstream and downstream of a parcel of land that is relatively rich in potassium and that export increased with discharge. If that parcel remained unchanged from one year to the next but a greater volume of water moved through it one year, one would likely detect changes in both flow and concentration of potassium measured downstream to increase relative to the upstream measurements. The increase in potassium concentrations would be explained by flow rather than a change in land use.

In contrast, imagine that the same parcel of land instead had years where similar volumes of water moved through it but that a disturbance occurred causing more potassium to be exported. One would expect the concentration of potassium to increase downstream while the flow remained unchanged. In this scenario the additional potassium measured downstream would not be explained by changes in flow. Thus, by accounting for flow one can begin to differentiate between anomalies caused by changes to the landscape and those caused by changes in the volume of water moving through it.

In another scenario, envision that the majority of potassium was emitted from a point source on the parcel discharging at a constant rate regardless of the volume of water moving through the landscape. Increases in flow through the landscape would dilute the concentrations measured downstream whereas decreases in flow would concentrate potassium in samples collected downstream relative to a normal year. Thus, depending on the source and speciation of the parameter analyzed, changes in flow may dilute, concentrate, or have no discernable effect (Hirsch et al., 1982).

While flow-adjustment is effective to amplify signals originating from upstream changes in land use (natural or otherwise), there are limitations to this approach. For instance, water quality measurements collected from rivers capture (some portion of) both suspended solids and dissolved constituents. Increasing flow provides additional energy that can entrain more solids in water causing increased concentrations. The flow regime and site characteristics influence the tendency for sediment to be eroded, transported, or deposited. Further, the solubility characteristics of each parameter may also differ. These considerations necessitate a unique calibration of the flow-concentration relationships for each parameter at each site. Calibrating flow-concentration relationships for time series analysis also requires consideration.

Streamflow influence was accounted for by undertaking flow-adjustment of the sampled water quality concentrations. Flow-adjustment values herein equals the residuals resulting from the subtraction of variance in concentrations as predicted from flow-concentration relationships from measurement values (Helsel & Hirsch, 2002). The flow-concentration relationship was defined using the LOWESS method described by Cleveland (1979) as applied in R (R Core Team, 2017). The measured values prior to subtracting variability explained by flow were referred to as "unadjusted" values.

In some instances, the variability in the flow-adjusted concentrations (i.e. residuals) were unequal over time (aka heteroscedastic). In these instances, other factors or events may have occurred that influenced the concentration-flow relationships that may have compromised the reliability of the flow-adjustment. Where unequal variance in flow-adjusted time series was discovered and could not be corrected via data transformation (Box & Cox, 1964; Fox & Weisberg, 2011; R Core Team, 2017), flow-adjustment models were assumed to be invalid and were not applied.

The validity of flow-adjustment models was assessed by applying Breusch-Pagan tests to time series regressions of flow-adjusted concentrations for each parameter, at each site (Breusch & Pagan, 1979). From among the valid models, over- or under-fitting was avoided by selecting the maximum LOWESS span value (i.e. greatest smoothing) related to the output of Pettitt tests applied to cumulative model residual variances, (Breusch-Pagan) Chi-squared-, and (Breusch-Pagan) p-value outputs among the range of valid flow-adjustment models (Pettitt, 1979; Pohlert, 2018).

Appendix F: Methods and rationale for performing trend analysis

Trend analysis, with respect to the Framework, are tests performed using linear regression on a time series of water quality observations. In the trend analysis, the sampling dates were the independent variable and the measured concentrations (and flow-adjusted concentrations) were the dependent variables. The analysis determined if trends were not significant, increasing, or decreasing by calculating the magnitude and significance of regression line slopes.

If a trend in the sampled water quality concentration did not also occur in flow-adjusted values, the significance of a trend could be explained by the effects of changes in the volume of water flowing through the landscape rather than changes in the upstream landscape. Thus, the likelihood of finding another actionable explanation was considered to be low and that resources would be better spent exploring other issues. However, if a trend was detected in flow-adjusted concentrations, then other explanations were needed to account for the observed changes in condition.

The trend analyses herein were conducted using the cenken function within NADA package (Lee, 2017) within the R computing environment (R Core Team, 2017). The slope and p-values represent the Akritas-Thiel-Sen nonparametric line estimates (Akritas et al. 1995; Helsel, 2005) calculated from unadjusted and flow-adjusted values and dates converted to decimal format using the lubridate::date_decimal function (Grolemund & Wickham, 2011).

Appendix G: Preparation of data for seasonal Kendall analysis

Four characteristics of the provincial datasets used in seasonal Kendall analysis warrant consideration. Each imposes limitations on the conclusions that can be drawn.

1. The temporal span of data collected for each parameter, monitoring station, and season were not always consistent
2. Temporal data gaps were present in some datasets
3. Where data gaps were present, pooled data from nearby monitoring stations was used to fill them
4. Data were not adjusted for flow

The influence of annual variability is more prominent in results from locations and parameters monitored over shorter spans of time. Not all SK trend results herein represent the same span of time. Sampling under the provincial monitoring program has not been uniform for each station, parameter, and season.

Historically, some seasons may have been sampled more than others at some locations. The provincial monitoring program has changed over time. For example, some stations and/or parameters were monitored quarterly instead of monthly in the past. To mitigate this and other issues, quality control criteria were set for the creation of the datasets used for analysis. These criteria were applied consistently across all monitoring stations and parameters.

Consistent with criteria advocated by Helsel and Hirsch (2002), trend analyses were not applied if a data gap spanned more than one-third of the total span. Some isolated measurements were collected during periods of interrupted monitoring. Unless observations spanned three consecutive years with at least four samples in each, temporal data gaps were considered to span across them.

Monitoring has been discontinued at some locations. Therefore historical trends were extrapolated to the present. However, each dataset included at least three years of data since 2006. This was selected as the criteria as it would encompass a period of rapid economic development within the LAR. Further, this criterion would preserve the potential to expand the analysis to other provincial monitoring program sites within the MacKenzie River basin if necessary.

Data from nearby monitoring stations were sometimes pooled to expand the datasets. This filled data gaps resulting from interruptions and/or historical changes in provincial monitoring programs. Care was taken to pool only sites that were within reasonable proximity to one another. However, different conditions at the pooled sample sites may have introduced more variability.

Lastly, all SK trend analyses used unadjusted data. Most stations did not have flow estimates available at the time of analysis. This prevented the development of flow-adjustment models. Therefore, one cannot rule out the rate of flow as a contributing factor. Some trends may be artifacts of (or obscured) by changes in flow over time. Attribution of trends to changes in land use may require additional supporting evidence going forward. To respect these limitations, interpretations consist of prioritizing areas of interest to further investigation and analysis.

Despite any limitations, trend analyses provide non-random, reproducible, and defensible information to guide and prioritize future investigations. Future efforts will prioritize areas where positive trends are most likely. Unlikely or negative trends will not exclude areas from future consideration should new information come to light. For brevity, only the significance of trends is included in this report. The magnitude of slopes will be presented with more contextual detail in forthcoming reports.

Appendix H: Categorization of Seasonal Kendall Analysis Results

Fifteen categories grouped output from SK analysis. Uncertainty was categorized by adapting analytic standards from the US intelligence community (Clapper, 2015). Ranges in p-value output from SK analysis related to expressions of likelihood therein as outlined in Table H1. These expressions appear in the figure (16) legend and correspond to the p-values in the table. Further subgroups were based on the direction of slope or a non-result. Slope direction consisted of either positive (increasing) or negative (decreasing).

Table H1: Expressions of likelihood and probability used to describe and categorize uncertainty in trend results derived from seasonal Kendall analysis.

Source	Expressions of likelihood and probability						
Clapper, 2015	Almost no chance	Very unlikely	Unlikely	Roughly even chance	Likely	Very likely	Almost certain (ly)
Clapper, 2015	Remote	Highly improbable	Improbable (improbably)	Roughly even odds	Probable (probably)	Highly probable	Nearly certain
Clapper, 2015	01 – 05%	05 - 20%	20 - 45%	45 - 55%	55 - 80%	80 - 95%	95 - 99%
Adapted p-values	> 0.95	> 0.80-0.95	> 0.55 - 0.80	> 0.45 -0.55	> 0.20-0.45	> 0.05 - 0.20	≤ 0.05

Sources refer to the United States ICD 203 (Clapper, 2015) and p-value ranges interpreted to align with the directive (Adapted p-values).

Appendix I: Analysis of Total Nitrogen Components

I.1 Total Kjeldahl Nitrogen (TKN)

TKN makes up a large fraction of total nitrogen (Figures 11, I1). Ammonia, ammonium, or fractions bound to organic substances are attributable to nitrogen measured as TKN. No limit for TKN appears in the framework. The maximum value in 2018 (0.94 mg/L) was within the range of historical values (before 2010) and in the period from 2010 to 2017.

Total Kjeldahl nitrogen is a component of total nitrogen. Nitrogen measured using this technique is attributable to ammonia, ammonium, or fractions bound to organic substances.

Trend analysis showed an increasing trend in unadjusted concentration that wasn't statistically significant at 'Old Fort' (Figure I1). Changes in flow volume obscured the significance and direction of a negative trend. While no significant or negative trend appeared in unadjusted measurements, TKN decreased at a rate of -0.00881 mg/L per year relative to the volume of flow.

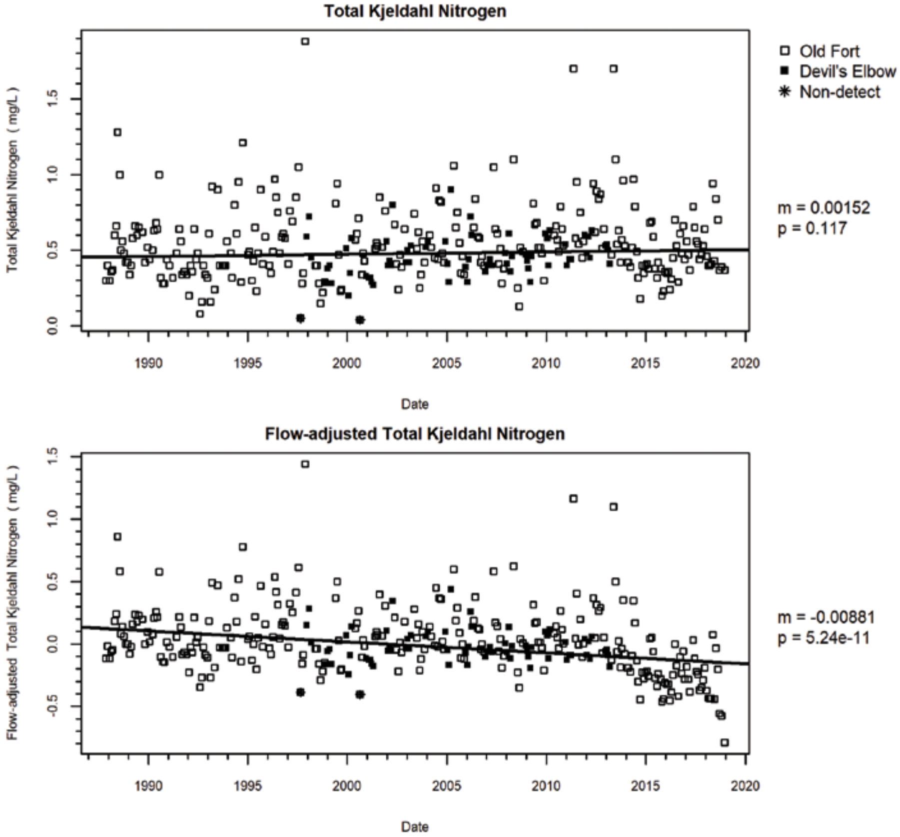


Figure I1: Time series plots of unadjusted concentrations (top) and flow-adjusted concentrations (bottom) of Total Kjeldahl Nitrogen from the Athabasca River at 'Old Fort'.

Trend lines represent Akritas-Theil-Sen line.

I.2 Nitrate (NO_3) plus Nitrite (NO_2)

Nitrate plus nitrite is a parameter that measures the sum of oxidized nitrogen. It is a portion of total nitrogen. No limit for nitrate plus nitrite exists within the framework. The maximum value in 2018 (0.27 mg/L) lies within the range of historical (before 2010) interim (2010 - 2017) values.

Nitrate plus nitrite showed an increasing trend in unadjusted concentration at ‘Old Fort’ (Figure I2). Concentrations increased at a rate of 5.88e-05 mg/L per year. The trend was also significant when adjusted for flow. After flow-adjustment, concentrations increased at a rate of 0.00721 mg/L per year.

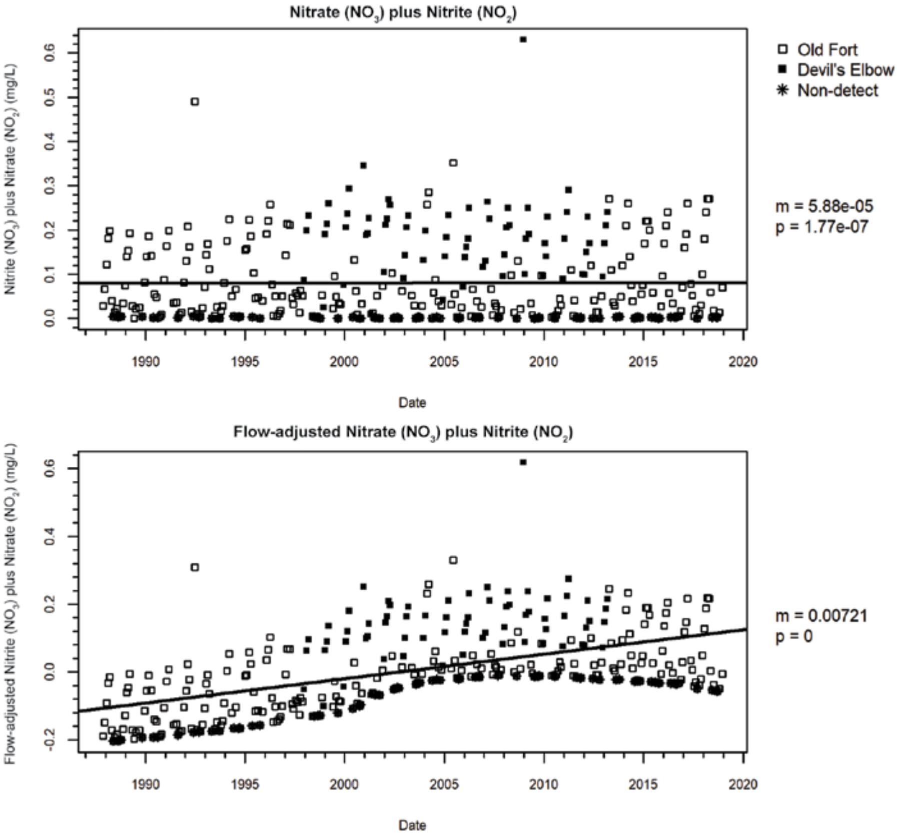


Figure I2: Time series plots of unadjusted concentrations (top) and flow-adjusted concentrations (bottom) of nitrate plus nitrite from the Athabasca River at ‘Old Fort’.

Trend lines represent Akritas-Theil-Sen line.

I.3 Nitrate (NO_3)

In 2018, no nitrate values crossed the limit (2.935 mg/L) set in the framework. Two values crossed the peak trigger value set at 0.264 mg/L. A maximum value (0.27 mg/L) equaled 102.3% of the peak trigger and 9.2% of the limit values, respectively. All 2018 measurements ranged within historical (before 2010) and interim (2010-2017) values. The dataset for nitrate spanned from 1999 to 2018. This analysis included all the available nitrate measurement data from this monitoring site. The shorter span, relative to nitrate plus nitrite, reflects the enhancement of monitoring at ‘Old Fort’ to include nitrate-specific measurements.

The trend analysis for nitrate showed a statistically significant decreasing trend at ‘Old Fort’ (Figure I3). The concentration of nitrate decreased at a rate of -0.000362 mg/L per year over this period. In contrast, flow-adjusted data showed a significant increasing trend. Concentrations increased at a rate of 0.0107 mg/L per year relative to the volume of flow.

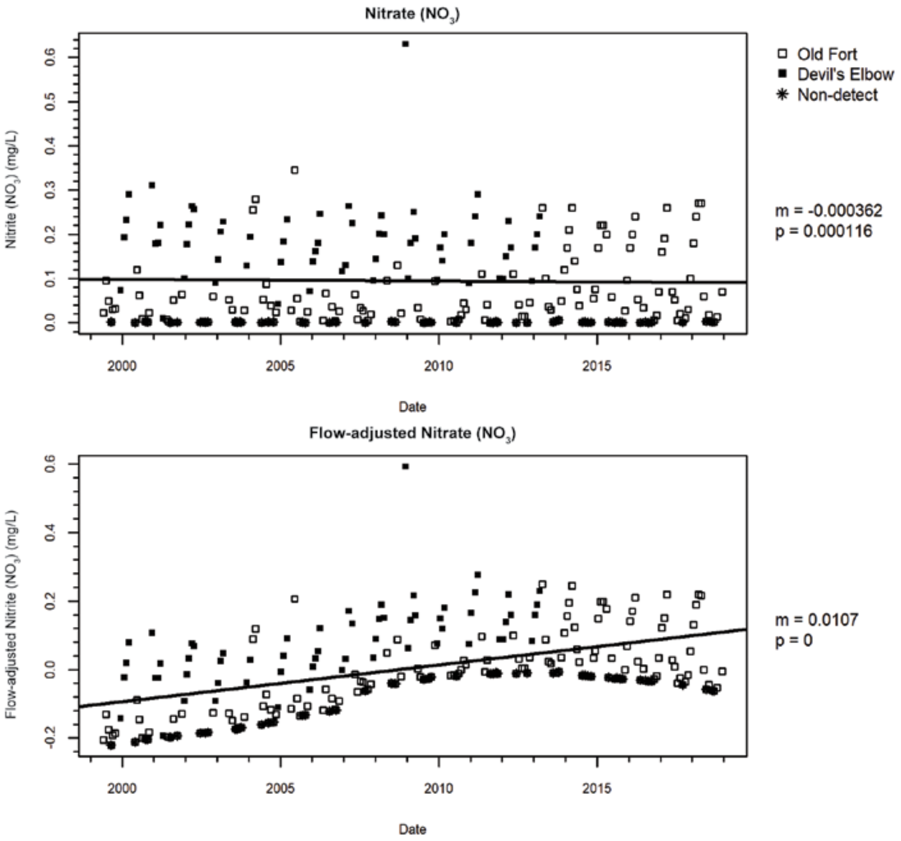


Figure I3: Time series plots of unadjusted concentrations (top) and flow-adjusted concentrations (bottom) of nitrate from the Athabasca River at ‘Old Fort’.

Trend lines represent Akritas-Theil-Sen line.

I.4 Nitrite (NO_2)

All nitrate measurements in 2018 were below detection limits. The dataset for nitrite contained a high proportion of non-detects (77.8%). For non-detects, the true values lie somewhere between 0 and the detection limit. As only partial information is available for the majority of the dataset, one should interpret the trend results with caution. For example, the calculated slope of the unadjusted trend predicts negative values for 2018 (not possible). Therefore, the trend slope was inaccurate despite statistical significance. However, there was no evidence that concentrations of nitrite have increased at ‘Old Fort’; in neither unadjusted nor flow-adjusted data (Figure I4).

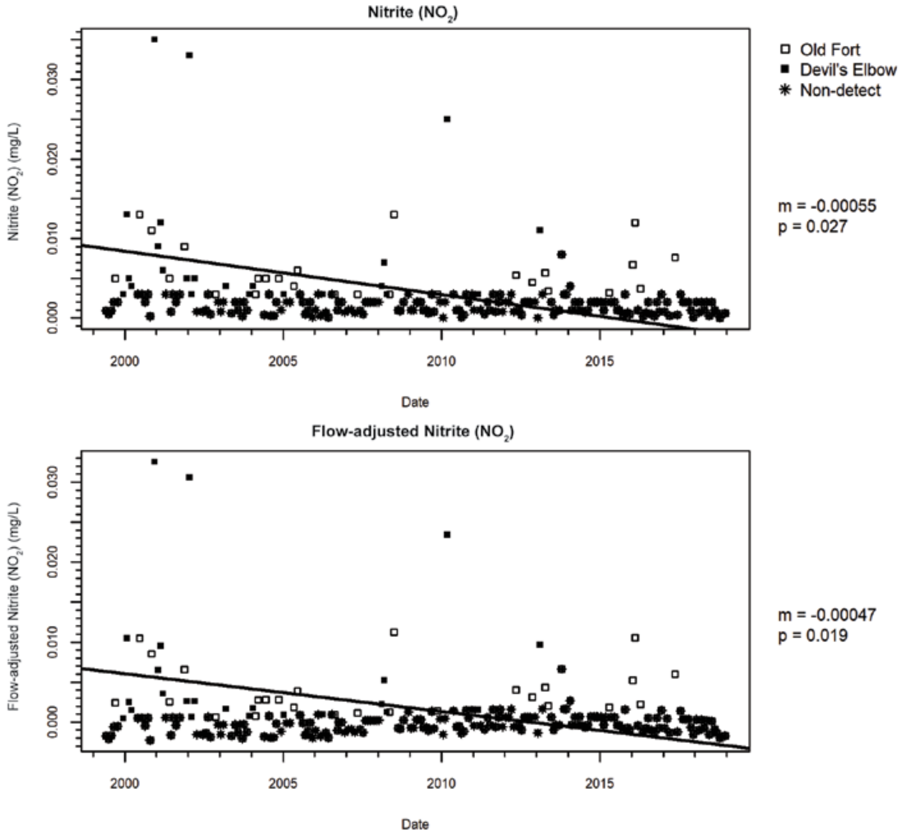


Figure I4: Time series plots of unadjusted concentrations (top) and flow-adjusted concentrations (bottom) of nitrite from the Athabasca River at ‘Old Fort’.

Trend lines represent Akritas-Theil-Sen line.

I.5 Interpretation of integrated nitrogen results at ‘Old Fort’

The analysis of total nitrogen at ‘Old Fort’ supports three conclusions and highlights an unknown. Conclusions that can be drawn are:

1. Concentrations have increased
2. Flow volumes do not explain increases in concentration
3. The composition of total nitrogen has changed over time
4. Unknown: seasonality of changes

Figure 11 presents evidence that total nitrogen concentrations have increased. The positive and statistically significant slope of the trend establish this. However, one may question the ecological significance of such a small rate of increase relative to recent values.

However, the composition of total nitrogen measured at ‘Old Fort’ appears to have changed. Unadjusted nitrate plus nitrite increased at ‘Old Fort’ (Figure I2). The trend in unadjusted TKN fell short of statistical significance (Figure I1).

Flow-adjustment brought trend directions for these total nitrogen components into sharper contrast. After adjusting, significant declines in TKN became apparent, particularly within the last five years (Figure I1). Nitrate plus nitrite levels increased between 1988 and approximately 2005 (Figure I2). Increases accelerated in the early 2000’s but have since levelled off. Neither of these transitions directly coincided with a step-change in the annual minima of (unadjusted) total nitrogen that occurred circa 2008 (Figure 11). Since these minimums tend to happen in late summer and early fall, this may indicate a seasonal influence not yet considered. Changes in the composition of total nitrogen may have ecological relevance due to changes in bioavailability (Kaushal & Lewis, 2003; 2005).

Measured individually, unadjusted trends in both nitrate and nitrite concentrations appear to decrease (Figures I3; I4). This seemingly contradicts the trend in nitrate plus nitrite (Figure I2). However, differences in the temporal span, sample sizes, and/or the proportion of non-detects for each parameter likely explain this.

Individual measurements of nitrate and nitrite started in 1999. A quarter (24%) of the 221 nitrate samples were non-detects. For nitrite, more than three quarters (78%) of 221 samples were non-detects. In contrast, measurements of nitrate plus nitrite started in 1987 and had a larger sample size (333). Non-detects made up less than a quarter of the observations (21.6%). Therefore, nitrate plus nitrite had more observations, over a longer period of time, and less frequent non-detects.

None of the components of total nitrogen are conservative as they migrate downstream. TKN is common in organic matter, which can be oxidized to form nitrate. Likewise, nitrate and nitrite can be assimilated by organisms. Therefore, upstream sources of nitrogen cannot be ruled out as potential sources based on their form. Patterns in the timing of annual fluctuations in concentration differ between TKN and nitrate plus nitrite. This would suggest that seasonal trends in these parameters were distinct and may inform efforts towards source-tracking.

The flow-concentration relationship for total nitrogen has changed over time at ‘Old Fort’. This prevented the calculation of flow-adjusted values. Thus, flow cannot account for the trend in total nitrogen in and of itself. In contrast, flow-adjustment models were successfully developed for the other nitrogen parameters. The trend in flow-adjusted TKN suggests that flow volumes explain increasing concentrations. In contrast, flow-adjusted nitrate plus nitrite (and nitrate) showed steeper increasing trends. This suggests that increases were obscured by flow volumes. The composition of total nitrogen may be in flux. Regardless of changes in total concentration, the timing of nitrate and TKN pulses could be ecologically relevant. Thus, seasonal changes in the composition of total nitrogen warrant further investigation at ‘Old Fort’.

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