Sonoma Technology, Inc.
Air Quality Research and Innovative Solutions

Network Evaluation of the Peace Airshed Zone Association



Final Report
Prepared for the
Peace Airshed Zone Association
Grande Prairie, Alberta

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Final Report
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Executive Summary

Sonoma Technology, Inc. (STI) performed an evaluation of the Peace Airshed Zone Association (PAZA) ambient air quality monitoring network. This network evaluation covers continuous and passive monitoring networks within PAZA that are currently in operation. This report documents STI's methodology, findings, and recommendations.

The PAZA requested a network evaluation and recommendations for improving the monitoring network to better meet the evolving needs of its stakeholders. The PAZA also described a series of new monitoring objectives and emerging issues. Historically, the primary monitoring objective was to ensure compliance with regulatory monitoring requirements of Alberta's Environmental Protection and Enhancement Act approval holders, with Alberta's Ambient Air Quality Objectives, and later with the Canada-Wide Standards. However, in recent years, the Airshed monitoring concept adopted in Alberta has shifted the focus from compliance monitoring to a broader mission of operating a network with regional objectives.

Recommendations to improve the current monitoring network to better meet these objectives are listed here. The order of the recommendations is not in any particular priority; we recommend the PAZA board identify the recommendations that best meet their monitoring objectives to improve the monitoring network.

- Replace current passive monitoring of ozone and NO_2 with passive measurements of benzene, toluene, ethylbenzene, and xylenes (BTEX) compounds to assess spatial and temporal patterns in speciated hydrocarbons.
  - Consider reducing the number of SO_2 passive monitoring sites and/or moving them closer to specific facilities of concern.
  - Consider using passive measurements in targeted saturation studies of relevant pollutants near sources (e.g., facilities, roadways, airport, construction) or before and after studies around new facilities to assess the localized impact of a given source.
- Consider moving sites to more optimal locations.
  - The Smoky Heights monitoring site should be moved west to better monitor facility emissions, or moved to a location like Rycroft or Clairmont (or other locations listed in the suitability analysis in Section 4.5).
  - The Evergreen Park monitoring site is not in a representative neighborhood and is influenced by micro-scale emissions (i.e., a facility across the street). Neighborhoods like "Countryside South" or the area southeast of Wood Lake would be more representative of concentrations downwind of the central corridor of Grande Prairie.
- Consider measuring additional parameters at the Henry Pirker and Rover stations to better characterize sources and pollutants that are not currently measured in the network:
  - Speciated hydrocarbon measurements (continuous BTEX analyzers cost about $45,000 CAD) or canister sampling and laboratory analysis.
  - A PM_{10} or TSP monitor to assess larger particle concentrations that result from agricultural tilling and unpaved road dust.

  - An Aethalometer to measure black carbon; these instruments are relatively inexpensive and are excellent for identifying wood smoke events (wildfire or winter residential wood burning) and diesel PM.

- Implement consistent, modern instruments and methods for measuring $PM_{2.5}$ throughout the network. TEOM monitors underestimate ambient $PM_{2.5}$ during the winter months when ammonium nitrate is present.

- Determine whether the level of monitoring resources devoted to monitoring SO_2 is necessary for meeting compliance requirements. SO_2 concentrations are below objectives of concern and are decreasing over time, and SO_2 emissions are lower than those of other pollutants. Measuring other pollutants emitted by facilities, such as speciated hydrocarbons, may be of greater value in meeting multiple monitoring objectives.

1. Introduction

Sonoma Technology, Inc. (STI) evaluated the Peace Airshed Zone Association (PAZA) ambient air quality monitoring network. This network evaluation covers both continuous and passive monitoring networks that are located within PAZA and are currently in operation. This report documents STI's methodology, findings, and recommendations.

1.1 PAZA Overview and Project Background

The Peace Airshed Zone Association is a multi-stakeholder, not-for-profit society established to maintain an ambient air quality monitoring network in the northwest region of Alberta, Canada. PAZA is governed by a multi-stakeholder Board of Directors with members from industry, government, non-government organizations, and the public. PAZA's Technical Committee is primarily responsible for oversight of the monitoring network, provides technical guidance, and is responsible for the development of this network evaluation.

PAZA covers 38,500 square kilometers of northwest Alberta. The PAZA region is of mixed use: it contains a mixture of agricultural lands, forested lands, the City of Grande Prairie and smaller communities, First Nations and Métis lands, natural areas, upstream oil and gas activities, and forestry activities and is a major transportation corridor to the north. The Airshed stretches from the Peace River south to the top of Township 64 and is adjacent to a Provincial border.

The PAZA requested a network evaluation and recommendations for improving the monitoring network to better meet the evolving needs of its stakeholders. The PAZA also described a series of new monitoring objectives and emerging issues. Historically, the primary monitoring objective was to ensure compliance with regulatory monitoring requirements of Alberta's Environmental Protection and Enhancement Act (EPEA) approval holders, with Alberta's Ambient Air Quality Objectives (AAAQO), and later with the Canada-Wide Standards (CWS). However, in recent years, the Airshed monitoring concept adopted in Alberta has shifted the focus from compliance monitoring to a broader mission of operating a network with regional objectives.

In the future, ambient air quality monitoring will play a role in triggering air quality management activities and assessing the efficacy of those activities. At the same time, stakeholders in the PAZA are interested in emerging local issues, such as public health, new facilities, and regional development. The existing monitoring locations may not be adequate to meet these evolving needs. Therefore, PAZA has requested a network evaluation and recommendations for improving the monitoring network to better meet the evolving needs of its stakeholders. As with any monitoring network, resources are constrained and should be allocated to focus on meeting objectives as efficiently as possible.

1.2 PAZA Monitoring Objectives and Emerging Issues

PAZA wishes to maximize the informational value of the monitoring network in accordance with the monitoring objectives and guided by the emerging issues listed below.

Monitoring Objectives

- Monitor to ensure compliance to Environmental Protection and Enhancement Act (EPEA) Approvals.
- Measure and assess air quality relevant to Alberta Ambient Air Quality Objectives (AAAQOs) and Canada-wide Standards (CWS).
- Understand the spatial distribution of monitored pollutants in the region.
- Identify regional air quality trends and emerging issues.
- Characterize specific geographic locations or sources.
- Provide appropriate information to evaluate potential population exposure to ambient air quality.
- Provide information required to understand air quality impacts on the environment and population.
- Improve the ability to identify and apportion pollutant sources for purposes of air quality management.
- Provide suitable input and validation information for dispersion modeling.

Emerging Issues

- Local emissions will likely increase within the next five years due to the addition of industrial facilities to the region.[1] Besides contributing emissions to the region, the proposed expansion will likely bring additional monitoring resources as well.
- Emissions from local oil and gas development are not well characterized and drilling activity is rapidly increasing. Residents have expressed concern about the potential effects of this activity on air quality.
- There is increasing scrutiny of $PM_{2.5}$ monitoring data because $PM_{2.5}$ concentrations may trigger management plan actions under the CWS. The PAZA currently operates a variety of continuous $PM_{2.5}$ monitoring technologies and needs to understand quantitative measurement differences between the various newer technologies and the historical ones.
- There is an increased frequency of resident concerns about air quality impacts such as increased industrial activities, trans-boundary sources, increased transportation, and smoke from wood burning stoves and wildfires.
- There is a need to consider diffuse, unregulated sources and population growth in the region and their impacts on air quality.
- The recent addition of an industry continuous monitoring station in the Falher, Alberta, area. The procurement of this station in two years' time will bring additional monitoring resources.

[1] Examples include increasing industrial development in the County of Grande Prairie #1 along Highway #2 in Clairmont and Sexsmith and increasing heavy oil activities in the Peace River Oil Sands located near the northeast boundary of the PAZA region.

- The implementation of the new National Air Quality Management System including the components of place-based air quality management through “air zones” within provincial and territory boundaries and larger trans-boundary “regional airsheds” and Alberta’s enhanced Air Quality Management System.

Recognizing that all of these monitoring objectives and emerging issues are important, the PAZA has specifically decided not to prioritize the different objectives and issues. Most monitoring objectives have not been explicit goals of the monitoring network in previous years, although some have been implicitly recognized in guiding the monitoring network siting, pollutants, and duration. For example, passive monitors have been used to characterize the spatial distribution of pollutants since 2003. Historical trends in air quality have been tracked at the Henry Pirker monitor for almost ten years. Population exposure measurements in the form of the Air Quality Health Index (AQHI) are reported at the Henry Pirker and Beaverlodge sites.

1.3 Network Evaluation Approach

STI uses a general framework for performing network evaluations as described in the U.S. Environmental Protection Agency’s (EPA) network evaluation guidance document (Raffuse et al., 2007). **Figure 1-1** shows a flowchart of the general evaluation approach. The network assessment recommendations in this report are intended to be as feasible and scientifically justified as possible, but do not take into account other considerations (as listed in Step 5 of the flowchart). These other considerations include the historical objectives of the monitoring sites, jurisdictional boundaries, available monitoring resources, other pollutants monitored at these sites, and monitoring objectives not included for this assessment. These and other unstated considerations may influence which, if any, of the recommendations should be implemented by regional stakeholders in Step 6.

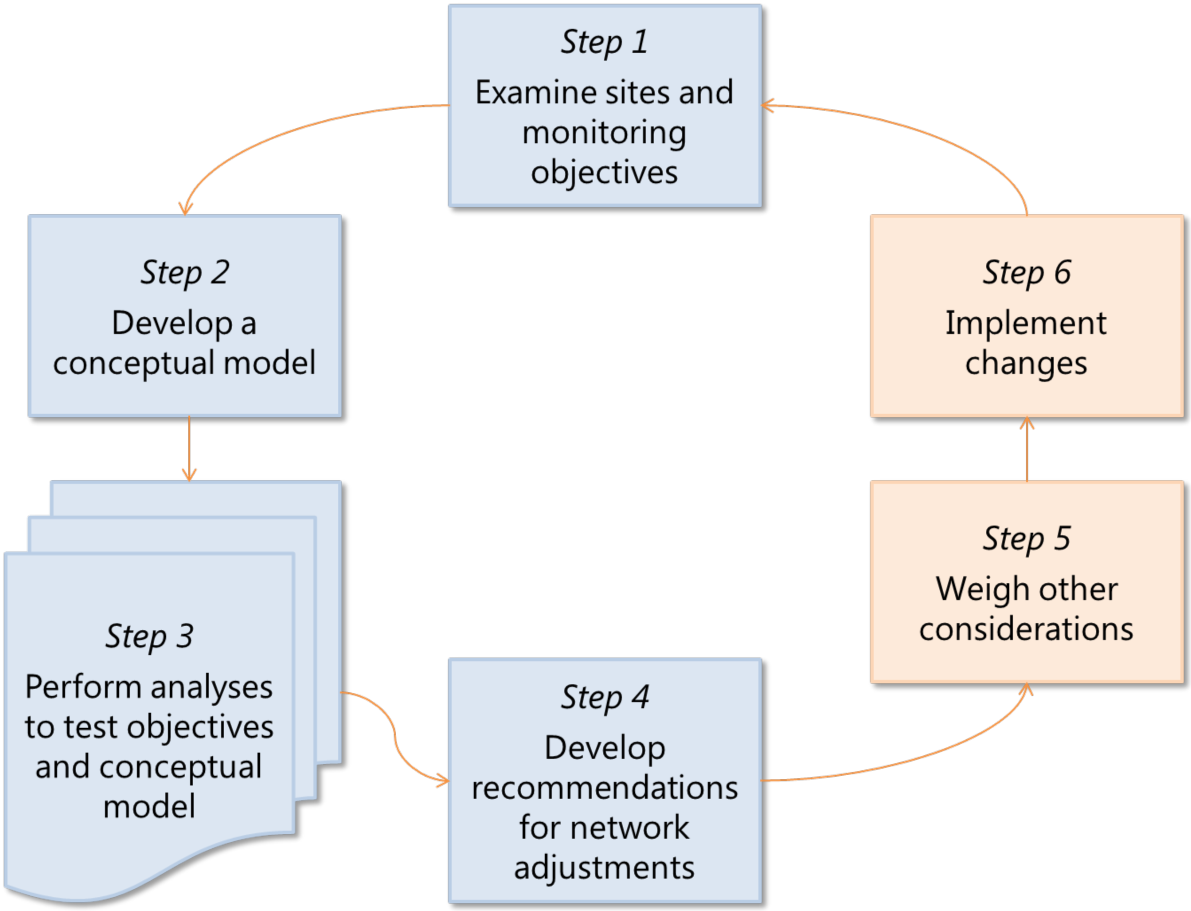


Figure 1-1. General framework for performing a network evaluation.

1.4 Overview of This Report

This report is organized into sections that mirror the general framework outlined above. Section 2 provides an overview of the existing monitoring network and a description of the conceptual model of air pollution in the airshed. Section 3 describes the analysis methods used in the network evaluation. Section 4 contains the results of the analyses. Section 5 summarizes the performance of the monitoring network compared to its monitoring objectives and includes a list of recommendations for better meeting these objectives. Section 6 contains references cited in this report, and the Appendix contains additional figures showing analysis results.

2. Monitoring Network Description

2.1 Monitoring Sites and Pollutants

The 2013 PAZA monitoring network consists of both continuous and passive monitoring sites. Continuous (i.e., data reported as hourly duration) monitoring occurs at seven locations:

- three sites established primarily for regulatory compliance purposes: Falher, Smoky Heights, and Valleyview.
- two community monitors: Henry Pirker and Evergreen.
- natural area/upwind site: Beaverlodge.
- Rover: currently at Sunset House, this monitor is relocated as needed to investigate different areas.

A map of these monitoring sites, showing the current location of the Rover, is shown in **Figure 2-1**. Locations of mobile monitoring by Rover monitors over the years are shown in **Figure 2-2**.

Table 2-1 lists the continually monitored pollutants at these locations in 2012. Pollutants monitored within the network include ozone, oxides of nitrogen (NO, NO_2, NO_x), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), total reduced sulfur (TRS), carbon monoxide (CO), particulate matter (PM) with aerodynamic diameters less than 2.5 micrometers ($PM_{2.5}$), methane (CH_4), non-methane hydrocarbons (NMHC), total hydrocarbons (THC), and ammonia (NH_3). For the full data record in the PAZA, see the Alberta Ambient Air Data Management System (AAADMS), more commonly known as the Clean Air Strategic Alliance's (CASA) data warehouse (Clean Air Strategic Alliance, 2012).

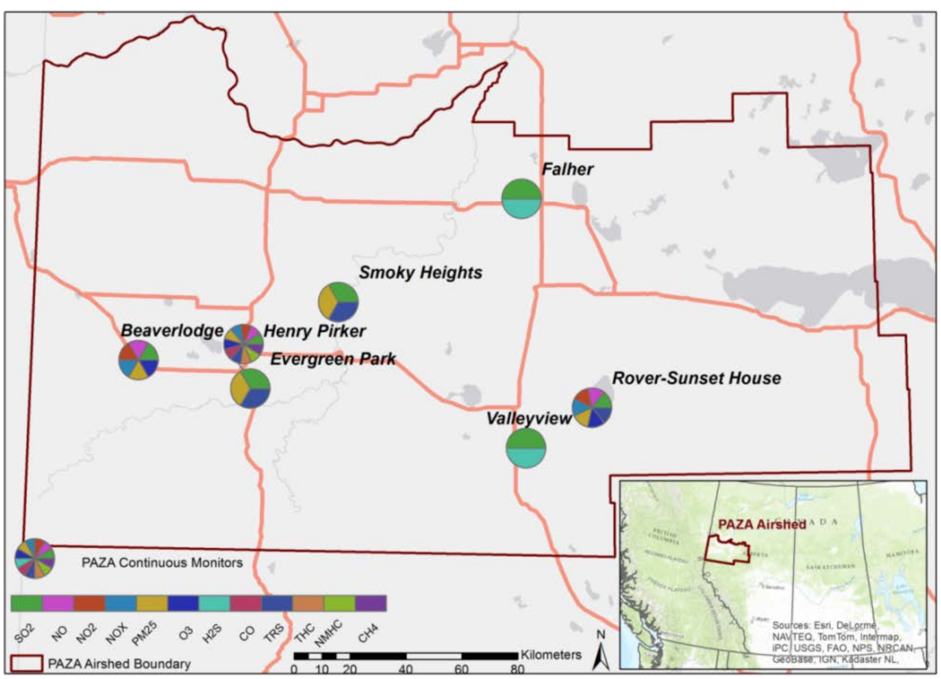


Figure 2-1. Map of continuous monitoring sites operating in 2012 in the PAZA airshed.

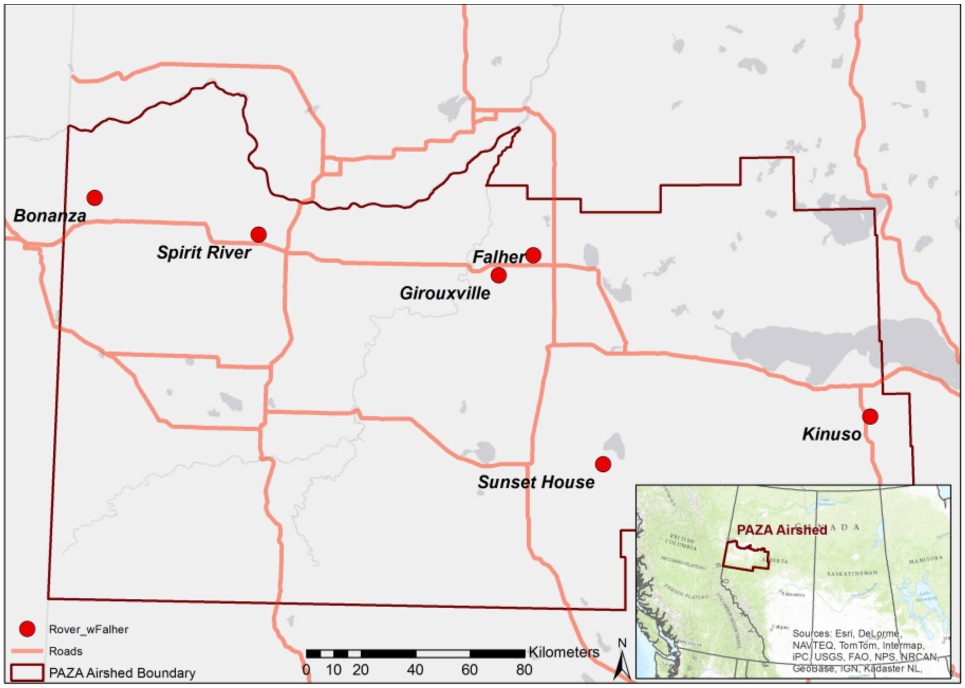


Figure 2-2. Map of current and past Rover monitoring locations in the PAZA airshed.

Table 2-1. List of continuous measurements made at the different monitoring sites in 2012. Sites in red are Rover locations over different time periods.

Site	SO_2	$PM_{2.5}$	TRS	NO	NO_2	NO_x	O_3	H_2S	CO	CH_4	NMHC	THC	NH_3
Henry Pirker	X	X	X	X	X	X	X		X	X	X	X	
Beaverlodge	X	X		X	X	X	X						
Evergreen Park	X	X	X										
Smoky Heights	X	X	X										
Falher	X							X					
Valleyview	X							X					
Kinuso	X		X	X	X	X	X						
Spirit River	X	X	X	X	X	X	X						
Sunset House	X	X	X	X	X	X	X						
Bonanza	X			X	X	X	X						
Girouxville	X		X			X		X					X

In addition to continuous measurements, passive measurements are made at many locations for four pollutants. The passive samplers are exposed to ambient air for one month. The samples collected are used to determine monthly average concentration data, which are then used to investigate spatial variability, assess trends, and characterize seasonal variations in concentrations. Passive samples are currently collected for H_2S at 3 sites and for SO_2, NO_2, and ozone at approximately 43 sites. **Figure 2-3** shows passive sampling locations for 2012 and identifies pollutants measured at each site.

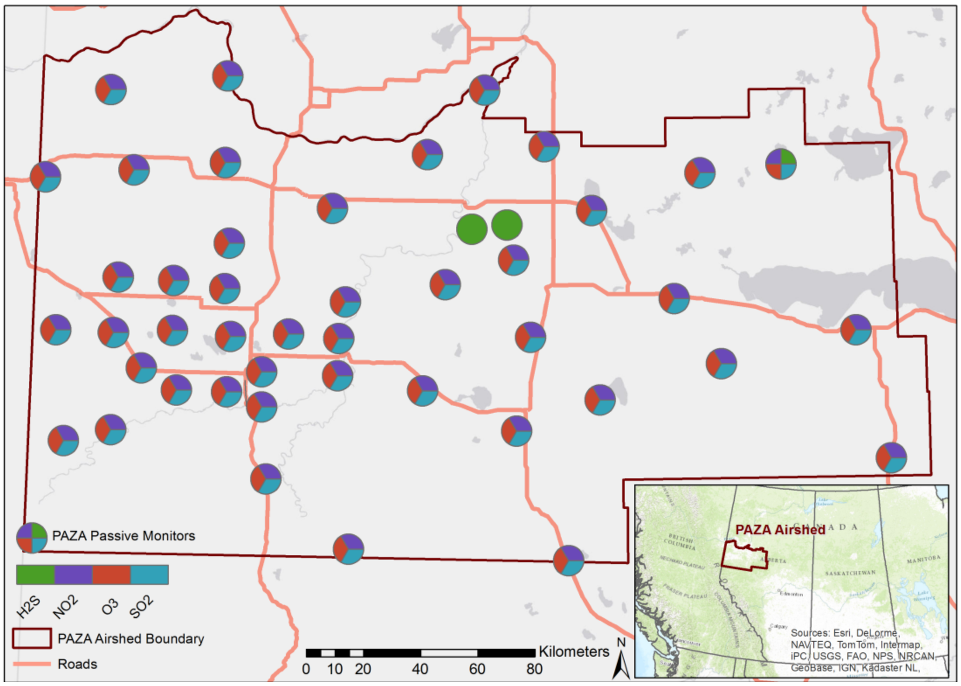


Figure 2-3. Map of passive monitoring sites operating in 2012 in PAZA. Colors in the circles identify the pollutants being sampled (green for H_2S, purple for NO_2, red for ozone, and light blue for SO_2).

Air monitoring outside of the PAZA network was briefly investigated, but sites within 50 km of the network boundary were all operated by industrial facilities and were not expected to be publicly available. Thus, sites outside of the PAZA boundaries were not considered useful for augmenting the PAZA network and were not included in this evaluation.

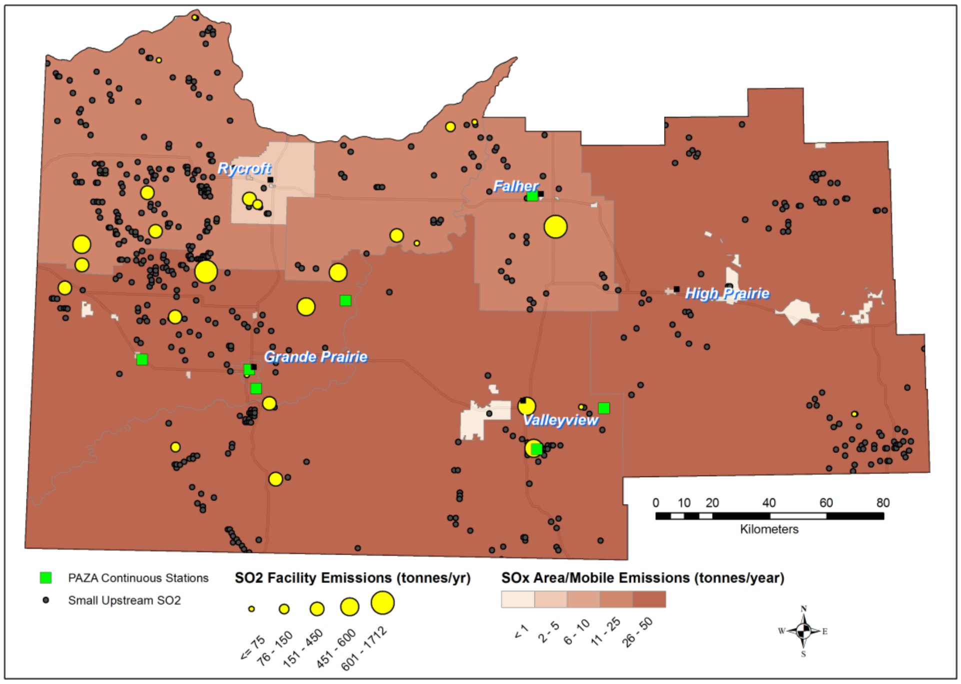
2.2 Conceptual Model

A conceptual model is a mental model used to represent our understanding of the network. The conceptual model forms the basis for the network recommendations, which are provided in the Discussion and Recommendations section of this report (Section 5). A conceptual model of a monitoring network must consider emissions sources, population density, meteorology and climatology, pollutants of interest, existing monitoring network locations, and monitoring objectives. We discuss our conceptual model of each of these areas in the subsections below, with the exception of monitoring objectives (Section 1.2) and locations (discussed in the preceding section).

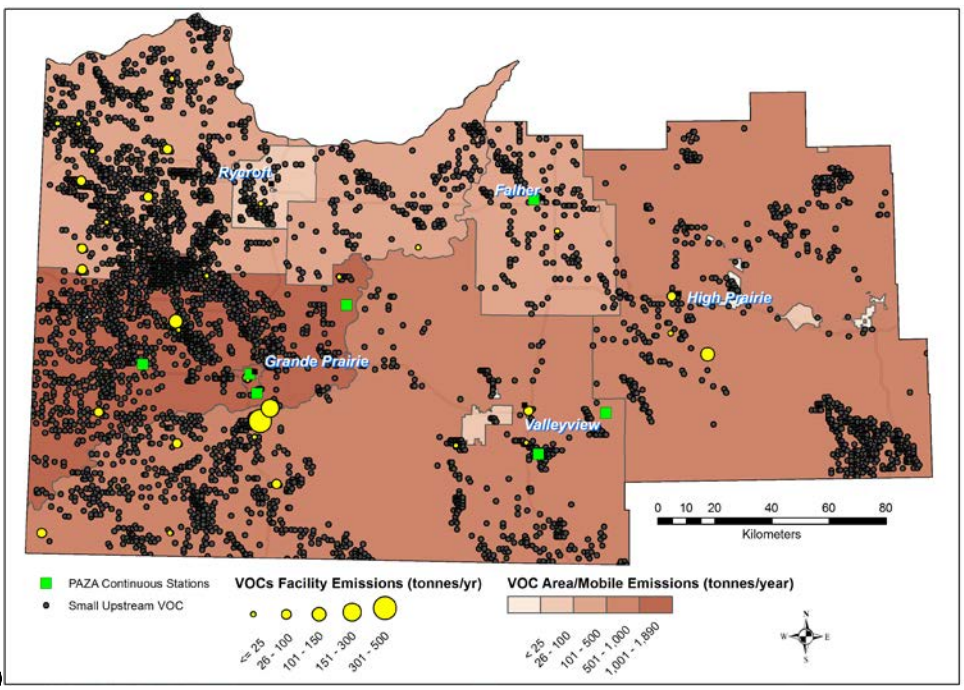
2.2.1 Emissions Sources

The PAZA is an airshed with a number of large industrial emissions sources. These sources emit a variety of pollutants that are monitored under compliance approvals. There is also significant oil and gas extraction and development within multiple large areas in, and adjacent to, the airshed. Oil and gas extraction can lead to emissions, as can the conventional and unconventional drilling processes. Moreover, the drilling operations themselves involve numerous onroad and offroad mobile emissions sources (e.g., trucks, construction equipment). In addition, emissions from transportation sources such as motor vehicles and other area sources are emitted from within the populated areas of the airshed. For some pollutants, such as NO_x, the area and mobile emissions can be larger than the large industrial emissions.

Maps of SO_2 /SO_x and volatile organic compound (VOC) emissions within PAZA are shown in **Figure 2-4**. Large industrial facilities from Environment Canada's National Pollutant Release Inventory (NPRI) from 2011, PAZA's small facility inventory from 2012, area and mobile emissions sources from ESRD's 2008 inventory broken out by subdivision, and upstream oil and gas locations from the Alberta Energy Regulator (AER, formerly Energy Resources Conservation Board) as of 2008 are all included in this figure. Additional maps for emissions of NO_x and $PM_{2.5}$ are available in the Appendix.



(a)



(b)

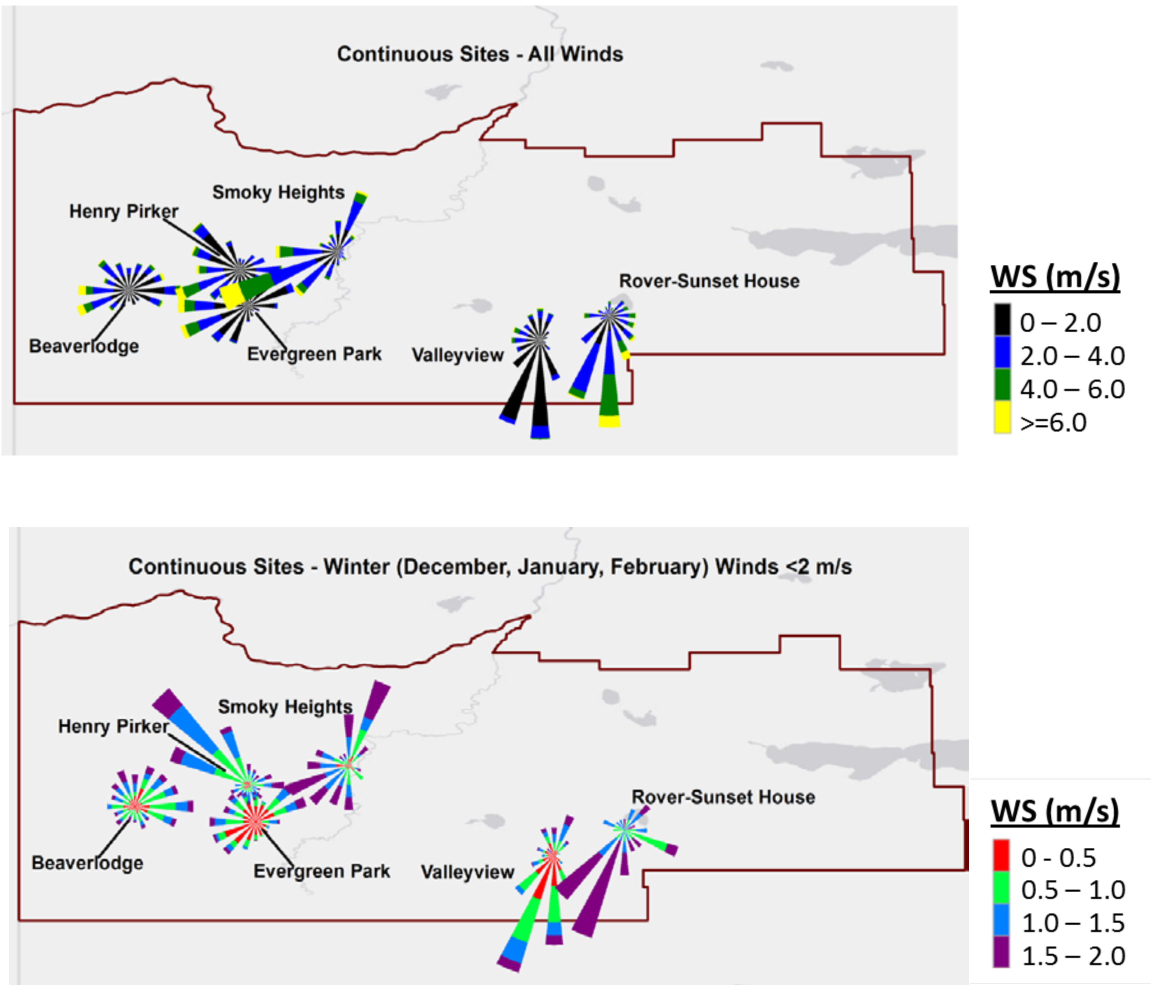
Figure 2-4. Maps of emissions in PAZA for (a) SO_2/SO_x and (b) VOCs. Facility and upstream emissions are shown as point locations, while area/mobile emissions are distributed by census subdivision areas as shaded polygons.

2.2.2 Population

There is low population and low population density within the PAZA Airshed. The total population of the airshed was approximately 113,000 in 2011, of which just under half live in the city of Grande Prairie (55,032). Other towns and villages are much smaller, and none exceeds a population of 5,000. Given the typical emissions from residential and commercial activities and the relatively low emissions contribution from the transportation sector, we anticipate that the low population will produce low emissions from these sectors outside of Grande Prairie. We also note that Grande Prairie is a central retail hub in northwest Alberta and northeastern British Columbia, thus generating additional traffic and emissions from residents of the surrounding rural communities.

2.2.3 Meteorology and Climatology

Meteorology at the four monitoring sites in the western portion of the airshed is predominantly associated with westerly flow. Beaverlodge, Henry Pirker, Evergreen, and Smoky Heights all display a predominantly westerly flow; however, site-to-site variations may cause the wind to be more southerly or northerly, and westerly flow does not predominate during the winter months under low wind speed conditions. The Valleyview and Sunset House sites show flow that is predominantly southerly under both high and low wind speeds. In all cases, the presence of nearby river valleys and bodies of water has a strong influence on local winds and channels local wind flows near the sites. This is especially apparent at Henry Pirker, Smoky Heights, Valleyview, and Sunset House. **Figure 2-5** shows wind roses under all conditions and under low wind speed conditions (<2 m/s) in winter months in 2010-2012.



(a)

(b)

Figure 2-5. Wind roses from 2010-2012 under (a) all conditions (b) wintertime low wind speeds (<2 m/s). Bars show the fraction of time winds originated from a given direction.

Climatologically, Grande Prairie has a relatively cold but humid continental climate. The highest amount of precipitation occurs during the summer months between June and August. The cold winter temperatures may result in inversions that can trap pollution, despite the general topographical flatness of the airshed. The weather and inversions should result in higher concentrations of PM, CO, and NO_x during the winter months. VOC emissions from non-evaporative sources should also be enhanced by cold temperatures (e.g., cold-start emissions); however, evaporative VOC emissions would likely be higher during the warmer months.

2.2.4 Pollutants of Interest

The pollutants of interest in this monitoring network are those which can help inform the monitoring objectives. Among currently monitored pollutants, the focus of the monitoring network is on SO_2, H_2S, ozone, NO_2, NO_x, and $PM_{2.5}$. Additional pollutants are monitored at only a few locations, generally to ensure compliance of local potential emissions sources.

3. Methods

STI performed a series of analyses to test the conceptual model and preliminary network recommendations. These analyses were either quantitative or qualitative. The goal of each analysis was to improve our conceptual model and refine or change the preliminary recommendations on the basis of our improved understanding. Techniques for assessing technical qualities of monitoring networks may be grouped into three broad categories: site-by-site comparisons, bottom-up methods, and network optimization.

- Site-by-site comparisons rank individual monitors according to specific monitoring objectives.
- Bottom-up analyses examine data other than monitoring data (e.g., emissions or population information) to assess optimal placement of monitors to meet monitoring objectives.
- Network optimization analyses evaluate proposed network design scenarios.

A thorough description of each method type is described in Raffuse et al. (2007).

Several analysis methods were used to assess the PAZA air monitoring network. **Table 3-1** lists the analysis methods used and the monitoring objectives that each method addresses. A suite of analyses was performed in order to cover all objectives. Sections 3.1 through 3.7 describe the network assessment analyses we performed (in the order shown in Table 3-1). Results of the analyses are discussed in Section 4.

Table 3-1. Analysis methods used and the monitoring objectives that each method addresses.

Monitoring Objective	Measured Concentration	Trends	Monitor-to-Monitor Correlation	Area Served	Emissions Served	Population Served	Suitability Modeling
Establish compliance to EPEA approvals	•		•	•	•		•
Measure air quality relative to AAAQOs, CWS, CAAQS	•	•				•	
Understand the spatial distribution of pollutants	•		•	•			•
Identify regional air quality trends		•			•		
Characterize specific sources and locations	•	•		•	•		•
Provide information to evaluate air quality impacts on people and the environment	•	•	•	•	•	•	•
Improve ability to identify and apportion pollutant sources for purposes of air quality management.	•	•			•		•
Provide suitable input and validation information for air quality models	•				•		

3.1 Measured Concentration Analysis

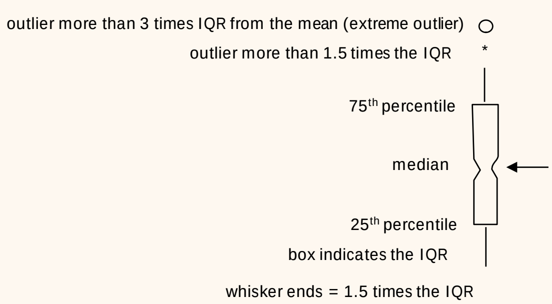
The Measured Concentration analysis is used to identify sites within the monitoring network that measure the highest and lowest pollutant concentrations. Sites that measure high pollutant concentrations are important for assessing compliance and population exposure, and for performing air quality model evaluations. Conversely, sites with relatively low concentrations are candidates for relocation or removal. High and low concentrations can be compared to AAAQOs and CWS to determine if concentrations are above or below thresholds of concern.

In addition, the measured concentration analysis can be used to identify whether spatial variability across the measurement sites

We created notched box-whisker plots for pollutants measured in both continuous and passive monitoring networks. These plots appear in Section 4 and in the Appendix. **Figure 3-1** provides instructions for interpreting notched box-whisker plots.

How to Interpret Notched Box-Whisker Plots

A notched box-whisker plot illustrates the distribution of concentrations. The notch is centered on the median concentration, widening to the size of the box to illustrate the 95% confidence interval in the median concentration value. The edges of the box illustrate the 25th and 75th percentile concentrations. The whiskers indicate values that are 1.5 times the interquartile range (IQR). Star outliers fall between 1.5 and 3 times the IQR. Circle outliers are greater than 3 times the IQR.



The notch and extents of the notch indicates the 95% confidence interval; when comparing notched box-whisker plots, if the notch of one box does not overlap with the notch of another box, the median values are statistically significantly different at the 95% confidence interval. If the notches overlap, the median values are not statistically significantly different.

Figure 3-1. Instructions for interpreting notched box-whisker plots (SYSTAT software). Note that mean concentrations are also included as red dots in our plots.

3.2 Trend Impacts

The purpose of the Trend Impacts analysis is to identify regional air quality trends and emerging issues. STI evaluated trends in pollutants with at least five years of valid monitoring data. Sites and parameters with fewer than five years of data were plotted, but trends are unlikely to be statistically significant over short time periods and were not examined in detail.

This quantitative analysis provides trend length and significance. Notched box-whisker plots were created for pollutant trends in both continuous and passive monitoring networks.

3.3 Monitor-to-Monitor Correlation

The purpose of the Monitor-to-Monitor Correlation analysis is to determine whether pollutant concentrations correlate temporally. We compared concentrations measured at one monitor to concentrations measured at other monitors using Pearson correlation coefficients. Pearson product-moment correlation coefficients are a measure of the linear correlation between two variables *X* and *Y*, giving a value between 1 and -1, inclusive. Monitor pairs with correlation coefficient values near 1 are considered highly correlated and may be redundant; these should be ranked lower than monitor pairs with correlation coefficient values near zero. Values near -1 indicate negative correlations, but we do not expect ambient measurements to have negative correlations. Monitors that do not correlate well with other monitors exhibit unique temporal concentrations and are likely to be important for assessing local emissions, transport, and spatial coverage. Monitors with concentrations that correlate well with concentrations at another monitor may be redundant and considered candidates for removal. This analysis was performed for each pollutant measured at more than one site in the continuous and passive monitoring network. Data from 2010–2012 at passive sites were used in the analysis; only data from 2012 were used for continuous sites, given the much larger number of available samples.

Determining the monitor-to-monitor correlation in a network requires at least two steps: (1) determining the temporal correlation between monitors through a regression analysis of concentrations; and (2) ranking the monitor's uniqueness. Step 1 was accomplished by calculating Pearson correlation coefficients, R, between each monitoring pair. Simple linear regressions can introduce error in the correlation coefficients because they assume the ordinal axis has no error. Site pairs with R values greater than 0.8 were deemed highly correlated and were ranked lower than site pairs with correlation coefficient values near zero. A count of sites considered highly correlated was then tabulated for each pollutant.

3.4 Area Served Analysis

The purpose of the Area Served analysis is to determine the spatial coverage of each monitoring site to identify spatial gaps or redundancies in the overall monitoring network. The first step in an Area Served analysis is to map the air quality sites using geographic information system (GIS) software. The next step involves generating Thiessen polygons (also called Voronoi diagrams) within the GIS software. Thiessen polygons are applied as a standard technique in geography to assign a zone of influence or representativeness to the area around a given point; in this case, a monitoring site. Calculating Thiessen polygons is one of the simplest quantitative methods for determining an area of representation around sites. Monitoring sites outside the PAZA airshed were not included in the Area Served analysis, as these monitors are typically industry-operated and are not likely to provide data for use by PAZA.

Figure 3-2 is a graphical representation of the steps involved in the Area Served analysis. Using Thiessen polygons is a quantitative analysis that provides area values.

Because the Thiessen polygon approach does not consider surface wind speed and direction, surface wind pattern information depicted in Section 2.2.3 must be assessed separately when evaluating the area representation of each site.

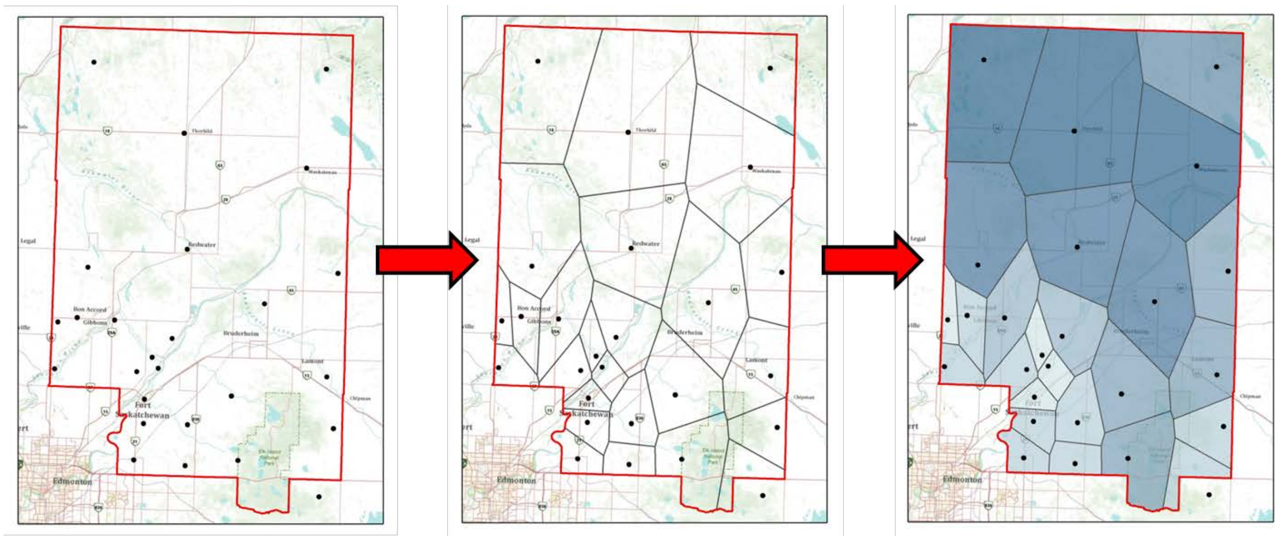


Figure 3-2. Steps of the Area Served analysis. The map on the left depicts the monitoring sites (black dots). The middle map shows Thiessen polygons (black lines) surrounding each monitoring site. The last map shows color-coded Thiessen polygons in which monitors that represent large geographic areas are darker colored polygons.

3.5 Emissions Served Analysis

The purpose of the Emissions Served analysis is to identify (1) the proximity of emissions sources to monitoring sites and (2) sources likely to affect each site. The Emissions Served analysis involved mapping locations of industrial facility emissions sources with locations of monitoring sites. For this analysis, industrial point source emissions data were acquired from both the NPRI (representing the year 2011) and the PAZA local facility inventory (2012). Area and mobile source emissions by census subdivision were also included and apportioned as occurring equally throughout the area. This approximation is likely to cause some spatial misattribution of emissions around Grande Prairie, but should be a good estimate in most of the rest of the airshed.

The Emissions Served analysis, in combination with the Area Served analysis, identifies key emissions areas, areas that are not monitored well, and areas with too many monitors relative to emissions sources. This quantitative analysis also identifies monitors that are closest to emissions sources. **Figure 3-3** is a graphical representation of the steps involved in the Emissions Served analysis.

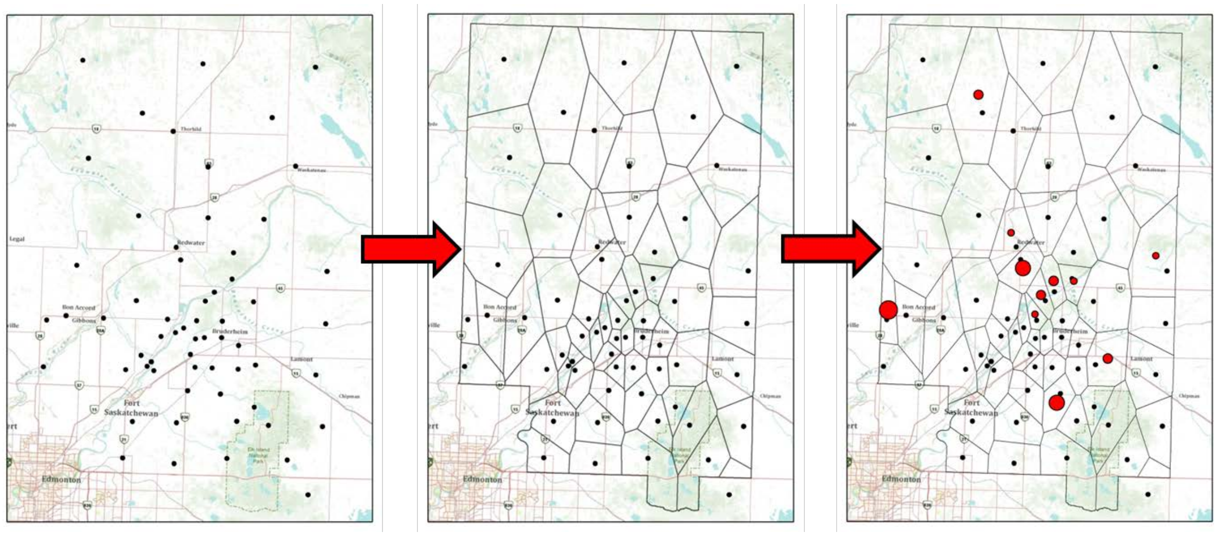


Figure 3-3. Steps of the Emission Served analysis. The map on the left depicts the monitoring sites (black dots). The middle map shows Thiessen polygons (black lines) surrounding each monitoring site. The last map depicts the location and emissions magnitude (red dot size) of industrial facility sources overlaid on the Thiessen polygons.

3.6 Population Served Analysis

The purpose of the Population Served analysis is to determine the population coverage represented by each monitoring site. Sites representing the greatest population numbers rank highest in this analysis. The Population Served analysis is used to identify populations likely to be represented poorly for exposure to the most important regulatory pollutants. Population data were acquired from the Statistics Canada 2011 census at the dissemination block level. The population density values were imposed on the Area Served polygons (from the previous analysis) and the number of people living in each polygon was calculated.

This quantitative analysis identifies which monitors represent the largest populations, based on proximity. Population density relative to existing monitor locations is also investigated as part of this analysis.

3.7 Suitability Analysis

Suitability modeling is a method of identifying suitable monitoring locations using specific criteria. For example, suitability modeling can be used to determine possible locations for new air quality monitoring sites on the basis of criteria such as emissions source influence, proximity to populated areas, urban or rural land use, and site accessibility. That being said, it is important to remember this is a qualitative analysis designed to refine monitoring location selection. To select the final site location, a more detailed and localized approach including logistics information (such as power and road accessibility) would be needed

Map layers representing the important suitability criteria can be compiled and merged to develop a composite map representing the combination of these criteria for a defined area.

Furthermore, each map layer input can be assigned a weighting factor based on the relative importance of each layer in the overall suitability model. For example, when determining suitable locations for placing a new air quality monitor, each criterion can be prioritized in terms of its relative importance. If the monitoring objective is to measure air quality in densely populated areas, a map layer representing population density would be given priority and a correspondingly high weighting factor in the overall model. The resulting suitability map output would favor areas of high population density.

The Environmental Systems Research Institute's (Esri) ArcGIS software, Spatial Analyst, was used for this analysis. Spatial Analyst is raster-based software that provides a platform for developing and manipulating gridded data. Spatial Analyst can be used to develop suitability models that produce maps highlighting "suitable" geographic areas based on defined model criteria. The map calculator within the Esri Spatial Analyst extension was used to weight and combine the map layers and produce suitability models. **Equation 1** shows an example of a map calculator expression:

([Layer_1]*.40 + [Layer_2]*.12 + [Layer_3]*.09 …) **(1)**

In this example, Layer_1, Layer_2, and Layer_3 represent individual map layers, and decimal values are the weighting factors applied to each layer. Layer 1 is weighted most heavily because it should have the most influence in the model. **Figure 3-4** illustrates a conceptual approach used to develop a suitability model.

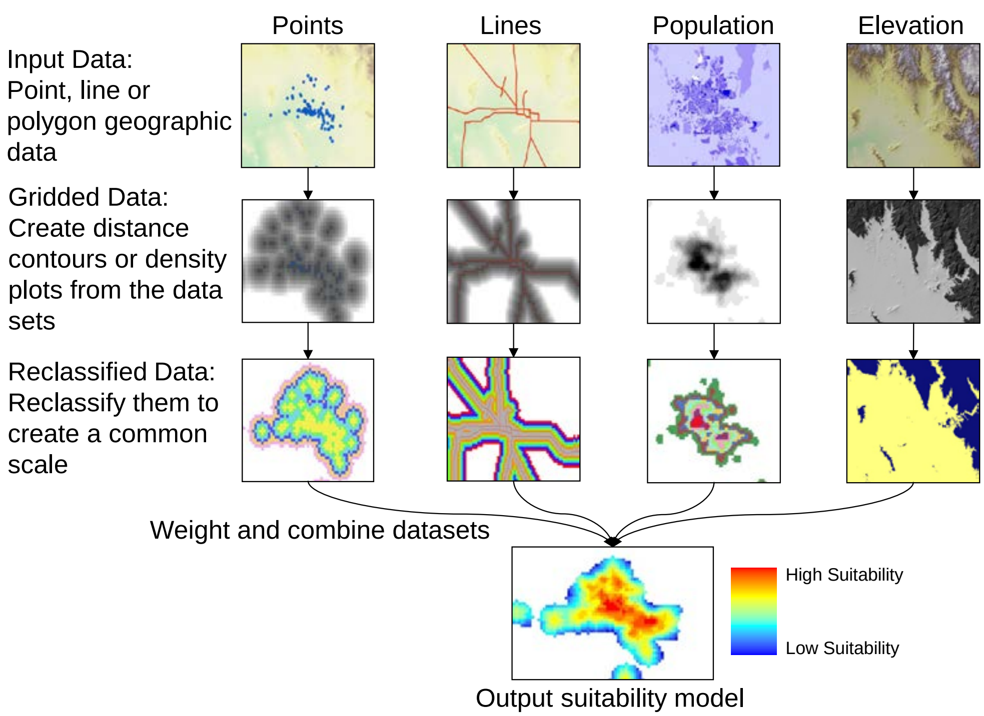


Figure 3-4. Conceptual approach used to develop a suitability model.

For this analysis, three modeling scenarios were developed to meet the following objectives: (1) identify areas and population centers most likely to be affected by emissions, (2) compare identified areas to existing continuous monitors' locations, and (3) identify potential areas that are not near existing monitors that would be suitable for monitor placement. Layers used in this analysis included distance to industrial point sources, distance to active oil/gas wells, distance to major roads (i.e., highways), distance to rail lines, distance to existing monitors, and land cover classification.

The first modeling scenario served as the base case model in that the input map layers were given equal weight. The model also incorporated a map layer depicting distance from existing monitors, where areas far away from each monitor were deemed more suitable than areas in close proximity. All model scenario weights are shown in **Table 3-2**.

The second modeling scenario included a unique weight factor for each map layer. As mentioned above, weighting individual layers allows certain layers greater influence in the model. Based on emissions source contribution estimates provided by the FAP and AEW, higher weights were given to map layers representing distances from industrial facility locations and active oil/gas wells. Conversely, distance from rail lines and major roads were given a lower weight due to their relatively low emissions contributions in the PAZA airshed. This model also weighted populated areas high in order to capture populated areas most likely affected by emissions. Distance from existing monitors was excluded in the second model; this allowed us to compare existing monitor locations to the areas identified by the model as desirable monitor locations.

The third model was similar to the second; however, it included the existing monitor locations so that we could exclusively identify areas and population centers that are impacted by local source emissions but not monitored. Therefore, the highest weight was given to a map layer illustrating areas beyond 10 kilometers for each existing monitor location. Subsequent map layer weighting mimicked the second modeling scenario.

Table 3-2. The weighting scheme for each of the three modeling scenarios.

Geographic Layer	Weighting Scheme	Model 1 Weight	Model 2 Weight	Model 3 Weight
Distance to existing continuous monitors	Farther from existing monitors = more suitable	Equal	0%	50%
Distance to industrial facilities locations	Closer to industrial facilities = more suitable	Equal	32%	8%
Distance to major roads	Closer to high activity roads = more suitable	Equal	5%	3%
Distance to small roads	Closer to small roads = more suitable	Equal	3%	2%
Distance to heavy-duty vehicle (HDV) roads	Closer to high HDV activity roads = more suitable	Equal	7%	4%
Distance to trans-loading facilities	Closer to facilities = more suitable	Equal	4%	3%
Distance to rail lines	Closer to rail lines = more suitable	Equal	4%	3%
Distance to populated areas	Higher populated areas = more suitable	Equal	20%	10%
Distance to Concentrated Animal Feeding Operations (CAFOs)	Closer to CAFOs = more suitable	Equal	5%	3%
Distance to airports	Closer to airports = more suitable	Equal	5%	1%
Unique land cover areas	Water = not suitable Urban = most suitable Other categories = midlevel suitability	Equal	15%	13%

4. Analysis Results

The following results document the analyses performed to test the conceptual model and better characterize existing concentrations across the PAZA monitoring network. Methods for each of the analyses are documented in Section 3. Results for each analysis are described individually, with a short summary of the implications for the monitoring network described at the beginning of each subsection. Analyses performed include

1. Measured concentrations
2. Trend impacts
3. Monitor-to-monitor correlation
4. Area served
5. Emissions served
6. Population served
7. Suitability modeling

4.1 Measured Concentrations

The measured concentrations analysis used available continuous and passive measurements to identify spatial variability in concentrations and to compare concentrations to AAAQO and CWS health threshold levels. This type of analysis also gives information on hot-spot concentrations and specific source types. The following sections describe results for SO_2, NO_2, and other pollutants. Additional figures showing measured concentrations are available in Section A.1 of the Appendix.

4.1.1 SO_2

Sulfur dioxide is the most measured pollutant in the network. It is measured in both the passive and continuous networks. The notched box-whisker plot at **Figure 4-1** shows the 2012 measurements from the passive monitoring network. Concentrations were low at all sites, with median and mean concentrations at all sites below 0.5 ppb. The highest observed monthly average concentration was 1.5 ppb at the Webber Creek site. The annual AAAQO for SO_2 is 8 ppb and the 30-day AAAQO is 11 ppb; neither objective was close to being exceeded. Spatial variability in SO_2 concentrations was also low, with most sites having average concentrations between 0.2 and 0.3 ppb. We note that the summary statistics calculated for the individual sites may be relatively "noisy" for passive measurements due to the sample size (n = 12). However, the agreement and consistency among sites provides us with sufficient statistical power to be confident in the general range of concentrations observed.

The notched box-whisker plot at **Figure 4-2** shows the continuous (hourly) SO_2 concentrations from 2012 at all sites except Falher, which did not have a full year of monitoring data. Although some outliers exceeded 2 ppb, the y-axis is restricted to a maximum of 2 ppb in order to better display the typical hourly concentration range. The median and mean concentrations at the continuous sites are comparable to those observed with the passive measurements. The highest observed concentrations occurred at Valleyview, where a few hourly observations were above 50 ppb; none exceeded 100 ppb. The 1-hr AAAQO is 182 ppb and has not been exceeded in the PAZA since 2007. Annual mean concentrations varied by a factor of two across the network, but median concentrations were all approximately 0.1 ppb.

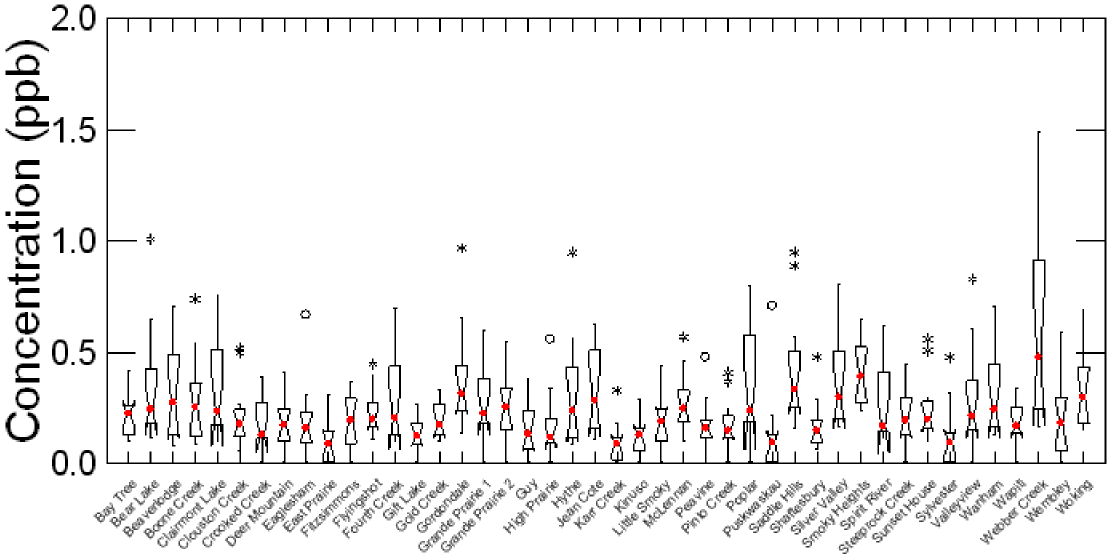


Figure 4-1. Notched box-whisker plot of measured concentrations of SO_2 from the passive monitoring network in 2012.

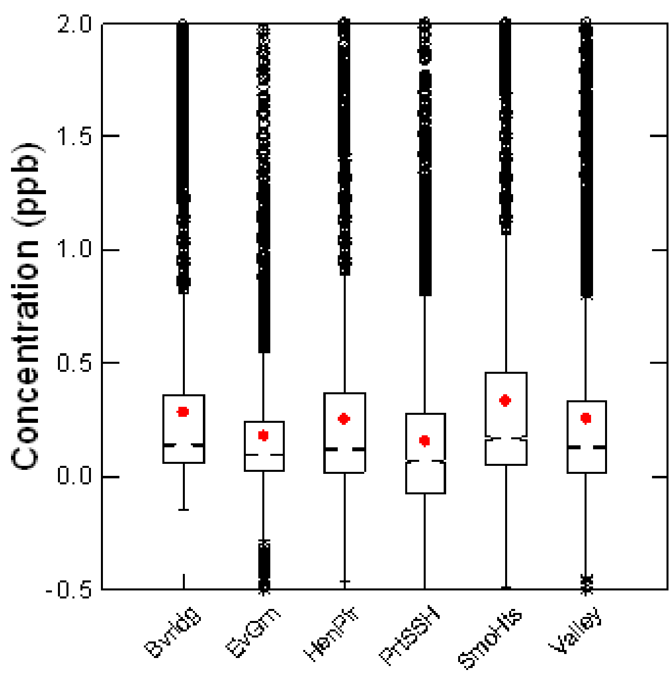


Figure 4-2. Notched box-whisker plots of SO_2 concentrations measured at the continuous monitoring stations in 2012. Red dots indicate mean concentrations. Bvrldg is Beaverlodge, EvGrn is Evergreen, HenPir is Henry Pirker, PrtSSH is the Rover at Sunset House, SmoHts is Smoky Heights, and Valley is Valleyview.

4.1.2 NO_2

Nitrogen dioxide is measured in both the passive network and at three continuous monitoring sites. **Figure 4-3** shows the 2012 measurements from the passive monitoring network as a notched box-whisker plot. Concentrations were low at all sites outside of Grande Prairie; however, concentrations at Grande Prairie were 3 to 5 times higher than at all other sites. The highest observed monthly average concentration was 16 ppb at the Grande Prairie 2 site. The annual AAAQO for NO_2 is 24 ppb; annual mean concentrations are well below this objective. Outside of Grande Prairie, many sites had very low concentrations of less than 1 ppb.

The notched box-whisker plot at **Figure 4-4** shows the continuous NO_2 concentrations from 2012 at the three sites. The median and mean concentrations at the continuous sites are significantly higher than those observed with the passive measurements; the annual mean concentrations at Henry Pirker and Beaverlodge are about twice as high as those observed with passive measurements. This discrepancy between the two measurement methods at multiple sites (and over multiple years not shown here) indicates that the two methods are not comparable. Given the calibrations and audits required for continuous measurement methods, we expect that the continuous monitors are more reliable than the passive diffusion samplers. Given the discrepancy, it may be worthwhile to check the audits and calibrations for NO_2 to ensure they are traceable to a standard NO_2 concentration. However, it is also important to note that chemiluminescent NO_2 analyzers will have a positive bias in the presence of peroxy acetyl nitrate (PAN) or nitric acid (HNO_3). This potential bias could account for some of the discrepancy, but we don't expect significant variations in the concentrations of PAN and HNO_3 in the distance between Beaverlodge and Henry Pirker, Nonetheless, the NO_2 concentrations at these two sites differ by at least a factor of three. We note that despite the discrepancy, NO_2 passive measurements appear to be reliable as a spatial proxy, but the absolute concentrations are likely underestimated at all sites.

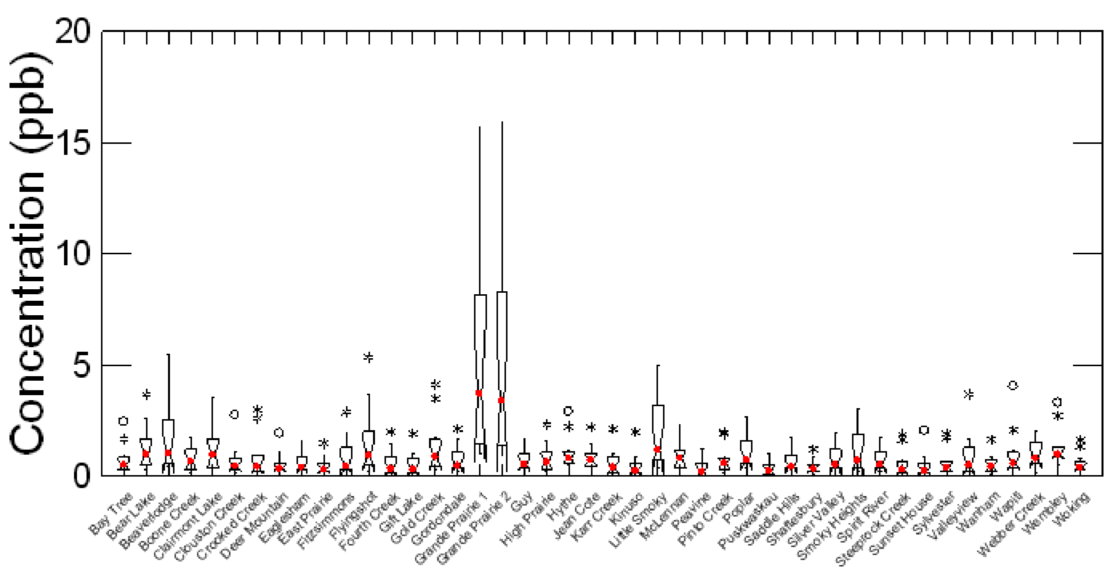


Figure 4-3. Notched box-whisker plot of measured concentrations of NO_2 from the passive monitoring network in 2012.

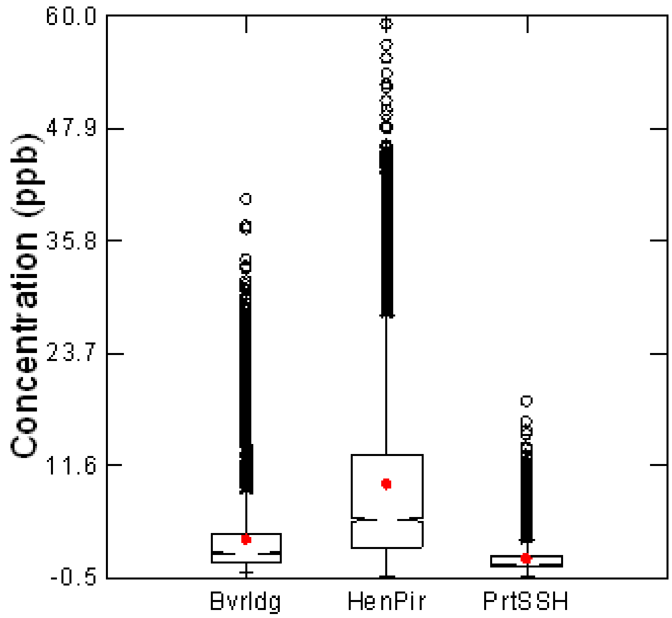


Figure 4-4. Notched box-whisker plots of NO_2 concentrations measured at the continuous monitoring stations in 2012. Red dots indicate mean concentrations. Bvrldg is Beaverlodge, HenPir is Henry Pirker, and PrtSSH is the Rover at Sunset House.

4.1.3 Other Pollutants

Ozone concentrations were measured in the passive network and at three sites. Ozone is a regionally distributed pollutant, and concentrations displayed little spatial variability across the airshed. Concentrations measured in Grande Prairie are slightly lower than at other sites (**Figure 4-5**) because of local NO_x emissions that were available to react with the ozone. Passive measurements indicate that the highest average concentrations were in the northwestern portion of the airshed. One-hr average ozone concentrations were well below the AAAQO of 82 ppb.

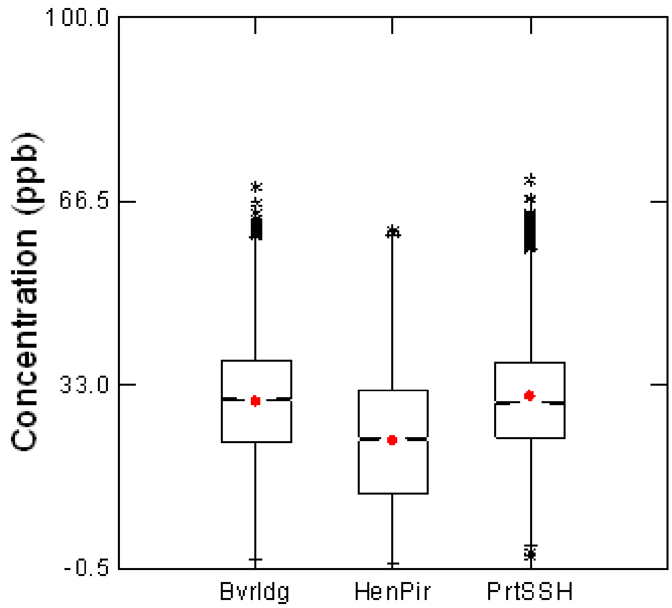


Figure 4-5. Notched box-whisker plots of ozone concentrations measured at the continuous monitoring stations in 2012. Red dots indicate mean concentrations. Bvrldg is Beaverlodge, HenPir is Henry Pirker, and PrtSSH is the Rover at Sunset House.

Average TRS concentrations were below 0.5 ppb at all sites, as shown in **Figure 4-6**. The median concentration was significantly higher at the Evergreen site than at the three other continuous sites in the network. Concentrations were lowest at Smoky Heights. Hydrogen sulfide, which is expected to be the largest component of TRS, has a 24-hr AAAQO of 3 ppb and a 1-hr AAAQO of 10 ppb. The highest hourly value observed was just under 4 ppb at the Henry Pirker site.

$PM_{2.5}$ concentrations from 2012 are shown in **Figure 4-7**. Average and median concentrations are highest at Beaverlodge and Henry Pirker. However, instrument differences are likely to account for at least some of the differences in concentrations: the low concentration sites are all operating TEOM monitors, while the high concentration sites are using a Sharp and a TEOM-FDMS instrument, which should better represent true ambient $PM_{2.5}$ concentrations. As demonstrated at studies in Edmonton and the scientific literature, the older TEOMs volatilize off some of the semi-volatile $PM_{2.5}$ mass, thus under-reporting $PM_{2.5}$ concentrations (Allen et al., 1997; McCarthy et al., 2013). This is particularly problematic in the winter months. Thus, direct comparisons of $PM_{2.5}$ concentrations between sites should not be made until comparable instrument methods have been deployed.

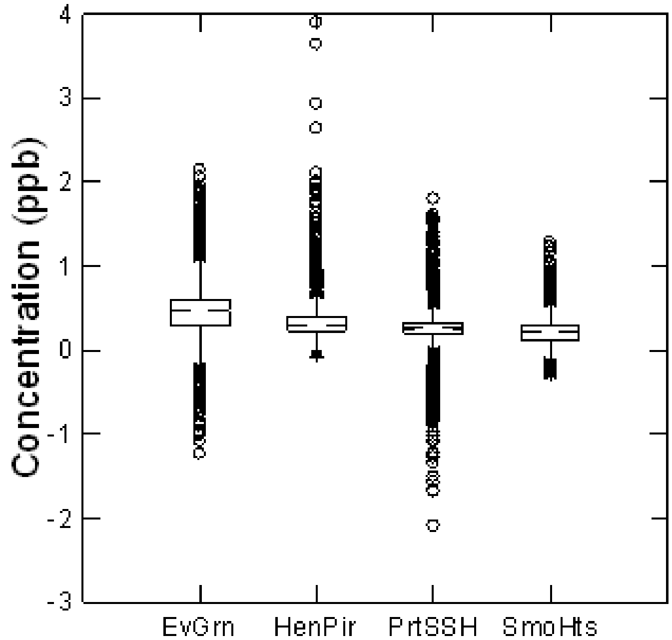


Figure 4-6. Notched box-whisker plots of total reduced sulfur concentrations measured at the continuous monitoring stations in 2012. Red dots indicate mean concentrations. EvGrn is Evergreen, HenPir is Henry Pirker, PrtSSH is the Rover at Sunset House, and SmoHts is Smoky Heights.

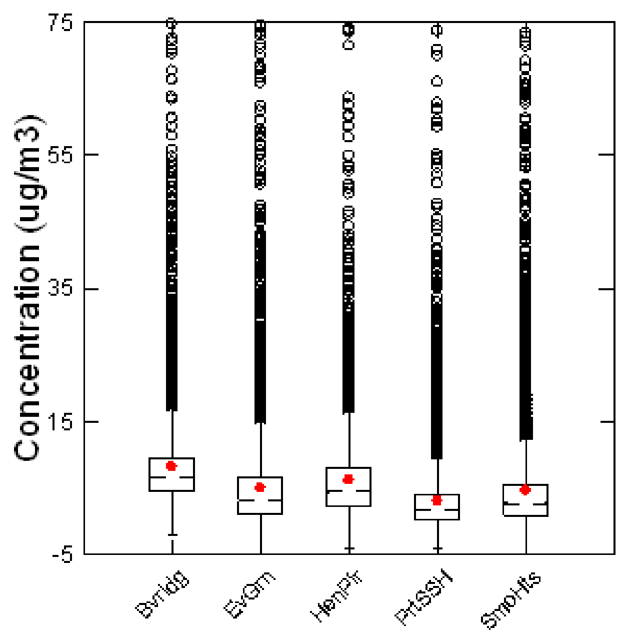


Figure 4-7. Notched box-whisker plots of $PM_{2.5}$ concentrations ($\mu g/m^3$) measured at the continuous monitoring stations in 2012. Red dots indicate mean concentrations. Bvrldg is Beaverlodge, EvGrn is Evergreen, HenPir is Henry Pirker, PrtSSH is the Rover at Sunset House, and SmoHts is Smoky Heights. Note that some of the difference in concentration is likely due to instrument technology differences.

4.2 Trend Impacts

The trends analysis used available continuous and passive measurements to identify temporal variability in concentrations. This type of analysis also gives information on compliance and potential emerging issues. Trends were investigated at all sites for all pollutants with at least a five-year trend record. Selected trends are shown here, and additional trends figures are available in Section A.2 of the Appendix. We note that sites with the longest trend records are the most valuable for identifying air quality trends.

For passive measurements, trends in the annual mean concentrations were visually inspected for a subset of sites and for the overall average across all sites in the Airshed. For continuous measurements, trends in median and mean concentrations were inspected visually for all sites with at least five years of monitoring data. Differences in the first three years and last three years of a given trend period were considered significant if the confidence intervals in the median concentrations did not overlap.

Figures 4-8 and 4-9 show the trends in SO_2 concentrations at selected passive monitoring sites and at the Beaverlodge and Henry Pirker continuous sites. The passive SO_2 concentrations show the annual means at selected sites and across the entire network. SO_2 concentrations have declined over time across the network by about 0.05 to 0.1 ppb. However, the year-to-year variability in annual mean concentrations can be on the order of 0.1 ppb (e.g., the bumps in 2006, 2007, and 2010). Continuous measurements of SO_2 show the same pattern, with low median and mean concentrations, that have declined since 2006. Overall, it appears there is a small but statistically significant decline in SO_2 concentrations within the airshed. We note that trace-level analyzers may be necessary to characterize trends in the future as SO_2 concentrations continue to approach values of 0.2 ppb.

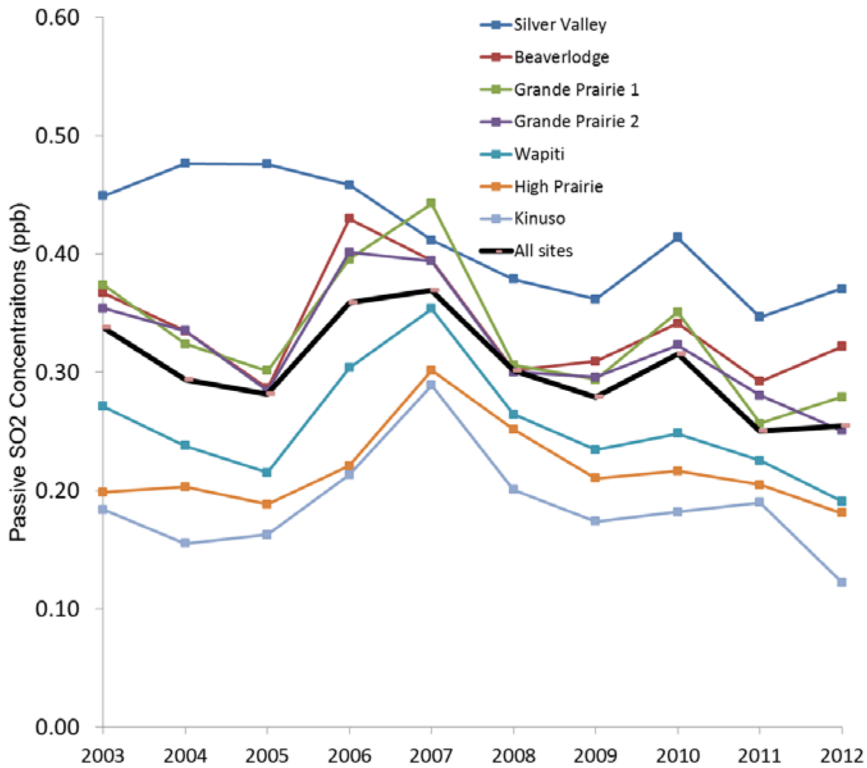


Figure 4-8. Trends in annual average SO_2 concentrations (ppb) at selected passive monitoring sites.

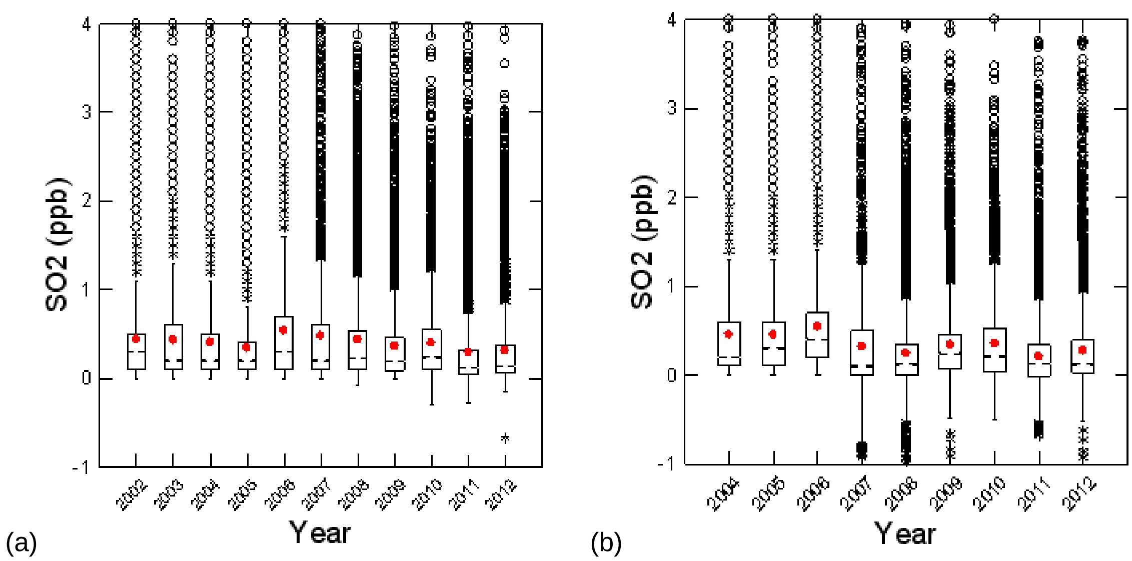


Figure 4-9. Trends in continuous SO_2 concentrations (ppb) at (a) Beaverlodge and (b) Henry Pirker monitoring sites. Red dots indicate mean concentrations.

Figures 4-10 and 4-11 show the trends in NO_2 concentrations at selected passive monitoring sites and at the Beaverlodge and Henry Pirker continuous sites. For the passive

NO_2 concentrations, the annual means are shown at selected sites and across the entire network. NO_2 concentrations have declined over time, and there was an especially significant drop in 2011 and 2012. This recent drop may be due to the recent economic downturn that has affected Canada. Annual mean NO_2 concentrations in Grande Prairie decreased by about 10% in the last two years. Once again, note that continuous measurements of NO_2 and passive measurements have a discrepancy in absolute concentrations.**Figure 4-12** shows the trends in other pollutant concentrations measured at the Henry Pirker station, including CO, 8-hr average ozone, $PM_{2.5}$, total hydrocarbons, and TRS. Carbon monoxide concentrations have clearly decreased, while all other pollutants have shown increasing concentrations over time. Ozone concentration increases are likely a result of less titration from local NO_x emissions. The increase in $PM_{2.5}$ concentrations is largely a result of a change in the instrument method that occurred in 2010; smoke from wildfires in the last three years have also increased PM concentrations. Total hydrocarbon concentrations have increased from the early years to the recent high values in 2009, 2010, and 2012. This may be a result of increased local emissions from the industrial growth in Grande Prairie, from increased emissions from upstream oil and gas extraction, or from some combination of those two factors. Finally, TRS concentrations are slightly higher in the later years than in the early years, excluding 2004. It is important to note that all of these concentrations are low in absolute terms, despite their increasing values.

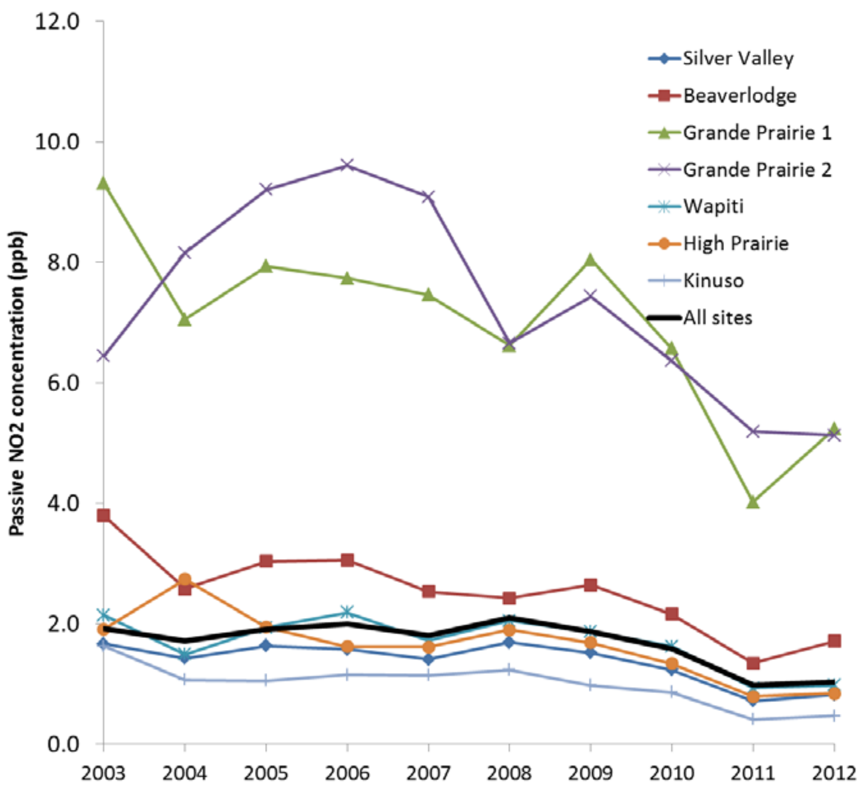


Figure 4-10. Trends in annual average NO_2 concentrations (ppb) at selected passive monitoring sites.

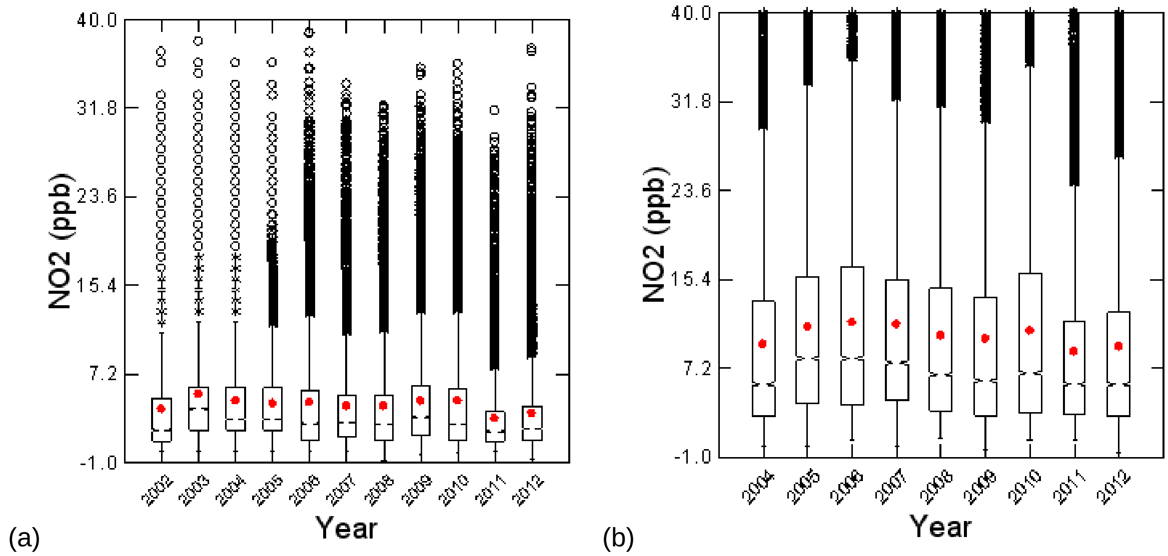


Figure 4-11. Trends in continuous NO_2 concentrations (ppb) at (a) Beaverlodge and (b) Henry Pirker monitoring sites. Red dots indicate mean concentrations.

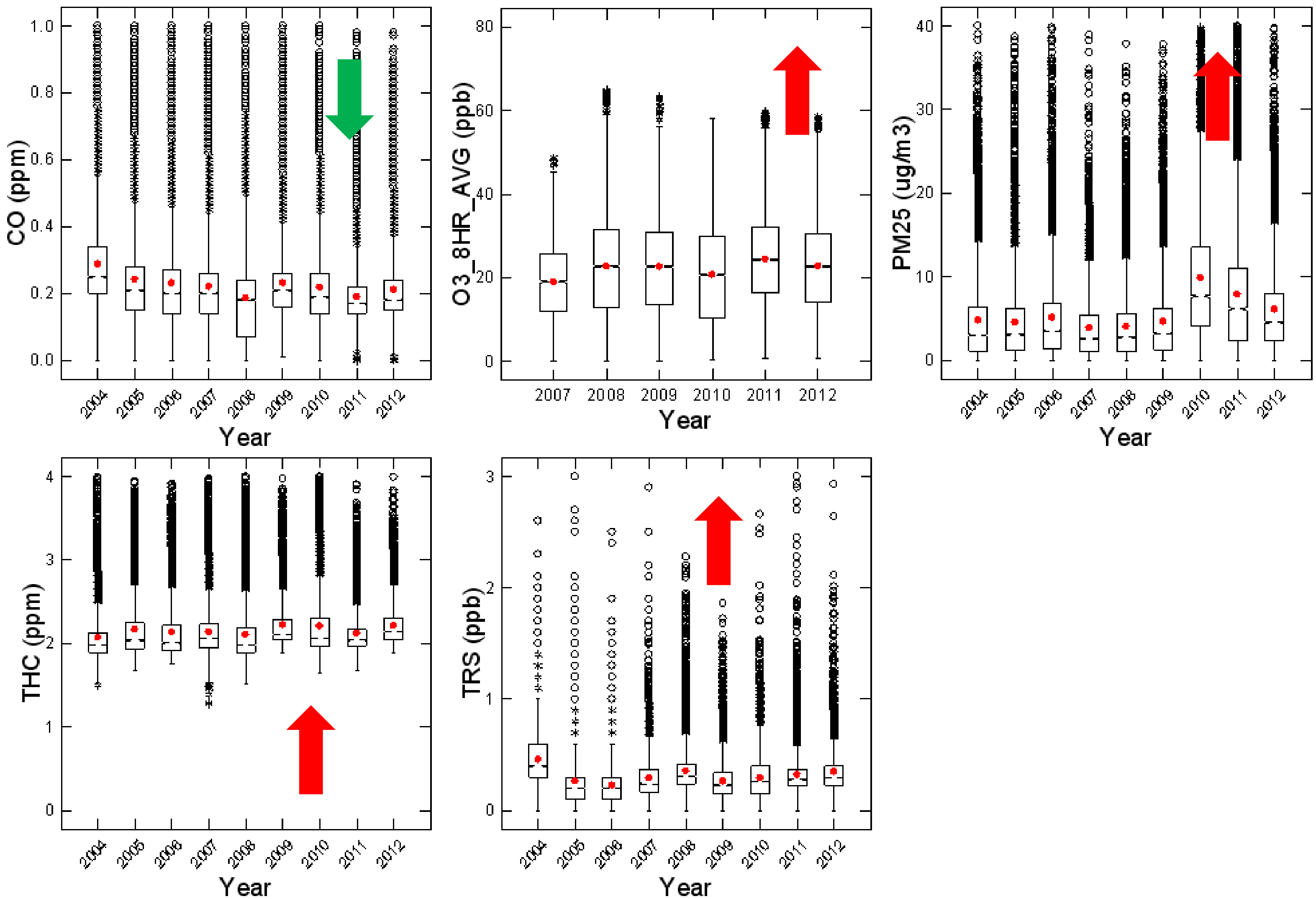


Figure 4-12. Trend plots for pollutants monitored at the Henry Pirker monitoring site. Arrows indicate whether concentrations of the median and mean are increasing (red arrow) or decreasing (green arrow) with statistical significance. Red dots indicate mean concentrations.

4.3 Monitor-to-Monitor Correlations

The correlation analysis was used to identify redundancy in the monitoring network and was based on available continuous measurements from 2012 and monthly average passive measurements from 2010-2012. This analysis indicates spatial and temporal variability in concentrations and indicates which sites are most important (unique) for understanding concentrations throughout the network. Additional figures for NO_2 and SO_2 passive measurements are available in Section A.3 of the Appendix. Pearson matrices for continuous measurements indicated no sites with correlation coefficients above 0.8 and are thus not shown.

Pearson correlation matrices were generated for all pollutants with more than one measurement site. R values greater than 0.8 are correlated, while those greater than 0.9 are highly correlated and indicate potential redundancy between sites. **Figure 4-13** shows the correlation between passive measurement sites for ozone. Orange and red cells indicate a high degree of correlation, while yellow or white cells are relatively unique. The large amount of red and orange in Figure 4-13 indicates that ozone concentrations are highly correlated. SO_2 and NO_2 had less correlated sites, but were still showed a high degree of site-to-site correlation (see Appendix).

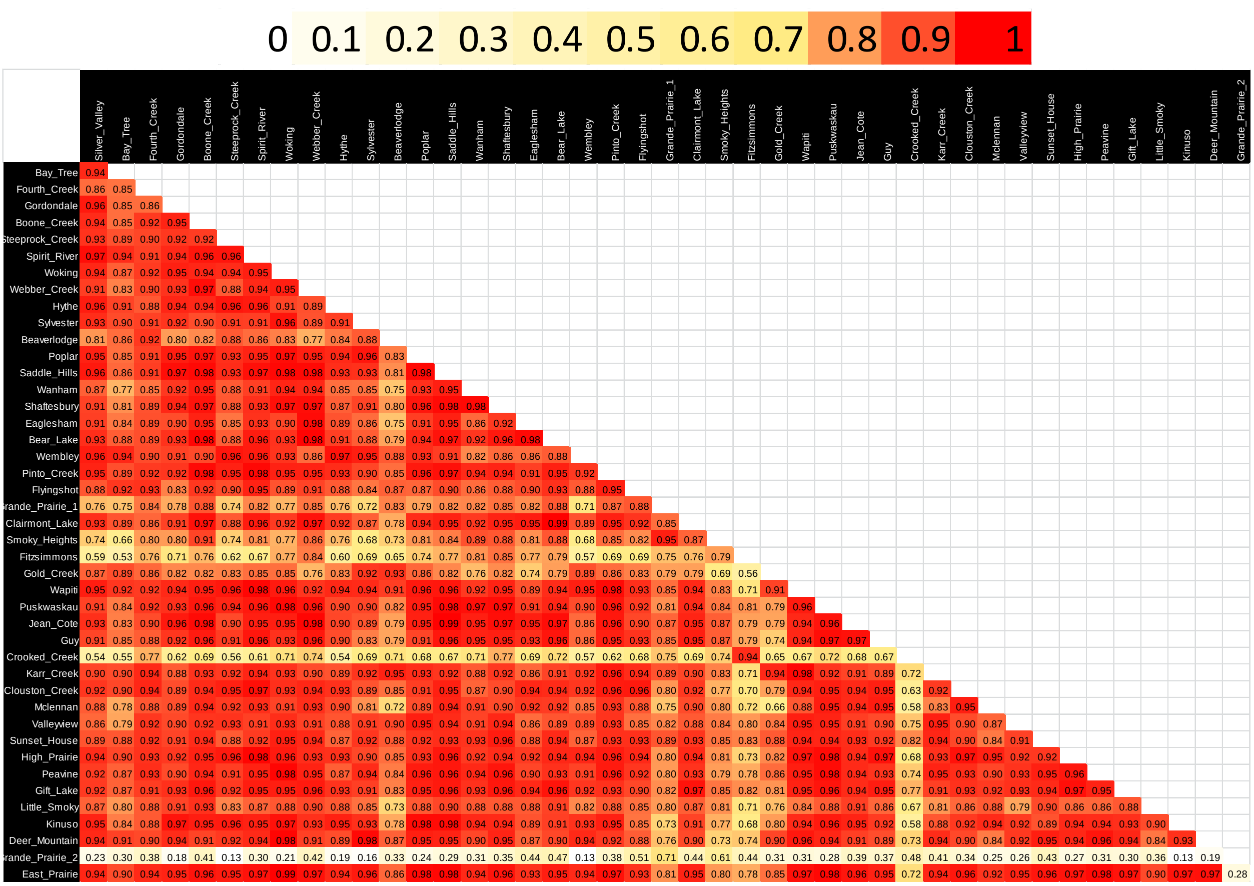


Figure 4-13. Correlation matrix indicating Pearson Coefficient (R) values for passive monitoring network for ozone for the years 2010-2012. Values above 0.9 are highly correlated and may indicate redundancy.

Table 4-1 shows the relative redundancy of each passive monitoring site for ozone, NO_2, and SO_2. The number of sites with which an individual monitoring site had an R greater than 0.8 was tabulated for each site. Sites were then rank-ordered by the number of correlated sites. The average rank for ozone, NO_2, and SO_2 was then averaged to identify the sites with the least value for all three pollutants and to assign a "redundancy ranking." Puskwaskau was the most redundant site in the passive network; in contrast, sites at the bottom of the table are the most important for understanding spatial variability and identifying unique concentration areas. If passive monitoring is continued, sites near the top of the list would be least important and are the best candidates for removal.

Table 4-1. Summary of the correlation analysis for passive sites measuring NO_2, SO_2, and ozone. Sites are rank-ordered by their average correlation rank with other sites. Puskwaskau is the most redundant site in the passive network.

Page 1 of 2

Site Name	NO_2 R>0.8	NO_2 Rank	Ozone R>0.8	Ozone Rank	SO_2 R>0.8	SO_2 Rank	Average Rank	Redundancy Rank
Puskwaskau	35	38	40	35	16	44	39.0	1
Gift Lake	37	43	41	41	11	32	38.7	2
Boone Creek	35	40	40	35	12	34	36.3	3
Poplar	36	41	39	28	11	32	33.7	4
Flyingshot	35	39	40	35	7	25	33.0	5
High Prairie	30	30	40	35	12	34	33.0	6
Silver Valley	29	28	38	20	16	44	30.7	7
Valleyview	24	17	39	28	16	44	29.7	8
Sunset House	11	5	42	43	14	40	29.3	9
Steeprock Creek	27	25	38	20	15	42	29.0	10
Bear Lake	31	32	38	20	12	34	28.7	11
Clairmont Lake	29	27	38	20	13	38	28.3	12
Woking	39	44	38	20	5	20	28.0	13
East Prairie	26	22	42	43	4	17	27.3	14
Gordondale	36	42	37	11	8	27	26.7	15
Hythe	24	19	38	20	14	40	26.3	16
Shaftesbury	24	18	41	41	5	20	26.3	17
Webber Creek	34	37	39	28	2	11	25.3	18
Fourth Creek	25	21	39	28	6	24	24.3	19
Peavine	34	36	38	20	4	17	24.3	20
Wapiti	14	8	40	35	10	30	24.3	21
Deer Mountain	21	11	38	20	13	38	23.0	22
Karr Creek	32	33	40	35	0	1	23.0	23
Saddle Hills	23	15	40	35	4	17	22.3	24
Spirit River	21	12	40	35	5	20	22.3	25
Clouston Creek	33	35	38	20	2	11	22.0	26

Table 4-1. Summary of the correlation analysis for passive sites measuring NO_2, SO_2, and ozone. Sites are rank-ordered by their average correlation rank with other sites. Puskwaskau is the most redundant site in the passive network.

Page 2 of 2

Site Name	NO_2 R>0.8	NO_2 Rank	Ozone R>0.8	Ozone Rank	SO_2 R>0.8	SO_2 Rank	Average Rank	Redundancy Rank
Pinto Creek	25	20	40	35	2	11	22.0	27
Smoky Heights	32	34	25	4	9	28	22.0	28
Wembley	30	31	38	20	1	10	20.3	29
Wanham	17	10	38	20	10	30	20.0	30
Fitzsimmons	27	24	8	3	7	25	17.3	31
Sylvester	23	16	38	20	3	15	17.0	32
Beaverlodge	26	23	28	7	5	20	16.7	33
Grande Prairie 1	22	14	26	5	10	30	16.3	34
Grande Prairie 2	22	13	1	1	12	34	16.0	35
Kinuso	30	29	36	10	0	1	13.3	36
Little Smoky	28	26	37	11	0	1	12.7	37
Crooked Creek	17	9	2	2	3	15	8.7	38
Bay Tree	11	6	35	8	2	11	8.3	39
Guy	10	4	38	20	0	1	8.3	40
Eaglesham	9	2	38	20	0	1	7.7	41
Jean Cote	5	1	38	20	0	1	7.3	42
Gold Creek	13	7	26	6	0	1	4.7	43
McLennan	10	3	36	9	0	1	4.3	44

4.4 Area, Emissions, and Population Served Analyses

The area, emissions, and population served analyses are used to identify sites that are particularly important for the monitoring network because of the area covered (more area being better), magnitude of emissions covered, and proximity to population. This analysis indicates sites that are most important for spatial, emissions, and population coverage. Additional maps are available in Section A.4 of the Appendix.

Figure 4-14 depicts the area and population represented for the passive network. Polygons are colored to indicate the population represented; most passive monitors represent less than 2,500 people. The area represented is also shown, although it is difficult to gauge the actual values from the map alone. **Table 4-2** ranks the passive monitors by population, area, and emissions (SO_x and NO_x emissions from facilities, area, and mobile). Higher ranks indicate better representativeness.

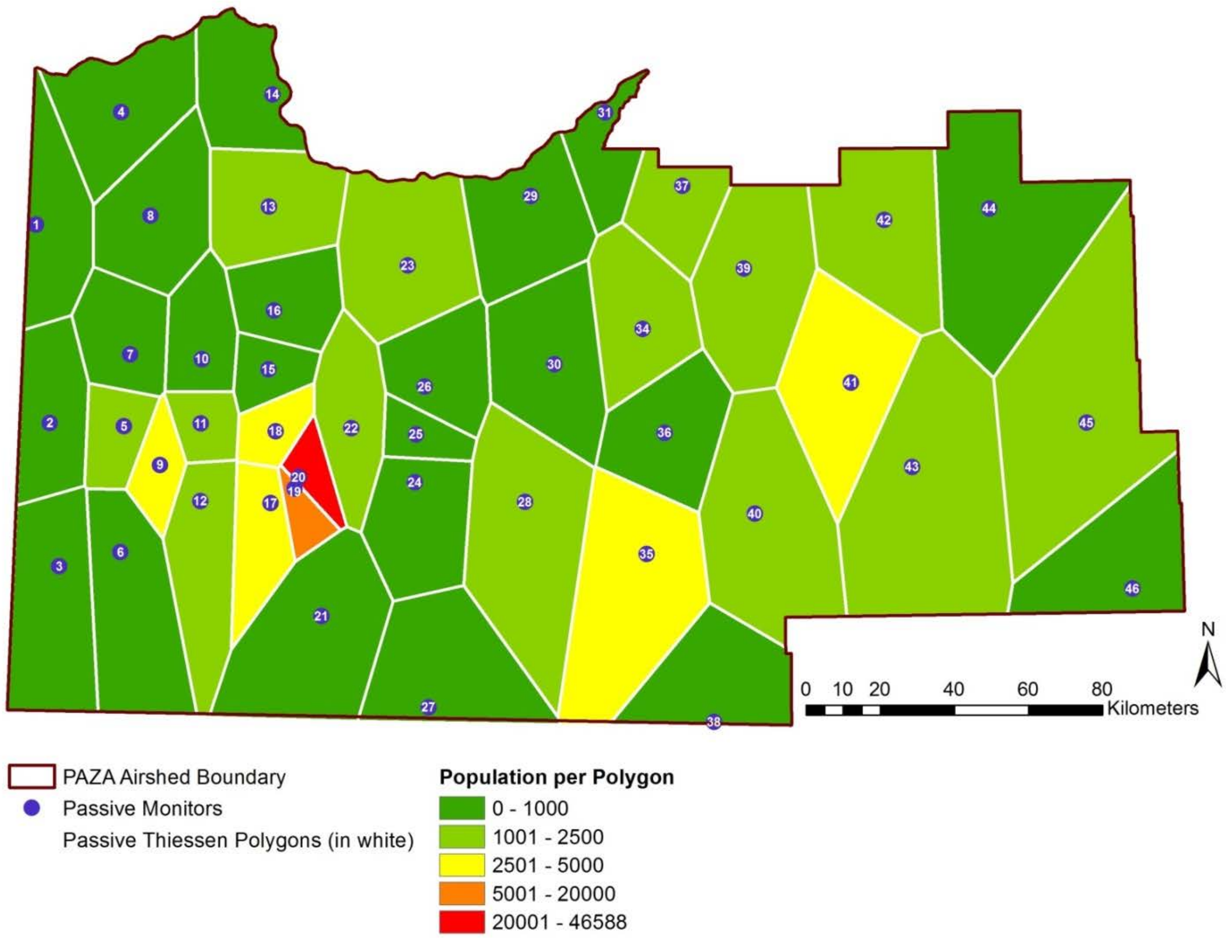


Figure 4-14. Population and area representativeness calculated using Thiessen Polygons for passive monitoring network locations (ozone, NO_2, and SO_2).

Table 4-2. Passive monitor rankings for population, area, and emissions representativeness. Sites (shown in Figure 4-14) are ordered by the average rank across all three categories, with the most important passive monitors listed first.

Page 1 of 2

Monitor # on Map	Name	Population	Population Rank	Area (km^2)	Area Rank	Summed Emissions (NO_x and SO_x)	Emissions Rank	Average Rank
35	Valleyview	3541	5	1820	6	2312	8	6
41	High Prairie	4186	3	1387	9	1132	27	13
12	Wembley	1912	12	962	24	2893	4	13
43	East Prairie	1494	15	2705	1	1171	24	13
39	McLennan	1251	18	1426	8	1890	15	14
28	Crooked Creek	1443	16	1863	5	1558	20	14
19	Grande Prairie Pinnacle	16963	2	188	44	4773	1	16
20	Grande Prairie Henry Pirker	46588	1	222	43	3029	3	16
22	Clairmont Lake	2022	11	788	29	2228	9	16
23	Wanham	1384	17	1387	10	1196	22	16
40	Sunset House	1009	21	1876	4	1150	25	17
6	Pinto Creek	369	34	1316	13	2754	6	18
45	Kinuso	2492	8	2693	2	663	43	18
8	Gordondale	481	31	1074	18	2419	7	19
21	Gold Creek	0	40	1653	7	2139	11	19
30	Puskwaskau	765	27	1242	15	1838	17	20
29	Eaglesham	964	22	1039	19	1728	18	20
17	Flyingshot	2636	7	552	35	1647	19	20
13	Spirit River	1653	13	992	22	1141	26	20
7	Boone Creek	506	29	691	31	3278	2	21
42	Peavine	1515	14	1361	11	727	39	21
3	Sylvester	0	40	1268	14	1924	13	22
5	Hythe	2066	10	418	37	1230	21	23
44	Gift Lake	897	24	2079	3	682	41	23
16	Woking	924	23	670	32	1906	14	23
34	Guy	1186	19	1001	21	1068	30	23
2	Steeprock Creek	369	33	812	28	2205	10	24

Table 4-2. Passive monitor rankings for population, area, and emissions representativeness. Sites (shown in Figure 4-14) are ordered by the average rank across all three categories, with the most important passive monitors listed first.

Page 2 of 2

Monitor # on Map	Name	Population	Population Rank	Area (km^2)	Area Rank	Summed Emissions (NO_x and SO_x)	Emissions Rank	Average Rank
15	Saddle Hills	489	30	341	38	2883	5	24
18	Bear Lake	3460	6	303	41	1110	28	25
37	Jean Cote	2144	9	607	33	1035	33	25
26	Smoky Heights	333	37	765	30	2004	12	26
4	Silver Valley	514	28	1083	17	950	34	26
9	Beaverlodge	4042	4	329	39	908	36	26
27	Karr Creek	0	40	1318	12	1072	29	27
11	Poplar	1066	20	320	40	1179	23	28
36	Clouston Creek	789	25	976	23	941	35	28
10	Webber Creek	341	36	591	34	1890	16	29
24	Wapiti	769	26	928	25	737	38	30
1	Bay Tree	350	35	863	26	1061	31	31
14	Forth Creek	385	32	814	27	827	37	32
46	Deer Mountain	0	40	1208	16	671	42	33
38	Little Smoky	0	40	1036	20	223	44	35
31	Shaftesbury	324	38	469	36	1037	32	35
25	Fitzsimmons	0	40	290	42	690	40	41

Figure 4-15 illustrates the emissions representativeness for the SO_2 continuous monitoring network. Total facility emissions are summed up for each polygon and depicted with a polygon color scheme; higher emissions have darker colors. SO_2 emissions for the airshed are highest in the northwest quadrant, with Beaverlodge and Henry Pirker representing the highest emissions numbers.

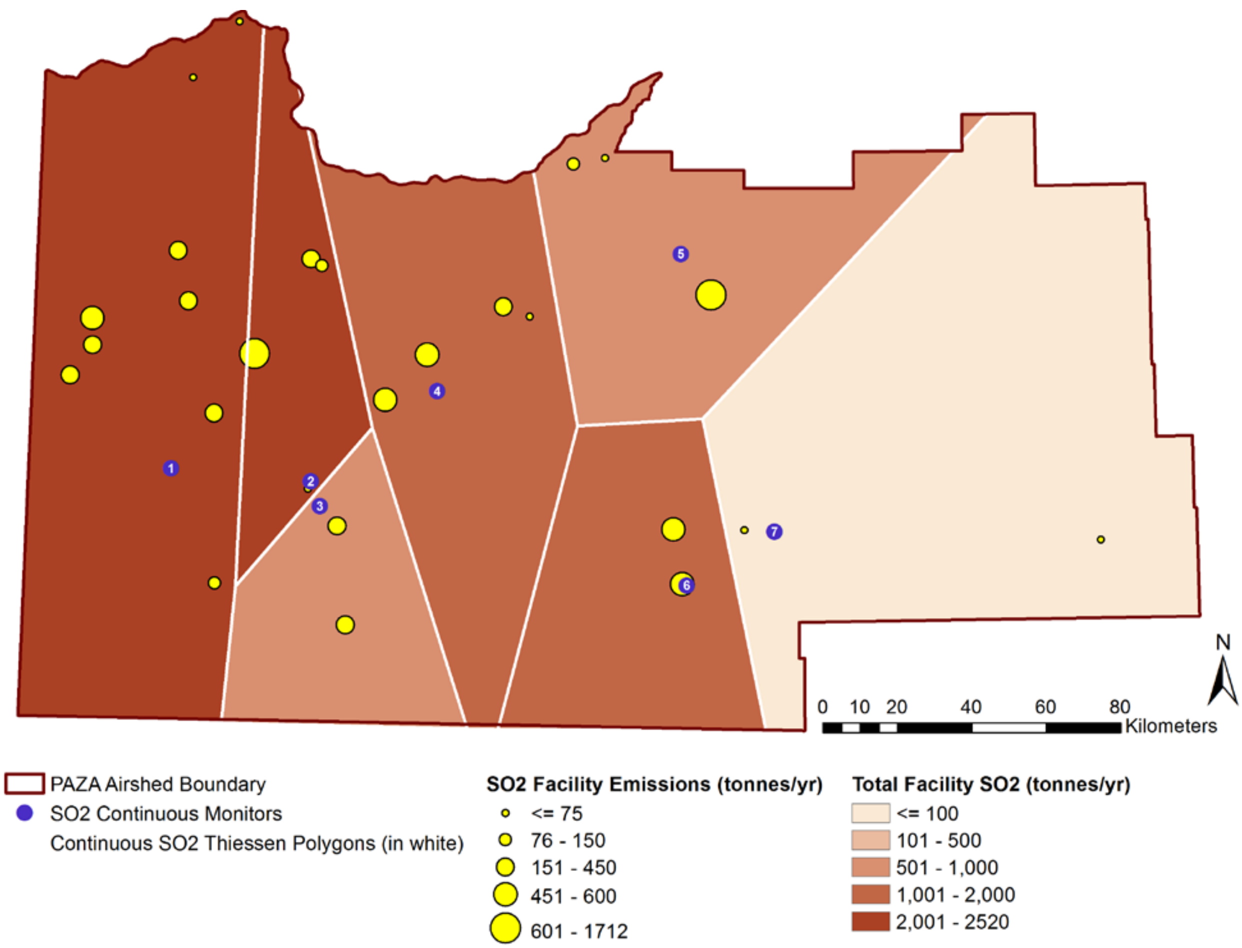


Figure 4-15. SO_2 facility emissions represented by each continuous SO_2 monitoring location. Individual facilities are shown as yellow circles, while the total facility emissions represented by each monitor are shown by the colored polygon.

4.5 Suitability Analysis

The suitability analysis is used to identify locations that are particularly suitable for monitoring locations as indicated by a series of underlying weighted factors. This analysis indicates where sites should be located or moved. Our analysis included three scenarios to illustrate potentially suitable monitoring locations. These scenarios are illustrated in the following three figures.

Figure 4-16 illustrates areas that may be suitable for monitoring locations because of proximity to population centers, emissions, and distance to transportation corridors. The figure shows Henry Pirker in a particularly suitable area and Smoky Heights in a relatively unsuitable location. Falher, Evergreen Park, and Beaverlodge are shown in moderately suitable areas.

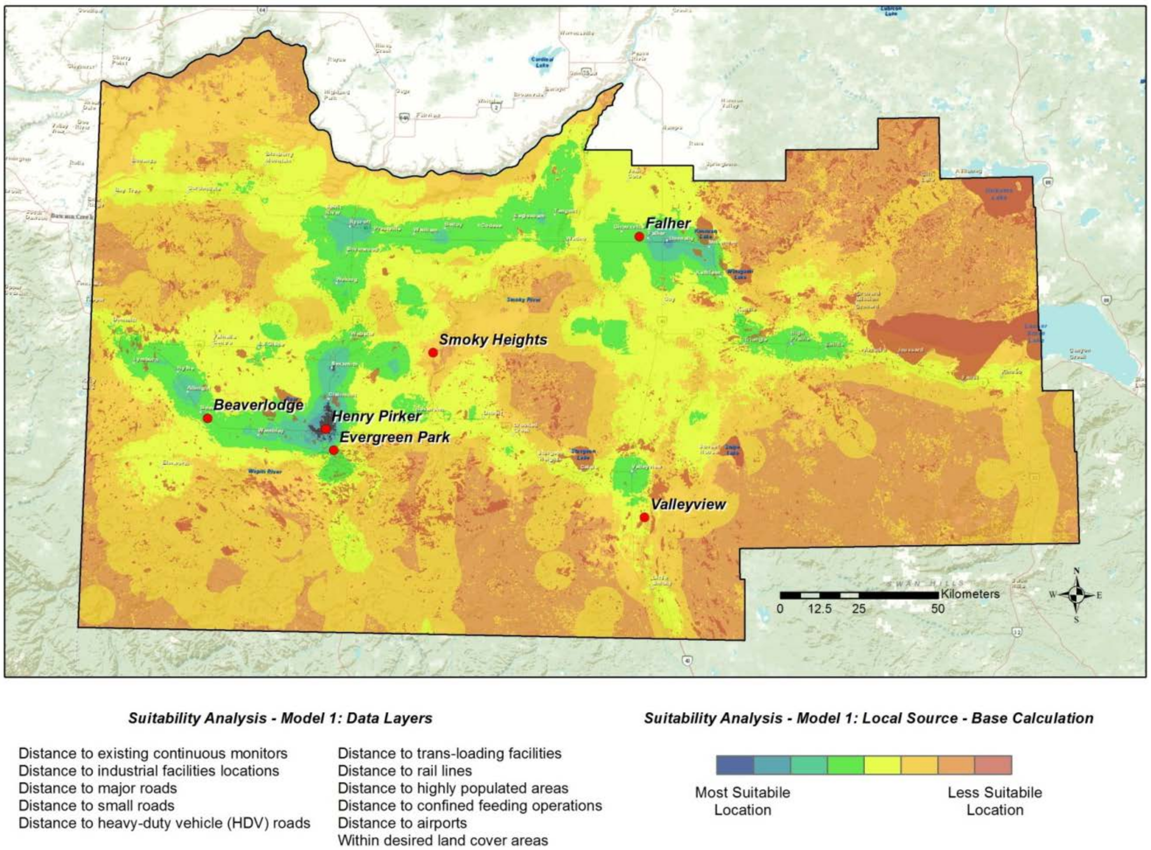


Figure 4-16. Suitability map for the base scenario indicating optimal locations of monitoring sites. Current locations of monitoring sites are also shown (Rover not shown).

Figure 4-17 identifies suitable monitoring locations without including information about current site locations (i.e., without downweighting areas near existing monitors). Additionally, areas near permitted facilities are highlighted as more suitable than in the previous scenario, as shown by circles around each facility. In this scenario, Henry Pirker is still the most suitable location, but Evergreen Park and Valleyview become much more suitable than in the previous scenario. If compliance monitoring of the local facilities is the goal of these stations, then they are adequately located. In contrast, Smoky Heights is still identified as an unsuitable location, being too far east and south of nearby facilities.

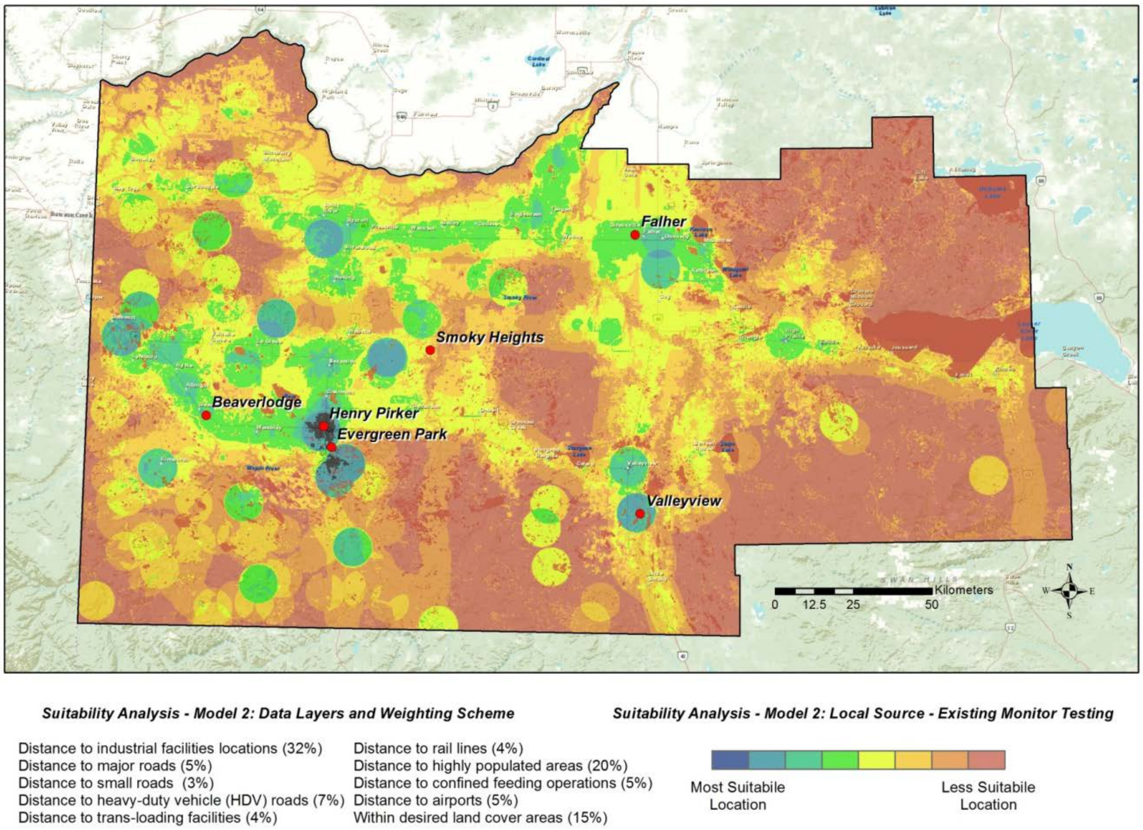


Figure 4-17. Suitability map for the optimal monitor location scenario indicating suitable locations of monitoring sites in relation to permitted facilities and population. Current locations of monitoring sites are also shown (Rover not shown).

Finally, **Figure 4-18** adds a buffer around existing monitoring sites, as proximity to other monitoring locations would likely provide redundant information on air quality in those areas. This map identifies areas in the airshed that are not monitored but include population centers and emissions that may warrant monitoring. Here, the Rycroft and Spirit River area is shown as a suitable area for monitoring. Other locations with high suitability include Sexsmith, Clairmont, West of Smoky Heights, Valleyview (the town), and High Prairie. These areas may be suitable locations for Rover deployment, or even for permanent monitoring if resources permit.

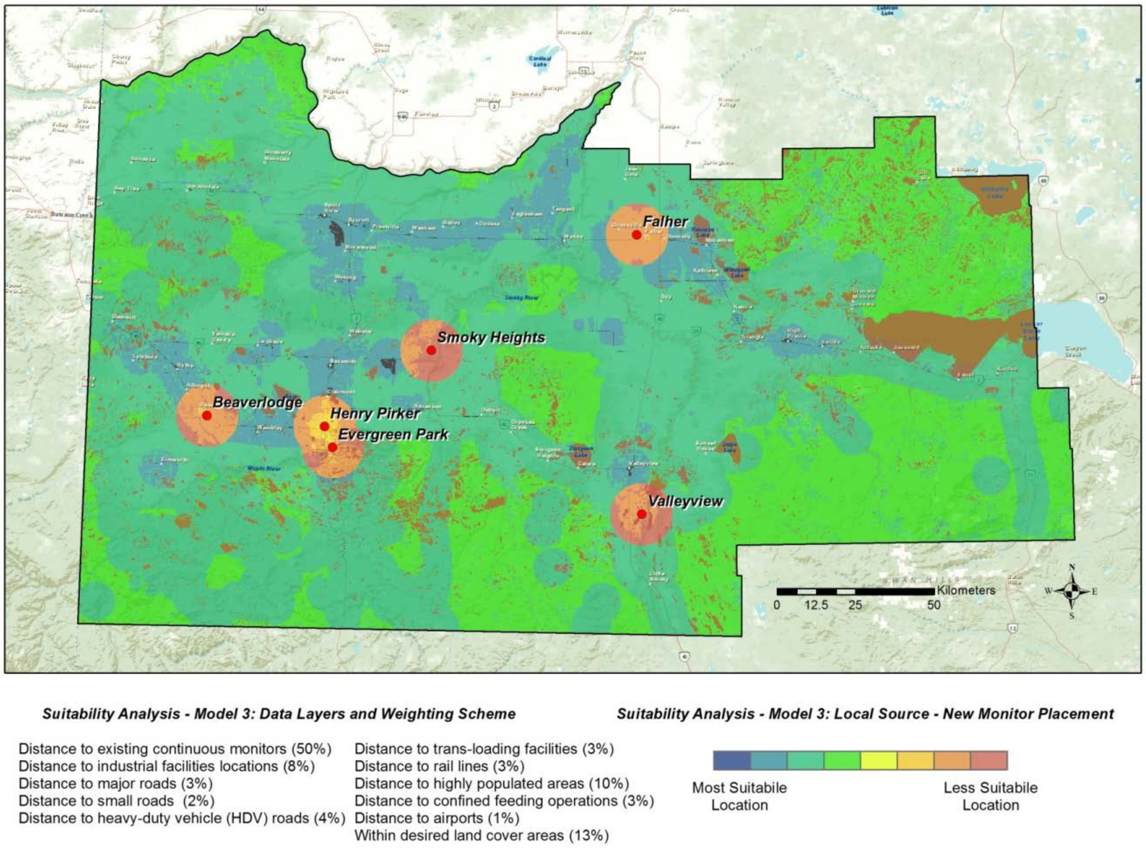


Figure 4-18. Suitability map for the new monitor location scenario indicating optimal locations of monitoring sites when accounting for current locations of monitoring sites. Current locations of monitoring sites are also shown (Rover not shown).

5. Discussion and Recommendations

5.1 Network Strengths and Weaknesses

The network evaluation identified a number of network strengths and weaknesses in meeting the monitoring objectives listed in Section 1.2. Strengths of the network include:

- Long-term trend sites for the passive network, and Henry Pirker and Beaverlodge sites for the continuous network, can be used to monitor compliance, identify emerging issues, and characterize changes in air quality as new facilities emerge and population grows. Ensuring that measurement methods remain comparable and representative of ambient air in these long-term sites should be a priority.
- Grande Prairie, the largest population center in the airshed, is represented by an AQHI monitoring site (Henry Pirker).
- The passive network provided excellent long-term spatial and temporal coverage of monthly average SO_2, NO_2, and ozone concentrations.
- The Rover station allows flexibility in deployment to address local issues and to characterize specific geographic locations, sources, or areas with emerging issues.
- Concentrations of most monitored pollutants in the airshed are very low most of the time. The pollutant most likely to exceed the AAAQO and CWS is $PM_{2.5}$, which is driven mainly by sporadic wildland fires that are not directly controllable.
- Monitoring resources are likely to increase as additional facilities are permitted in the airshed.

Despite this impressive list of strengths, the monitoring network still has gaps and weaknesses in meeting current monitoring objectives. Weaknesses of the network include:

- Excessive monitoring resources are dedicated to monitoring SO_2 (passive network and seven continuous sites) despite relatively low emissions compared to other key pollutants and no exceedances of the AAAQO since 2007.
- Passive network measurements of NO_2 and ozone are redundant and no longer needed. The information they provided is sufficient to assess current spatial and temporal variability.
- Grande Prairie monitoring locations, especially at the Evergreen site, may not be representative of residential areas or population exposure.
- The passive network is poorly suited for population representation.
- The Smoky Heights continuous station is poorly located to represent population, area, or emissions.
- $PM_{2.5}$ instruments currently deployed are not comparable. TEOMs tend to underestimate ambient $PM_{2.5}$ concentrations, especially in the winter months.
- There are no measurements of speciated VOCs in the airshed, despite extensive upstream oil and gas extraction. Total hydrocarbon concentrations at the Henry Pirker

station have increased over time. Benzene, toluene, ethylbenzene, and xylenes (BTEX) are all included in the AAAQO target list. BTEX could be measured with passive samplers, or a continuous BTEX analyzer could be deployed.

- Documentation of rationale and objectives for current monitoring locations is absent or insufficient. Future network assessments would benefit from better documentation of site objectives, method change dates, and site meta-data such as pictures.

5.2 Network Site and Objective Rankings

As a means of providing a semi-quantitative assessment of the values of each of the continuous monitoring sites, we ranked the value of each monitoring location on a scale of 0 to 3 for eight of the monitoring objectives. A score of zero indicates the site is not meeting the monitoring objective at all, while a score of three indicates the site is meeting the objective well. **Figures 5-1 and 5-2** illustrate the result of this scoring system as a way of identifying which sites are most useful for meeting each monitoring objective, and which monitoring objectives are being met well by the network as currently configured. Note that the entire passive network is ranked as a single entity. The maximum possible score is 24.

Henry Pirker is the most valuable site in the current network and is meeting the most monitoring objectives. The Rover site is the second most valuable, primarily because of its ability to characterize different locations or sources through its mobile capability. Both of these sites also ranked highly because of their large suite of measured compounds; each additional parameter provides synergistic value for identifying sources. Beaverlodge is also rated highly because of its long trend record and large number of pollutants monitored. Evergreen, Falher, Smoky Heights, and Valleyview are all significantly less valuable for the same reason. In addition, all of them have potential issues where they would be potentially more valuable if relocated to better represent local population or emissions sources.

The passive network was moderately valuable, but primarily for understanding spatial distributions. Due to their low temporal resolution, passive samples are less valuable for identifying sources, providing information on population exposure, and understanding variability in concentrations in short time frames. Moreover, as discussed in earlier sections, they have high redundancy and have already provided the information needed to assess current spatial and temporal variability.

The monitoring objectives that are best met by the current network are ensuring compliance to EPEA approvals and understanding spatial variability across the airshed. The objective of identifying regional air quality trends is being met at some of the stations and by the passive network. The objective of measuring air quality to meet relevant objectives and standards is being well met by some of the stations (e.g., Beaverlodge, Henry Pirker)..

The current network is poorly suited to identifying and apportioning sources since there are few, if any, speciation markers that could be used to do source apportionment at this time. Information required to evaluate air quality impacts on the population and environment is partially being provided by the Henry Pirker station, but additional measurements of VOCs would be useful to confirm that emissions from upstream oil and gas extraction are below levels of concern. Finally, the objective related to input and validation data for dispersion models would be better met if additional pollutants were available to ensure that concentrations representative of a given facility are being identified and appropriately apportioned.

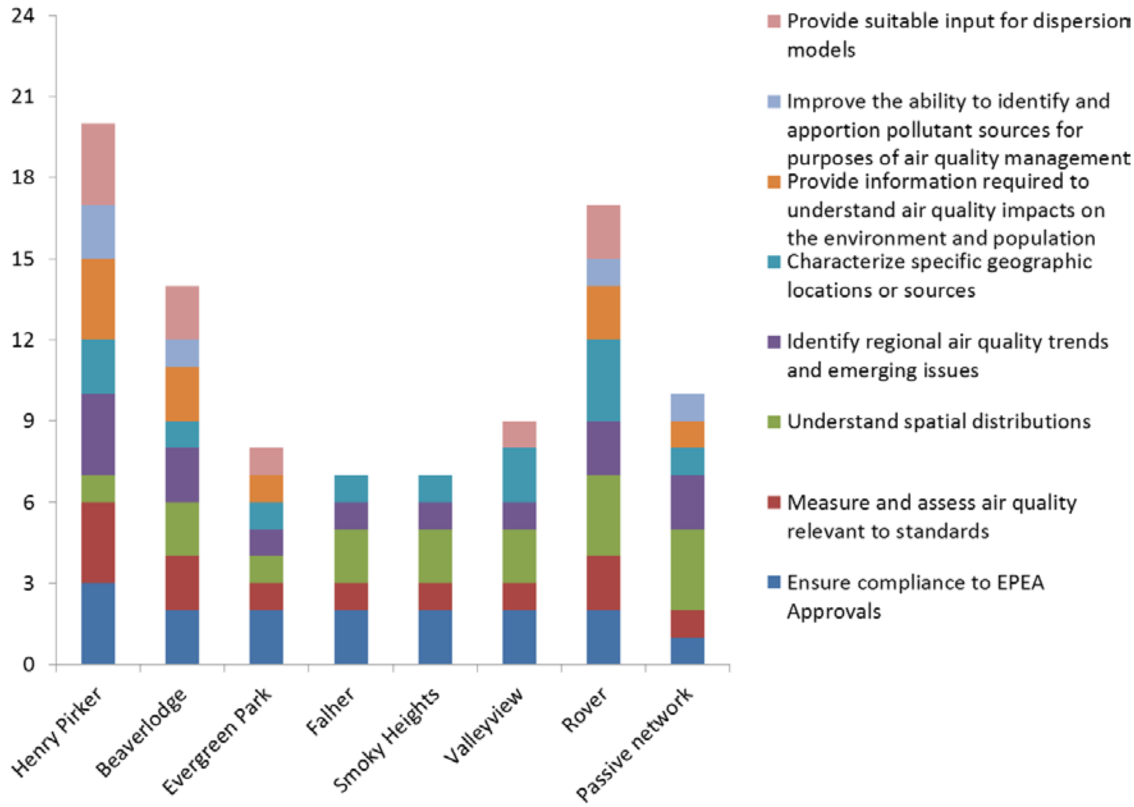


Figure 5-1. Site rankings for each of the monitoring sites in the network. The Rover site is considered the mobile station, not just its current location at Sunset House. The passive network includes all sites as a single entity.

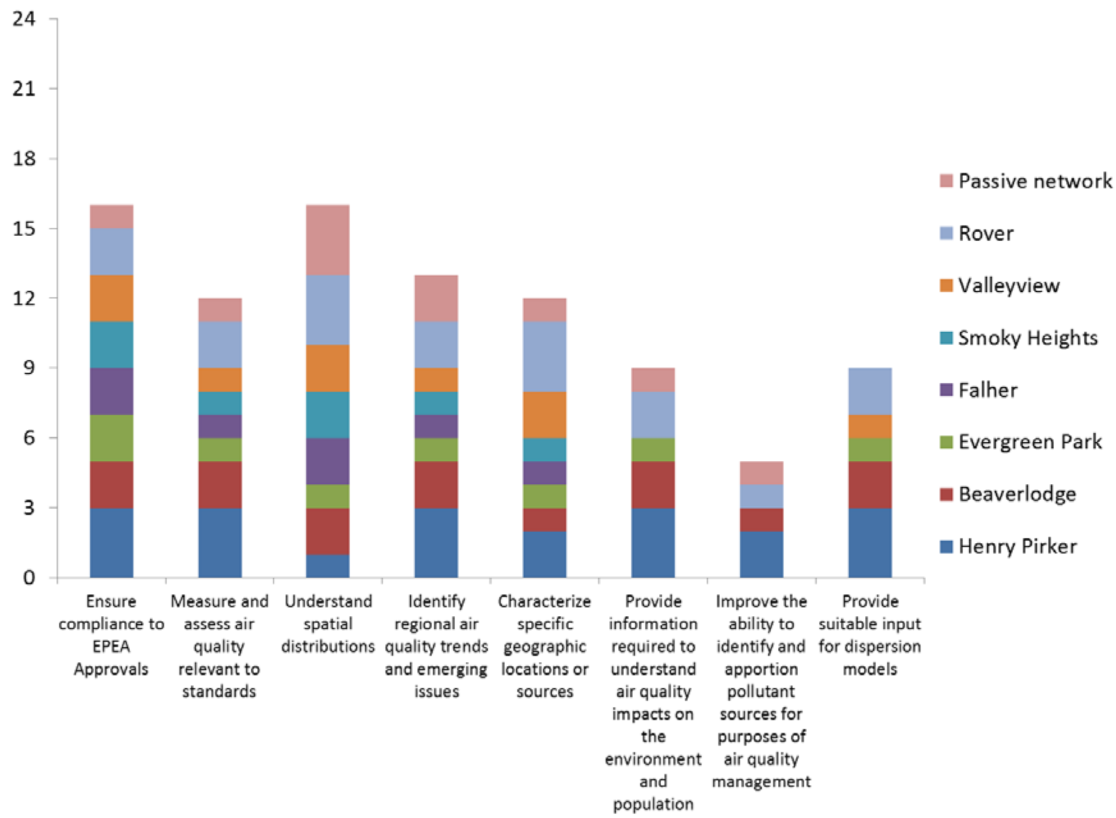


Figure 5-2. Monitoring objective rankings for the current network. Each objective is ranked by the sites' capabilities to meet an individual objective.

5.3 Recommendations

Recommendations to improve the current monitoring network to better meet its objectives are listed here. The recommendations are not in any particular order of priority; we recommend that the PAZA board identify the recommendations that best meet their monitoring objectives to improve the monitoring network.

- Replace current passive monitoring of ozone and NO_2 with passive measurements of benzene, toluene, ethylbenzene, and xylenes (BTEX) compounds to assess spatial and temporal patterns in speciated hydrocarbons.
  - Consider reducing the number of SO_2 passive monitoring sites and/or moving them closer to specific facilities of concern.
  - Consider using passive measurements in targeted saturation studies of relevant pollutants near sources (e.g., facilities, roadways, airport, construction) or before and after studies around new facilities to assess the localized impact of a given source.

- Consider moving sites to more optimal locations.
  - The Smoky Heights monitoring site should be moved west to better monitor facility emissions, or moved to a location like Rycroft or Clairmont (or other locations listed in the suitability analysis in Section 4.5).

  - The Evergreen Park monitoring site is not in a representative neighborhood and is influenced by micro-scale emissions (i.e., a facility across the street). Neighborhoods like “Countryside South” or the area southeast of Wood Lake would be more representative of concentrations downwind of the central corridor of Grande Prairie.

- Consider measuring additional parameters at the Henry Pirker and Rover stations to better characterize sources and pollutants that are not currently measured in the network:
  - Speciated hydrocarbon measurements (continuous BTEX analyzers cost about $45,000 CAD) or canister sampling and laboratory analysis.
  - A PM_{10} or TSP monitor to assess larger particle concentrations that result from agricultural tilling and unpaved road dust.
  - An Aethalometer to measure black carbon; these instruments are relatively inexpensive and are excellent for identifying wood smoke events (wildfire or winter residential wood burning) and diesel PM.

- Implement consistent, modern instruments and methods for measuring $PM_{2.5}$ throughout the network. TEOM monitors underestimate ambient $PM_{2.5}$ during the winter months when ammonium nitrate is present.

- Determine whether the level of monitoring resources devoted to monitoring SO_2 is necessary for meeting compliance requirements. SO_2 concentrations are below objectives of concern and are decreasing over time, and SO_2 emissions are lower than those of other pollutants. Measuring other pollutants emitted by facilities, such as speciated hydrocarbons, may be of greater value in meeting multiple monitoring objectives.

6. References

Allen G., Sioutas C., Koutrakis P., Reiss R., Lurmann F.W., and Roberts P.T. (1997) Evaluation of the TEOM method for measurement of ambient particulate mass in urban areas. *J Air Waste Manag Assoc*, **47**(6), 682-689.

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McCarthy M.C., Ekstrand A.L., Penfold B.M., Minor H.A., and O'Brien T. (2013) Network assessment of the Edmonton Capital Region. Prepared for Wally Qiu, Alberta Environment and Sustainable Resource Development, Edmonton, Alberta, by Sonoma Technology, Inc., Petaluma, CA, STI-912055-5601-FR, March 28.

Raffuse S.M., Sullivan D.C., McCarthy M.C., Penfold B.M., and Hafner H.R. (2007) Ambient air monitoring network assessment guidance: analytical techniques for technical assessments of ambient air monitoring networks. Guidance document prepared for the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, by Sonoma Technology, Inc., Petaluma, CA, EPA-454/D-07-001 (STI-905212.02-2805-GD), February. Available at http://www.epa.gov/ttnamti1/files/ambient/pm25/datamang/network-assessment-guidance.pdf.

Appendix

Additional Figures

A.1 Measured Concentrations..................... page A-1
A.2 Trends.. page A-7
A.3 Correlations... page A-9
A.4 Area/Population/Emissions Served........ page A-11

A.1 Measured Concentrations

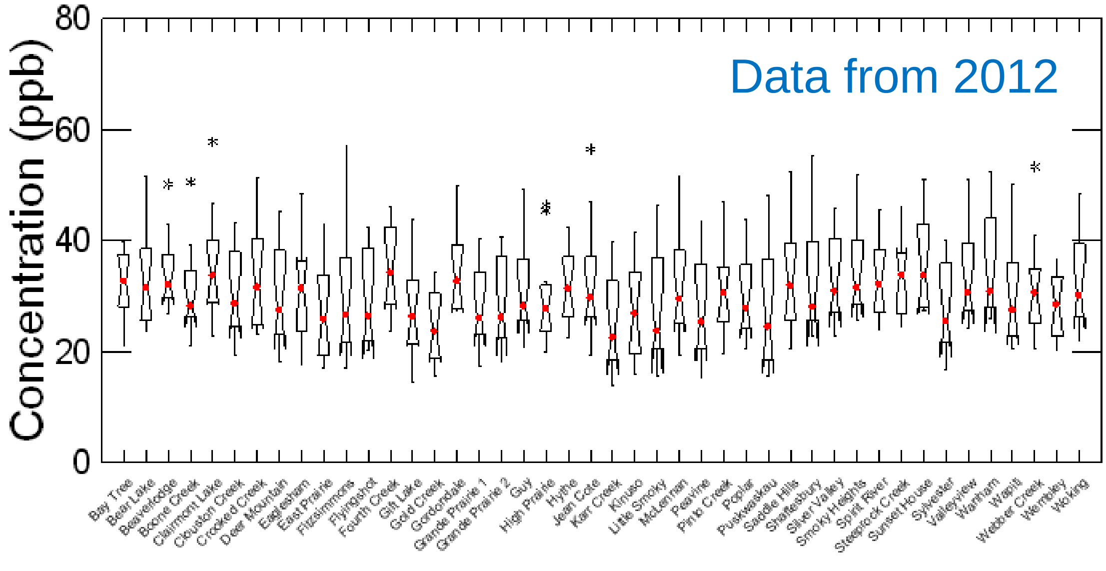

Figure A-1. Passive ozone concentrations (ppb) from 2012. Passives have a 30-day sampling period.

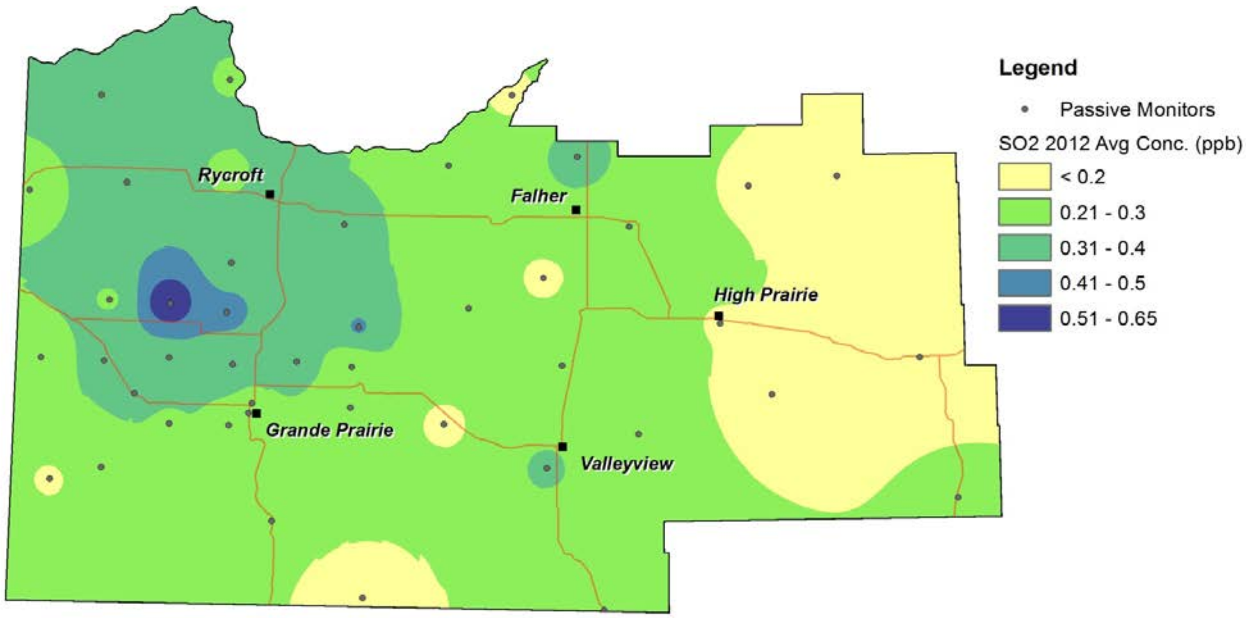

Figure A-2. Map depicting interpolated average SO_2 concentrations from the passive monitoring network in 2012.

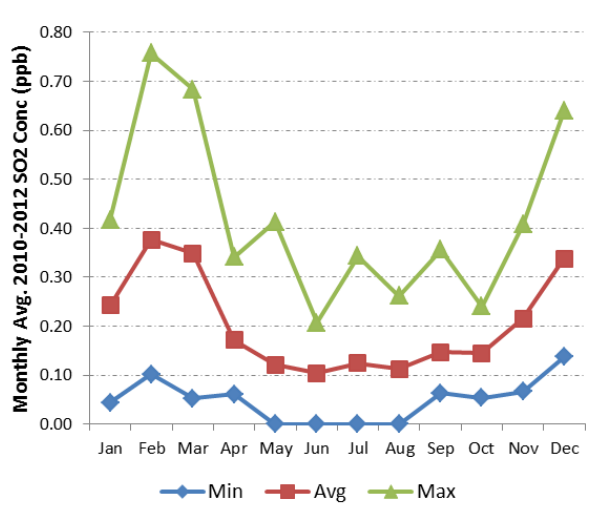

Figure A-3. Monthly minimum, average, and maximum concentrations for SO_2 between 2010 and 2012.

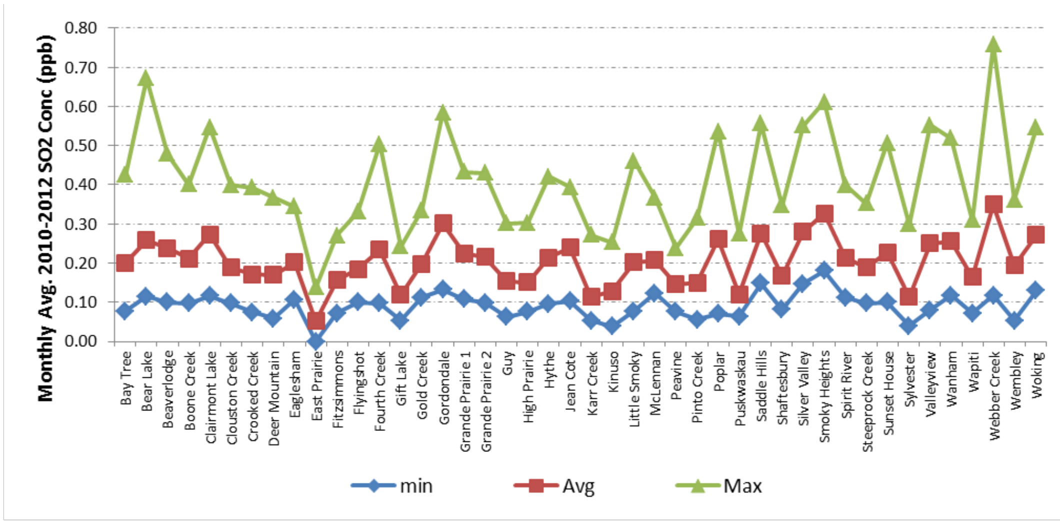

Figure A-4. Site-specific minimum, average, and maximum concentrations for SO_2 between 2010 and 2012.

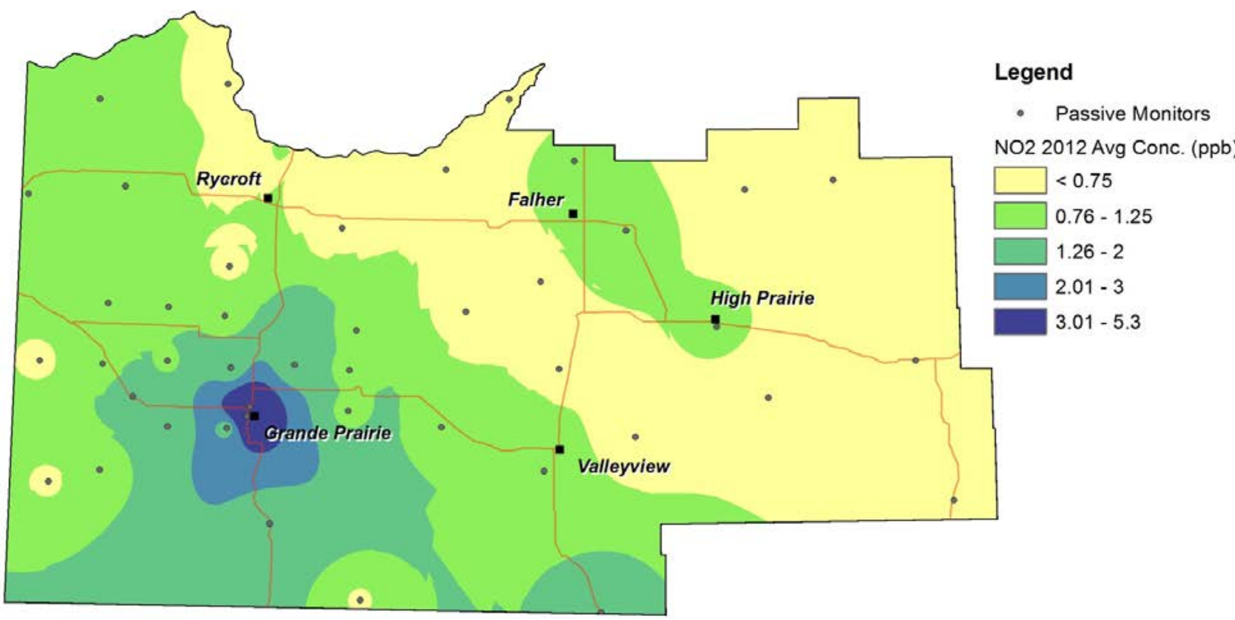

Figure A-5. Map depicting interpolated average NO_2 concentrations from the passive monitoring network in 2012.

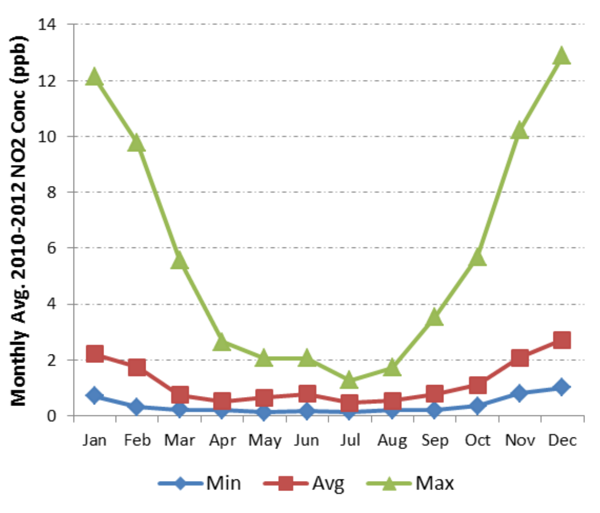

Figure A-6. Monthly minimum, average, and maximum concentrations for NO_2 between 2010 and 2012.

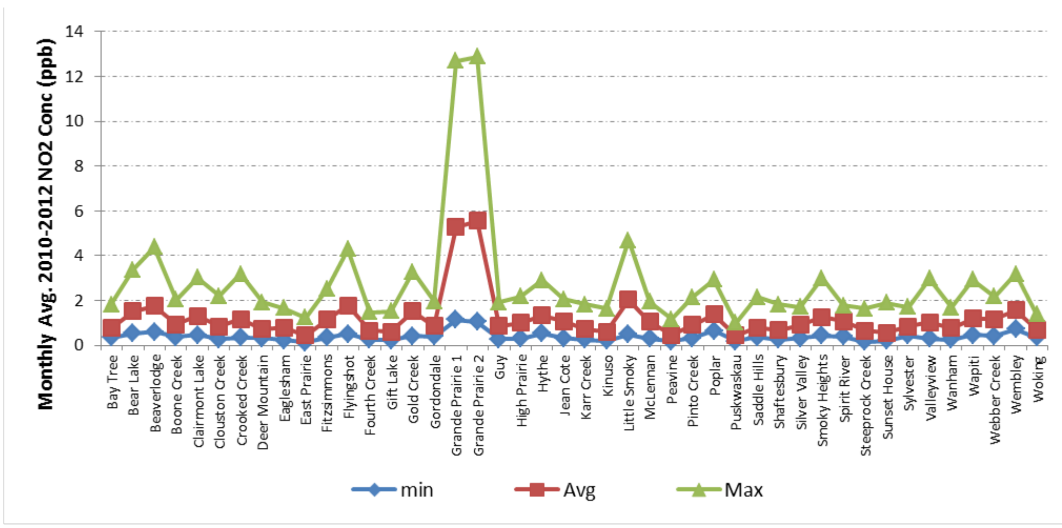

Figure A-7. Site-specific minimum, average, and maximum concentrations for NO_2 between 2010 and 2012.

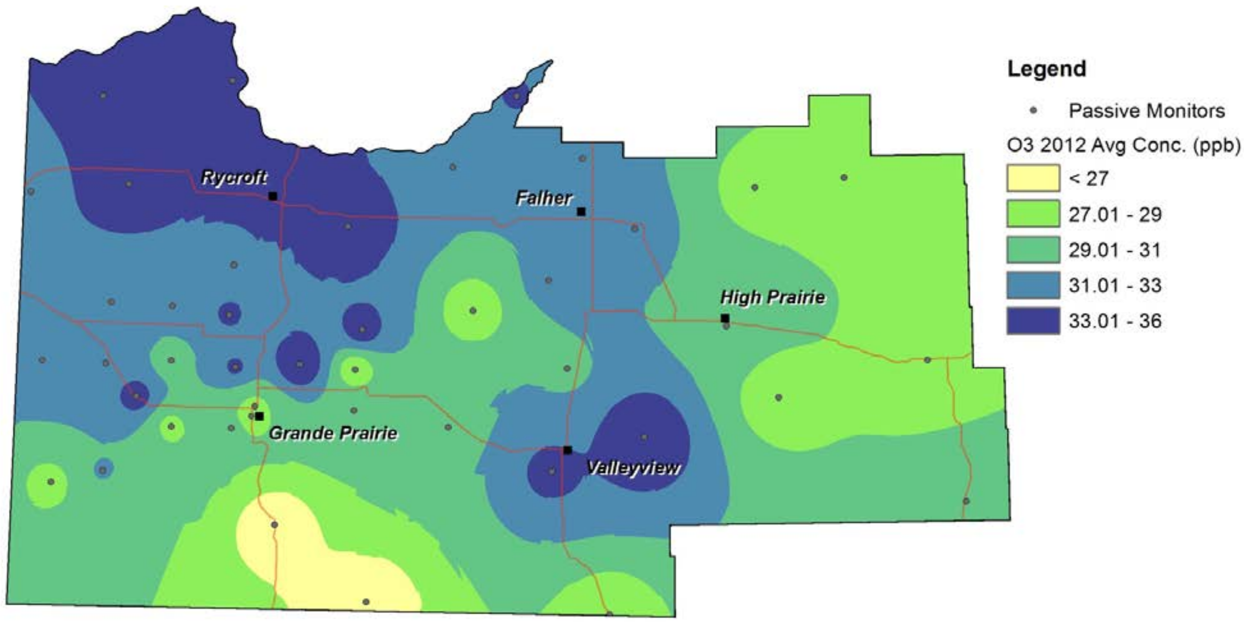

Figure A-8. Map depicting interpolated average ozone concentrations from the passive monitoring network in 2012.

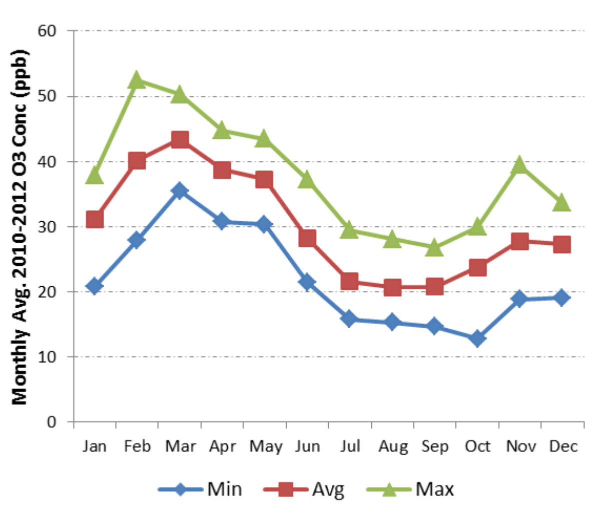

Figure A-9. Graph depicting monthly minimum, average, and maximum concentrations for ozone (O_3) between 2010 and 2012.

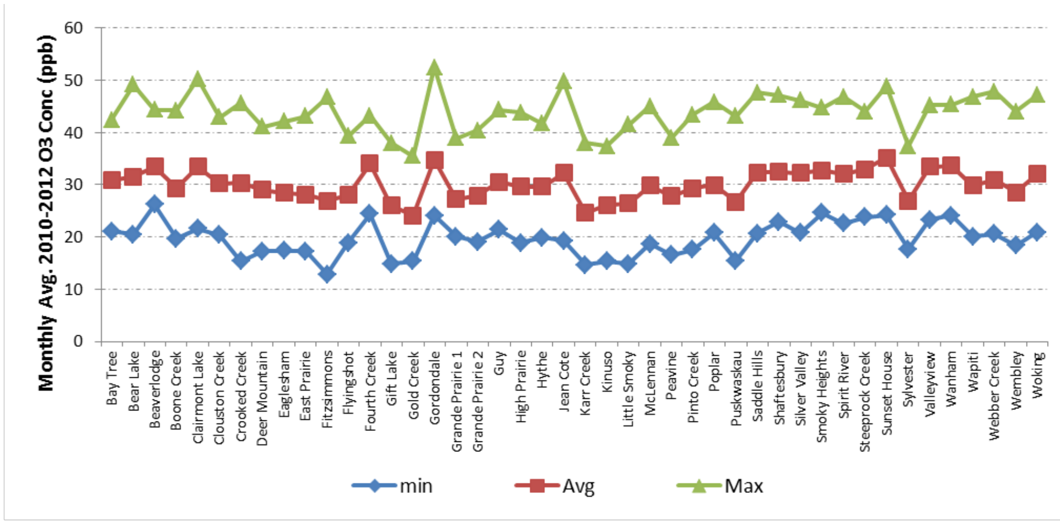

Figure A-10. Graph showing site-specific minimum, average, and maximum concentrations for O_3 between 2010 and 2012.

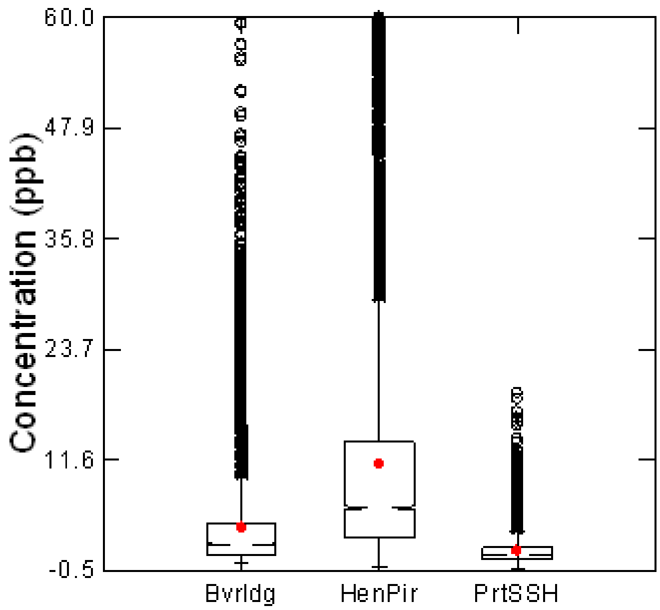

Figure A-11. Notched box plot depicting 2012 continuous NO_x concentrations.

A.2 Trends

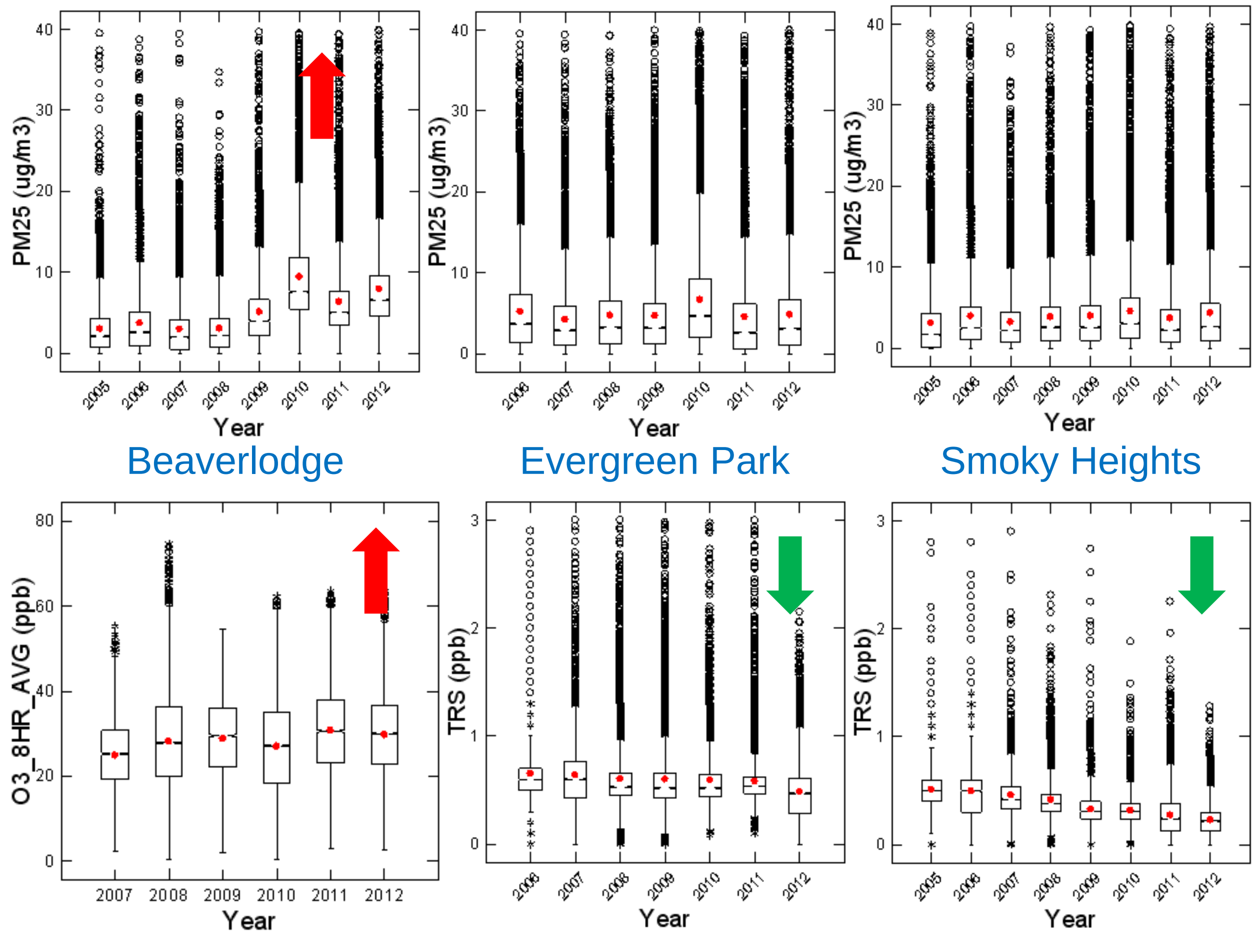

Figure A-12. Notched box-whisker plots showing trends in $PM_{2.5}$, 8-hr ozone, and TRS concentrations at Beaverlodge, Evergreen Park, and Smoky Heights monitors. Red dots indicate mean concentrations. Arrows show whether concentrations of the median and mean are significantly increasing (red arrows) or decreasing (green arrows).

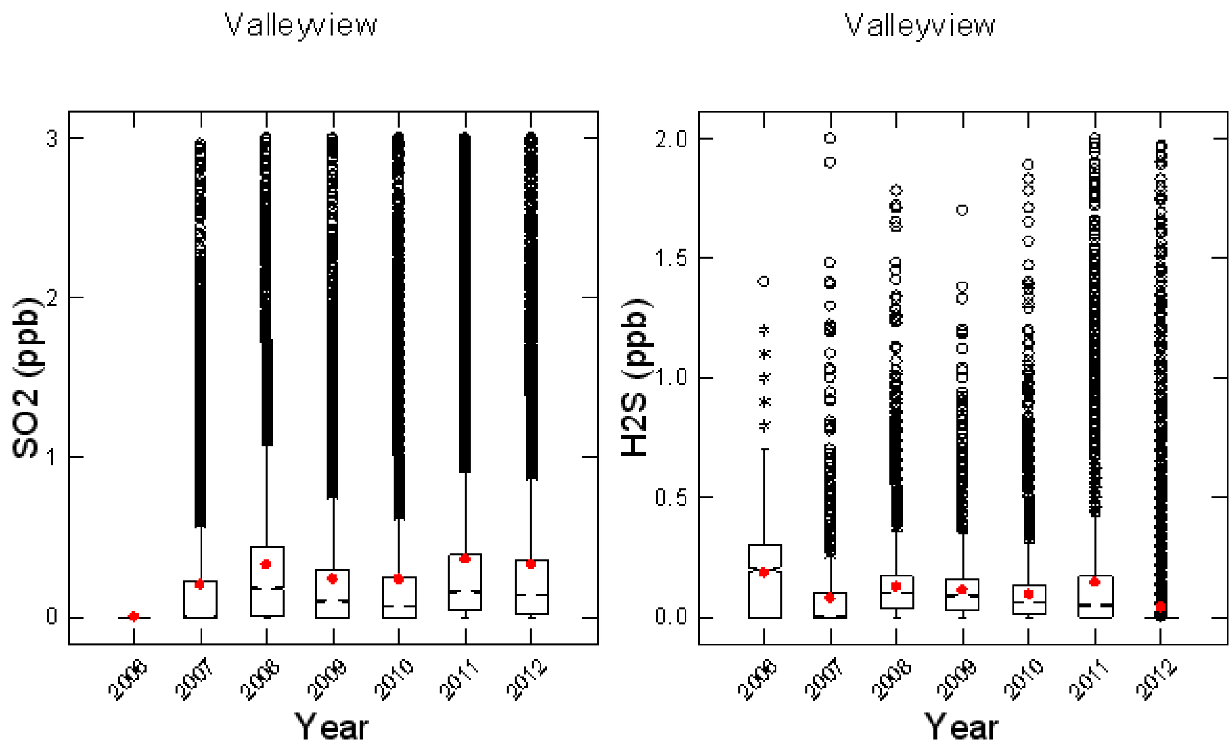

Figure A-13. Notched box-whisker plot depicting SO_2 and H_2S concentration trends at the Valleyview monitor. Red dots indicate mean concentrations.

A.3 Correlations

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

	Silver Valley	Bay Tree	Fourth Creek	Gordondale	Boone Creek	Steeprock Creek	Spirit River	Woking	Webber Creek	Hythe	Sylvester	Beaverlodge	Poplar	Saddle Hills	Wanham	Shaftesbury	Eaglesham	Bear Lake	Wembley	Pinto Creek	Flyingshot	Grande Prairie 1	Clairmont Lake	Smoky Heights	Fitzsimmons	Gold Creek	Wapiti	Puskwaskau	Jean Cote	Guy	Crooked Creek	Karr Creek	Clouston Creek	Mclennan	Valleyview	Sunset House	High Prairie	Peavine	Gift Lake	Little Smoky	Kinuso	Deer Mountain	Grande Prairie 2
Bay Tree	0.71																																											
Fourth Creek	0.92	0.73																																										
Gordondale	0.88	0.76	0.84																																									
Boone Creek	0.89	0.78	0.75	0.92																																								
Steeprock Creek	0.85	0.91	0.83	0.85	0.85																																							
Spirit River	0.87	0.48	0.86	0.87	0.73	0.66																																						
Woking	0.93	0.72	0.85	0.93	0.92	0.89	0.87																																					
Webber Creek	0.93	0.72	0.91	0.93	0.88	0.85	0.86	0.90																																				
Hythe	0.85	0.91	0.76	0.88	0.91	0.96	0.68	0.90	0.84																																			
Sylvester	0.81	0.78	0.81	0.82	0.80	0.92	0.71	0.91	0.78	0.87																																		
Beaverlodge	0.85	0.85	0.89	0.92	0.86	0.83	0.76	0.80	0.91	0.83	0.72																																	
Poplar	0.87	0.83	0.81	0.97	0.94	0.89	0.81	0.94	0.92	0.95	0.84	0.89																																
Saddle Hills	0.77	0.65	0.74	0.92	0.84	0.82	0.79	0.89	0.88	0.83	0.77	0.77	0.91																															
Wanham	0.79	0.43	0.60	0.84	0.86	0.61	0.79	0.87	0.74	0.68	0.68	0.63	0.79	0.79																														
Shaftesbury	0.77	0.59	0.71	0.93	0.85	0.72	0.86	0.89	0.87	0.79	0.70	0.77	0.93	0.95	0.84																													
Eaglesham	0.77	0.57	0.51	0.66	0.86	0.71	0.53	0.82	0.64	0.77	0.74	0.52	0.73	0.61	0.80	0.63																												
Bear Lake	0.84	0.71	0.81	0.96	0.87	0.83	0.83	0.90	0.94	0.85	0.75	0.87	0.94	0.97	0.79	0.95	0.59																											
Wembley	0.84	0.84	0.81	0.87	0.87	0.94	0.72	0.94	0.82	0.92	0.97	0.78	0.90	0.84	0.74	0.78	0.77	0.84																										
Pinto Creek	0.83	0.95	0.82	0.86	0.85	0.97	0.66	0.87	0.82	0.97	0.89	0.86	0.91	0.80	0.60	0.74	0.67	0.83	0.95																									
Flyingshot	0.84	0.91	0.84	0.95	0.90	0.93	0.76	0.90	0.89	0.94	0.87	0.92	0.97	0.88	0.70	0.86	0.64	0.92	0.93	0.96																								
Grande Prairie 1	0.77	0.82	0.81	0.92	0.83	0.77	0.73	0.76	0.86	0.79	0.66	0.98	0.88	0.78	0.64	0.80	0.44	0.88	0.74	0.82	0.92																							
Clairmont Lake	0.91	0.59	0.86	0.91	0.88	0.72	0.88	0.87	0.93	0.73	0.66	0.89	0.85	0.83	0.85	0.85	0.62	0.90	0.73	0.71	0.81	0.86																						
Smoky Heights	0.92	0.82	0.93	0.92	0.84	0.87	0.82	0.86	0.91	0.85	0.80	0.95	0.87	0.76	0.70	0.74	0.58	0.86	0.84	0.87	0.91	0.92	0.89																					
Fitzsimmons	0.93	0.65	0.80	0.88	0.91	0.78	0.88	0.93	0.86	0.84	0.78	0.80	0.89	0.76	0.84	0.82	0.82	0.79	0.79	0.76	0.81	0.73	0.87	0.83																				
Gold Creek	0.69	0.81	0.71	0.76	0.73	0.88	0.60	0.82	0.64	0.83	0.95	0.68	0.77	0.71	0.61	0.62	0.63	0.69	0.95	0.89	0.86	0.66	0.57	0.76	0.66																			
Wapiti	0.80	0.69	0.78	0.77	0.76	0.86	0.72	0.89	0.71	0.80	0.97	0.66	0.77	0.71	0.72	0.64	0.74	0.68	0.93	0.82	0.80	0.60	0.66	0.78	0.79	0.94																		
Puskwaskau	0.94	0.78	0.94	0.92	0.84	0.92	0.88	0.93	0.93	0.88	0.86	0.89	0.90	0.86	0.72	0.80	0.62	0.90	0.88	0.89	0.91	0.84	0.88	0.95	0.87	0.79	0.83																	
Jean Cote	0.70	0.30	0.39	0.57	0.77	0.48	0.51	0.70	0.58	0.57	0.47	0.41	0.60	0.57	0.84	0.61	0.88	0.57	0.56	0.45	0.46	0.36	0.67	0.46	0.72	0.35	0.48	0.50																
Guy	0.77	0.47	0.52	0.75	0.88	0.64	0.64	0.81	0.75	0.73	0.56	0.60	0.78	0.78	0.87	0.80	0.85	0.77	0.65	0.60	0.65	0.57	0.79	0.60	0.82	0.43	0.54	0.66	0.93															
Crooked Creek	0.79	0.67	0.73	0.81	0.78	0.80	0.78	0.89	0.69	0.81	0.93	0.67	0.81	0.70	0.76	0.71	0.75	0.68	0.89	0.80	0.80	0.63	0.66	0.76	0.86	0.89	0.96	0.82	0.49	0.57														
Karr Creek	0.83	0.70	0.85	0.91	0.87	0.82	0.78	0.88	0.90	0.77	0.80	0.87	0.87	0.90	0.78	0.85	0.61	0.93	0.87	0.82	0.89	0.86	0.90	0.86	0.75	0.75	0.76	0.86	0.56	0.70	0.70													
Clouston Creek	0.81	0.64	0.80	0.95	0.87	0.76	0.88	0.92	0.87	0.78	0.81	0.82	0.92	0.92	0.86	0.95	0.63	0.93	0.85	0.78	0.89	0.84	0.88	0.81	0.84	0.75	0.78	0.85	0.56	0.73	0.81	0.93												
Mclennan	0.82	0.57	0.60	0.76	0.81	0.71	0.67	0.85	0.72	0.78	0.71	0.59	0.77	0.75	0.86	0.74	0.82	0.77	0.80	0.73	0.72	0.58	0.74	0.71	0.75	0.68	0.69	0.75	0.83	0.82	0.68	0.71	0.70											
Valleyview	0.79	0.59	0.78	0.90	0.82	0.75	0.82	0.89	0.85	0.73	0.78	0.77	0.84	0.93	0.85	0.89	0.59	0.93	0.85	0.76	0.85	0.79	0.88	0.80	0.72	0.75	0.75	0.83	0.58	0.71	0.72	0.96	0.95	0.78										
Sunset House	0.65	0.48	0.63	0.82	0.71	0.64	0.75	0.77	0.81	0.67	0.57	0.68	0.81	0.95	0.70	0.93	0.43	0.93	0.67	0.64	0.76	0.71	0.78	0.63	0.63	0.50	0.48	0.73	0.50	0.72	0.50	0.82	0.86	0.65	0.88									
High Prairie	0.89	0.79	0.73	0.87	0.98	0.87	0.69	0.93	0.81	0.91	0.85	0.79	0.90	0.78	0.86	0.77	0.91	0.80	0.90	0.87	0.87	0.75	0.81	0.83	0.90	0.80	0.84	0.83	0.78	0.84	0.84	0.82	0.82	0.85	0.78	0.60								
Peavine	0.88	0.78	0.89	0.93	0.90	0.87	0.80	0.91	0.95	0.85	0.88	0.91	0.92	0.85	0.75	0.83	0.68	0.89	0.90	0.86	0.93	0.87	0.87	0.92	0.83	0.79	0.82	0.90	0.54	0.68	0.78	0.94	0.89	0.72	0.87	0.72	0.86							
Gift Lake	0.91	0.69	0.86	0.97	0.94	0.82	0.88	0.95	0.95	0.83	0.83	0.89	0.93	0.89	0.88	0.90	0.73	0.93	0.87	0.81	0.90	0.86	0.95	0.90	0.90	0.73	0.80	0.91	0.66	0.80	0.80	0.94	0.95	0.77	0.92	0.79	0.89	0.96						
Little Smoky	0.82	0.64	0.77	0.97	0.86	0.74	0.87	0.85	0.87	0.77	0.71	0.88	0.89	0.85	0.84	0.88	0.57	0.90	0.75	0.73	0.87	0.91	0.92	0.89	0.86	0.67	0.71	0.87	0.52	0.71	0.76	0.84	0.91	0.69	0.85	0.77	0.80	0.86	0.93					
Kinuso	0.86	0.70	0.85	0.90	0.88	0.75	0.81	0.87	0.84	0.74	0.79	0.89	0.84	0.75	0.83	0.78	0.65	0.82	0.84	0.78	0.86	0.87	0.91	0.91	0.83	0.76	0.80	0.84	0.57	0.65	0.80	0.92	0.90	0.71	0.88	0.63	0.86	0.91	0.94	0.89				
Deer Mountain	0.85	0.64	0.91	0.80	0.74	0.82	0.85	0.89	0.81	0.73	0.89	0.76	0.77	0.75	0.68	0.70	0.61	0.75	0.86	0.78	0.79	0.67	0.78	0.82	0.82	0.81	0.91	0.89	0.43	0.53	0.87	0.84	0.84	0.58	0.80	0.60	0.76	0.84	0.85	0.74	0.85			
Grande Prairie 2	0.73	0.66	0.74	0.94	0.82	0.67	0.83	0.80	0.80	0.73	0.66	0.88	0.87	0.80	0.78	0.88	0.49	0.86	0.72	0.72	0.87	0.93	0.86	0.83	0.80	0.66	0.65	0.79	0.42	0.62	0.74	0.83	0.93	0.59	0.83	0.75	0.75	0.82	0.88	0.96	0.89	0.71	
East Prairie	0.80	0.64	0.80	0.95	0.81	0.72	0.87	0.80	0.91	0.76	0.64	0.91	0.89	0.85	0.72	0.89	0.47	0.91	0.68	0.71	0.86	0.92	0.90	0.87	0.82	0.56	0.60	0.87	0.44	0.67	0.66	0.81	0.87	0.59	0.79	0.81	0.71	0.85	0.90	0.96	0.81	0.70	0.92

Figure A-14. NO_2 passive monitor correlations. About 30% of sites have correlations greater than 0.9 with most other sites in the network.

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

	Silver_Valley	Bay_Tree	Fourth_Creek	Gordondale	Boone_Creek	Steeprock_Creek	Spirit_River	Woking	Webber_Creek	Hythe	Sylvester	Beaverlodge	Poplar	Saddle_Hills	Wanham	Shaftesbury	Eaglesham	Bear_Lake	Wembley	Pinto_Creek	Flyingshot	Grande_Prairie_1	Clairmont_Lake	Smoky_Heights	Fitzsimmons	Gold_Creek	Wapiti	Puskwaskau	Jean_Cote	Guy	Crooked_Creek	Karr_Creek	Clouston_Creek	Mclennan	Valleyview	Sunset_House	High_Prairie	Peavine	Gift_Lake	Little_Smoky	Kinuso	Deer_Mountain	Grande_Prairie_2
Bay_Tree	0.71
Fourth_Creek	0.70	0.41
Gordondale	0.79	0.44	0.64
Boone_Creek	0.90	0.77	0.53	0.72
Steeprock_Creek	0.88	0.67	0.57	0.75	0.95
Spirit_River	0.76	0.58	0.93	0.57	0.63	0.63
Woking	0.92	0.62	0.58	0.72	0.84	0.81	0.70
Webber_Creek	0.66	0.38	0.49	0.72	0.65	0.72	0.35	0.59
Hythe	0.85	0.84	0.66	0.66	0.86	0.82	0.75	0.70	0.53
Sylvester	0.71	0.87	0.28	0.46	0.85	0.73	0.48	0.64	0.27	0.77
Beaverlodge	0.68	0.74	0.72	0.55	0.79	0.73	0.73	0.51	0.50	0.85	0.71
Poplar	0.81	0.67	0.52	0.71	0.86	0.87	0.47	0.64	0.84	0.82	0.64	0.75
Saddle_Hills	0.68	0.30	0.77	0.65	0.47	0.54	0.66	0.58	0.75	0.54	0.06	0.43	0.61
Wanham	0.79	0.50	0.95	0.72	0.67	0.71	0.91	0.69	0.57	0.80	0.42	0.79	0.66	0.74
Shaftesbury	0.72	0.20	0.69	0.70	0.47	0.61	0.60	0.67	0.67	0.51	0.09	0.28	0.58	0.88	0.72
Eaglesham	0.48	0.07	0.28	0.59	0.36	0.53	0.20	0.40	0.51	0.41	0.04	0.09	0.52	0.54	0.40	0.76
Bear_Lake	0.78	0.52	0.77	0.75	0.74	0.78	0.72	0.59	0.74	0.82	0.43	0.74	0.82	0.84	0.84	0.75	0.55
Wembley	0.51	0.69	0.52	0.45	0.67	0.58	0.61	0.43	0.20	0.69	0.73	0.87	0.49	0.08	0.58	-0.01	-0.04	0.40
Pinto_Creek	0.65	0.79	0.34	0.41	0.78	0.69	0.48	0.46	0.25	0.80	0.86	0.77	0.68	0.13	0.45	0.08	0.18	0.51	0.78
Flyingshot	0.84	0.66	0.47	0.67	0.91	0.85	0.52	0.67	0.57	0.84	0.77	0.76	0.86	0.42	0.61	0.41	0.43	0.72	0.63	0.88
Grande_Prairie_1	0.83	0.79	0.49	0.68	0.91	0.83	0.53	0.69	0.62	0.90	0.79	0.78	0.91	0.50	0.63	0.47	0.43	0.76	0.60	0.78	0.89
Clairmont_Lake	0.86	0.59	0.62	0.88	0.82	0.82	0.55	0.71	0.84	0.76	0.58	0.67	0.91	0.73	0.71	0.69	0.51	0.87	0.41	0.54	0.79	0.85
Smoky_Heights	0.83	0.57	0.89	0.75	0.72	0.75	0.87	0.75	0.68	0.69	0.46	0.75	0.67	0.78	0.87	0.67	0.31	0.76	0.60	0.47	0.62	0.60	0.75
Fitzsimmons	0.80	0.60	0.87	0.62	0.76	0.75	0.89	0.75	0.52	0.81	0.52	0.81	0.67	0.68	0.92	0.65	0.33	0.78	0.63	0.52	0.65	0.72	0.65	0.83
Gold_Creek	0.44	0.46	0.59	0.33	0.19	0.21	0.69	0.48	0.04	0.39	0.24	0.25	0.06	0.39	0.52	0.43	0.03	0.29	0.24	0.14	0.08	0.13	0.20	0.52	0.51
Wapiti	0.81	0.57	0.58	0.85	0.79	0.81	0.62	0.81	0.61	0.71	0.57	0.58	0.68	0.57	0.68	0.62	0.59	0.66	0.59	0.50	0.67	0.73	0.75	0.76	0.69	0.25
Puskwaskau	0.86	0.66	0.76	0.87	0.76	0.82	0.78	0.82	0.70	0.81	0.54	0.65	0.72	0.72	0.84	0.76	0.53	0.80	0.52	0.47	0.63	0.68	0.80	0.85	0.79	0.61	0.82
Jean_Cote	-0.17	0.00	0.27	-0.16	-0.17	-0.27	0.25	-0.19	-0.27	0.13	-0.23	0.21	-0.18	0.10	0.22	-0.10	-0.09	0.06	0.24	-0.01	-0.12	-0.02	-0.24	0.01	0.30	0.15	-0.03	-0.07
Guy	0.69	0.34	0.41	0.74	0.72	0.75	0.40	0.68	0.50	0.58	0.50	0.43	0.65	0.43	0.54	0.64	0.64	0.61	0.32	0.39	0.65	0.73	0.71	0.47	0.65	0.12	0.75	0.63	-0.12
Crooked_Creek	0.79	0.34	0.78	0.71	0.53	0.57	0.71	0.79	0.62	0.53	0.21	0.40	0.55	0.82	0.77	0.86	0.50	0.63	0.21	0.19	0.48	0.49	0.67	0.81	0.75	0.60	0.64	0.78	0.02	0.56
Karr_Creek	0.02	-0.24	0.24	0.24	-0.20	-0.05	0.14	0.02	-0.06	0.05	-0.29	-0.14	-0.12	0.10	0.28	0.36	0.45	0.05	-0.07	-0.15	-0.07	-0.19	-0.08	0.03	0.11	0.41	0.03	0.26	0.20	0.10	0.33
Clouston_Creek	0.59	0.19	0.69	0.62	0.47	0.60	0.55	0.34	0.59	0.59	0.16	0.51	0.65	0.75	0.71	0.77	0.64	0.89	0.15	0.33	0.56	0.53	0.72	0.58	0.57	0.18	0.43	0.60	-0.04	0.53	0.53	0.22
Mclennan	0.53	0.34	0.60	0.46	0.56	0.52	0.43	0.28	0.56	0.59	0.40	0.73	0.74	0.50	0.63	0.37	0.17	0.71	0.42	0.47	0.64	0.68	0.72	0.53	0.55	-0.13	0.36	0.36	0.01	0.40	0.35	-0.23	0.68
Valleyview	0.88	0.63	0.64	0.84	0.86	0.86	0.66	0.78	0.67	0.88	0.64	0.67	0.83	0.67	0.78	0.72	0.61	0.88	0.46	0.57	0.78	0.88	0.90	0.69	0.75	0.26	0.85	0.84	-0.07	0.79	0.62	0.02	0.71	0.61
Sunset_House	0.81	0.45	0.80	0.86	0.70	0.77	0.76	0.71	0.72	0.76	0.35	0.64	0.71	0.81	0.87	0.80	0.66	0.87	0.47	0.41	0.64	0.65	0.80	0.84	0.76	0.34	0.86	0.89	0.07	0.60	0.74	0.23	0.74	0.51	0.86
High_Prairie	0.86	0.52	0.78	0.70	0.76	0.84	0.83	0.78	0.62	0.78	0.47	0.62	0.68	0.78	0.84	0.81	0.58	0.86	0.40	0.46	0.64	0.65	0.74	0.82	0.79	0.40	0.77	0.84	-0.07	0.60	0.69	0.06	0.75	0.49	0.86	0.90
Peavine	0.75	0.53	0.71	0.58	0.67	0.78	0.70	0.59	0.62	0.74	0.40	0.61	0.75	0.80	0.74	0.80	0.64	0.88	0.31	0.48	0.62	0.71	0.73	0.72	0.77	0.36	0.63	0.74	0.01	0.63	0.65	0.02	0.82	0.55	0.79	0.76	0.87
Gift_Lake	0.76	0.62	0.53	0.87	0.80	0.81	0.55	0.68	0.68	0.79	0.57	0.64	0.78	0.62	0.65	0.60	0.63	0.80	0.54	0.56	0.72	0.82	0.84	0.68	0.65	0.19	0.92	0.83	0.02	0.74	0.53	0.00	0.57	0.45	0.91	0.86	0.74	0.70
Little_Smoky	0.54	0.38	0.53	0.51	0.45	0.52	0.48	0.47	0.45	0.69	0.25	0.43	0.59	0.58	0.67	0.71	0.67	0.68	0.19	0.22	0.40	0.64	0.56	0.37	0.66	0.27	0.54	0.62	0.27	0.64	0.53	0.33	0.62	0.45	0.75	0.65	0.62	0.71	0.63
Kinuso	0.08	0.15	0.01	0.09	0.12	0.18	0.07	0.24	0.05	0.29	0.07	0.02	0.11	0.00	0.21	0.23	0.39	0.08	0.05	-0.06	-0.02	0.19	-0.03	-0.11	0.28	0.15	0.23	0.27	0.30	0.35	0.10	0.42	-0.02	-0.18	0.26	0.18	0.16	0.16	0.25	0.68
Deer_Mountain	0.85	0.49	0.71	0.82	0.73	0.82	0.68	0.80	0.73	0.72	0.43	0.54	0.76	0.79	0.79	0.88	0.72	0.80	0.36	0.37	0.61	0.72	0.83	0.79	0.76	0.33	0.89	0.87	-0.10	0.76	0.79	0.13	0.69	0.50	0.89	0.91	0.89	0.84	0.84	0.74	0.28
Grande_Prairie_2	0.78	0.73	0.65	0.82	0.86	0.86	0.66	0.70	0.63	0.84	0.74	0.83	0.81	0.48	0.77	0.51	0.39	0.75	0.74	0.65	0.74	0.86	0.83	0.74	0.79	0.32	0.83	0.84	-0.03	0.77	0.55	0.02	0.53	0.59	0.85	0.75	0.69	0.68	0.86	0.62	0.26	0.78
East_Prairie	0.74	0.59	0.83	0.68	0.68	0.69	0.77	0.62	0.58	0.78	0.56	0.83	0.70	0.55	0.90	0.53	0.23	0.72	0.67	0.49	0.60	0.67	0.72	0.79	0.77	0.37	0.65	0.77	0.04	0.44	0.60	0.11	0.58	0.73	0.74	0.77	0.73	0.59	0.61	0.59	0.16	0.73	0.80

Figure A-15. SO_2 passive monitor correlations; as expected, SO_2 monitors show much less correlation than NO_2 or ozone monitors.

A.4 Area/Population/Emissions Served

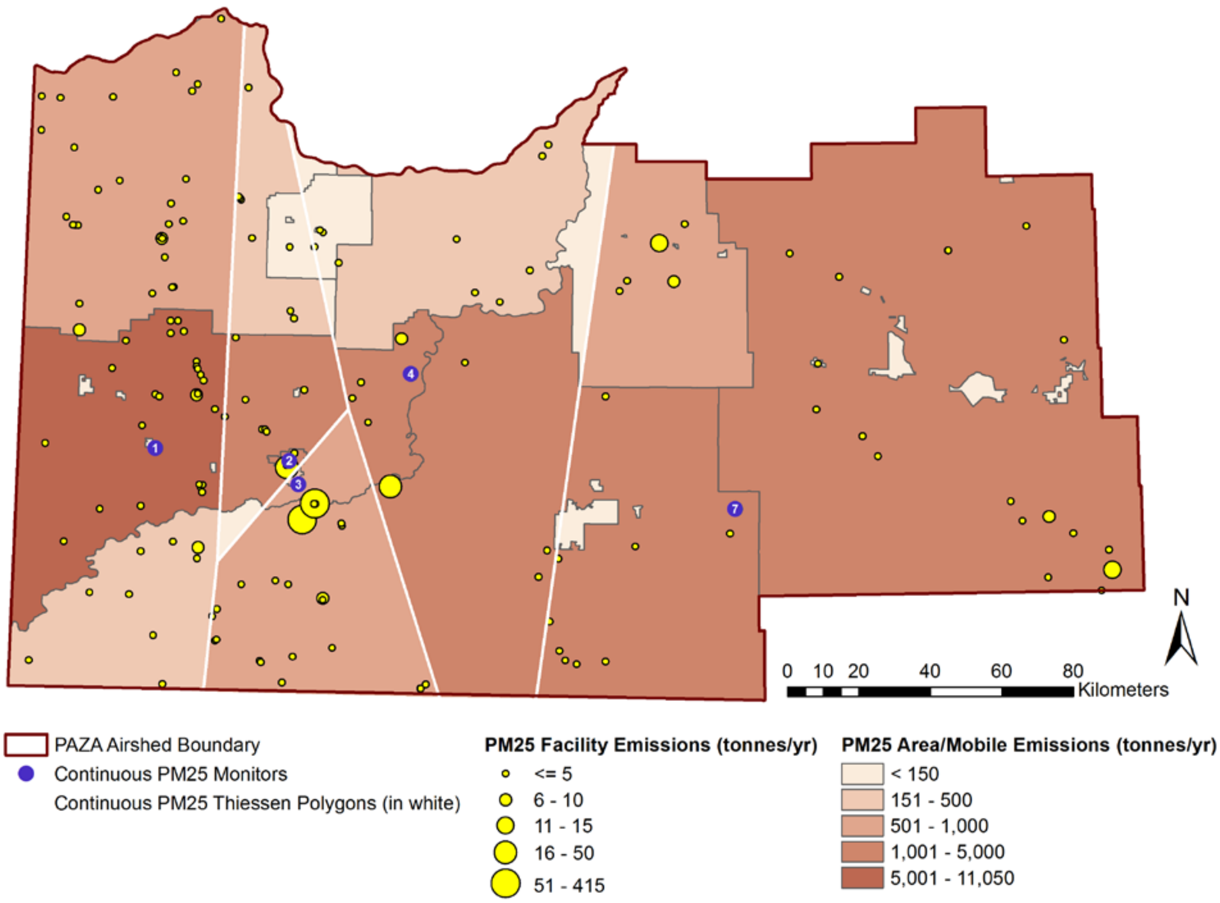

Figure A-16. $PM_{2.5}$ Thiessen polygons with facility and area/mobile emissions.

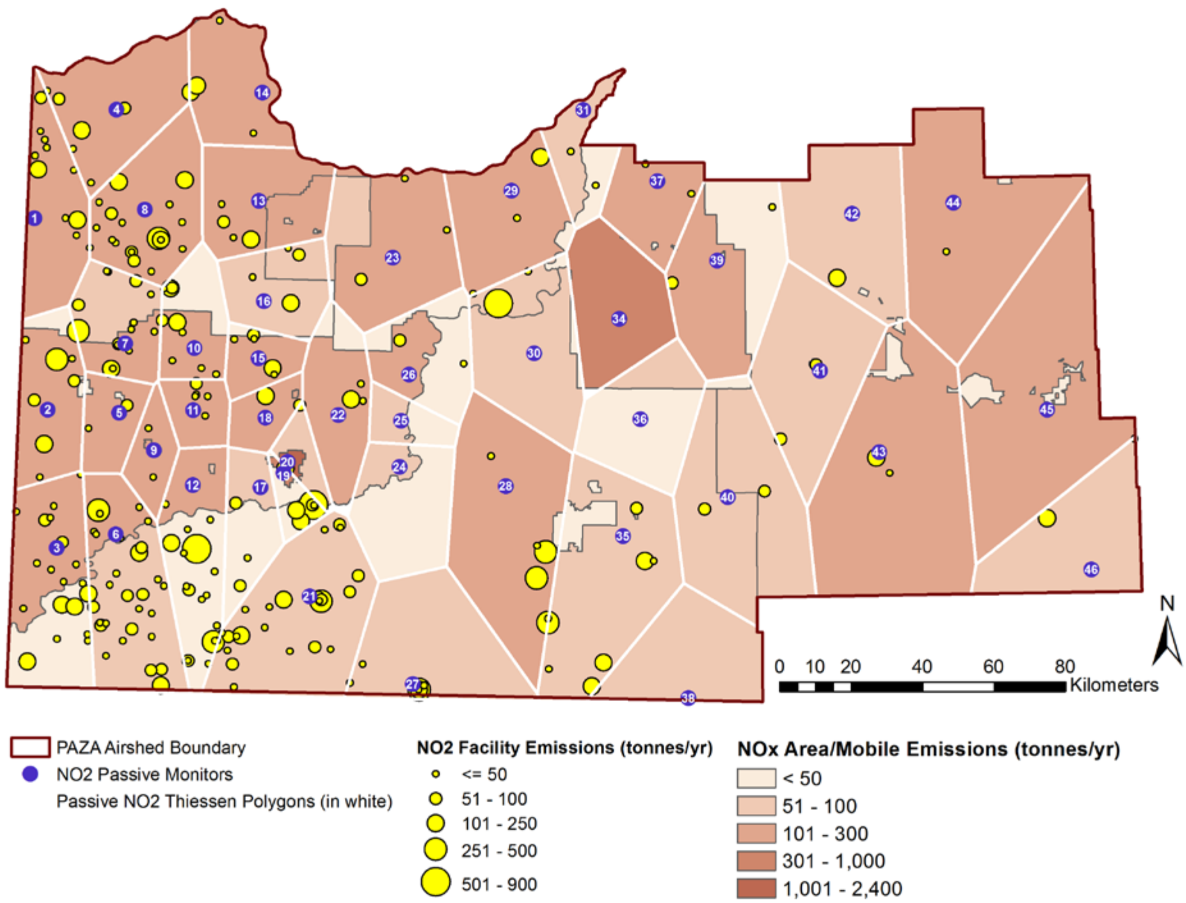

Figure A-17. NO_2 Thiessen polygons with NO_2 and NO_x area/mobile and facility emissions.

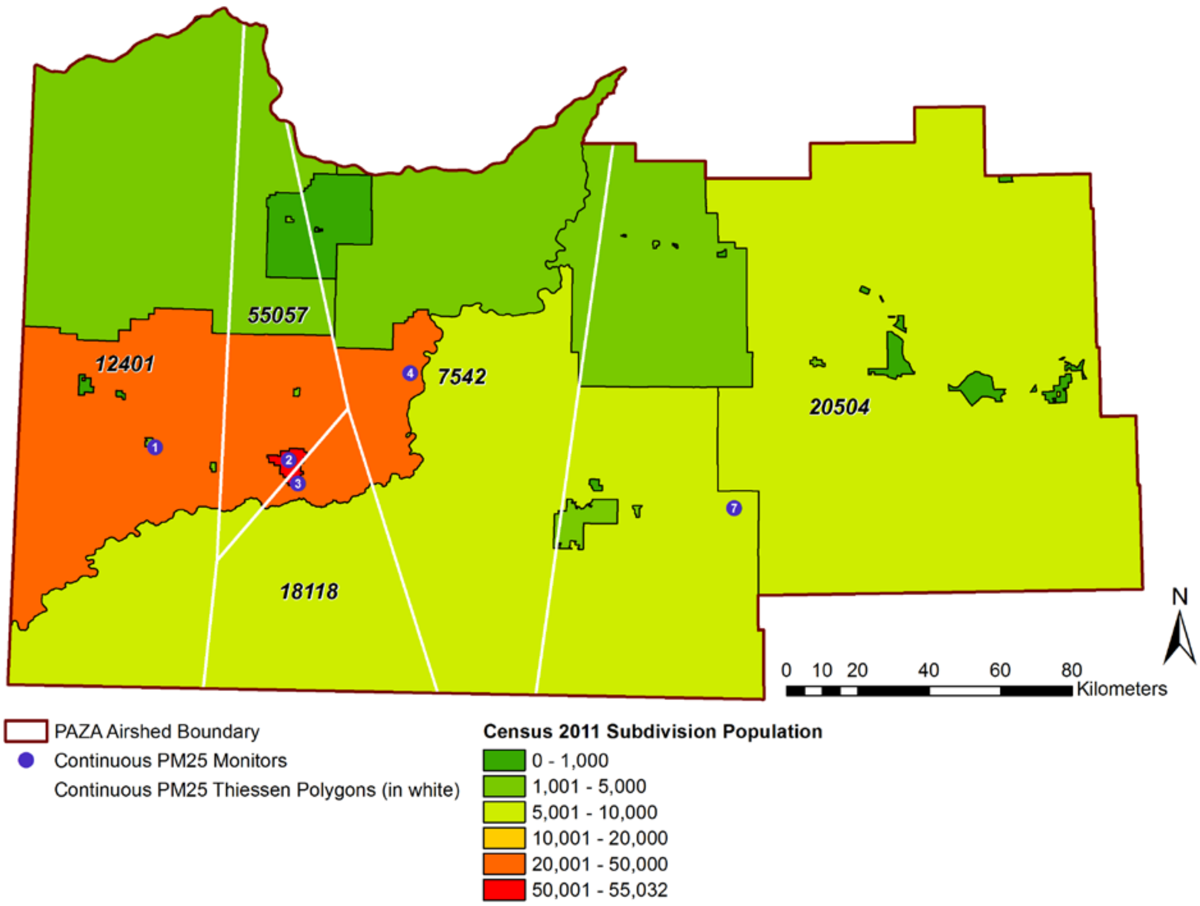

Figure A-18. $PM_{2.5}$ Thiessen polygons, shown with subdivision population. Numbers inside the polygons show population served by each monitor.

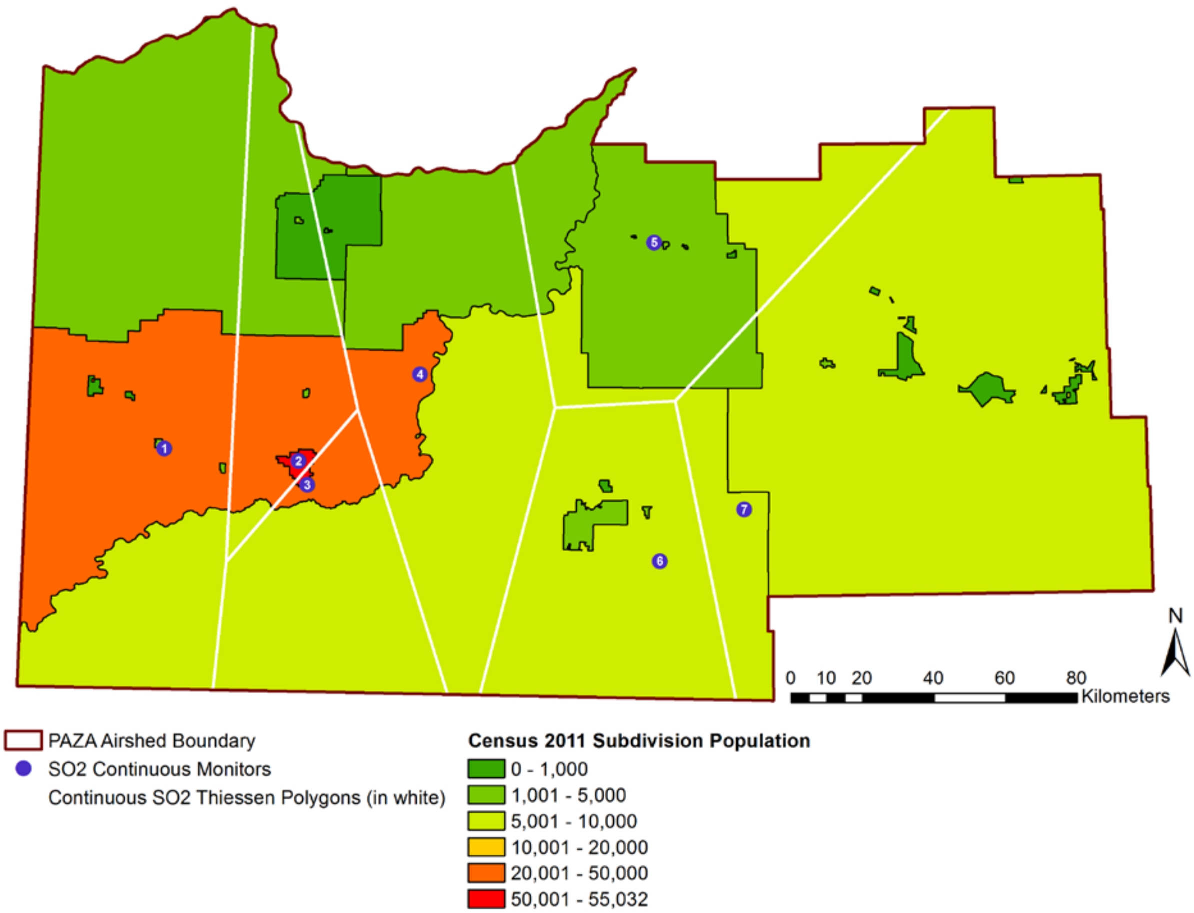

Figure A-19. SO_2 Thiessen polygons shown with subdivision population.