EPB 642

Saskatchewan
Air Dispersion Modelling Guideline

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PREFACE

The Saskatchewan Air Quality Modelling Guideline is developed to ensure consistency in carrying out air dispersion modelling for regulatory applications in the Province of Saskatchewan. The recommendations in this guideline are used to support the confirmation that Saskatchewan Ambient Air Quality Standards (SAAQS) are met. The guidance document will be reviewed periodically to ensure that up-to-date information and models are available for predicting air quality in Saskatchewan.

To facilitate dispersion modelling in the province, the Ministry of Environment has developed Regional Meteorological Data Sets (Appendix G). The regional meteorological files can be downloaded from the ministry's website. The ministry has also prepared guidelines on calculating air contaminant background/baseline concentrations (Appendix J) that are to be added to the modelled concentrations. In addition, a Modelling Report Checklist is available (Appendix L) to ensure the air quality analysis report is complete.

Some information on models is included in this guideline. However, the user should refer to the user's guides or reference material for the model being used.

All web links provided in this document are only guaranteed to be current at the time of publication of this document. If these sites are no longer available, it is the responsibility of the reader to use the best information available.

Please contact the Inquiry Centre at 1-800-567-2442 if you require clarification on the content of this document or to request additional meteorological files.

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1. INTRODUCTION

This guidance document is intended to ensure consistency in carrying out air dispersion modelling in the province of Saskatchewan. There may be some circumstances where different approaches to modelling from those in this document are more appropriate. In these circumstances, justification for the approach must be provided.

Modelling is an important tool that assists in understanding the impacts of emission sources on the environment near or distant and can be used to predict future scenarios from short-term events to long-term trends. Potential impacts of modelled contaminant concentrations are typically compared to applicable standards or objectives.

The Saskatchewan air quality regulatory requirements are mandated through:

- *The Environmental Management and Protection Act, 2010.*
- Industrial Source (Air Quality) Chapter (Chapter E.1.2) of the Saskatchewan Environmental Code.
- *The Environmental Assessment Act.*
- *The Oil and Gas Conservation Act.*

The purpose of these acts and codes is to ensure that air quality impacts on human health and the environment are minimized and that Saskatchewan's Ambient Air Quality Standards (SAAQS) and Saskatchewan Emission Limit Standards are met. Industries in Saskatchewan are required to show that the surrounding area is not unacceptably adversely affected by contaminants they release and that ambient concentrations meet the results-based objectives. This can be done using approved air dispersion models, which can calculate selected areas ambient concentrations of contaminants given information about the emissions, terrain and meteorology.

Modelling is often required for the development of approvals, environmental impact assessments or environmental protection plans for source construction, operation or expansion. Modelling may be conducted to design sources and air quality monitoring programs. Models can be used to determine air quality under certain weather conditions or emission scenarios. Air dispersion modelling requires knowledge of the physical properties of sources, local meteorology and terrain.

This document provides guidance for short-range (less than 50 km) modelling for regulatory applications. Short-range modelling can be accomplished with validated and recommended steady-state plume models.

This document is not intended to provide technical description or to discuss the theory behind the models to be used, but references to that information are provided and some technical information is provided in the Appendices to help support some of the recommendations provided in this guideline. This guideline does not constitute rulemaking by the Ministry of Environment and may not be relied upon to create a right or benefit, substantive or procedural, enforceable by law or in equity by any person.

The guideline is directed to source owners, modellers, Qualified Persons, permittees, regulators and consultants involved in any aspect of modelling.

The information presented in this document represents the ministry's guidance at the time of publication. The approved dispersion models listed in this document will be updated at times. **It is the responsibility of the user to ensure they are using the most updated model available on the US EPA website**. In the event a newer modelling software version is released during a modelling exercise and prior to it being completed, the modelling results will be considered as valid. The ministry supports innovation and is open to improved modelling methodologies if the alternative method can provide scientifically defensible results.

A report modelling checklist is provided in Appendix L and provides a quick overview of the components of air dispersion modelling.

2. AIR DISPERSION MODELS

AERSCREEN, AERMOD and CALPUFF are the recommended models to be used in Saskatchewan.

The recommended approach to air dispersion modelling should begin with a screening model. The screening model will indicate whether a more detailed, refined model is required to estimate pollutant concentrations more accurately at receptor locations.

These models typically require emission characteristics, structural information, modelling domain, surrounding terrain information, representative meteorology, appropriate receptor density, baseline concentrations and/or information on additional sources in the domain that may contribute to the impact.

Recommended models are approved models typically used to model air emissions in Saskatchewan. Approved models are those that are scientifically defensible for their intended use.

AERSCREEN is the recommended screening model. AERMOD and CALPUFF are the recommended refined models. AERMOD is typically appropriate for most Saskatchewan conditions and CALPUFF is recommended as described in Section 2.1.3.

In most cases, the “regulatory default” option should be selected. There will be some situations in Saskatchewan where selected “non-default” options could be used. Any deviation from the default options should be clearly identified and rationale provided.

A brief description of recommended models and their applicability is provided in the following sections and supplemented in Appendix A.

2.1 Model Types and Application

2.1.1 AERSCREEN

Screening models are known to produce estimates of possible worst-case one-hour concentrations for a single source without the need for on-site or real-time meteorological data. They tend to be used as an initial assessment, with the use of more refined models being required if the model predicts potential concerns. If maximum predicted concentrations are considerably lower than the appropriate standards or objectives, additional modelling may not be required.
AERSCREEN is a single source screening-level air quality model based on AERMOD dispersion algorithms which use a matrix of meteorological conditions that

represents a wide range of possible conditions. If needed, terrain and building information can also be considered in AERSCREEN. The model calculates the maximum concentration by distance for a single source and can find the scenario for the maximum concentration without the need for hourly meteorological data. AERSCREEN also includes conversion factors to estimate "worst-case" three-hour, eight-hour, 24-hour and annual concentrations.

The AERSCREEN program is currently limited to modelling a single stack (either uncapped or capped), horizontal stack, rectangular or circular area, flare, or volume source.

2.1.2 AERMOD

Refined modelling will be used for most air quality assessments in Saskatchewan. It involves the use of the more sophisticated U.S. EPA AERMOD and CALPUFF models and the use of regional meteorological data sets to provide more realistic and detailed results of air quality impacts. These models provide more information on time and space concentration distribution and require more detailed input data such as terrain, surface features, upper air meteorological data and hourly surface meteorological data. Refined models are used when there are multiple sources, when screening models predict readings greater than allowable limits or if the emissions are considered a potentially higher risk to sensitive receptors. They can be used to identify potential contributing sources, worst-case meteorological conditions, and areas of concern as well as help design a monitoring network.

If an air quality assessment shows the appropriate standards or objectives are met using conservative modelling assumptions (i.e. assuming all processes are emitting at maximum emission rate simultaneously and continuously), there is no need for additional modelling. However, refined modelling can include emissions scenario refinements such as operating hours, variable emission rates or modifications to the facility. If there are exceedances of the appropriate standards and/or objectives, then further assessment of the number of exceedances and locations and maximum concentrations may be needed.
AERMOD is a regulatory straight-line, steady-state Gaussian plume dispersion model. For calculating one-hour average concentrations, the plume is assumed to travel in a straight line without significant changes in stability or wind speed. AERMOD consists of three components: AERMET (processes available meteorological data); AERMAP (for terrain base elevations for receptors and sources); and AERMOD, which calculates the concentrations.

AERMET uses surface characteristics (surface roughness, Bowen ratio and albedo) when producing the meteorological files (see Section 8.3). This can be done using the preprocessor AERSURFACE, which reads the U.S. Geological Survey Land Cover datasets and a table of surface characteristics that vary by land type cover and season to produce the meteorological files used by AERMOD.

If there are buildings that could affect the plume behaviour, AERMOD incorporates the Plume Rise Model Enhancements (PRIME) building downwash algorithms. Building Profile Input Program (BPIP) must be used to generate the necessary PRIME

downwash parameters which then form part of the input file for AERMOD (refer to Section 6).

AERMOD may be used to model contaminant emissions from many sources including a combination of multiple source types such as point, volume, area, open pit and both buoyant and non–buoyant line source types. AERMOD enables emission rates to be treated as constant or varied by month, season, hour-of-day or other optional periods of variation. These variable emission rate factors may be specified for a single source or a group of sources.

AERMOD modelling is primarily for when the assessment is less than 50 km from the sources. If an assessment is required beyond 50 km, the user should use CALPUFF. In additional situations of low wind speeds, complex terrain and inclusion of deposition or secondary pollutants the user can use CALPUFF.

2.1.3 CALPUFF

CALPUFF model is a multi-layer, multi-contaminant, non-steady state Lagrangian puff dispersion model that simulates the effects of time, space and varying meteorological conditions on contaminants. The CALPUFF system includes three main components: CALMET, CALPUFF and CALPOST. CALMET is a meteorological model that develops a three-dimensional gridded modelling domain for the hourly wind and temperature fields based on terrain and land use information. CALPUFF uses the fields generated by CALMET to simulate contaminant dispersion and transformation. CALPOST is used to process the output files generated by CALPUFF.

The CALPUFF model can be used to predict pollutant concentrations, wet and dry deposition, chemical transformation (secondary particulates), and visibility (extinction coefficient), as well as fogging and icing. The CALPUFF model handles airflows influenced by complex terrain and land-water interfaces and has chemical transformation algorithms. CALPUFF has advantages over AERMOD during calm winds and stagnant conditions. CALPUFF contains algorithms that allow it to emulate AERMOD at short distances which enables CALPUFF to be used for both short distances and long-range transport.

Many model options can be used in CALPUFF and CALMET. The ministry recommends using the options provided in Appendix I. Any parameters in the input file that are not listed in the appendix should be set to the default values unless justification is provided to use other values.

2.1.4 Other Approved Models

Other approved models can be used if they are specialized to specific situations or tasks, or if AERMOD and CALPUFF are not suitable for the situation. Refer to Appendix A and the respective user’s guides for more detailed information about each model and specific data input requirements.

The use of a specialized model may be appropriate on a case-by-case basis. The justification should be provided, clearly stating the reasons why the refined models are not appropriate. The justification should demonstrate that the specialized model

is more suitable than the recommended refined models while still being representative. All models used for regulatory purposes should be publicly available and USEPA-approved.

Figure 2-1 presents a flow diagram for air dispersion modelling in Saskatchewan illustrating how a facility may start with screening, refined or other models to demonstrate compliance with Saskatchewan Ambient Air Quality Standards (SAAQS) or other guidelines approved by the ministry. In some cases, it may be appropriate to skip the screening model and use a refined or specialized model. Each air dispersion model has different capabilities.

Table 2-1 summarizes the capabilities of the screening and refined models. The table shows that except for small simple sources, the refined model, AERMOD, will likely be the model of choice for most situations.

Table 2-1: Summary of Model Capabilities

	Screening	Refined	
	AERSCREEN	AERMOD	CALPUFF
Terrain (above stack base)	√	√	√
Hourly Meteorological Data		√	√
3-Dimensional Meteorological Data			√
Multiple Sources		√	√
Point, Area, Volume Sources	√	√	√
Line Sources		√	√
Flares	√	√	√
Horizontal and Capped Stacks	√	√	√
Variable Emission Rate		√	√
Chemical Transformation			√
Building Downwash	√	√	√
Gridded Receptors		√	√
Physical Land Characteristics	√	√	√
Plume Visibility and Fog			√
Stagnation Conditions			√
Deposition (Gases / Particles)		√	√
Acid Deposition (Nitrate/Sulphate)			√
Shoreline Effects			√
Regional Air Zone Modelling			√
Long-Range Transport (>50 km)			√
Roadway Emissions		√	

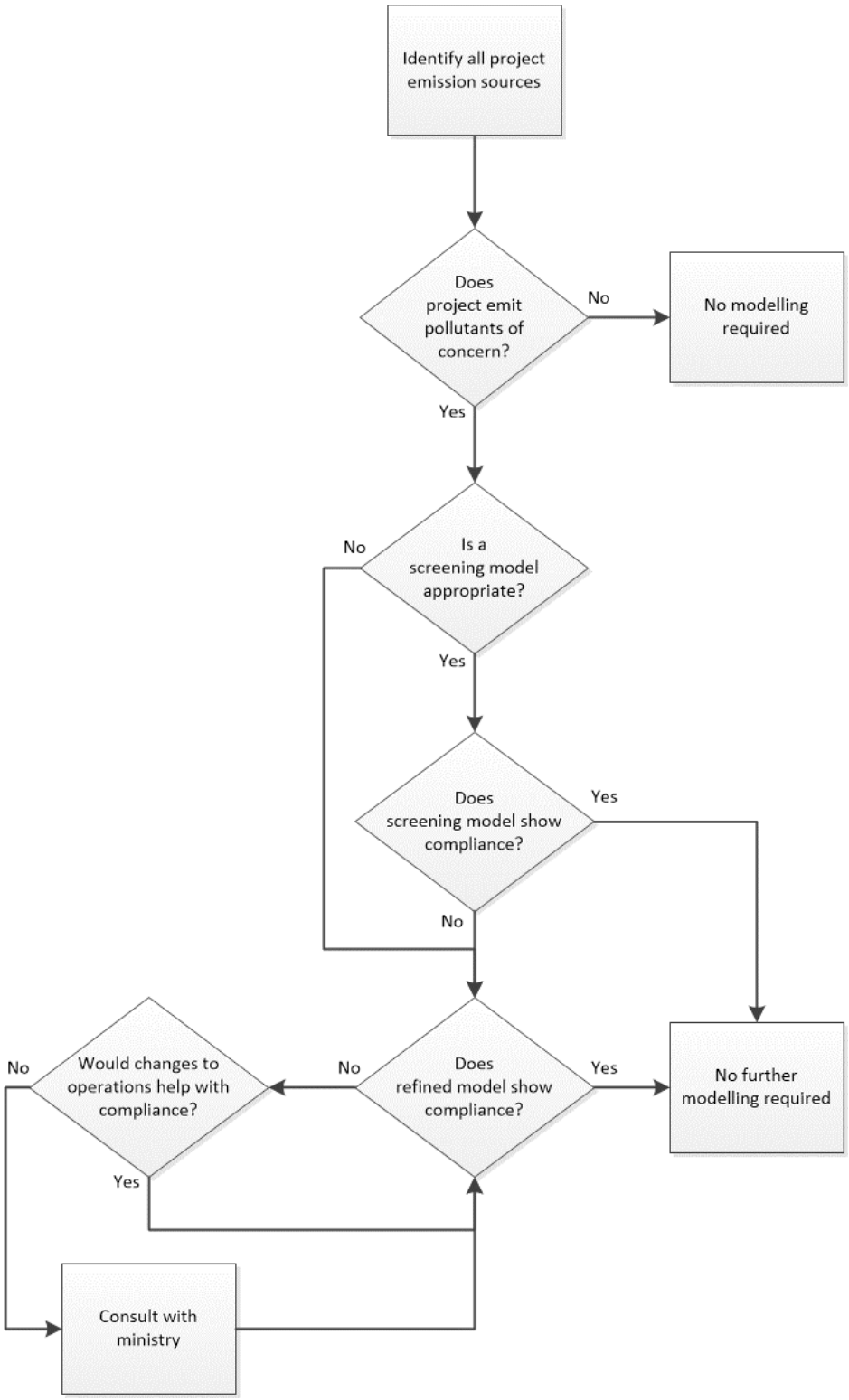

Figure 2-1: Air Dispersion Modelling Flow Diagram

3. MODEL PLAN

No air dispersion model will generate perfect results. The accuracy of the outputs depends highly on the inputs used in the model. The intent is to estimate concentrations as representatively as possible to predicted maximum concentrations under actual conditions.

Decisions that should be addressed in a modelling plan include:

- Model choice and appropriateness;
- The size of the area to be modelled and the type of terrain;
- Sensitive receptors (environment or human);
- The type of pollutants to be considered related to SAAQS and other guidelines;
- The sources of emissions and representative emission rates;
- Regional meteorology;
- The inclusion of other nearby emission sources;
- The inclusion of ambient background concentrations; and
- The determination of compliance criteria or results-based objectives to apply.

SAAQS includes standards only for a limited subset of contaminants including particulate matter, sulphur dioxide, nitrogen dioxides and carbon monoxide. However, all contaminants from the facility, which may have an impact on ambient air quality, should be evaluated for modelling and, if not listed in SAAQS, can be compared against other jurisdictional objectives such as:

- Ontario Ministry of the Environment (Ontario's Ambient Air Quality Criteria)
- Alberta Ministry of Environment and Protected Areas. (Alberta Ambient Air Quality Objectives).
- Texas Commission on Environmental Quality. (Toxicity Factor Database).

Screening-level modelling assessments require the least amount of effort and in most cases should produce more conservative results. Conversely, air dispersion modelling assessments using a refined model are more intensive but provide more representative results.

The modelling input data is comprised of four primary components.

- **Emission data** – Includes the types of sources as well as the physical properties. Additional information is provided in Section 4. Section 5 provides information on the different types of emission scenarios to consider.
- **Building downwash** – Section 6 explains what to consider when a building may affect the flow or transport or pollutants.
- **Terrain and Domain** – Section 7 provides additional information on the terrain and receptor set-up.
- **Meteorological data** – Additional information on using the ministry's meteorological data files or on setting up the meteorological data is provided in Section 9.

In all assessments, tables listing the values used in the modelling input, including source parameters and emission rates for all sources, should be included. Certain electronic copies of output files should also be included, which will help in reviewing the modelling report. This may include the output listing files, error files, the contour plot files and any threshold violation files.

4. EMISSION SOURCES

Air dispersion models can model various source types in a way that is representative of a study area. This section identifies the source types and main emission sources that may be considered, as well as approaches to treat time-varying emissions. For regulatory purposes, the ministry requires the use of the source group "ALL" in AERMOD, which considers all the sources at the same time.

4.1 Emission Types

The main emission sources used in most modelling can be categorized into four types based on the geometric shape (i.e. point, area, volume and line sources). For screening models, only one source type can be used for each model run. As shown in Table 2-1, different models have different capabilities to support various types of sources. The following sections outline the primary source types and their input requirements for both screening and refined models.

The emissions rates for all pollutants from all sources should be reviewed to determine whether they need to be considered in the modelling.

4.1.1 Point Sources

A point source is a stationary discrete source where pollutants are emitted into the atmosphere from a single point of origin. The most common type of point source is air stacks. Information on how to treat horizontal stacks and stacks with rain caps is explained in Section 4.3.5. Flares are also considered point sources but require additional considerations as detailed in Sections 4.1.5 and 11.

The source parameters typically required for point sources include the location (in UTM or grid coordinates), the emission rate of the contaminants modelled (g/s), the stack height (m), inside stack diameter (m) at the release height, stack exit temperature (K) and stack exit velocity (m/s) or actual flow rate (m^3/s).

4.1.2 Area Sources

An area source is a source that releases pollutants into the atmosphere that are distributed over a stationary spatial two-dimensional flat plane. Typically, there is no temperature difference from ambient temperature, vertical velocity, initial mixing or dilution required for area sources. Area sources are typically sources with low-level or ground-level fugitive releases where the emissions occur over an area (e.g. landfills, storage piles, open pit mines, slag dumps, settling ponds and lagoons), but can include an area consisting of multiple point or line sources.

Parameters normally required for area sources include the coordinates of the area perimeter, the emission release height (m) and the mass emission flux rate of the pollutant modelled (i.e. $g/s/m^2$).

4.1.3 Volume Sources

A volume source is a three-dimensional source that releases pollutants into the atmosphere at a stationary release point that has an initial width and depth and assumes evenly mixed emissions of the pollutants being modelled. Volume sources include releases from a variety of industrial sources such as aggregate storage piles, tanks, fugitive leaks from an industrial facility, multiple vents and conveyor belts.

The parameters normally required for volume sources include the coordinates of the volume dimensions, emission release height (centre of volume) (m), initial vertical and lateral dimensions (m) and the mass emission rates. Table 4-1: presents the calculation method for determining values for the initial lateral dimension (σ_{yo}) and initial vertical dimension (σ_{zo}) for volume sources.

Table 4-1: Estimating Initial Lateral and Vertical Dimensions for Volume and Line Sources

Dimension	**Type of Source**	**Procedure for Obtaining Initial Dimension**
Initial Lateral Dimension (σ_{yo})	Single Volume Source	σ_{yo} = (side length)/4.3
	Line Source Represented by Adjacent Volume Sources	σ_{yo} = (side length)/2.15
	Line Source Represented by Separated Volume Sources	σ_{yo} = (centre to centre distance)/2.15
Initial Vertical Dimension (σ_{zo})	Surface-Based Source	σ_{zo} = (vertical dimension of source)/2.15
	Elevated Source on or Adjacent to a Building	σ_{zo} = (building height)/2.15
	Elevated Source not on or Adjacent to a Building	σ_{zo} = (vertical dimension of source)/4.3

4.1.4 Line Sources

A line source is a source that emits pollutants into the atmosphere, which are distributed over a linear path. Some examples of line sources are roadways, rail lines and certain conveyor belts. Parameters normally required for line sources include the dimensions of the line and the mass emission rates.

For consideration of traffic-related emissions from roadways, a specialized traffic air dispersion model may need to be used.

4.1.5 Flare Sources

Flare sources are point sources with an ignition source at the top of the stack and are used to burn off excess gases. AERMOD, CALPUFF and AERSCREEN all support flares directly through their flare source type option. The plume rise for flares is based on an effective buoyancy flux parameter. The plume rise is calculated from the top of the flame, assuming that the typical wind flow results in the flame being bent 45 degrees from the vertical.

In CALPUFF, AERMOD and AERSCREEN the input for radiative heat loss (per cent) is required to account for the per cent of heat lost from the flame to the atmosphere. Section 11 provides information on how to calculate the fraction of radiative heat loss based on the composition of the gas being flared.
The calculation methodology for determining the appropriate stack pseudo-parameters and the detailed approach for modelling flares is described in Appendix K.

4.2 Stack Composition

4.2.1 $PM_{2.5}$ Stack Emissions

Particulate emissions from stacks can result through three processes.

1) Direct emission as a solid or liquid.
2) Gases condense to form particles after exiting the stack as the vapours cool to ambient temperature.
3) Gases react downwind with other gases or water vapour to form secondary fine particulates.

During stack testing, only the particulates from direct emission (known as filterable and condensable) are measured and in some stack tests, only the filterable portion of the particulate emissions is measured. In some situations, the condensable portion of the total particulate emission is only a small fraction but for other sources, like veneer dryers, the condensable portion can be >5x the filterable portion of the total particulate emissions. All the condensable particulates can be considered fine particulates ($PM_{2.5}$.).

If using stack testing data, it is important to know whether condensable $PM_{2.5}$ was included. If only filterable $PM_{2.5}$ was sampled, then the emission input data may have to be adjusted to consider the condensable portion. The rationale for this can be supported with similar stack sampling data or emission estimates.

Emissions due to other secondary particulates are not considered in most modelling. However, there are certain cases where they should be assessed such as acid deposition or long-range impacts of fine particulates. Since the formation of secondary particulates involves chemical reactions, CALPUFF should be used.

4.2.2 NO_2: NOx In Stack Ratio

Ambient air quality standards exist only for NO_2 but the emission rates from stacks are reported as nitrogen oxides (NO_x), which is defined as the combination of NO_2 and NO (nitric oxide). Stack sampling data showed that the fraction of NOx emitted as NO_2 can range from less than 0.01 to just over 0.8 (i.e. one – 80 per cent). The fraction is commonly referred to as the In-Stack Ratio (ISR). The higher ISR (i.e. > 0.25) tend to occur from sources with low NOx emissions (i.e. < 400 ppm). Typically, it is assumed that all NOx emissions are emitted in the form of NO_2 when converting from ppm to mg/m^3 or g/s for stack emissions.

For initial NO_2 impact assessments, modelling should be done assuming 100 per cent NO_x conversion to NO_2. Section 10.2 explains how the NOx-modelled concentrations are converted.

4.3 Additional Sources

During some air quality studies, modellers or Qualified Persons may encounter certain source configurations that require additional consideration. The following sections outline modelling techniques on how to account for the additional consideration of such scenarios.

4.3.1 Roadways

Some factors affecting roadway emission rates that should be considered in modelling assessments include paved vs. unpaved, silt loading, vehicle speed and the frequency and type of dust suppressant.

Refer to the refer to the Haul Road Workgroup Final Report Submission to EPA-OAQPS in modelling emissions from hauls roads.

4.3.2 Fugitive Emissions

Fugitive emission sources are typically near the ground and have the greatest impact near the source. Fugitive emissions, such as those from parking lots, or storage piles, can be significant contributors to particulate emissions from a facility. Other sources of fugitive emissions include leaking valves at gas facilities, treatment ponds or major spills of volatile liquids. These types of emissions should be included in modelling assessments if the emissions are significant or if emissions contain metals or other hazardous substances.

Fugitive emission sources are often difficult to characterize since their emissions may vary with wind speed, temperature and time of day or process changes. Compounding this is the control efficiency of mitigation measures applied to reduce emissions, which may only be crudely estimated. If no better emission information is available, e.g., from a site-specific monitoring program, fugitive emissions may be estimated from reputable sources as appropriate.

When modelling fugitive emissions care should be given to the choice of appropriate source type, i.e., whether the choice of an area source or volume source to best represent the nature of the emissions. Consideration should also be given to seasonal variability of the emissions from these sources where appropriate.

4.3.3 Liquid Storage Tanks

Storage tanks are generally either fixed roof tanks or floating roof tanks. In the case of fixed roof tanks, most of the emissions occur through a vent with some additional contribution from hatches and other fittings. In the case of floating roof tanks, most of the emissions occur through the seals between the roof and the wall and between the deck and the wall with some additional emissions from fittings such as ports and hatches.

Approaches for modelling impacts from emissions from these storage tanks are as follows.

Fixed roof tanks

Fixed roof tanks should be modelled as a point source representing the vent, which is usually in the centre of the tank. The tank itself should be treated as a building for downwash conditions.

Floating roof tanks

Floating roof tanks should be modelled as a circle of eight (or more) point sources evenly spaced around the perimeter of the tank. The tank itself should be treated as a building for downwash conditions. Total emissions should be equally distributed among the circle of point sources.

All tanks

Since there is negligible plume rise from tanks, the stack gas exit velocity should be set to near zero. If a tank is being modelled as a building with point sources used to represent the vents or emission points, the diameter should be at or near zero.

AERMOD also allows stack tip downwash to be turned "off" in the Control options, but this turns it off for all stacks, which may not be appropriate. In addition, the stack temperature should be set equal to the ambient temperature. This is done in AERMOD and AERSCREEN by entering a value of 0.0 K for the stack gas temperature. The recommended stack parameters are summarized in Table 4-2.

Table 4-2: Recommended Stack Parameter Values for Modelling Tanks

Velocity	Diameter	Temperature
0.001 m/s	0.001 m	Ambient

If the tank contents are heated, the temperature may be adjusted to a constant value that is based on the temperature of the tank contents. Provide a clear rationale if the recommended values from Table 4-2 are not used.

4.3.4 Pits and Quarries

Emissions from pits and quarries are different from most other ground-level sources. A portion of the emissions is retained in the pit and they are typically emitted from a smaller area of the pit opening. These sources are typically modelled as either area or volume sources. AERMOD is the only recommended model that is set up to directly handle emissions from a pit. The OPENPIT source type in AERMOD simulates the unique way emissions are emitted from pits and quarries.

Some of the key parameters required by the OPENPIT source option include:

- **Source Location**: This is the x and y coordinates (m) of the southwest corner of the pit.
- **Base Elevation**: The elevation (m) of the top of the pit where the emissions are simulated to occur.
- **Length of Sides**: The length and width (m) of the pit opening. These are used to calculate the effective depth of the pit.
- **Pit Volume**: The total volume (m^3) of the pit. This is used to calculate the effective depth of the pit.
- **Release Height (m)**: This is the average release height above the base of the pit (centre of volume). This parameter cannot exceed the effective depth of the pit, which is calculated based on the volume of the pit and specified length and width. For multiple sources within the pit, the specified release height should be based on the average source height within the pit.

4.3.5 Horizontal Sources and Capped Sources

For both horizontal stacks and capped vertical stacks (rain caps), there is very little or no initial vertical velocity and any vertical velocity is mainly dependent on the buoyancy. Depending on the set-up of a stack with a rain cap, the exit velocity may have a downward movement and the plume may originate from a lower point than the actual physical stack height.

With horizontal and capped sources, it is necessary to modify the source input parameters to minimize the effects of momentum while leaving the buoyant plume rise calculations unchanged. Both AERMOD and AERSCREEN can represent this by using the source type options for modelling horizontal (POINTHOR) and capped sources (POINTCAP). With these options, the vertical momentum is suppressed while the buoyancy of the plume is conserved. The user specifies the actual stack parameters of release height, exit temperature, exit velocity and stack diameter and AERMOD performs the necessary adjustments to account for plume rise and stack tip downwash. For horizontal releases, the model assumes that the release is oriented with the wind direction. For plumes with negligible buoyancy, the stack exit temperature can be set to 0 K which automatically sets the exit temperature to the ambient temperature.

In CALPUFF, these sources are handled using the vertical momentum flux factor (FMFAC) for point sources. The value is either 1 (full momentum) for a vertical stack with no restrictions or 0 for horizontal or capped stacks. For situations when time-varying point source emission files (i.e. PTEMARB.DAT) are required, the TIDATA (7) option in the file is equivalent to FMFAC.

For alternate models, the suggested methodology is similar to that in the U.S. EPA Model Clearinghouse Memo 93-II-09 (U.S. EPA, 1993) and Tikvart (1993).

4.4 Non-Continuous Emissions

Sources of emissions at some facilities may emit only during certain periods of operations. Both AERMOD and CALPUFF can model variable emission conditions that represent operational conditions. This is done either by using an external file with hourly emission rates for each source or by applying a factor ranging from 0 to 1, such that 0 is entered for the periods when there are no emissions and 0.5 represents 50 per cent of the maximum emission rate for the selected time periods. This emission factor can be applied to all time periods which are one hour or greater. Varied emissions conditions can be specified by using selected keywords like SEASON, MONTH or HRODY for season, month or hour of the day, respectively. Please refer to the AERMOD User's Guide (U.S. EPA 2022(b)) for information on the various emission rates that can be used and how to use these options.

For periods of variable exit temperature and/or velocity (start-ups and shutdowns), an external hourly emission file should be prepared including mass emission rate, exit velocity and temperature, which can vary on an hour-by-hour basis over the entire modelling period.

4.4.1 Wind Erosion

Emissions from sources such as storage piles are strongly dependent on wind speed and the moisture of the material. This will result in the emission rate being highly variable throughout the year. Therefore, it is recommended to model these emission sources as variable emissions.

There are several equations available to estimate emission rates based on wind speed, the source of material being emitted and the moisture of the material. These

calculated values can be input into an hourly emission file for modelling. This allows for more representative emissions from sources that are susceptible to wind erosion. The AERMOD model allows for emission rates to be varied by six wind speed categories and those default values can be adjusted. Once a correlation between emissions and wind speed categories is established, the model will then vary the emissions based on the wind speeds in the meteorological data. This can be important when modelling PM_{10} for exceedances of the SAAQS because maximum concentrations from fugitive sources tend to occur during periods of light winds.

4.5 Combining Individual Sources

There are cases where a facility may have numerous minor sources (e.g. vents or short stacks) in a confined area. To simplify the setup and to reduce the modelling computational time, these multiple sources may be combined into a volume or area source.

When selecting potential sources to combine, the following factors should be considered.

- The source characteristics must be similar (e.g. similar stack heights, exit velocity and temperature for point sources). (e.g. A stack and a stockpile can not be grouped, but several similar stockpiles can be grouped);
- Emission rates from the individual sources must be similar with no one source with significantly higher emission rates;
- Sources must be located in the same general area;
- The source must not be too close to the property line where there are residents in the vicinity; and,
- Operating period of sources must be the same.

When applying this approach, the choices of the size and location of the volume or area sources representing the combined sources should be selected conservatively. In most cases, the volume source height would be the same as the building height or lower. For area sources, the effective radius would be the average radius of all combined sources and not an estimated radius of the area.

4.6 Cumulative Assessment of Nearby Sources

One of the main purposes of air dispersion modelling is to determine whether emissions from a facility are predicted to result in SAAQS exceedances. In many cases, there may be elevated levels of a contaminant already in the ambient air. This existing amount of pollutant can be estimated as a baseline concentration if that information is available. If unavailable, emissions from sources outside of the facility in the general area need to be assessed for the purpose of modelling. Typically, low-emissions sources like comfort heating or vehicle emissions do not need to be considered However, adjacent facilities emitting the same pollutant should be included.

Pre-project – existing sources only
Project only – proposed facility only
Post-project –all existing sources and proposed facility

Emissions from all sources within 5 km of the facility being assessed should be examined to determine whether the impact from these emissions would contribute noticeably to the maximum concentrations, which may result in potential exceedances. It is recommended to use a screening model to identify significant sources. The threshold criterion for including additional sources is if modelling indicates that the maximum concentration contributes an additional 5 percent of the SAAQS of the pollutant of concern. All major sources located within 10 km from the modelled facility, but further than 5 km, should also be considered to determine their impact on the ambient air quality levels.

Modelling existing sources only should be defined as a **"Pre-project case".** The facility-only modelling should be defined as a **"Project only case".** The modelling including all existing sources and the proposed facility should be defined as **"Post-project case".**

5. EMISSION SCENARIOS TO BE CONSIDERED

The accuracy of a dispersion model is strongly dependent on the input data that is provided for the model. Having a good understanding of all emissions sources at a facility as well as the facility's operating conditions is key to building a model representative of operating conditions. Examples of methods used to determine emission rates from processes are provided in Appendix B.

All emission rates used by a facility for modelling should be conservative.

Emission rates from all sources in a facility to be modelled should be assessed to determine if they need to be included in the model. Typically, if emissions from a source are greater than five per cent of the total emissions for that specific pollutant, then it should be included in the modelling assessment. A description of the method used to calculate the emission rates should be provided in all modelling reports as well as example calculations used.

Emission rates from most sources are not constant and will vary depending on facility operating conditions, processes, or schedules. It is important to understand the impact typically expected from a facility as well as the worst-case scenario (i.e. maximum impact).

When conducting an air dispersion modelling assessment, several different emissions scenarios may be considered.

- Maximum emissions scenario;
- Operating emissions scenario;
- Start-up and shutdown scenarios;
- Malfunctions, maintenance and emergency scenarios, and;
- Special case scenario.

5.1 Maximum Emissions Scenario

All emission rates used by a facility for modelling should be conservative. The most conservative approach is to assume that all operations are occurring simultaneously releasing the maximum contaminant emissions from all sources for all hours (all equipment operating concurrently if possible). It is the responsibility of the modeller or Qualified Person to determine the emission rates which will result in the maximum impact.

For modelling one-hour concentrations, the maximum emission rates should be based on the maximum one-hour average emissions expected in a year. If modelling results show non-compliance for the 24-hour concentration, then modelling can be redone using the expected maximum daily emission rate to calculate the maximum 24-hour concentration.

In some situations, the maximum emission rate may result in predicted concentrations exceeding their applicable air quality standard or objective. Remodelling can be done using emission rates to reflect a more typical emissions scenario. Before any remodelling, the frequency and location of potential exceedances, as well as the probability of exceedances occurring, should be examined to determine whether remodelling is a suitable approach or whether it may be more beneficial to consider source mitigation. If remodelling is required, then the results from both the maximum emissions scenario and the more typical emissions scenario should be provided in the air quality assessment report.

5.2 Operating Emissions Scenario

For realistic operation modelling, using emission rates that are typically expected during the operation of the facility can give a comparison of what may be typically compared to the worst-case scenario. For facilities that only operate during part of a day or season or for facilities where emission rates are highly variable, more data and increasingly complex model inputs may be required. A more representative emission scenario can include the consideration of:

- Hours of operation;
- Variable emission rates; and
- Intermittent emission sources.

5.3 Start-ups and Shutdowns

Plant startups and shutdowns can occur periodically due to maintenance or designated vacation periods. These processes impact emissions over the related time periods. As an example, process upsets or problems with the air pollution control system can impact emissions. As result, over short periods of time, upset emissions are often expected to be greater than normal source emissions (U.S. EPA, 2005).

Startups and shutdowns are typically addressed on a case-by-case basis. If there is no increase in emission rates during start-ups and shutdowns or the increase in emissions is minor (i.e. < 10 per cent) and little change in exit temperature or velocity, start-up and shutdown modelling is not required. If a facility has a start-up and shutdown frequently (i.e. every few days or more), start-up and shutdown activities should be considered as part of normal operations.

Assessment of start-ups and shutdowns for all facilities should be included in air quality assessments. If a company determines modelling of start-up or shutdown is not required, rationale must be provided in their report as well as the frequency of occurrence of start-ups and shutdowns and the estimated emission rates expected during start-up and shutdown.

5.4 Malfunctions and Emergency Scenarios

High emissions may be expected from malfunctions and emergency scenarios.

Depending on the location and the size of a facility, an air quality assessment for these scenarios may not be required. However, for facilities located in or near a community or for large industrial sources, the emissions during malfunctions and emergency scenarios may be significant and some assessment of their impact should be completed.

The emission rates used for a malfunction or an emergency situation should be provided in the report with rationale. Depending on the frequency of events the emissions from these processes may be considered as part of “normal” operations.

The following are examples of each type of scenario:

- **Malfunction** – A problem with an air pollution control system can result in high emissions of pollutants over short periods of time until the system is repaired.
- **Emergency** – Flares can burn off excess gas in large amounts for safety purposes.

6. BUILDING DOWNWASH

Buildings or structures located near stacks, especially short stacks, influence plume dispersion and predicted ambient concentrations. Airflows are either forced around or up and over the building or other obstructions. On the lee side of the building, there is more shear resulting in more turbulence with airflow dragged towards to surface further downwind.

If a plume gets caught in this cavity, elevated concentrations can result. If the plume escapes the cavity but remains in the turbulent wake, it may be carried downward and dispersed more rapidly by the turbulence. This can result in either higher or lower concentrations than would occur without the building (see Figure 6-1). Building downwash should be accounted for, when it exists, when modelling for stack sources but should not be used when modelling for area, volume or open pit sources. Appendix C provides guidance on how to set up each model to account for building downwash effects and the different options that may be considered.

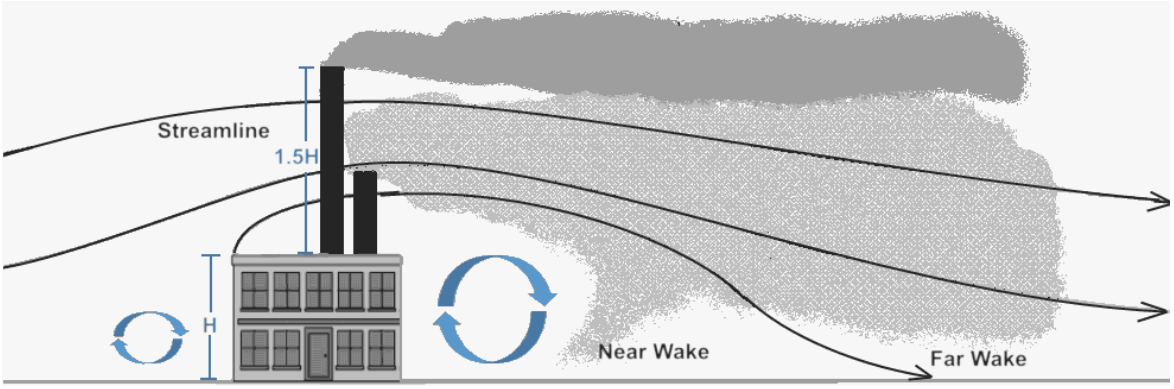

Figure 6-1: Building Downwash

The height to which the turbulent wake has a significant effect on the plume is generally considered to be approximately the building height plus 1.5 times the lesser of the building height or width. This results in a height of 2.5 times the building height for cubic or squat buildings and less for tall, slender buildings. Since it is considered good engineering practice to build stacks taller than adjacent buildings by this amount, this height came to be called Good Engineering Practice (GEP) stack height.

7. MODEL INPUT – DOMAIN AND RECEPTOR LOCATIONS

7.1 Modelling Domain

A modelling domain is a geographic area in which the required air quality analyses are conducted. The modelling domain should include all locations where there is a significant impact (maximum concentration) from the emissions of source(s). The definition of significant impact is any area where the modelled concentrations of pollutants from the project are greater than 10 per cent of their respective ambient air quality objectives/standards when all relevant industrial sources are considered. Typically, the modelling domain should be a 20 km by 20 km grid with the modelled source(s) near the centre of the area. The domain can be smaller for short stacks or larger for all stacks with buoyant emissions and it must

The modelling domain should be large enough to cover all areas where predicted impacts are expected to be a least 10% of the respective ambient air quality standards or objectives.

be within a 50 km distance to be considered applicable for Gaussian dispersion models.

Other factors to consider when determining the size or shape of the modelling domain are:

- Extending the domain to cover areas just outside the domain that are considered sensitive receptors (e.g. hospitals or schools) or communities;
- Extending the domain to cover areas just outside the domain where there is a sudden positive change in elevation;
- Changing the shape of the domain based on terrain (e.g. elongated domain for valleys);
- Extending the domain to cover areas just outside the domain, which has other emission sources that could affect the overall conclusion of the modelling assessment; and,
- For models like CALPUFF, the domain should be big enough to capture the potential recirculation of pollutants.

In many cases, the domain used in CALMET to set up the meteorological database should be larger than the domain chosen for CALPUFF. The CALMET domain should be large enough to include any terrain affecting the flows that determine the dispersion within the CALPUFF domain.

The only area within the modelling domain, which is not assessed, is the facility property. The facility property is determined by the facility fence line and/or the perimeter of the disturbed area that defines where public access is normally restricted. If a facility is located within a larger related facility boundary, the plant property is assumed, for modelling purposes, to be the plant boundary of the encompassing facility. If a public access road passes through the facility, the facility boundary is the perimeter along the road allowance.

7.2 Receptor Locations

Receptor selection is critical to ensure the location(s) where significant impacts (maximum concentrations) are captured. In selecting receptor locations, it is important to identify all sensitive receptors in the modelling domain. Receptors are not required within the facility boundary, which is being assessed except when public roads go through that property.

Various types of receptor grids can be used in dispersion modelling and they are outlined in Appendix D. Further information on each receptor type can be found in the user manual for each model.

For screening models, the receptor locations are placed along a straight line at regular intervals extending from a source to 10 km. Therefore, it can be used as an initial assessment to determine where the area of maximum impact is expected to occur.

7.3 Flagpole Heights

The height of the receptor is known as the flagpole height. The flagpole height should be based on the purpose of the modelling. One example of using a flagpole receptor height is to calculate concentration at an average breathing height (e.g. 1.5 meters). For vegetation impacts involving clusters of trees, the flagpole height could be based on the average height of the treetop canopy. All flagpole heights should be identified in all modelling reports.

8. MODEL INPUT - GEOGRAPHICAL INFORMATION

Terrain elevations relative to the facility can have a significant impact on the flow of a plume and the predicted concentrations. The AERMOD and CALPUFF models make use of complete three-dimensional digital elevation information. It is important to include terrain data extending beyond the modelling domain because the airflow in certain models, like CALMET, may be influenced by elevated terrain several kilometres away.

8.1 Coordinate System

The terrain pre-processors, AERMAP and TERREL, used for AERMOD and CALMET, respectively, require digital terrain in Universal Transverse Mercator (UTM) coordinates. There are three zones covering the province of Saskatchewan (i.e. zones 12 - 14) with most of the region in zone 13 (Figure 8-1). In a rare situation when modelling covers two zones, the zone identified in the model would be the zone where major emission sources are located.

The modeller should ensure that all model objects (sources, buildings, receptors) are defined in the same horizontal datum. The North American datum of 1983 (NAD83) is the preferred datum to use for modelling in Saskatchewan.

Figure 8-1: UTM zones covering Saskatchewan, showing the central meridian for zone 12

8.2 Terrain Processing

The consideration of a terrain type is dependent on the modelled area. For situations where the terrain around the facility is relatively flat and there is a single source, AERSCREEN can be used with a flat terrain option. The ministry recommends that terrain information be incorporated into AERMOD and CALPUFF. AERMAP or TERREL may be used to assign elevations to the receptors and to generate hill heights.

Digital elevation model (DEM) data are available for the province of Saskatchewan from a variety of acceptable sources in several different formats. Examples of sources include:

Canadian Digital Elevation Data (CDED) provided by Natural Resources Canada is terrain data in USGS DEM compatible formats at scales of 1:50,000 and 1:250,000:
ftp.maps.canada.ca/pub/nrcan_rncan/archive/elevation/geobase_cded_dnec/

Geospatial Data Extraction:
maps.canada.ca/czs/index-en.html

The CDED data are based on the NAD83 horizontal reference datum. Additional information on terrain data, as well as a figure showing the terrain file set up for the province of Saskatchewan, is provided in Appendix E.

The use of Shutter Radar Topography Missions (SRTM) terrain data is not recommended as treetop elevation can be interpreted as ground elevation.

The use of the 1:50,000 terrain data is recommended for improved accuracy. In some cases, site-specific information may be best represented by facility-generated data when active terrain changes are being done on-site, such as in open pits. Regardless of what terrain data is used, it is recommended to check the accuracy of the terrain files before running AERMOD.

8.3 Land Use Characterization

Characterization of representative land use data in the vicinity of a site is necessary to determine the appropriate surface characteristics, which govern how plumes are dispersed. Surface characteristics such as roughness, albedo and Bowen Ratio are used by AERMET in the development of the surface meteorological data (.sfc files). Each surface characteristic has numerical values applied to them which are used in the model to determine the airflow over a terrain that would be representative of each land use category.

Land characteristics should be as representative of Saskatchewan conditions as possible.

Appendix F provides information on how surface characteristics were determined as well as how to apply these values in the model. Additional information on determining surface characteristics can be found in the AERMOD Implementation Guide (U.S. EPA, 2022(c)) or the U.S. EPA AERSURFACE guide (U.S. EPA 2020). The AERSURFACE program assists in the selection of appropriate surface characteristics in the vicinity of the modelled facility.

For CALMET, a file of land data in the form of gridded land use types is required by the CTGPROG preprocessor, which produces a file with the fractional land use for each computational grid cell in the modelling domain. This file is used by MAKEGEO to create a gridded land use type and surface parameters that make up the GEO.DAT file.

The Saskatchewan Regional Meteorological Data Sets have been prepared using vegetation type and land use data from the MODIS-20 database provided with the Weather Research Forecast (WRF) data. The surface characteristics required by AERMOD were calculated from the WRF data using the Mesoscale Model Interface (MMIF) program to produce monthly values for the five years. If the closest meteorological file available is not representative of the land where the

modelled facility is to be located, then the nearest meteorological file with similar land characteristics and airflow should be used.

There may be a situation when wind sector-dependent surface characteristics may have to be determined on a site-specific basis, or the surface characteristics near the site do not match any of the fully processed Regional Meteorological Data Sets. In those situations, an explanation of any changes should be provided in the assessment and the values used should be based on the ministry's recommended default values provided in this document.

8.3.1 Urban/Rural

The land use procedure is the recommended procedure in Saskatchewan to determine whether a site is urban or rural. This procedure examines the land use within a 3 km radius around the facility to be modelled. If more than 50 per cent of the area is accounted for by land use categories ranging from multi-family dwellings to commercial and industrial use, it is classified as urban. Otherwise, the site is classified as rural.

For AERMOD, the urban option (URBANOPT) is used to account for the urban heat island effect, which can increase convective turbulence during nighttime stable conditions above a level calculated in the AERMET preprocessor and for the decomposition of SO_2. Site-specific turbulence measurements should not be used when applying AERMOD's urban option to avoid double counting the effects of enhanced turbulence due to the urban heat island effect (U.S. EPA 2022(c)). Factors that affect the selection of the urban option in AERMOD include the population density and the location of a facility relative to the urban core. If a facility is located close to the edge of an urban area, the urban heat island option should be selected, especially if it is downwind from the urban area, since the urban heat island is not a localized effect but more of a regional effect (U.S. EPA 2022(c)).

8.3.2 Surface Roughness Length

Surface roughness values in AERMOD are more important in stable atmospheric conditions than in neutral/unstable conditions. The surface roughness length/height (Z_o) is a measure of the height of obstacles to the wind flow. Typically, the surface roughness length is estimated to be about one-tenth the height of the obstacle but less than 1.4 m.

MMIF can calculate hourly surface roughness lengths from WRF. These hourly values are averaged to determine a monthly average value to be used in AERMET. Information on how to calculate the surface roughness for AERMET and CALMET is provided in Appendix F.

8.3.3 Albedo

Albedo is the fraction of incoming solar radiation that is reflected from the surface back into the atmosphere. The amount of incoming radiation is used to estimate the strength of convective turbulence during unstable conditions. A high albedo surface would cause morning inversion to break up later than in the morning, resulting in any pollution trapped under that inversion layer remaining over that location for a

longer time. In valleys during the winter with a strong inversion, an area with a low albedo may result in the pollution remaining over that location for several days.

Since the albedo of a surface can change hourly depending on the solar angle (highest at low sun angles and the lowest near solar noon) as well as the wavelength, the albedo values used in dispersion modelling represents the albedo value, in the visible spectrum range, at noon when the sun it at its maximum angle. A region with coniferous forest can have a high albedo of 0.9 or greater after a large snowfall but the albedo can drop to <0.2 within a few days once the snow has dropped from the branches. Also, the albedo of fresh snow can decrease at a rate of about 0.006/day as this fresh snow ages and as much as 0.07/day as it melts when temperatures are above zero (Gray et al., 1987).

The MMIF program reads the noontime albedo and calculates the hourly albedo for all daylight hours. For nighttime, a default value of 1 is used for the albedo. The ministry has five years (2012-2016) of monthly average noontime albedo values available for the whole province at 0.25-degree intervals to help compare albedo at a facility to that provided for the meteorological site. This data was compiled from the NASA Earth Observations website at neo.gsfc.nasa.gov/ and is available at geohub.saskatchewan.ca/.

In situations where the albedo values need to be determined for a specific location, information on how to calculate the albedo for AERMET and CALMET is provided in Appendix F.

8.3.4 Bowen Ratio

Bowen ratio is the ratio of the sensible heat flux to the latent heat flux and is used to calculate the heat loss/gained from the surface by determining the amount of moisture that exists at the surface. The latent heat flux predominates over bodies of water or regions covered by vegetation, whereas the sensible heat flux predominates in desert regions and over cities (Wallace and Hobbs, 1977).

Information on how to calculate the Bowen ratio for AERMET and CALMET is provided in Appendix F.

8.3.5 Anthropogenic Heat Flux

Anthropogenic (man-made) heat flux can be a substantial input into the urban energy balance, especially in Saskatchewan during the autumn, winter and early spring as well as at night. Only urban and residential areas would have anthropogenic heat flux values assigned to them. All other land use categories would have zero for the anthropogenic heat flux.

The anthropogenic heat flux is used to set up CALPUFF, but it is not used in AERMOD. AERMOD handles the urban heat flux through the URBANOPT switch.

8.3.6 Soil Heat Flux

Soil heat flux, also known as heat flux density, is the amount of thermal energy that moves through an area of soil in a unit of time. The soil heat flux is positive when

the soil receives energy and negative when the soil loses energy (cools). AERMOD does not use the Soil Heat Flux in its calculations, but CALMET does when setting up the meteorological file for CALPUFF. Table F.6 shows the ministry's recommended default values for the soil heat flux based on land use and season.

Information on how to calculate the soil heat flux for CALMET is provided in Appendix F.

8.3.7 Leaf Area Index

The leaf area index (LAI) is a dimensionless quantity that characterizes plant canopies. AERMOD does not consider LAI in its calculations, whereas CALPUFF uses LAI when modelling dry deposition. The LAI values shown in Table F.7 were derived from (Zhang, Brook & Vet, 2003) and (Zhang, et. al., 2002)

Information on how to calculate the LAI for CALMET is provided in Appendix F.

9. MODEL INPUT — METEOROLOGICAL INFORMATION

9.1 Comparison of Screening and Refined Model Requirements

Meteorological data are essential for air dispersion modelling and require appropriate data as input.

AERSCREEN uses a MAKEMET processor to generate a set of screening meteorological data that is dependent on the surface characteristics around the modelled site and provides three options for generating the screening meteorology based on surface characteristics (Appendix A).

AERMOD uses hour-by-hour meteorological data that must be processed through AERMET into a form that AERMOD can use as input. AERMET can process three types of meteorological data.

1) Hourly surface observations at a meteorological station.
2) One upper air station (twice daily data).
3) Hourly data from an optional on-site or nearby meteorological site. AERMET can also rely on the numerical weather predictions (NWP) model to produce meteorological data.

The AERMET processor will create two files to represent the meteorology over the modelling domain. A surface file (.sfc) of calculated hourly boundary layer parameters and measured meteorology and a profile file (.pfl) of one or more level observations of wind speed direction, temperature and standard deviation of the fluctuating wind components.

For CALPUFF, CALMET merges all available meteorological files, including a surface data file (SURF.DAT), upper air file (UP.DAT), precipitation file (PRECIP.DAT) and the NWP file (PROG.DAT) into one binary file. All required upper air data is combined into one UP.DAT file and all required surface meteorological data is combined into one SURF.DAT file.

Unlike AERMET, which generates one set of meteorology representing the whole modelling domain, CALMET generates meteorology at evenly distributed grids identified by the user based on terrain and land type. Terrain and surface characteristics of albedo, surface roughness Bowen

ratio, anthropogenic heat flux, soil heat flux and leaf area index can be input for each computational grid cell before running CALMET.

Further information on setting up the meteorological files to be used by CALMET can be found in Appendix H-2.

9.2 Meteorological Data for the Province of Saskatchewan

9.2.1 Saskatchewan Regional Meteorological Data Sets

The ministry has developed a series of fully processed AERMOD-ready screening meteorological data sets that will be referred to as "Regional Meteorological Data Sets". The Regional Meteorological Data Sets contain five years of hourly meteorological data (~43,800 hours) representing the years 2012 to 2016.

Regional Meteorological Data Sets were generated from Weather Research and Forecasting (WRF) model using a Mesoscale Model Interface (MMIF) program and AERMET, and they are spaced approximately every 100 km throughout the province (Figure 9-1). The output .sfc files for AERMOD record one line for every hour, starting with hour one and ending with hour 24, such that hour three would contain the period from 2:01 a.m. to 3:00 a.m. local standard time. Details on how the Regional Meteorological Data Sets were prepared are available in Appendix G.

The relevant files for each Regional Meteorological Data Set are available at: geohub.saskatchewan.ca/datasets/aermod-input-file-download-by-location-.

Each zipped file is based on the latitude and longitude for which that file represents (i.e. 492N1016W represents 49.2 latitude and 101.6 longitude). All AERMOD modelling in Saskatchewan should be conducted using one of these processed meteorological data sets. Meteorological observations from a site-specific collection program, either on-site or nearby, can be used as an addition to provide localized conditions over that site.

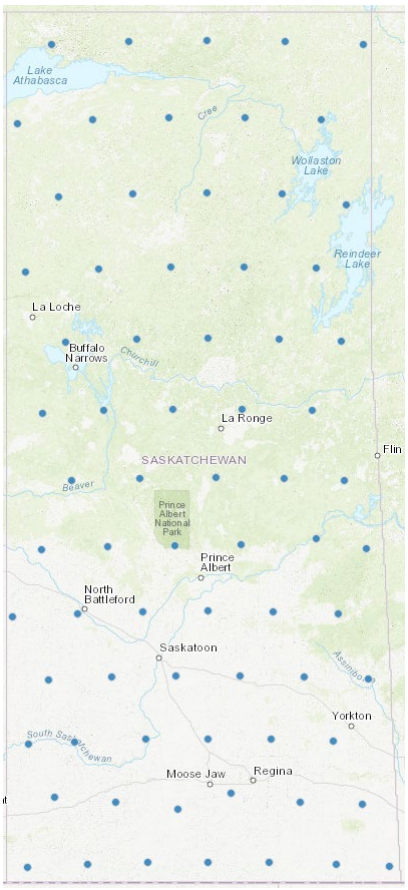

Figure 9-1: Saskatchewan Air Dispersion Meteorological sites

9.2.2 Modified Meteorological Data Sets

The Regional Meteorological Data Sets were prepared assuming that the surface characteristics around the facility are relatively uniform. If the facility to be modelled has surface characteristics that do not match any of the available fully processed AERMOD-ready meteorological data files, the fully processed Regional Meteorological Data sets may not be appropriate. In these cases, it is recommended to use AERMET to recompile the MMIF-generated meteorological files using more representative land use data.

If other meteorological data, such as on-site data or other computational-derived data, is used justification should be provided explaining why that option was selected.

9.2.3 Other Surface Meteorological Data

If the modelling study is being undertaken to assess the impact at specific receptors or to match modelled and monitored data which does not cover the period in the Regional Meteorological Data Set, the choice of nearby surface meteorological data becomes more important. Justification for the use of any alternate source of meteorological data should be provided to the ministry as well as all quality assurance checks done on the data (U.S. EPA, 1995(a)) and the methodology to be used for its processing/handling. For assessing the impact at specific receptors, a

minimum of one year of meteorological data is required. If there is more than one year of on-site meteorological data available, then either all or at least five years of available valid data should be used. Additional information on selecting and setting up a representative surface meteorological dataset is provided in Appendix H. NWP models can be used to generate site-specific upper air data that can be manipulated into a form that may be used with surface data. A detailed description of the sources and methods used to generate this numerically generated meteorological dataset is required when this option is chosen.

9.3 Calm Wind Conditions

Calm winds can result in emissions accumulating in an area. Stagnation occurs when calm wind conditions persist for many hours or days. With stagnation, dispersion is minimal due to limited turbulence and transport of the emissions from the area as well as the recirculation of contaminants.

The wind speed limit that defines calms will vary depending on the jurisdiction but is typically defined as wind speeds below 0.5 m/s or less than the anemometer starting threshold. In AERMOD, a calm wind is normally defined as any wind speed less than 0.5 m/s. AERMOD will skip the hours when the wind speed is defined as calm and will not calculate concentrations for those hours. AERMOD will not calculate daily concentrations if there are more than eight hours in that day that are skipped due to calm conditions and/or missing data. This may be significant when modelling in areas with a high frequency of calm winds.

If an alternate meteorological station is to be used, then all hours with wind speeds less than 0.5 m/s should have the wind speeds adjusted to be 0.5 m/s and the wind direction should be recorded as is. In situations when the wind direction is missing or steady from one specific direction due to the wind speeds being too light to cause the wind vane to shift, then a 30-degree random wind fluctuation should be applied to the wind direction for those hours based on the last hour when the winds speed was strong enough to show a valid wind direction.

If an alternate meteorological station to be used in modelling is subject to frequent and prolonged stagnations, the Regional Meteorological Data Sets should be used.

9.4 Missing Data

All Regional Meteorological Data Sets prepared by the ministry have no missing hours of data. Missing data may occur when alternate meteorological data is used in the modelling.

When using alternate meteorological data, it is recommended to have at least 90 per cent data completeness for all parameters required by the model for each year with no more than two consecutive weeks of missing data.

To increase the data completeness, use the data filling procedures based on the Meteorological Monitoring Guidance for Regulatory Modeling Applications (U.S. EPA, 2000) to fill missing data gaps.

- If there are multiple measurements at different levels on a tower, then missing data for one level can be replaced by data from an alternative level. Corrections can be made

based on established vertical profiles or historical correlations. This method is the preferred approach to fill longer missing data periods.

- If the missing period is four hours or less, use linear interpolation from the last valid hour. For transition periods (e.g. sunrise/sunset).
- For periods greater than four hours, determine if data from a nearby representative site are available to substitute missing hours. An assessment to determine whether this data is representative should involve an examination of the surrounding terrain, surface characteristics and height.
- For datasets with large data gaps in the day or night (i.e. anything greater than eight hours), replace the entire day or night period with the previous valid data from that site.

Any missing data which are filled should be flagged to assist in the interpretation of model output and the uncertainty associated with the concentrations predicted during periods of substituted data.

10. Air Quality Assessment

10.1 Existing Concentration

To properly compare modelling results to air quality standards or objectives, the existing air quality needs to be added to the modelled concentration to get the total concentration expected in the modelling domain. The existing air quality includes surrounding sources as well as sources from long-range transport.

Before comparing to any ambient air quality Standards or Objectives, background or baseline concentrations need to be considered.

Quite often the term baseline and background are used interchangeably, but there is a difference.

Background concentrations are those that result from long-range transport of pollutants that can not be locally controlled and they tend to be consistent over a wide region. Those include natural sources like forest fires, volcanic eruptions, wind-blown dust or anthropogenic sources like primary and secondary pollutants from long-range transport.

Baseline concentrations include background levels as well as the impact of local activities and tend to be localized covering an area less than 10 km in radius. Baseline concentrations are the contribution of all sources except the source(s) being modelled. Typically, background concentrations are applied to modelling results from sources in rural areas whereas baseline concentrations are applied to modelling results in urban or industrial areas.

Ambient background and/or baseline concentrations of the air contaminants being modelled should be added to the modelled concentrations to assess air quality against referenced standards and objectives.

10.1.1 Regional Background Concentrations

Regional background concentrations are required for sites located in rural or remote locations where the impact on air quality from local sources is minimal. Air quality monitors that are in areas not affected by local sources may be designated as "background monitors" and used to provide regional background data for modelling of sources in the region. The ministry has processed measured concentrations from

a series of monitoring locations to provide an estimate of background concentrations (refer to Appendix J).

As a conservative screening approach, a single value is chosen for the background for each contaminant and applied to every hour of each year and for every location within the modelling domain. However, background concentrations for most contaminants will vary throughout the year (e.g. O_3 and PM_{10}) and should be used if available. Appendix J provides guidance on calculating background concentrations. It also provides typical regional concentrations if no other data is available. Supporting rationale and data should be provided by the modeller or Qualified Person on what approach and results were used for background concentrations.

10.1.2 Regional Baseline Concentrations

In most cases, the use of the conservative regional background concentrations will be sufficient to describe current ambient conditions. However, in areas where there are many minor sources (e.g. urban areas) or other significant sources emitting the same contaminants that are being modelled, these sources should be considered. Air quality data collected in the vicinity of the proposed source or at a representative site may be used as baseline values.

A description of the methods used to determine a baseline concentration(s) should be included in all air quality assessments. Include a table showing the modelling results, the baseline/background concentration for the contaminants modelled and a sum of the modelled and baseline/background concentrations.

Both AERMOD and CALPUFF can accept an external hour-by-hour time-varying baseline/background concentration file. The use of this option with representative data and matching years of meteorological data would result in modelling results that represent ambient air quality conditions as realistically as possible. This approach would not be suitable for ozone as the chemical transformation process cannot be appropriately handled in AERMOD and CALPUFF.

10.2 Nitrogen Conversion

Once NOx exits the stack, it undergoes a series of complex atmospheric reactions that may result in production or reduction in NO_2 concentrations. Therefore, the fraction of NO_2 emitted from the stack, based on the ISR, will vary as the plume travels away from the stack. NO can quickly react with ozone (O_3) and certain VOC compounds to produce NO_2. In rural areas, it is typically O_3 that dominates the conversion rate of NO to NO_2. The conversion for NO to NO_2 should be accounted for.

The following recommended methods for estimating the concentration of NO_2 are presented in the order of preference. For all methods, the background/baseline concentration should be added to the modelled concentration after the NO_2 conversion is applied.

10.2.1 Total Conversion Method

The most conservative screening approach is to assume 100 per cent of the nitrogen oxides emitted are instantly converted to NO_2. If this assumption shows that the

maximum modelled concentration is exceeding the applicable air quality standards, then the alternate methods below can be used. Results from the Total Conversion Method should be presented as part of any assessment for all scenarios.

10.2.2 Ambient Ratio Method (ARM)

ARM is no longer available in AERMOD versions 18081 and newer.

10.2.3 Ambient Ratio Method 2 (ARM2)

The Ambient Ratio Method 2 (ARM2) is an extension of the ARM method based upon the premise that the NO_2/NO_x in a plume change as it is transported but reaches an equilibrium value some distance away from the source. Data has been compiled from over 580 stations in North America covering the period from 2001 to 2010 to determine a conversion factor that can be used to calculate the portion of NO_x in a plume that is converted to NO_2 (RTP Environmental, 2013). An equation was developed based on the 98th percentile NO_2/NO_x ratios for each bin of NO_x concentrations.

The polynomial defining the ARM2 ratio for AERMOD (v19191) is $(-1.1723e^{-17})x(NO_x)^6 + (4.2795e^{-14})x(NO_x)^5 + (-5.8345e^{-11})x(NO_x)^4 + (3.4555e^{-8})x(NO_x)^3 + (-5.6062e^{-6})x(NO_x)^2 + (-2.7383e^{-3})x(NO_x) + 1.2441$ where NO_x is the predicted ground level concentration in µg/m3. Note that the upper and lower bounds of this conversion are defined by the minimum and maximum NO_2/NO_x ratio as defined within the assessment.

Current guidance from the U.S. EPA and the ministry recommends a minimum ARM2 ratio of 0.50 to maintain an appropriate level of conservatism in the results.

10.2.4 Plume Volume Molar Ratio Method (PVMRM)

For relatively isolated and elevated point sources, it is recommended to use the PVMRM. The PVMRM determines the conversion rate for NO_x to NO_2 based on a calculation of NO_x moles emitted into the plume and on the number of moles of ozone contained within the volume of the plume between the source and the receptor. The initial in-stack NO_2/NO_x ratio of the emitted plume is also considered. This method accounts for plume merging and calculates a resultant plume volume from multiple sources to calculate the ambient NO_2/NO_x ratios. The PVMRM (MACTEC, 2004; Hanrahan, 1999) option is incorporated into AERMOD.

PVMRM is considered as an alternate method and justification of its use should be provided. If the PVMRM is to be used, the following defaults are recommended:

- For baseline O_3, use monthly background values in accordance with calculations detailed in Appendix J or pre-calculated ministry concentrations.
- A NO_2/NOx equilibrium ratio = 0.90 unless information is available to justify using a different value.
- The determination of the short-range NO_2/NO_x equilibrium is dependent on the in-stack ratio for all sources.

PVMRM is not recommended for large groups of sources, area or line sources and near-surface releases, including roadways.

10.2.5 Ozone Limiting Method (OLM)

The ozone limiting method (OLM) involves an initial comparison of the estimated maximum NO_x concentration and the ambient ozone concentration to determine which is the limiting factor to NO_2 formation (Cole and Summerhays, 1979). If the concentration of NO_x is greater than the ozone concentration, then the formation of NO_2 is limited by the ambient ozone concentrations.

The following equations are used in the OLM to calculate NO_2 levels based on modelled NO_x concentrations.

If $[O_3] > 1.59*(1\text{-ISR})*[NO_x]$ then $[NO_2] = ISR*[NO_x] + 1.53*(1\text{-ISR})*[NO_x]$ otherwise $[NO_2] = 0.96*[O_3] + ISR*[NO_x]$.

Note units for concentrations are in $\mu g/m^3$.

According to the above equations, if the ozone concentration is greater than (1 – ISR) of the predicted NO_x concentrations, all the NO_x is assumed to be converted to NO_2. The OLM assumes that a portion of the NO_x emissions are generated as NO_2. The remaining NO_x emissions are assumed to be in the form of NO, which reacts with ambient levels of ozone to form additional NO_2. This method assumes there are no other chemical reactions (i.e. no reaction of NO with organic radicals to produce NO_2) and assumes that there is no photodissociation of NO_2 in the plume.

The use of the OLM is not recommended for highly populated communities or in areas with a lot of industrial activity.

For CALPUFF, each source must be treated separately and then summed to determine the total NO_2. When using this method all NOx emissions must be entered as NOx and NO_2 should not be included as an input emission.

10.2.6 RIVAD/ARM3 and RIVAD/ISORROPIA

The ministry does not recommend the use of RIVAD/ARMs or RIVAD/ISORROPIA for the conversion of NO_x to NO_2. Therefore, when modelling with CALPUFF, the chemistry option should be disabled. All NOx emissions should be entered as NOx and NO_2 should not be included as an input emission.

10.3 Post-Modelling Processing

The type of output submitted to the ministry is integral in demonstrating the impact that a facility may have on the surrounding environment. This information should be sufficient to demonstrate the modelling is scientifically defensible and the objectives of the assessment have been met. The information submitted should include but not be limited to:

- Tables of maximum predicted concentrations, distances from source(s) and frequency of exceedances (if any are predicted).
- Figures showing isopleths of maximum concentrations by averaging times (e.g. one-hour, 24-hour, annual);
- Input/output model control files; and,

- Any other information that may be necessary to demonstrate modelling and compliance with SAAQS.

The assessment report must include enough information so that the reviewer can understand the methodology and assumptions that were made and can support the elections/decisions made in the assessment.

10.3.1 Averaging Times

AERSCREEN only provides results on an hourly average basis. AERMOD and other advanced models can calculate concentrations at various averaging times which are factors of 24 (i.e. 1, 2, 3, 4, 6, 8, 12, 24). These averages are discrete averages recorded every n^{th} hour (e.g. there are three eight-hour averages per day (1-8, 9-16, 17-24)). This may result in elevated levels getting missed if pollution episodes occurred at the end of one time period and the start of the following period. In addition, multiple averaging times can be specified in a single run.

The following conversion factors are only intended for use in air dispersion modelling.

10.3.2 Conversion Factors for Screening Models

If using AERSCREEN when comparing to 24-hour or annual criteria, the maximum one-hour concentrations produced by the model should be converted to a maximum 24-hour or annual average concentration. This is done using conversion factors as described below (U.S. EPA 2021). These conversions are automatically applied when using AERSCREEN.

When using the AERSCREEN model, the following ratios should be used to convert one-hour maximum concentration to longer-term averages:

C_avgt=C_hour (ratio).

Table 10-1: Recommended Conversions Factors used in AERSCREEN.

Averaging Time	Multiplying Factor (Ratio)
3 hours	1.0
8 hours	0.9
24-hours	0.6
Annual	0.1

10.3.2.1 Conversion Factors for Sub-Hourly Values

AERMOD has the capability of modelling using one-minute meteorological data. Conversion factors can be used to convert the peak one-hour average concentrations from refined models (e.g. AERMOD) to compare with standards for shorter averaging times such as a half-hour standard or a 10-minute odour-based standard. The ministry recommends the following power law equation to convert concentrations from one hour to the desired minutes:

$$C_p = C_m \left(\frac{T_m}{T_p}\right)^{0.28}$$

Where:

C_p = Mean concentration for the new averaging time [µg/m^3].
C_m = Mean concentration for one-hour averaging time [µg/m^3].
T_m = Averaging time for 1 hour [60 minutes].
T_p = New averaging time [minutes].

10.3.3 Unit Conversion for Concentrations

Most air quality standards for gases are provided as ppb (parts per billion) or ppm (parts per million) whereas the modelled output is provided as µg/m^3 (micrograms per cubic metre). The concentration of a gas can be converted from µg/m^3 to ppb using the ideal gas law equation, which is dependent on the ambient temperature, atmospheric pressure and molecular weight of the pollutant. For simplicity and consistency, the conversion for air quality standards in most jurisdictions is based on standard conditions (T_{std} = 25°C, P_{std} = 101.325 kPa). The following equation can be used based on the standard conditions.

[µg/m^3] = [ppm] x 40.874 x (molecular weight of pollutant [g/gmol]).

10.3.4 Modelling Output

Modelling should be done for the five complete years of representative meteorological data. At times, the maximum modelled concentrations can be due to rare and unusual meteorological conditions that are considered outliers. Therefore, hourly averages above the 99.9th percentile for each receptor in each year can be disregarded (i.e. the ninth-highest hourly average would be reported). For averaging periods between two – 12 hours, all the hourly averages must be included in the calculation, then the first highest value can be disregarded. For all averaging periods 24 hours or greater, all the hourly averages must be included in the calculation and no values can be disregarded.

Alternatively, the five-year data set could be run as one singular model. In this scenario, the eighth-highest hourly and first-highest two – 12-hour average blocks can be disregarded. No values can be disregarded for the 24-hour or greater averaging period. For the hourly averages, this represents a 99.98th percentile and a very conservative approach. If this approach complies with applicable limits, individual years do not need to be modelled. Annual averages for each of the five years still need to be calculated and reported.

The maximum concentration in those five years should be recorded for each receptor point. A table showing the modelled maximum concentration for each pollutant, as well as the modelled maximum plus background or baseline concentration, should be provided with all assessments. Maps showing the isopleths of these maximum concentrations are the best method to report the maximum concentration for each receptor and should

The maximum modelled concentration for all receptors should be included in the assessment report.

be provided as well. If there are exceedances of the SAAQS or any other objective for the pollutants modelled, then one of the isopleths should represent that objective level. The selection of intervals and the number of isopleths plotted on each graph should be enough to easily interpret the map. Isopleths need to provide a good visual representation of the concentrations. Typically, the lowest isopleth should be the lowest of 10 µg/m^3 or 10 per cent of the ambient standard or objective of the pollutant being modelled. The modeller can adjust the scales as necessary as long as details of the isopleth are not being washed out. For example, the SAAQS for NO2 is 300 ug/m3. If the max modelled concentration is 30 ug/m3, it would be inappropriate to scale to 300. The lowest isopleth should be appropriate to the levels measured.

Note: For the purposes of modelling, all metrics should be removed (e.g. 3 year average of the annual 98th percentile). The value listed in the SAAQS is considered to be the limit.

All averages in AERMOD greater than one-hour are block averages (e.g. the eight-hour average applies to either midnight to 8:00 a.m., 9:00 a.m. to 4:00 p.m. or 5:00 p.m. to midnight, inclusively). Therefore, the recommendation for averages greater than one hour, excluding annual averages, is to initially calculate the averages as block averages (AERMOD default). If, after adding background and the impact of other sources, the maximum concentration is greater than 70 per cent of the SAAQS, then running averages should be calculated.

Isopleths showing exceedance frequency for the full monitoring period above a certain threshold concentration should be provided, if applicable. Typically, the threshold concentration is based on the ambient standard or objective of the pollutant being assessed and the time period being modelled. For cases when there are exceedances, the isopleth intervals should be selected to easily interpret the impacts visually and should include an isopleth showing at least one exceedance. The maximum number of exceedances as well as the location should be identified on the map.

For determining the annual average, the model should be run five times (once for each year of meteorological data) and the highest annual average for each receptor should be recorded and plotted on a map showing isopleths of the concentrations. Any exceedances of the annual standard of the pollutant modelled should be identified on the map as well as the location with the highest concentration.
The annual air quality standard for TSP is based on a geometric mean whereas models only predict annual averages. If the annual average is below the air quality standard for TSP, then use the average value as the geometric mean. If the average value shows exceedances of the air quality standards for TSP, the geometric mean for each year will have to be calculated for any receptors with exceedances based on all the modelled daily values for that year. The isopleths can be the average or combined. Exceedances should be displayed in a table accordingly. All modelled daily values equal to zero should be converted to 0.1 µg/m^3.

All figures showing isopleths should be overlaid on a map where at least 90 per cent of the map includes the full modelling domain. All maps should display the topography as well as identify the source(s) modelled and any communities or sensitive receptors. To adequately interpret and understand modelling results, additional isopleths can be included showing a smaller domain focussing on impacted areas.

It is the modeller or Qualified Person's responsibility to ensure modelling results are comparable to applicable limits or objectives in determining compliance.

11. Flaring

Flaring may be necessary for burning excess gases rather than releasing these gases directly into the atmosphere.

The treatment of a flare in dispersion modelling is more complicated than a stack source since the duration may be less than one hour and the gas composition and flow rates will vary during the duration of the flare.

There are four main types of flaring.

- **Continuous**: Typically used at chemical plants, refineries, and oil batteries to dispose of excess waste gas rather than venting them directly into the atmosphere. These should be modelled as continuous sources.
- **Routine**: Intermittent but controlled or occurs at a scheduled interval. They may include a pipeline blow-down to depressurize a pipeline or scheduled maintenance. They tend to be several minutes to several hours.
- **Non-routine**: Intermittent and will occur under unplanned or abnormal conditions. Some examples include by-pass flaring for plant safety or emergency shut-down conditions. The durations tend to be several minutes to several days.
- **Well Test**: This results in excessive amounts of gas being released from a well to determine the amount of gas that exists in a reservoir below the surface. These flares can last for several hours to several days and SO_2 impacts can at times exceed 1,000 $\mu g/m^3$, depending on the composition of the gas and the surrounding terrain.

The flare should be modelled for the purpose for which they will be used. Some flares are designed to handle both routine and non-routine flare events. Flows during non-routine flare events are much larger than those during routine flare events. This would lead to modelled plume rise being much higher for non-routine flare events which may result in areas of maximum impacts being at different locations. Therefore, it is important to monitor appropriate scenarios expected for a particular flare/incinerator.

11.1 Source Parameters

As per Section 4.1.5, AERMOD, CALPUFF and AERSCREEN contain a FLARE source option, which calculates stack pseudo-parameters (i.e., stack height and diameter and exit velocity) to appropriately characterize the flare to ensure that the resulting plume rise and spread are reasonably representative. AERMOD and AERSCREEN allow the user to enter a value for the

radiative heat loss fraction rather than the default value of 0.55. AERMOD also provides the options for stack temperature and exist velocity, rather than using the default values of 1273 K and 20 m/s, respectively. In CALPUFF, the stack pseudo-parameters can vary depending on wind speeds, which determines the angle of the flame (Exponent, 2019). For radiative heat loss, the ministry's recommended method is similar to the Ontario Ministry of Environment (Ontario Ministry of Environment and Climate Change, 2017(b)) which considers the molecular weight of the gas stream.

R = (MW)/3 + 21.

Where:
R = radiative heat loss (per cent).
MW = molecular weight of the gas stream.

Additional information on how this is used to determine pseudo-stack parameters is outlined in Appendix K.

The flare design and performance should meet the requirements of the Saskatchewan Ministry of Energy and Resources when needed using the Saskatchewan Upstream Flaring and Incineration Requirements, S-20.

11.2 Intermittent Emissions from Routine and Non-Routine Flaring

In many cases, flaring can occur intermittently for short durations. Modelling the worst-case scenarios is recommended to show due diligence to protect people and the environment. When modelling these events, it is important to include the probability of the flaring events occurring.

For flaring events which last several hours and have a very gradual decrease in emissions during the period, each hourly emissions scenario should be assessed using AERSCREEN. If any of those hours show levels near or exceeding the one-hour SAAQS then refined modelling is required for each of those periods, assuming a continuous source, to assess the hourly impacts. The probability of the event occurring needs to be included in any assessment. The average of the one-hour maximum concentration of each hour scenario modelled (up to the first 24 hours) using AERSCREEN should be calculated to determine if there are any exceedances of the 24-hour SAAQS. Consideration needs to be made to account for the number of hours during flaring compared to the number of hours of no flaring in those 24 hours and a baseline concentration should be included.

11.3 Well Test Flaring

In areas of oil and gas exploration, a process known as well test flaring is quite common, especially for areas with a high content of H_2S in the gas (known as sour gas). The flaring of the H_2S results in high emission of SO_2 gases from these flares.

Since well-test flaring is planned and tends to be short-term, dispersion modelling for the full five years is not required. Only the month when the flaring is planned as well as the adjacent months (i.e. three months per year equals 15 months in total) are required for the assessment.

For vegetation impact, the flagpole height should be set to the average height of the vegetation canopy in the region of the flare. The output files and maps provided in the assessment should be similar to those for normal modelling assessment with the addition of vegetation locations showing potential impacts and seasonal consideration. A wind rose for the meteorological period used for modelling should also be provided.

Table 11-1 SO_2 Concentrations Criteria for the Onset of Acute Visible Foliar Injury (SENES, 2007)

Number of consecutive hours with conc. above given level	Daytime April - June ($\mu g/m^3$)	Daytime July - Sep ($\mu g/m^3$)	Nighttime April-Sep ($\mu g/m^3$)	Anytime Oct-March ($\mu g/m^3$)
1	1306	1741	4724	7086
2	832	1110	3025	4538
3	639	852	2331	3496
4	530	707	1937	2906
5	459	612	1678	2517
6	408	543	1493	2239
7	369	491	1352	2028
8	338	451	1241	1861
9	313	417	1150	1725
10	292	390	1075	1612
11	275	366	1011	1516
12	260	346	956	1434

11.4 Other Flaring Models from Relevant Jurisdictions

Due to the complicated nature of the treatment of a flare in dispersion modelling, the Ministry of Environment recognizes that there are other appropriate tools developed in other jurisdictions that may be more suitable for evaluating flare-type emission calculations for specific situations.

12. Special Topics

12.1 Lake Effects

Since AERMOD does not treat the effect of shoreline fumigation, CALPUFF in Hybrid mode is recommended. The NWP model output blended with observations in CALMET is an effective way to include the 3-D sea and land breeze effects in the meteorological fields. To properly treat the lake effects, overwater meteorological data are required. In addition, if the effects of the TIBL on the plumes are occurring at scales smaller than the CALMET grid spacing, then a sub-grid scale treatment can be invoked. This treatment requires the X, Y coordinates of one or more shorelines in a COASTLN.DAT file. The purpose of this file is to better resolve the relationship between the shoreline and source locations during periods conducive to onshore fumigation events. Further instructions on the treatment of coastline effects and the required data are found in the CALPUFF user manual (Exponent (2011)).

Shoreline fumigation only needs to be considered for stacks within 1 km of the shoreline of a large body of water. Shoreline fumigation does not occur for emissions from ground-level sources like area or volume sources.

12.2 Odour Modelling

Odour emissions may be modelled using any of the approved air dispersion models. For some odorous contaminants like total reduced sulphur (TRS), the mass emission rates are entered as g/s and the resultant concentrations output by the model are in $\mu g/m^3$. For other odorous contaminants, the concentrations are typically expressed in odour units per cubic metre (OU/m^3). For modelling purposes, multiply the OU/m^3 in the exhaust by the volumetric flow in cubic metres per second (m^3/s) to obtain emission rates in OU/s.

For screening models, multiply the calculated emission rate in OU/s by 1,000,000, so that the results are in OU/m^3 for comparison to criteria. AERMOD has the option to change the emission output factor to one so that emissions do not need to be multiplied by 1,000,000.

As odours are detected by humans and are defined as a nuisance, odour modelling should be assessed at sensitive receptors where human activities regularly occur. Examples of these sensitive receptors are listed in Appendix D.5.

The ministry has developed a set of recommended ambient odour criteria (subject to change) to be used for dispersion modelling assessment in Saskatchewan (Guo and Yu, 2011). These are presented in Table 12-1 and are based on a one-hour average time and vary depending on the land use surrounding the facility. In addition, compliance is based on achieving the criteria at a minimum of 99.5 per cent of the time.

Table 12-1: Recommended Ambient One-Hour Odour Criteria for Odour Dispersion Modeling in Saskatchewan (99.5^{th} percentile)

Odour criteria	Land Use
1 OU/m^3	Urban residential zones
2 OU/m^3	Urban commercial zones or mixed residential and commercial zones
4 OU/m^3	Industrial or restricted business zones and rural zones with mixed utilisation
6 OU/m^3	Industrial or agricultural zones with predominantly agricultural utilisation

12.3 Fogging, Icing and Plume Visibility

The possibility of fog or icing occurring due to emissions can be an issue (primarily in cold seasons) for facilities that emit large amounts of water vapour. Even though there are no air quality objectives for fog, icing or plume visibility, severe icing or fog can cause a safety hazard and may have to be considered for areas located near residents, airports or high-traffic roads.

For this type of assessment, CALPUFF with the FOG algorithm is recommended. The FOG module in CALPUFF has two modes. The Plume mode (MFOG=1) is used to determine the length and height of the visible plume due to condensation, and the Receptor mode (MFOG=2) is used to indicate whether ground-based fog or ice is occurring. To determine the length and height of visible plumes, CALPUFF is used with a single hourly meteorological data file in ISC meteorological format which includes hourly wind speed, direction, temperature, stability class and mixing height.

CALPUFF has two source preprocessors for water emissions. One for mechanically forced cooling tower plumes (CTEMISS) and one for combustion turbines (FGEMISS – Flue Gas Emission Pre-processor). Hourly emissions of water vapour and excess temperature from each cooling tower are computed by CTEMISS for the current cell configuration and ambient conditions. The FGEMISS preprocessor produces an external variable emission input file containing water emissions and temperature-dependent parameters. CALPUFF models the dispersion of these emissions and provided cloud information in a specialized format for further analysis. These preprocessors create CALPUFF-ready PTEMARB.DAT variable water vapour emission files as input to the CALPUFF-ISC fog model. Note, these preprocessors can work only with the Schulman-Scire building downwash algorithm.

12.4 Particle Deposition Size Fraction

Particulate matter can be emitted from a variety of sources including stacks emissions, open burning, coal piles, road dust and vehicle emissions. On some occasions, stack sampling reports or manufacturer's specifications have provided a particle size distribution, which can be used in modelling. If the particulate matter is just reported as total suspended particulates (TSP), there are options to identify size fractions. Typically, the TSP contains a high portion of $PM_{2.5}$ from the combustion source and a very low portion of $PM_{2.5}$ from crustal emissions like road dust or coal piles. The U.S. EPA AP42 has information on emission factors to use for various sources to help determine the particulate size distribution. These size distributions are typically in three categories: fine particulate matter ($\leq PM_{2.5}$), coarser matter smaller than 10 µm ($> PM_{2.5}$ and $\leq PM_{10}$) or coarser matter ($> PM_{10}$).

To properly assess the impact of particulate ($PM_{2.5}$, PM_{10}, and TSP), it is necessary to first determine the particle size distribution and then the aerodynamic properties of particle size. Both AERMOD and CALPUFF can model particulate deposition for a range of user-specified particulate sizes, mass fractions and densities. With this option, a range of particle size categories is required along with information such as corresponding mass fractions and particle densities.

To determine the aerodynamic profiling by mass, use the following (Lawrence, 2012).

For AERMOD, it is necessary to first define the mass fraction. For this problem, a table of input values for particulate modelling is as follows:

Table 12-2: PM Granulometry distribution for seven PM species (particle density 1g/cm³)

PM Species	Size Range (µm)	Mean Particle Diameter (µm)	Mass Fraction	Mass Emission Rate (g/s)
P1 ($PM_{2.5}$)	0.50 - 0.75	0.625	0.1400	1.400
P2 ($PM_{2.5}$)	0.75 – 1.00	0.875	0.1400	1.400
P3 ($PM_{2.5}$)	1.00 – 1.25	1.125	0.1400	1.400
P4 ($PM_{2.5}$)	1.25 – 2.50	1.875	0.1400	1.400
P5 (PM_{10})	2.50 – 6.00	4.250	0.0885	0.885
P6 (PM_{10})	6.00 – 10.00	8.000	0.0885	0.885
P7 (PM>10)	> 10.00	20.000	0.2630	2.630

Where:
$PM_{2.5}$ (mass) = (P1 + P2 + P3 +P4).
PM_{10} (mass) = $PM_{2.5}$ (mass) + (P5 + P6), and
TSP (mass) = PM_{10} (mass) + P7.

The mass fraction for the different diameter bins associated with a particular PM species is assumed to be distributed uniformly.

For the CALPUFF model, it is recommended to use the information in Table 12.3 for deposition calculations.

To set the mass fraction in each diameter bin associated with a particular PM species to be distributed uniformly, the geometric sigma in CALPUFF is set to zero. CALPUFF uses the number of species size categories as input and ignores the number of categories as specified in the number particle size intervals (NINT) option. Concentrations for $PM_{2.5}$, PM_{10} and TPM can be calculated at the post-processing stage using CALSUM or POSTUTIL by adding the relevant PM size categories.

Both AERMOD and CALPUFF by default assume a particle density of 1 g/cm³. This should not be changed unless the proponent is modelling a source where the particle density is known to be considerably denser than the default value (e.g. a hard rock mining operation where particles can have a density as high as 5 g/cm³; Uranium operations may have densities as high as 10 g/cm^3 or more). To overcome this issue, pseudo particle parameterizations should be established. This can be done by retaining the geometric standard deviation at 1.242 µm and the NINT set to 5, but adjusting the geometric mean diameter to simulate how a particle would react if it had a density of 1 g/m^3 but maintaining the mass for a heavier particle (Lawrence 2012). Table 12.3 provides illustrative modifications to the input that would be required to model particles which have a significantly high density.

Table 12-3: Adjusted particulate diameter based on density

Particle density (g/cm^3)	Geometric mean diameter (µm)		
	$\leq PM_{2.5}$	$>PM_{2.5}$ and $\leq PM_{10}$	$>PM_{10}$
0.5	0.87	3.52	14.13
1	1.25	5.00	20.00
2	1.79	7.09	28.31
3	2.20	8.70	34.68
4	2.55	10.05	40.05
5	2.86	11.25	44.79

Where $< PM_{2.5}$ represents fine particles (P1 to P4 in Table 12.2) and $> PM_{10}$ represents the very coarse particles (P7 in Table 12.2), the use of a non-default particle density should be noted in the assessment and the justification as to why the non-default values were used.

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GLOSSARY OF TERMS

AERMAP:	The terrain preprocessor for AERMOD. AERMAP allows the use of digital terrain data in AERMOD.
AERMET:	The meteorological preprocessor for AERMOD.
AERMIC:	The joint work committee between the American Meteorological Society (**A**MS) and the U.S. **E**nvironmental Protection Agency (U.S. EPA), **R**egulatory **M**odel **I**mprovement **C**ommittee
AERMOD:	Short-range air dispersion model developed by AERMIC that incorporates planetary boundary layer theory and advanced methods for handling complex terrain. It is the Saskatchewan Ministry of Environment's recommended air dispersion model.
AERSCREEN:	A Screening model based on AERMOD that produces estimates of concentrations without the need for a representative set of meteorological data.
Air Emissions:	Contaminants released from a source into the air.
Albedo:	A portion of the incoming solar radiation reflected and scattered back to the atmosphere, which is an input data to AERMET.
Ambient Air:	The portion of the atmosphere surrounding a pollution plume in the study which is not enclosed in a building or structure.
AMS:	American Meteorological Society.
Approved Model:	The air dispersion model identified in this report as a preferred model to be used in Saskatchewan.
Block Average:	The average of a set of data calculated every Nth hour where N is the averaging period. The number of averaging periods in a day is 24/N.
Bowen Ratio:	The ratio of sensible heat to latent heat transport from the ground to the atmosphere.
CAAQS:	**C**anadian **A**mbient **A**ir **Q**uality **S**tandards
CALPUFF:	An advanced, non-steady-state puff dispersion model for assessing long-range transport of contaminants.
Calm:	In the Province of Saskatchewan (the province), CALM is defined as the weather condition where the wind speed is below 0.5 m/s.

CCME:	The **C**anadian **C**ouncil of **M**inisters of the **E**nvironment is an inter-governmental organization in Canada with members from the federal government, ten provincial governments and three territorial governments.
CDED:	**C**anadian **D**igital **E**levation **D**ata. Digital terrain files containing elevations covering Canada, typically at a consistent interval.
Complex Terrain:	Terrain exceeding the height of the stack being modelled.
DEM:	**D**igital **E**levation **M**odel. Digital terrain files containing elevations across a standard region typically at a consistent interval.
Dispersion Model:	A group of related mathematical algorithms used to estimate (model) the dispersion of contaminants in the atmosphere due to advection by the mean (average) wind and mixing by atmospheric turbulence (including both mechanical and thermal).
Emission Factor:	Calculation of the rate of release of contaminants to the atmosphere, typically based on a product production rate or a raw material consumption rate.
Flagpole Receptor:	Any point modelled that is located above ground level.
Inversion:	Any layer of the atmosphere where there is a vertical restriction of a parcel of air. In most cases, it is due to an increase in ambient air temperature with height.
ISCST:	**I**ndustrial **S**ource **C**omplex – **Short-Term** dispersion model. The old air dispersion model, which preceded AERMOD.
Lee side:	Side of a building or mountain, which is sheltered from the wind.
Mixing Height:	The height of the layer above the ground to which the lower atmosphere will undergo mechanical or turbulence mixing, producing a nearly homogeneous air mass.
Monin-Obukhov Length:	The height at which turbulence is generated more by buoyancy than by wind shear. The Monin-Obukhov Length has a negative sign under unstable conditions (upward heat flux) and is positive for stable conditions and approaches infinity as the actual lapse rate reaches the dry adiabatic lapse rate.
NWS	**National Weather Service:** A US government organization associated with the National Oceanic and Atmospheric Administration
$PM_{2.5}$	Particulate matter less than 2.5 micrometres per cubic metre. Also known as fine particulate matter.

PM_{10}	Particulate matter less than 10 micrometres per cubic metre. Also known as fine particulate matter.
Primary Contaminant:	Substance emitted from the source which does not break down or form other compounds.
Receptors:	User-defined spatial points used in the modelling exercise to determine concentrations of contaminants emitted from a source.
Running Average:	The average of a set of data over a period calculated for each hour in the database. The number of averaging periods in a day is 24. Also known as the rolling average or moving average.
SAAQS:	**S**askatchewan **A**mbient **A**ir **Q**uality **S**tandards. envrbrportal.crm.saskatchewan.ca/Pages/SEQS/Table20-SEQS-SAAQS.pdf.
Secondary Contaminants:	Pollutants which are formed after contaminant release from a source (e.g. reacting with other contaminants or with sunlight).
Screening Models:	A relatively simple analysis technique to determine if a given source is likely to pose a threat to air quality. Concentration estimates from the screening model are typically conservative.
Sensitive Receptors:	Points in a modelling domain which may require special attention or analysis. These may include, but are not limited to, residential areas, individual residences, schools, hospitals, commercial daycares and senior centres, parks, recreational areas, monitoring sites, endangered species and sensitive ecosystems.
Simple Terrain:	An area where terrain features are higher in elevation than the based on the stack but lower in elevation than the top of the stack of the source.
Surface Roughness Length:	The height above ground at which the wind speed theoretically becomes zero.
TSP	Total suspended particulate matter. Small particles that remain suspended in the air for an extended period.
Upper Air Data (soundings):	Meteorological data obtained from balloon-borne instrumentation or computer-generated prognostic model that provides information on pressure, temperature, humidity and wind at certain elevations above the surface of the earth.
U.S. EPA:	United States Environmental Protection Agency.

APPENDIX A
A. Brief Description of Approved Models

A.1 AERSCREEN

AERSCREEN is a single-source screening-level air quality model developed jointly by U.S. EPA and state modellers along with contractor support (U.S. EPA, 2021). AERSCREEN is an interactive command-prompt application that interfaces with MAKEMET for generating a matrix of meteorological conditions that represents a wide range of possible conditions and interfaces with the AERMOD model utilizing the SCREEN option to perform the modelling runs. If needed, it can interface with the program called AERMAP to automate the processing of terrain and the program called BPIPPRM to automate the processing of the building information.

The benefits of AERSCREEN as a screening model:

- AERSCREEN utilizes all the advantages of BPIPPRM used for building wake effects.
- AERSCREEN provides three options for generating the screening meteorology allowing for site-specific and seasonally varying surface characteristics for land classifications; and terrain details for the whole modelling domain are used in one run rather than each specific direction.
- AERSCREEN includes conversion factors to estimate "worst-case" three-hour, eight-hour, 24-hour and annual concentrations (1.0, 0.9, 0.6, 0.1, respectively) (U.S. EPA, 2021). For area sources, the 3, 8, and 24-hour average concentrations are equal to the 1-hour average, and no annual average concentration is calculated.
- AERSCREEN performs error checks on AERSCREEN inputs, AERMOD output and/or AERMAP output.
- AERSCREEN has several options to model NOx to NO_2 conversion, the option to adjust surface friction velocity based on AERMET algorithms, as well as inversion break-up and shoreline fumigation.

Inputs or options to AERSCREEN are:

- Physical properties for point, rectangular area, circular area, volume, capped stack, horizontal stack or flare sources;
- Building downwash information for point, capped stack, horizontal stack, and flare sources;
- Source elevation or terrain heights for sources and receptors via AERMAP;
- Minimum and maximum temperatures for MAKEMET;
- Minimum wind speed and anemometer height for MAKEMET;
- Surface characteristics for input to MAKEMET by the following methods:
    - user-specified surface characteristics – albedo, Bowen ratio, and surface roughness (no temporal or spatial variation),
    - seasonally varying surface characteristics for generic land use classifications based on Tables 4-1, 4-2, and 4-3 of the AERMET User's Guide (U.S. EPA 2022(a)) or,
    - Values listed in an external file, either an AERSURFACE output file or surface characteristics listed in an AERMET stage 3 input file.
- Minimum and maximum downwind distance for receptors to be modelled or discrete distances for receptors;
- A defined flagpole height;
- Urban/rural source classification, and urban population if urban source;
- Fence line distance for receptors.

The AERSCREEN program is currently limited to modelling a source.

A.2 AERMOD

AERMOD is a regulatory straight-line, steady-state Gaussian plume dispersion model specially designed by AERMIC (American Meteorological Society/EPA Regulatory Model Improvement Committee) to support the U.S. EPA's regulatory modelling programs (Cimorelli et al., 2005; U.S. EPA, 2022(b); Paine et al., 2003; Cimorelli et al., 2004). AERMOD was developed to replace the Industrial Source Complex Model-Short Term (ISCST3) as U.S. EPA's approved model. AERMOD is a multi-source air dispersion model that incorporates concepts such as planetary boundary layer theory and advanced methods for handling complex terrain. AERMOD has many input options, and those are described further throughout this document as well as the AERMOD user's manual (U.S. EPA 2022(b)). AERMOD consist of three components: AERMET which processes available meteorological data (U.S. EPA, 2022(a)); AERMAP which processes terrain data to produce terrain base elevations for receptors and sources (U.S. EPA, 2018); and AERMOD: which calculates the concentrations.

AERMOD can incorporate the Plume Rise Model Enhancements (PRIME) building downwash algorithms, which can enhance plume dispersion coefficients due to the turbulent wake and reduce plume rise caused by a combination of the descending streamlines in the lee of the building and the increased entrainment in the wake (Schulman et al., 2000). BPIP (Building Profile Input Program) should be used to generate the necessary PRIME downwash parameters which then form part of the input file for AERMOD.

The improvements of AERMOD over the ISCST3 model are:

- AERMOD requires two types of meteorological data files; a file containing surface scalar parameters and a file containing vertical profiles. These two files are generated by the U.S. EPA AERMET.
- For applications involving elevated terrain, the user must also input a hill height scale along with the receptor elevation. The U.S. EPA AERMAP program can be used to generate hill height scales as well as terrain elevations for all receptor locations providing a more realistic treatment of terrain impacts.
- AERMOD incorporates non-Gaussian plume shapes where appropriate where dispersion is a function of horizontal and vertical turbulence that varies with height.
- It tracks any plume mass that penetrates the elevated stable layer and then allows it to re-enter the boundary layer if appropriate.
- The impact of urban heat islands on turbulence is considered.
- AERMOD has a routine for processing averages when calm winds or missing meteorological data occur.
- It contains algorithms for modelling the effects of dry deposition of large particles and for modelling the effects of wet deposition for gases or particulates.
- There are output options specifically for comparing model results to the 24-hour $PM_{2.5}$, 1-hour NO_2 and 1-hour SO_2 CAAQS (CCME, 2020(a) and 2002(b), respectively). The 1-hour NO_2 and SO_2 standards are based on ranked values from the distribution of daily maximum 1-hour averages. When these contaminants are specified in the model inputs the methodology (based on the National Ambient Air Quality Standard) is set as default and may have to be physically disabled by the user if SAAQS are considered in an assessment.

Over complex terrain, AERMOD relies on a plume splitting algorithm to estimate the amount of plume that will be transported over this terrain. The portion of the plume that is trapped on the windward side

of the terrain is dispersed assuming a horizontal dispersion coefficient that is symmetric. This may not be accurate under certain meteorological conditions and the effects of the dispersion of the windward component of the plume may not be properly assessed. Because of this, it is preferable to use the CALPUFF model for assessments that involve complex terrain.

Additional details on AERMOD model formulations and options can be found in the AERMOD User Manual (U.S. EPA, 2022(b)), as well as the Revisions to the Guidelines on Air Quality Models (U.S. EPA, 2017).

AERMOD has options to output results in different ways, depending on the needs of the user. The following is a brief description of some of the options in AERMOD.

Tabular Results
The model predictions can be generated in tabular format using the RECTABLE and MAXTABLE keywords in the output. The RECTABLE keyword provides the highest, second-highest third-highest values, etc., by receptor. The MAXTABLE keyword provides a table of the overall nth highest concentrations, regardless of if these occur at the same receptor in multiple instances (i.e., on different days). For both keywords, the user has additional flexibility to specify for which averaging times the outputs are selected. For the MAXTABLE keyword, the user can also specify the number of overall maximum values (i.e., "MAXTABLE 24 10" for the top 10 values for the 24-hour averages) to summarize each averaging time selected.

Plot Files
The PLOTFILE keyword is used to generate a file that contains the maximum value or the nth highest value at each receptor included in the model inputs, for the specified averaging time. These files are mostly used to generate contour plots of the high values for graphical presentation (e.g., plots of 1-hour maximum NO_2 concentrations in the model domain). Plot files can also be imported into a spreadsheet program to easily identify the overall predicted maximum value in the model domain.

Plot files can also be generated to present the maxima for individual source groups (SRCGROUP).

Post Files
AERMOD has the option of using post files (POSTFILE) to output the model predictions for every hour in the meteorological data set at every receptor specified in the model inputs. These files are very useful for showing the time-varying trends in the model predictions at specific receptors. However, because they include all the model results, post files can be extremely large (i.e., five years of meteorological; data for just 100 receptors will use about 18 MB of disk space). It is recommended that post files be used at selected receptor locations, or over short durations or specific days. Post files can be specified to provide the hourly concentrations for all hours in the five-year meteorological period at a specific sensitive receptor, or to provide the hourly concentrations on a specific day at all receptors. POSTFILE can be used when comparing modelling results with monitoring results, or for a specific air quality event that occurred.

Threshold Files
Threshold violation files (MAXIFILE) can be specified to keep an account of exceedances of a user-specified concentration threshold. The date of the occurrence, the coordinate and the model-predicted concentration that is above a specified threshold are stored in the MAXIFILE for each occurrence. These files are useful for assessing the frequency of exceedances at specific receptor locations and are required for running the EVENT model in AERMOD. The EVENT model is used to complete source

contribution assessments of these exceedances. However, it should be noted that this option can produce large files if the runs have many receptors and there are a significant number of exceedances of the threshold.

Daytime Maximum Files

The CAAQS for SO_2 and NO_2 are based on the maximum hourly concentrations for each day. The MAXDAILY is an option to output daily maximum 1-hour values for each day processed. The MXDYBYYR provides an option to output data of daily maximum 1-hour values by year, for each year processed. Both options are only applicable for NO_2 and SO_2.

Source Grouping

In AERMOD when modelling is performed for several individual sources (i.e., point, volume, area or line) the use of source groups enables modelling results to be output for a specific group of sources. AERMOD automatically places the cumulative results from all sources into a group called ALL. Analysis of specific groups of sources may be performed by using the SRCGROUP option. Source groups enable modelling results that can be generated for specific groups of one or more sources. One example may be to assign each source to a separate source group to determine the different extent of effects from each source. This approach provides the maximum value for each source group, which may occur during different hours or days. As a result, this approach should not be used to attempt to assess the contribution of individual sources, unless the model is run for a specific hour or day in the meteorological data. For regulatory purposes, the ministry requires the use of the source group "ALL" in AERMOD, which considers all the sources at the same time.

A.3 CALPUFF

CALPUFF model is a multi-layer non-steady state Lagrangian puff dispersion model and includes three main components: CALMET, CALPUFF and CALPOST. CALMET is a meteorological model that develops a three-dimensional gridded modelling domain for the hourly wind and temperature fields based on terrain and land use information. CALMET has the option to use the output generated by a gridded numerical weather prediction model (e.g., WRF – Weather Research and Forecasting model). Typically, the spacing of the CALMET grid used in the modelling domain should be of the order of $1/10^{th}$ of the dimension of the features (e.g., valleys) in that domain. CALPUFF uses the fields generated by CALMET to advect puffs of contaminants simulating dispersion and transformation along the way. CALPUFF can be used with a three-dimensional meteorological grid or with a single station. CALPOST is used to process the output files generated by CALPUFF.

The CALPUFF model treats a continuous plume as a series of puffs, so the plume can follow a terrain feature, deform, or even split apart, and it can be applied under calm conditions. CALPUFF contains algorithms that allow it to emulate AERMOD at short distances because puff models only do well at distances beyond a few kilometres. With this capability, CALPUFF can be used for short distances as well as long-range transport as far as 300 km.

The CALPUFF model can be run in different modes, which reflect the source of input meteorology used for CALMET processing. There are many options and switches that can be used in both CALPUFF and CALMET. Ministry recommendations for specific options/switches are provided in Appendix I.

APPENDIX B
B. Methods Used to Estimate Emission Rates

As part of the modelling assessment, emission rates for sources to be modelled must be determined. The accuracy of a dispersion model is strongly dependent on the input data that is provided for the model. In many cases, companies prefer to have a higher emission limit than what is expected for a certain type of equipment. The high limit helps prevent the facility from being out of compliance due to problems that may develop with a source, and it allows companies to easily increase emissions in case of productivity increases at a later date. Modelling should be done using these higher limits.

There are several methods to determine emission rates from certain processes or facilities. The usefulness of these methods will depend on whether the source is new or existing.

- **Continuous Emission Monitors (CEM)** – Large industrial facilities that emit significant amounts of air contaminants often have CEM systems on their main stacks that measure emission rates as well as exit flow rate and temperature. This can provide average flow, maximum flow and even the variation in hourly data measured, which can be used in models.

- **Equipment Manufacturer Emission Specifications** – For new facilities or new additions to existing facilities, manufacturer specifications of emission rates for certain contaminants should be available. These emission rates may be available for different loads and operating conditions. Care and professional judgement should be used if the equipment is old, has been retrofitted, modified or not operating under optimum conditions.

  NPRI (National Pollutant Release Inventory) Toolbox – Located on the Environment and Climate Change Canada web site canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/report/sector-specific-tools-calculate-emissions.html It is a compilation of information related to the generation of NPRI submission information. There is some general information on emission factors and emission estimation techniques. There are useful equations, conversion factors and example emission calculations.

  U.S. EPA AP-42 – The U.S. Environmental Protection Agency maintains a web-based clearinghouse for emission factors (epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors) as well as documentations (U.S.EPA, 2005). An emission factor relates the quantity of a contaminant released to the atmosphere with an activity rate, amount of product processed, or mass of fuel consumed. Each emission factor is given a rate (i.e., A to E) to reflect their uncertainty. The U.S. EPA use data from past source testing campaigns to develop emission factors for a variety of industrial processes, operations and types of equipment, both with and without emission controls. Any source modelled with a low emission factor rating will be limited in its value due to its large uncertainty.

  Data from a similar facility in another location. In some situations, companies may build their facility based on one design using the same emission controls and engines/turbines. These companies may already have several facilities operating and have gathered emission data from those existing facilities. Data from an existing facility with very similar controls and engines can be used to develop emission factors in the modelling exercise.

Emission Tools – There are several models available that calculate emissions using methodology that is specific to a source type. One source is the U.S. EPA Emission Estimation Tools website at epa.gov/air-emissions-factors-and-quantification/emissions-estimation-tools. For vehicle emission estimates the best program available is MOVES (Motor Vehicle Emissions Simulator) at epa.gov/moves. In most cases, the emissions assume there are no chemical transformations through the process.

Stack Sampling Data - Stack sampling data provides a snapshot in time of the emission rates from a facility. In many cases, stack sampling is done for compliance reasons and because of this, stack sampling tends to be done when the facility is operating at optimal conditions. The standard procedure is to take three one-hour samples per test and average those three to calculate an emission rate. If this data is to be used, all data for the past five years should be reviewed and the highest of the three samples per test should be used as the worse case emission rate, this would be considered the most conservative. The only exception is if one of the high values was considered an outlier due to sample errors or known process upsets, or if it is proven that emissions at the facility have improved over the last seven years due to upgrades or installation of emission controls. Additional information on stack sampling for $PM_{2.5}$ is found in Section 4.2.1.

Engineering Calculations – Emission rates can be developed from fundamental scientific principles and measurements. It can be based on operating conditions, data from literature, thermodynamics and physical properties or can be based on direct measurements that are not considered validated source tests. The use of derived formulae may be an acceptable emission rate estimating method if the approach is clearly demonstrated through documentation and references based on sound scientific and engineering principles.

For additional reference the Ontario Ministry of the Environment and Climate Change "Procedure for Preparing an Air Emissions Summary and Dispersion Modelling Report" (Ontario Ministry of Environment, 2018). This document contains information on the use of emission factors, engineering estimates and other methods of estimating emission rates and information on methods of assessing the negligibility of sources or contaminants.

APPENDIX C
C. Building Downwash Effects

For dispersion modelling, the stack heights based on Good Engineering Practice (GEP) are used to determine whether building downwash would be considered. Also, the area of influence of nearby buildings needs to be considered to determine whether emissions from the stack would be influenced by those buildings. A building is considered sufficiently close to a stack to cause wake effects when the distance between the stack and the nearest part of the building is less than or equal to five times the lesser of the building height or the projected width of the building (width of the building "seen" by the wind blowing in a particular direction).

For each building, there is a Structure Influence Zone (SIZ) in which any stack within that SIZ is potentially affected by the building wake effect and should be included in the building downwash assessment. The SIZ is determined based on recommendations for U.S. EPA (Tikvart, 1988 and 1989). Downwind from a structure, the SIZ will be 5L (i.e. Area of Influence) but only 2L upwind from a structure. For crosswind flow the SIZ will be 0.5L as shown in Figure C-1 (Ontario Ministry of Environment, 2017(a)). L is the lesser of the height or the projected width of the building. When determining potential building effects, 360 degrees of wind direction is checked to determine the SIZ for each 10 degrees wind direction sector and the stacks that may be affected by downwash.

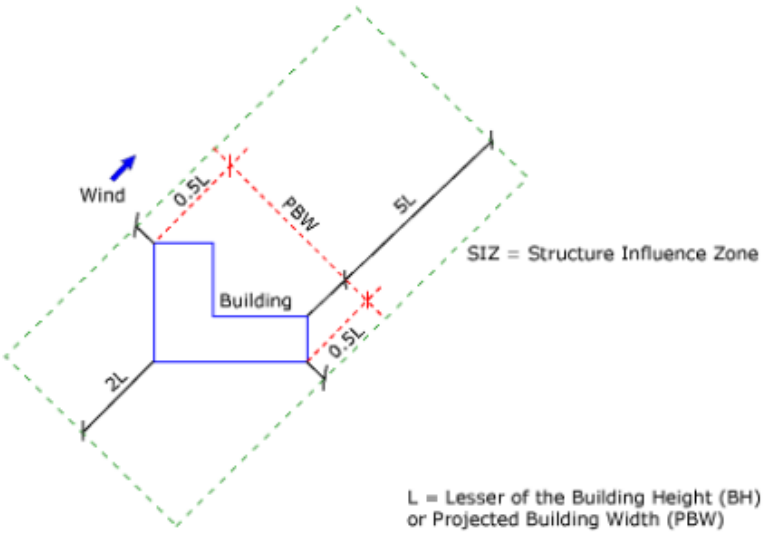


Figure C-1: Structure Influence Zone (SIZ)

C.1 Defining Buildings

To take account of local building effects, the models recommended in this guideline require information related to the dimensions and location of structures with respect to the stack. The U.S. EPA has developed a Building Profile Input Program (BPIP) for calculating downwash parameters to be used in modelling (see U.S. EPA 1995(d)). BPIPPRM is a BPIP program for PRIME (Plume Rise Model Enhancement). PRIME algorithm is the preferred method used in models to account for building downwash. The inclusion of the PRIME algorithm has generally produced more accurate results in air dispersion models compared to earlier algorithms. The improvements in PRIME include:

- Location of stacks relative to buildings is considered;
- Enhanced plume dispersion coefficients due to the turbulent wake;
- The deflection of streamlines up over the building and down the other side is considered;
- Reduced plume rise caused by a combination of descending streamlines in the lee of the building and the increased entrainment in the wake;
- The wind profile at the plume location is considered for calculating plume rise; and
- The plume captured in the recirculation cavity can be transported to the far wake downwind and treated as a volume source (Schulman, 1997).

Based on the GEP technical support document, (U.S. EPA, 1985), BPIPPRM is designed to determine whether a stack is subject to wake effects from a structure or structures. Values are calculated for GEP stack height and GEP-related building heights and projected building widths. An indication is given as to which stacks are being affected by which structure wake effects.

For multiple buildings, BPIPPRM determines building separation distances and fills in the gap between the buildings if they are sufficiently close. While BPIPPRM supports the use of tiers on a building, if there are several tiers on a single building it is often preferable to enter each tier as a separate building.

BPIPPRM uses the same input data as in BPIP, so no modification to the existing BPIP program is required. The following information is required to perform a building downwash analysis within BPIP.

- X and Y location and height (m) for all stacks;
- X and Y location for all building corners;
- Height (m) for all buildings. For building with more than one height or roofline, identify each height (tier); and
- Base elevations (m) for all stacks and buildings.

The BPIP User's Guide (U.S. EPA, 1995(b)) provides details on how to input building and stack data into the program.

In addition to the standard variables reported in the output file of BPIP (i.e., direction-specific building height (BUILDHGT) and width (BUILDWID)), BPIPPRM adds the following.

- **BUILDLEN**: Direction-specific projected length (m) of the building along the flow.
- **XBADJ**: Along-flow distance (m) from the stack to the centre of the upwind face of the projected building.
- **YBADJ**: Across-flow distance (m) from the stack to the centre of the upwind face of the projected building.

For a more detailed technical description of the U.S. EPA BPIPPRM model and how it relates to the PRIME algorithm see the Addendum to ISC3 User's Guide (Schulman, 1997).

C.2 Downwash Limitations in Models

There are several factors to consider when deciding whether BPIP or BPIPPRM should be used. One is the shape of the structures affecting the air flow and the other is the limitations of each model. The following is a brief description of how building downwash is applied to each model.

C.2.1 AERSCREEN

AERSCREEN can consider multiple buildings for a single stack. Parameters needed by AERSCREEN (U.S. EPA, 2021) for input, if downwash from only one single tier rectangle shaped building is to be accounted for, are:

- Building height (m);
- Maximum building horizontal dimension (m);
- Minimum building horizontal dimension (m);
- Orientation of maximum building horizontal dimension relative to the north;
- Angle from north of stack location relative to building centre; and
- Distance (m) between stack and building centre.

AERSCREEN has the option of reading a BPIPPRM input file for a single building. For situations where there are multiple tiers, buildings or more complicated geometries, an input file would have to be used.

An example building/stack configuration is shown in Figure C-2: AERSCREEN Building Downwash

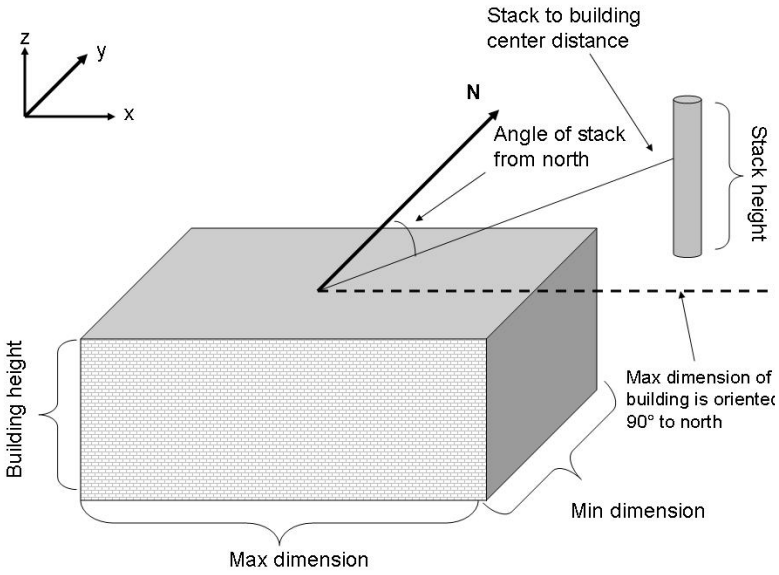


Figure C-2: AERSCREEN Building Downwash

C.2.2 **AERMOD/CALPUFF**

Both AERMOD and CALPUFF allow for the capability to consider downwash effects from multiple buildings as well as multiple stacks. It uses the same method as that used in AERSCREEN except a building need not be rectangular and may have many vertices (corners) and different tiers. This model uses direction-specific information for all building downwash cases typically at 10-degree intervals in a clockwise direction. Building downwash effects would have to be individually calculated for each stack

In most modelling cases, an output file produced using BPIP or BPIPPRM would have to be copied and pasted into the required input group for source and building information, however, there are programs available that can read the BPIP output file and write this information into the AERMOD input file.

PRIME was originally developed using a limited set of building profiles. It has been shown that in certain circumstances, particularly for complex structures, BPIPPRM may produce results that are not entirely

accurate. Studies of building downwash showed that the BPIP algorithm in the ISCST3 program performed better for buildings with an aspect ratio (building width/building height) greater than five (i.e. squat buildings) (U.S. EPA, 1997). Recent field and wind tunnel studies have shown that BPIPPRM can over-predict concentrations by a factor of 2-8 for certain building types (Petersen et al., 2017). On the other hand, there can be an under-prediction using certain building and terrain configurations (Petersen and Beyer-Lout, 2012). For a very wide and long smelter in Tennessee, it was shown that annual concentrations using AERMOD were 10 times greater than field observations (Schulman and Scire, 2012). Because building downwash can cause concentration predictions that exceed ambient standards, these estimates must be as accurate as possible.

Appendix D
D. Receptor Grid Setup Options

D.1 Multi-Tier Cartesian Grid

Cartesian receptor grids are a set of receptors that are defined by an origin with evenly (uniform) spaced receptor points in X and Y directions. Except for the use of screening models, all modelling assessments should use a Cartesian grid with pre-defined grid spacing. Since each receptor point requires computational time, it is not optimal to specify a dense network of receptors over a large modelling area. However, it is important to have a dense enough network of receptors to capture the areas of maximum impact, especially near a source where a slight change in wind direction would make a big difference in the path of the plume. As the plume travels downwind from the source, it will grow, and the extent of the area affected by the plume will increase. Therefore, the number of receptors downwind of a source could decrease resulting in a coarser grid density. This change in receptor density based on distance can be done using a multi-tier Cartesian grid. The advantage of this approach is that it gives the user a specific starting point with set criteria for the design of the receptor network and minimizes the number of receptors which directly affects model run times without sacrificing sufficient resolution to capture points of maximum impact. The following are the ministry's recommendations for determining the grid spacing based on distance from the source(s):

- 20 m receptor spacing in the general area of maximum impact and the property boundary;
- 50 m receptor spacing within 0.5 km from the source;
- 250 m receptor spacing within 2 km from the sources of interest;
- 500 m receptor spacing within 5 km from the sources of interest; and
- 1000 m receptor spacing beyond 5 km.

Figure D1 is an example of a multi-tier grid with an increased density of grid points near the site. These recommended spacing of the receptors are for guidance and will depend on several factors such as source types, distance to plant boundary (e.g., mining) or sensitive receptors. For short stacks or those facilities with significant fugitive or ground-based sources, the maximum concentration will occur near the property line. The plume has had little time to spread and may be quite narrow. The close spacing of the receptors in this area is necessary to capture the maximum concentration as the modelled concentration will change rapidly with distance from the source and from the centreline of the plume. Figure D1 also shows that the receptors within the plant boundary have been removed.

For the cases where a facility has a tall stack that is clear of building downwash, the maximum ground-level concentration will occur at some distance from the facility. The maximum concentration from a tall stack will be significantly lower than if the same mass of emissions was emitted from a shorter stack or as a fugitive source as the emissions from the tall stack are spreading in the horizontal and vertical directions as the plume moves away from the stack. The resulting ground-level concentrations from a tall source generally change more slowly with distance and a more diffuse grid will still adequately capture the maximum concentration. Additional receptors may be added to this minimum grid setup as explained in the following section.

Predefined receptor placement criteria are not optimized for all modelling conditions. For this reason, justification should be provided for any deviations from the standard grid spacing.

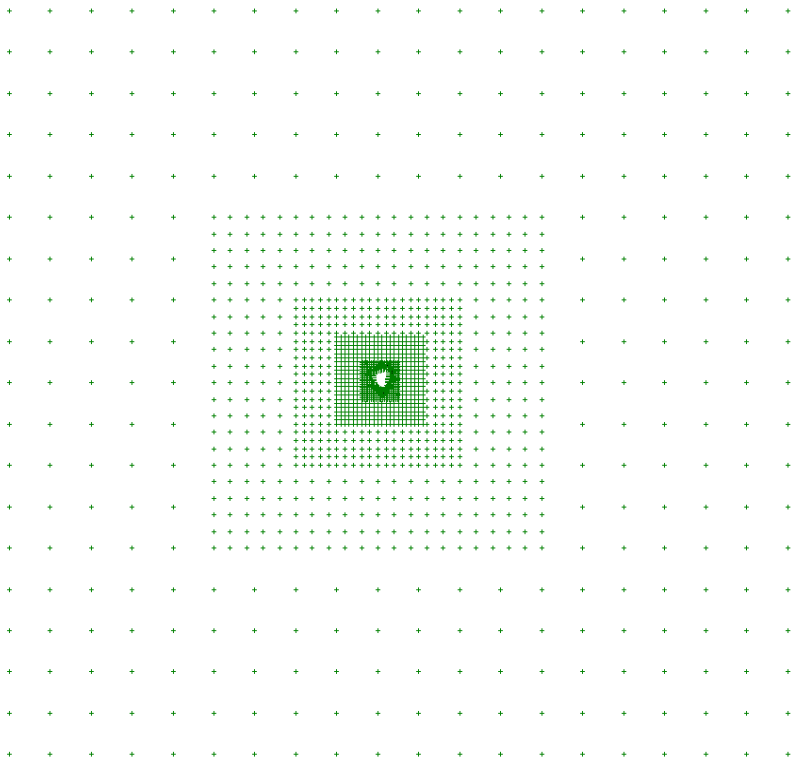


Figure D-1:Example of a Multi-Tier Grid Spacing

D.2 Cartesian Receptor Sub-Grids

In some scenarios, the model may need to be run an additional time to further refine the predictions due to the initial model showing maximum impact located in areas where there are a few receptors. Depending on the surrounding area, it may be necessary or desirable to place an additional Cartesian receptor grid, containing a finer receptor density to provide more details in that area. This can also apply to an area where there is a community or sensitive receptors, or in areas with complex terrain. The size of the additional receptor grid should be the greatest of 1 km by 1 km or large enough to sufficiently cover the area of concern. Figure D2 illustrates a sample uniform Cartesian receptor sub-grid nested inside the multi-tier grid.

The following are the ministry's recommendations for determining the grid spacing based on distance from the source(s) for areas where there are communities, sensitive receptors, complex terrain or areas of maximum impact:

- 50 m receptor spacing within 2 km from the sources of interest;
- 100 m receptor spacing within 5 km from the sources of interest; and
- 250 m receptor spacing beyond 5 km.

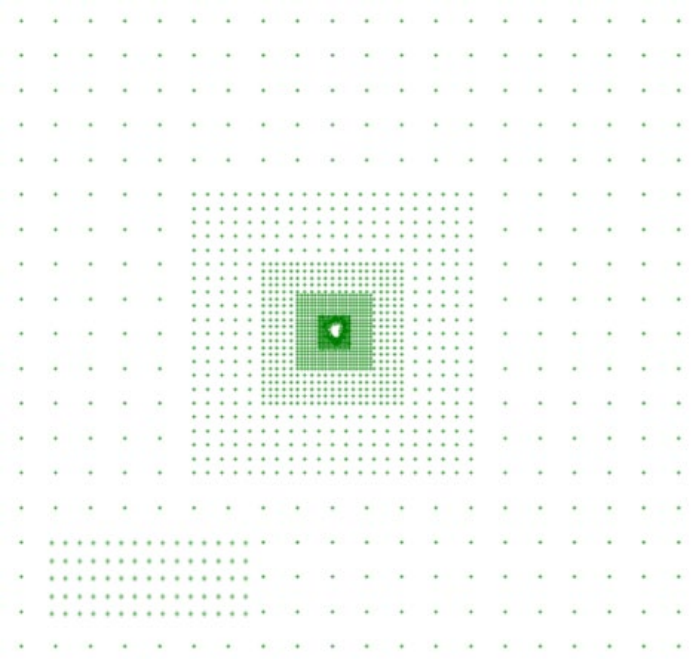


Figure D-2: Example of a Cartesian Grid Nested Inside a Multi-Tier Grid

D.3 Polar Receptor Grids

AERMOD also supports the use of polar receptor grids. These are receptor networks that are characterized by an origin with receptor points defined by the intersection of concentric rings, which have defined distances in metres from the origin, with direction radials at a specified degree spacing (typically 10 degrees). Polar receptor grids are designed primarily for single-source studies and are only suitable for cases where the maximum impact is near the facility. Unfortunately, the receptor spacing becomes too large too quickly in many studies as the distance increases from the source. This can be seen in Figure D-3

Except for screening models like AERSCREEN, the ministry does not recommend the use of polar receptors for determining compliance.

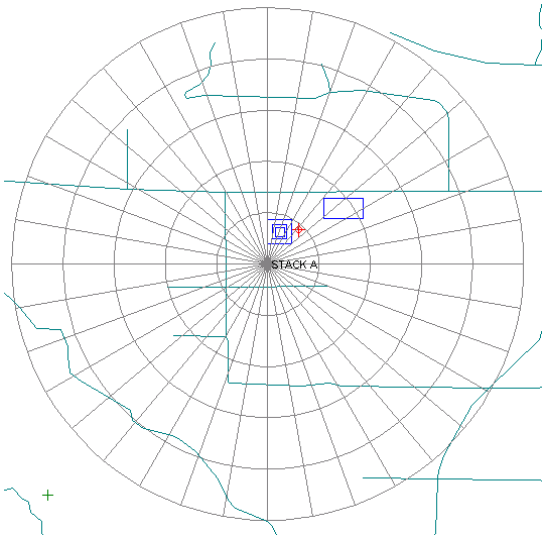


Figure D-3: Example of a Polar Grid

D.4 Fence Line Receptors

The ambient air quality objectives apply to areas where there is public access (i.e. outside of the plant boundary). The plant boundary is typically defined as the facility fence line or the perimeter of the area disturbed by the operation of the facility. The impact from receptors within the plant bound is not considered during the modelling assessment. However, some companies may choose to use those receptors for their internal assessment of their operations.

The ministry requires that receptors be placed along the fence line of the plant boundary to demonstrate compliance at the nearest possible reportable receptor to the source(s). Typically, a receptor network spaced at 20-metre intervals along the shape of the boundary is required. Figure D-4 is an example of the receptors along the fence line of the property and shows that receptors within the plant boundary were removed. This recommendation will apply to receptors along the perimeter of all public roads passing through these properties.

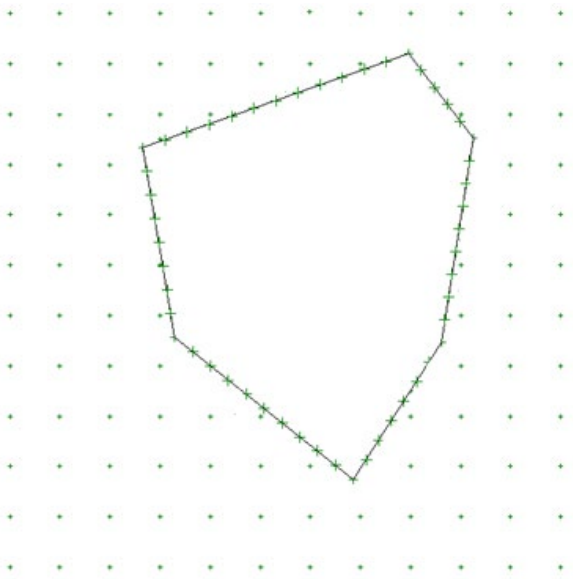


Figure D-4: Example of Fence line Receptors

The only allowed exception to the 20 m receptor spacing rule the property boundary is for very large area sources (i.e. the project boundary perimeter is larger than 50 km) where sampling at this rate will require excessive computing resources. If there are any sensitive receptors near the boundary affected by waiving the 20 m receptor spacing requirement, then the requirement for high-resolution sampling around the sensitive receptor takes precedence. All other receptor spacing rules still apply (Alberta Environment and Parks, 2021). In unusual situations, the modeller or qualified person has the option to deviate from the receptor spacing requirements where appropriate as long as adequate justification is provided.

D.5 Discrete Receptors

Receptor grids do not always cover precise locations that may be of interest in modelling projects. Specific locations of concern can be modelled by placing single receptors at desired locations. This enables the modeller to achieve data on specific points for which data is especially critical. Depending on the distance from the source, these specific points may be located several hundred metres from the nearest gridded receptor point.

Common locations of concern are known as sensitive receptors and can include, among others, the following:

- Residences;
- Schools;
- Hospitals and Health care facilities;
- Apartment buildings;
- Daycare centres;
- Air intakes on nearby buildings;
- Senior citizen's residences or long-term care facilities;
- Community and recreational centres/areas and sports facilities;
- Parks and camping grounds;
- Sensitive species; and,
- Protected species habitat.

Depending on the project resolution and location type, these can be characterized by a single discrete receptor or a series of discrete receptors. In some cases where there is an area of many discrete receptors, it may be better to use a Cartesian receptor sub-grid.

> AERMOD makes use of receptor elevation information for all terrain studies. Receptor elevation data is commonly obtained from digital terrain data in a variety of formats. The AERMOD model obtains receptor elevation and hill height values using AERMAP, its terrain pre-processor (see Appendix A). In some situations, it may be more convenient to just use all discrete receptors generate with the output being in a format like the multi-tier Cartesian grid.

There are no restrictions in AERMOD on the location of receptors relative to area sources. Receptors may be placed within the area and at the edge of an area source. AERMOD will integrate over the portion of the area that is upwind of the receptor. The numerical integration is not performed for portions of the area that are closer than 1.0 metres upwind of the receptor. Therefore, caution should be used when placing receptors within or adjacent to areas that are less than a few metres wide.

APPENDIX E
E. CDED Terrain File Set-up

Canadian Digital Elevation Data (CDED) provided by Natural Resources Canada are terrain data in USGS DEM compatible formats at scales of 1:50,000 and 1:250,000 (Government of Canada, 2007). Each file consists of gridded data of 1201 points in the east-west direction by 1201 points in the north-south direction, for a total of 1,442,401 elevation points. The differences between the two types of DEM files are as follows:

For the 1:50000 scale CDED, the post spacing is always 0.75 arc seconds along a profile in the south-north direction and varies from 0.75 to 3 arc seconds in the west-east direction, depending upon the geographic location of the cell. Over Saskatchewan, this results in a grid spacing of about 23 m in the south-north direction and a range of about 13-16 m in the west-east direction.

For the 1:250000 scale CDED, the post spacing is always 3 arc seconds in the south-north direction along a profile and varies from 3 to 12 arc seconds in the west-east direction, depending upon the geographic location of the cell. Over Saskatchewan, this results in a grid spacing of about 93 m in the south-north direction and a range of about 45-60 m in the west-east direction.

Figure E-1 shows the location of the 1:250,000 and 1:50,000 CDED terrain files for the whole province of Saskatchewan. The 1:250,000 files covering Saskatchewan are either for the grids 062-064 or 072-074 and each of those areas includes 16 additional sub-files ranging from A (bottom right) to P (top right) for a total of 51 files covering the whole province. Each one of the 1:250,000 CDED sub-files (i.e. 072G) consists of 16 sub-files of the 1:50,000 CDED terrain data ranging from 1 to 16. In all cases, the first 1:50,000 file (i.e., 073G01) starts in the bottom right of the 1:250,000 sub-file, and the last file (i.e., 073G16) ends in the top right corner of the 1:250,000 sub-file.

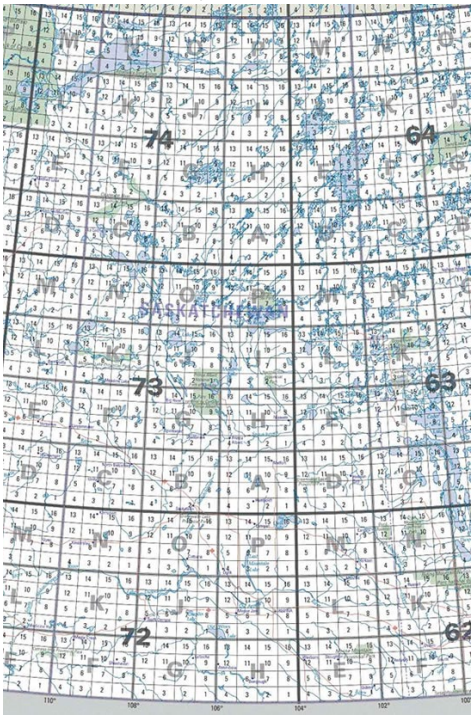


Figure E-1: CDED coordinates available for the whole province of Saskatchewan.

APPENDIX F
F. Recommended Values for Land Use Characterization

Characterization of representative land use data in the vicinity of a site is necessary to determine the appropriate surface characteristics, which govern how plumes disperse as they move away from a source. Each surface characteristic is given a numerical value in the model, which is used to determine the airflow over a terrain that would be representative of each specific land cover category. These values would vary depending on the type of land cover as well as the season. Both AERMET and CALMET have similar categories for each land type but use different codes for each type. The values used in AERMET are derived using AERSURFACE, which is based on the land type on the National Land Cover Database (NLCD) definitions. The land type category in the GEO.DAT file used in CALMET for each land type is different from that used in the User's Guide to AERSURFACE Tool. Table F.1 compares the difference in codes used in CALMET compared to NLCD.

Table F-1: Land Use Code used for each land type.

Description	CALMET land use type	NLCD Class number
Urban	10	24
Agricultural	20	81
Rangeland	30	71
Shrub	32	52
Transition Forest	40	33
Deciduous	41	41
Coniferous	42	42
Mixed	43	43
Small Water Body	51	11
Large Water Body	55	11
Wetland	60	90
Forested Wetland	61	91
Non-forested Wetland	62	92
Barren Land	70	31
Perennial Snow or Ice	90	12

Figure F.1 shows the distribution and type of land cover for the province of Saskatchewan. This data can be downloaded at the following website: geoappext.nrcan.gc.ca/arcgis/rest/services/FGP/canada_landcover_2015_en/MapServer.

An atlas of these maps can be retrieved at: atlas.gc.ca/lcct/en/index.html. A similar distribution was used to produce the Regional Meteorological Data Sets using WRF and the MMIF program.

This section includes several tables of recommended land use values based on land type and season. The values in these tables along with the information in Figure F.1 can be used in modelling. In most modelling situations, it is recommended to use the land use parameters identified in the available Regional Meteorological Data Sets.

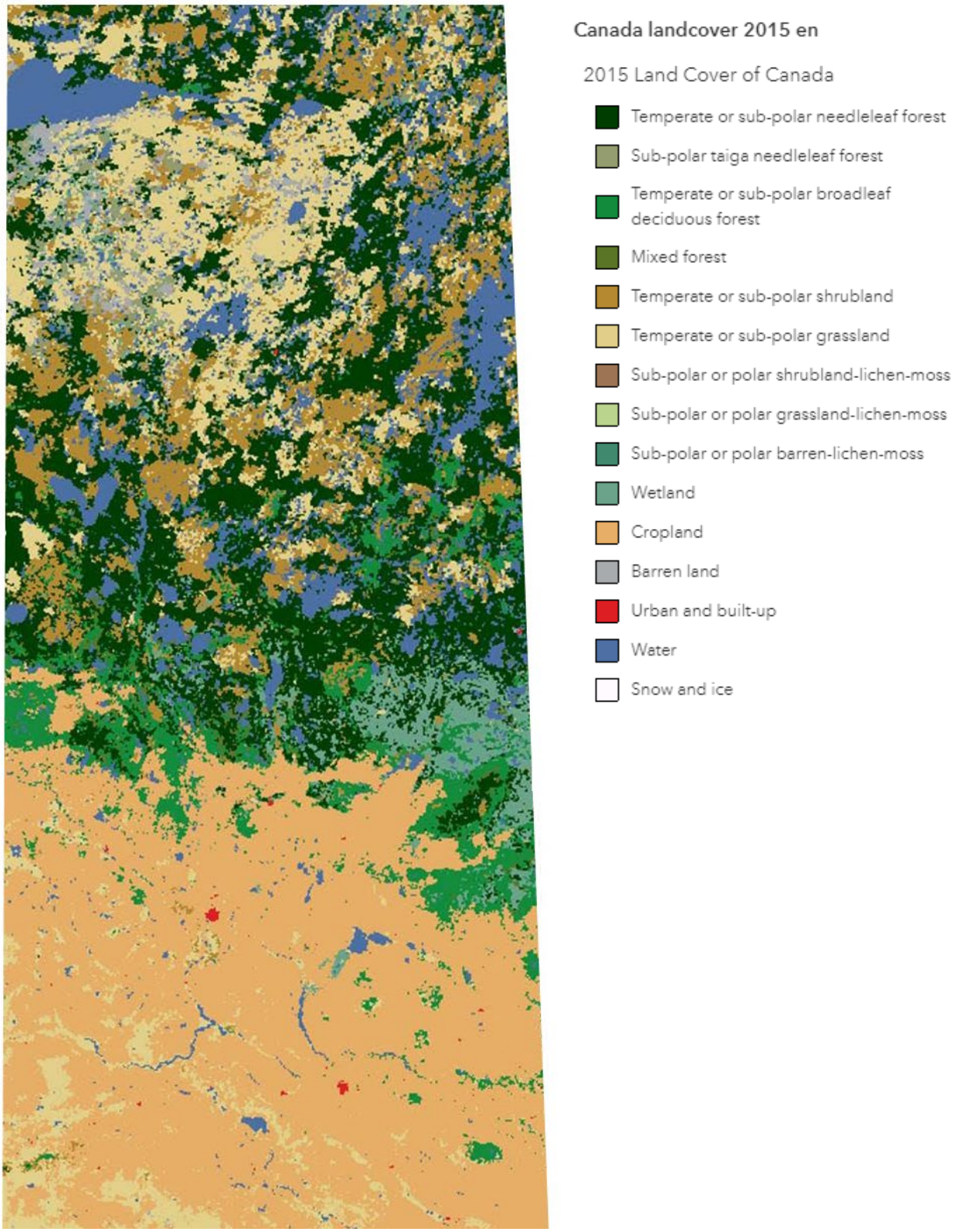


Figure F-1: Land Cover for Saskatchewan

These values are typical values based on season but may vary for each month depending on the weather in a particular year or latitude. One month may be more representative of one season for one year and another season for another year depending on the weather for each particular year. For example, snow remained on the ground a lot later in 2013 compared to 2015. Even though these tables provide values based on season, it is recommended to have monthly averages for these surface characteristics. Values should be adjusted slightly as each month transitions from one season to another.

The seasons are defined as:
1 – Wint- Late autumn after frost and harvest; or winter with very little or no snow
2 – WinS Winter with continuous snow on the ground
3 – Sprg - Transitional spring with partial green coverage or short annuals
4 – Sum - Midsummer with lush vegetation
5 – Aut - Period with unharvested cropland

Note that some values presented in Tables F.2 to Table F.4 are somewhat different from those presented in other documents like AERSURFACE User's Guide. The land characteristics in the Ministry's AERMOD-ready files were calculated based on values used in WRF. To be consistent with the WRF outputs and to avoid any conflicting parameters it was decided to use values similar to those recommended by WRF. For example, AERSURFACE recommends a surface roughness value of 1.3 m for forest areas, whereas WRF used 0.5 m as the maximum surface roughness. Using the AERSURFACE default value resulted in the daytime maximum mixing height during the winter being like that in the summer in northern latitudes.

There may be situations where values for the land use parameters need to be determined for a specific location. The following provides information on how to calculate these values. The AERMET Stage 3 input files are needed along with the revised land characteristic values to produce a new meteorological file to be used in AERMOD modelling. The Stage 3 input files are available, upon request, from the ministry. Proponents are required to explain the methodology for the determination of suitable land surface characteristics in the air quality assessment report.

F.1 Surface Roughness Length

The determination of the surface roughness length for AERMOD should be based on the land use within a three (3) kilometre upwind distance to the measurement site (U.S. EPA, 2020). This distance can be shorter for areas with high surface roughness lengths. Each land use type is given a value based on the information in Table F.2. The final value would be based on an inverse distance weighted geometric mean. The inverse distance weighted average was chosen in part due to the width of the area increases per linear sector with distance from the site. In locations where there may be several types of land use within a three-kilometre radius from a site, it may be easier to calculate a surface roughness length for different wind sectors which have the same land use rather than using a single value over the full circular area around the site. If wind sectors are chosen, the sector widths should be no smaller than 30 degrees. A different value can be applied to as many as 12 different wind sectors and none of these wind sectors should be overlapping another wind sector. These sectors must be defined in a clockwise direction from which the wind is blowing, with the north at 0°. The total sectors must cover the full circle so that the ending of one sector matches the beginning of the next sector (i.e. the beginning direction is considered a part of the sector, but the ending direction is not). Recently, a new option has been added to AERSURFACE to generate roughness length values for 16 sectors at 22.5 degrees each. As of December 2021, this option is for diagnostic purposes only and cannot be input into AERMET.

As well as having a unique surface roughness length for each wind sector, the value can vary depending on the season. The surface roughness length over a late summer crop area would be higher than that over a late winter crop area when that area is covered with snow. Table F-2 lists typical surface roughness lengths for a range of land-use types based on season. The values listed for some of the land types in Table F-2 are different from what is typically recommended in other guidelines or by the U.S. EPA (AEP, 2020, B.C. Ministry of the Environment, 2015 and U.S. EPA, 2020). For example, the surface roughness for evergreen forest in Table F-2 is 0.5 m whereas the standard value used elsewhere is 1.5 m. The values in Table F-2 were generated by WRF. The same physics that was used for calculating the surface roughness was used to calculate other parameters for AERSCREEN. It was believed that changing the surface roughness value would interfere with other parameters. A sensitivity test was done for a few sites in the forest region of northern Saskatchewan and compared to the ERA5 maximum mixing heights. Figure F-3 shows that even using values twice as high as what WRF calculated (i.e. maximum of 1.0m, lower than the default 1.3m), the daytime average maximum mixing heights were much higher and at some locations the mixing heights during the winter were as high as those during the summer. This seems to indicate that the mechanical mixing height at a higher surface roughness is more dominant than the convective mixing heights, even during the summer. This led to the decision to keep the values calculated by WRF for the surface roughness.

For AERMOD the meteorology is applied over a uniform grid covering the modelling domain. In CALMET, the meteorology will vary throughout the modelling domain based on the terrain and the type of land use. In each CALMET grid defined in the modelling domain, CALMET generates a set of meteorological conditions. Therefore, surface roughness lengths must be calculated for each of these grids. Like AERMOD, each land use type is given a value based on the information in Table F.2. A logarithmic weighting is computed for each grid based on the portion of land use type in each grid (Scire, et. al., 2000).

Table F-2: Seasonal Values of Surface Roughness (m)

	Wint	WinS	Sprg	Sum	Aut
Open Water	0.001	0.001	0.001	0.001	0.001
Perennial Ice/Snow	0.002	0.002	0.002	0.002	0.002
Developed, Open Space *	0.02	0.01	0.03	0.04	0.03
Developed, Low Intensity *	0.07	0.05	0.09	0.10	0.09
Developed, Medium Intensity *	0.30	0.20	0.30	0.30	0.30
Developed, High Intensity *	0.70	0.70	0.70	0.70	0.70
Barren Land (Rock/Sand/Clay)	0.05	0.01	0.05	0.05	0.05
Deciduous Forest	0.35	0.30	0.50	0.50	0.50
Evergreen Forest	0.50	0.50	0.50	0.50	0.50
Mixed Forest	0.45	0.40	0.50	0.50	0.50
Dwarf Scrub (Arid Region)	0.05	NA	0.05	0.05	0.05
Dwarf Scrub (non-arid Region)	0.10	0.05	0.10	0.10	0.10
Shrub/Scrub (Arid Region)	0.15	NA	0.15	0.15	0.15
Shrub/Scrub (Non-arid Region)	0.25	0.15	0.25	0.25	0.25
Grasslands/Herbaceous	0.04	0.02	0.09	0.12	0.08
Pasture/Hay	0.03	0.01	0.06	0.13	0.08
Cultivated Crops	0.04	0.01	0.07	0.14	0.09
Woody/Forest Wetlands	0.30	0.20	0.40	0.40	0.40
Shrub Wetland	0.20	0.10	0.20	0.20	0.20

* If near an airport - reduce the surface roughness length by ~50 per cent but within the range of 0.01 to 0.08 m

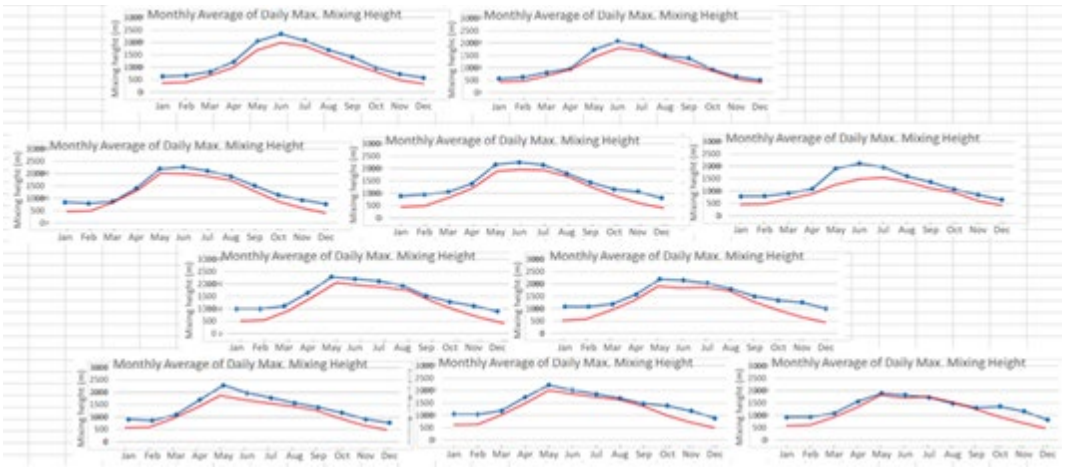


Figure F-2: Comparison of the Monthly Average of Daily Maximum Mixing Heights at sites in northern Saskatchewan using the ERA5 data and using the maximum surface roughness calculated using WRF.

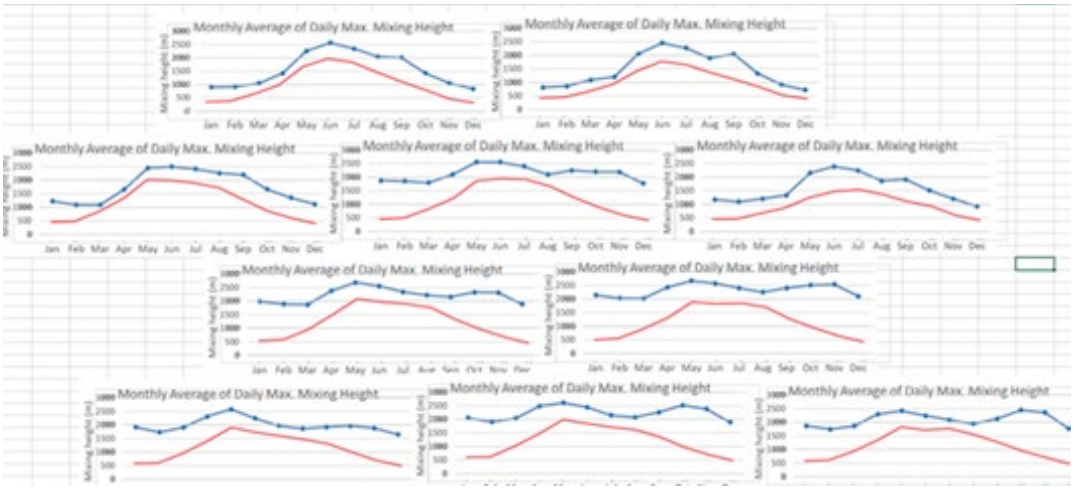


Figure F-3: Comparison of the Monthly Average of Daily Maximum Mixing Heights at sites in northern Saskatchewan using the ERA5 data and using two times the maximum surface roughness calculated using WRF.

F.2 Albedo

The ministry has compiled five years of monthly albedo values covering the province of Saskatchewan available at environment-saskatchewan.hub.arcgis.com/search?tags=air%20quality. The area covered by each value will vary depending on latitude ranging from an 11 km by 6.5 km area in the far south to an 11 km by 4.5 km area in the far north. Since it is recommended in AERMOD that the albedo should be based on a simple unweighted arithmetic mean (i.e. no direction or distance dependency) for a representative domain with a default domain defined by a 10 km by 10 km region centred on the modelling project, this data can then use as a replacement. If the modelling project is located between two or more values, then use a weighted average of those values.

Since the albedo values in CALMET are calculated for each of the grid identified in the modelling domain and those grids are typically about 1 km by 1 km, the user may wish to refer to Table F.3 to determine

the albedo at each grid location. Each land use type is given a value based on the information in Table F.3. An arithmetic weighting is computed for each grid based on the portion of land use type in each individual grid (Scire, et. al., 2000).

Table F-3: Seasonal Values of Albedo

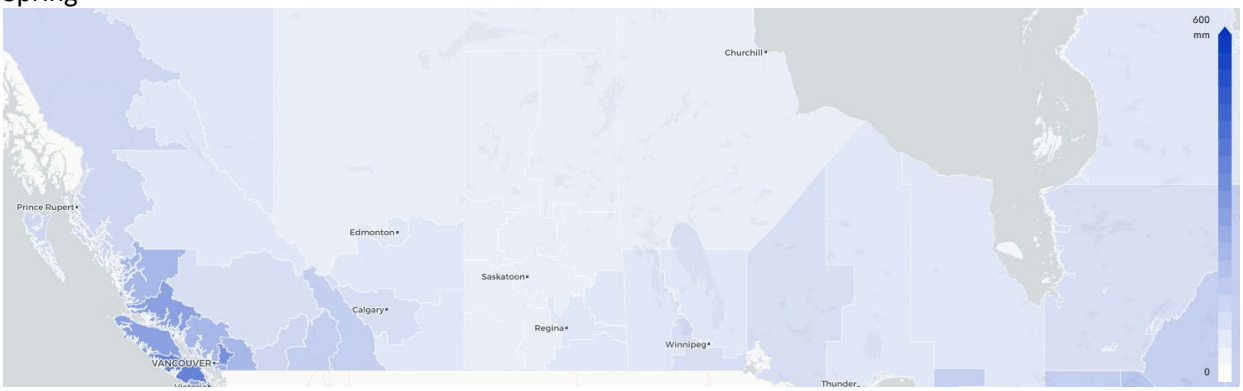
	Wint	WinS	Sprg	Sum	Aut
Open Water	0.10	0.10	0.10	0.10	0.10
Perennial Ice/Snow	0.70	0.70	0.60	0.60	0.60
Developed, Open Space	0.18	0.6	0.15	0.15	0.15
Developed, Low Intensity	0.18	0.45	0.16	0.16	0.16
Developed, Medium Intensity	0.18	0.18	0.18	0.18	0.18
Developed, High Intensity	0.18	0.25	0.18	0.18	0.18
Barren Land (Rock/Sand/Clay)	0.20	0.60	0.20	0.20	0.20
Unconsolidated Shore	0.14	0.30	0.14	0.14	0.14
Deciduous Forest	0.24	0.55	0.15	0.15	0.15
Evergreen Forest	0.18	0.40	0.11	0.11	0.11
Mixed Forest	0.21	0.48	0.13	0.13	0.13
Dwarf Scrub (Arid Region)	0.25	0.50	0.25	0.25	0.25
Shrub/Scrub (Arid Region)	0.25	0.50	0.25	0.25	0.25
Grasslands/Herbaceous	0.16	0.70	0.16	0.15	0.16
Pasture/Hay	0.17	0.77	0.14	0.16	0.18
Cultivated Crops	0.17	0.77	0.14	0.16	0.18
Woody Wetlands	0.14	0.30	0.14	0.14	0.14

F.3 Bowen Ratio

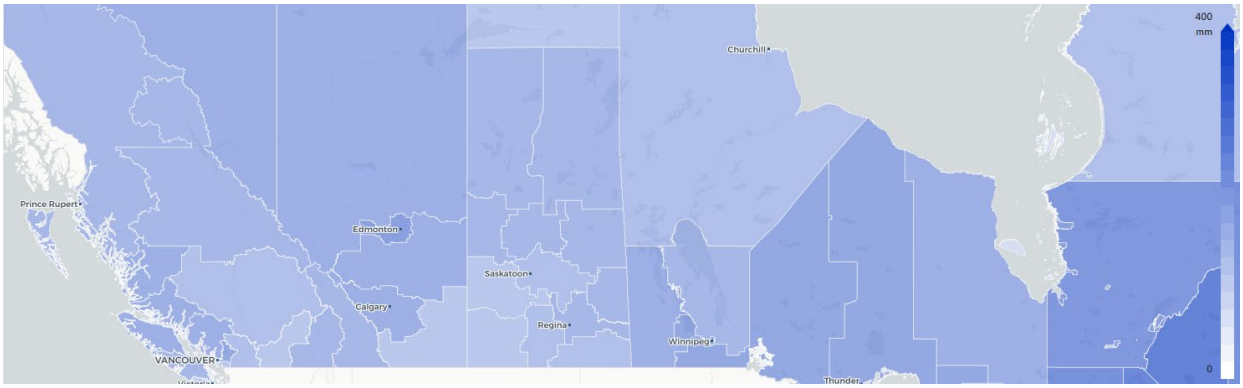
The determination of a daytime Bowen ratio for AERMOD should be based on a simple unweighted geometric mean (i.e., no direction or distance dependency) for a representative domain, with a default domain defined by a 10 km by 10 km region centred on the measurement site. Each land use type in that domain is given a value based on the information provided in Table F.4. The user should provide the rationale for the selected Bowen ratios if the ministry's recommended Bowen ratios are not used.

The Bowen ratio values listed in Table F.4 are typically higher than those recommended in AERSURFACE or other modelling guidelines. The wet period would be considered a period when the amount of precipitation is in the upper 30th percentile expected for that period and a dry period would be considered a period when the amount of precipitation is in the lower 30th percentile for that period. All Bowen ratio values used in modelling in Saskatchewan should be based on those in Table F.4.

Spring



Summer



Fall

Winter

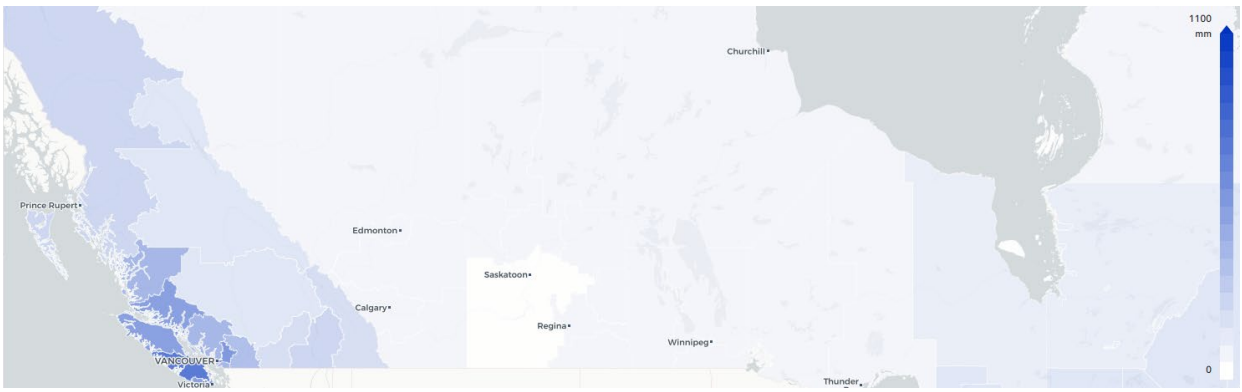


Figure F-4: Normal (1991 – 2020) rainfall expected for each health region across Canada

In CALMET the Bowen ratio must be calculated for each of the grids identified in the modelling domain. Like AERMOD, each land use type is given a value based on the information in Table F.4. An arithmetic weighting is computed for each grid based on the portion of land use type in each grid (Scire, et. al., 2000).

Table F-4: Seasonal Values of Bowen Ratio

	Average					Wet					Dry				
	Wint	WinS	Sprg	Sum	Aut	Wint	WinS	Sprg	Sum	Aut	Wint	WinS	Sprg	Sum	Aut
Open Water	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Perennial Ice/Snow	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0
Developed, Open Space	1.4	1.5	1.5	0.8	1.5	1.0	1.0	0.7	0.6	1.0	3.5	2.0	2.5	1.5	2.5
Developed, Low Intensity	1.7	1.5	1.8	0.6	1.6	1.1	1.0	0.9	0.3	1.0	3.5	2.0	3.0	1.1	2.7
Developed, Medium Intensity	1.8	1.5	2.2	0.7	2.0	1.2	1.0	1.1	0.4	1.2	4.0	2.0	3.5	1.3	3.0
Developed, High Intensity	2.2	1.5	2.5	1.1	2.4	1.4	1.0	1.4	0.6	1.4	4.5	2.0	4.5	1.5	4.0
Barren Land	2.2	1.5	2.7	1.7	2.3	1.6	1.0	1.5	1.3	1.5	4.0	2.0	4.0	3.0	3.5
Unconsolidated Shore	0.3	1.0	0.2	0.2	0.2	0.1	0.7	0.1	0.1	0.1	0.4	1.2	0.3	0.3	0.3
Deciduous Forest	1.5	2.0	1.43	0.4	1.2	0.6	1.0	0.6	0.3	0.6	2.5	2.0	1.7	0.7	2.2
Evergreen Forest	1.3	1.8	1.2	0.4	0.9	0.4	1.1	0.6	0.3	0.5	2.2	1.8	1.9	0.7	1.6
Mixed Forest	1.4	1.9	1.3	0.4	1.0	0.5	1.0	0.6	0.3	0.5	2.3	1.9	1.8	0.7	1.9
Shrub/Scrub (Non-arid Region)	2.0	1.4	1.7	1.3	1.5	1.3	1.0	1.5	1.1	1.2	4.0	1.5	3.0	3.0	4.0
Grasslands/Herbaceous	2.2	2.0	2.0	1.0	2.2	0.9	0.8	1.1	0.7	1.4	3.2	2.5	3.0	1.7	3.2
Sedge/Herbaceous	2.2	2.0	2.0	1.0	2.2	0.9	0.8	1.1	0.7	1.4	3.2	2.5	3.0	1.7	3.2
Pasture/Hay	1.4	2.0	1.5	0.5	1.6	1.0	1.2	0.7	0.3	0.9	3.5	3.0	2.5	0.9	2.5
Cultivated Crops	1.4	2.0	1.5	0.5	1.5	1.0	1.2	0.7	0.3	0.9	3.5	3.0	2.5	0.9	2.5
Woody Wetlands	0.3	1.0	0.2	0.2	0.2	0.1	0.6	0.1	0.1	0.1	0.4	1.2	0.3	0.3	0.3

The Bowen ratio in Table F-4 was determined based on guidance using observational data from studies in Saskatchewan and Alberta. These observations were based on hourly daytime values, where the definition of daytime was the period ranging from approximately three hours after sunrise to approximately three hours before sunset. Hourly values near sunrise and sunset can at times be negative resulting in very low Bowen values average for a particular month. Figure F-5 shows the diurnal pattern of the Bowen ratio values, calculated using measured sensible and latent heat flux values, for a short period from November 2018 to December 2019 at two sites near Calgary (crop and grassland) from sunrise to sunset. Values start increasing just after sunrise and peak just after noon and then steadily decrease until sunrise.

Table F-5 shows calculated monthly average Bowen ratios because on measured sensible and latent heat flux values at several sites in Saskatchewan from January 2012 to December 2016. All sites were located north of Prince Albert except for the agricultural site which was located southeast of Saskatoon. This table shows that monthly averages can be as high as nine during late winter.

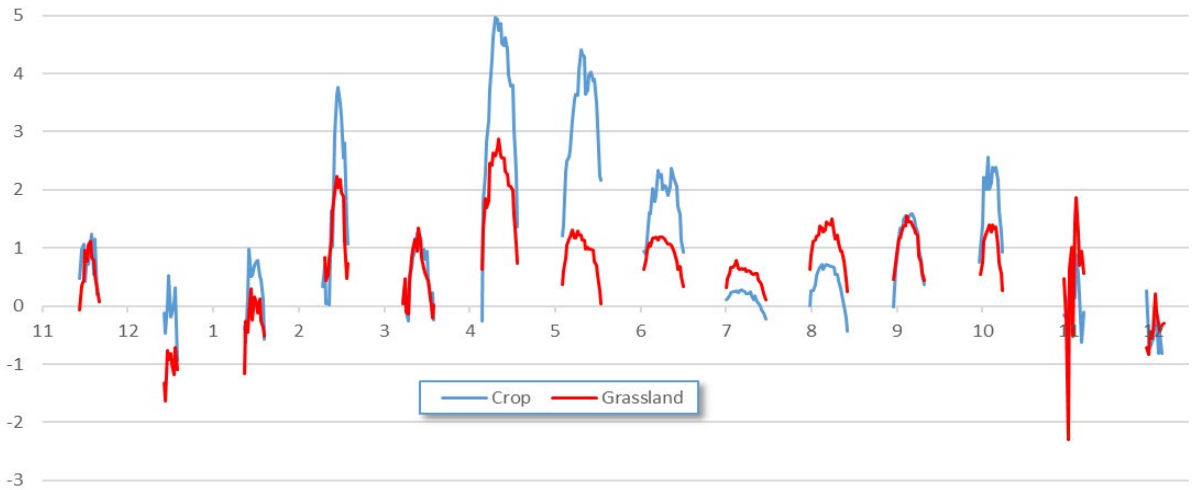


Figure F-5: Daytime Trend in Bowen Ratio at two sites near Calgary, Alberta from November 2018 to December 2019

Table F-5: Seasonal Values of Bowen Ratio

	BlackSpruce	Jackpine	Aspen	Fen	Agricultural
Jan	4.37	6.71	7.27	-0.43	2.78
Feb	7.36	9.37	9.16	0.35	2.46
Mar	8.11	9.30	7.87	0.73	1.73
Apr	6.06	6.66	5.67	0.75	2.12
May	2.87	3.85	3.11	0.68	2.09
Jun	1.52	1.83	0.87	0.61	0.85
Jul	1.10	1.37	0.43	0.46	0.44
Aug	1.04	1.55	0.41	0.56	0.57
Sep	1.36	1.82	0.83	1.12	1.68
Oct	1.80	2.14	2.85	1.75	2.15
Nov	2.57	3.73	4.31	1.54	1.69
Dec	5.34	6.56	5.61	3.38	2.41

F.4 Surface Heat Flux

The surface heat flux is only required for CALPUFF modelling. In CALMET the soil heat flux must be calculated for each of the grids identified in the modelling domain. Like the Bowen ratio approach, each land use type is given a value based on the information in Table F.5. An arithmetic weighting is computed for each grid based on the portion of land use type in each grid (Scire, et. al., 2000).

Table F-6: Seasonal Values of Soil Heat Flux

	Wint	WinS	Sprg	Sum	Aut
Urban	0.25	0.15	0.25	0.25	0.25
Agricultural	0.15	0.15	0.15	0.15	0.15
Rangeland	0.15	0.15	0.15	0.15	0.15
Shrub	0.15	0.15	0.15	0.15	0.15
Forest	0.15	0.15	0.15	0.15	0.15
Small Water Body	1.00	0.15	1.00	1.00	1.00
Large Water Body	1.00	0.15	1.00	1.00	1.00
Wetlands	0.30	0.30	0.30	0.30	0.30
Barren Land	0.15	0.15	0.15	0.15	0.15
Perennial Snow or Ice	0.15	0.15	0.15	0.15	0.15

F.5 Leaf Area Index

The leaf area index is only required for CALPUFF modelling when the deposition is a concern. In CALMET the leaf area index must be calculated for each of grids identified in the modelling domain. Like the Bowen ratio approach, each land use type is given a value based on the information in Table F.6. An arithmetic weighting is computed for each grid based on the portion of land use type in each grid (Scire, et. al., 2000).

Table F-7: Seasonal Values of Leaf Area Index

	Wint	WinS	Sprg	Sum	Aut
Urban	0.1	0	0.2	0.3	0.2
Agricultural	1	0	1	2	1.5
Rangeland	1	1	1	1	1
Shrub	0	0	0	0	0
Deciduous	0.1	0	0.8	3.4	1.9
Coniferous	5	5	5	5	5
Mixed	2.3	2.3	3.3	4.5	3.5
Water Body	0	0	0	0	0
Wetlands	0.1	0	0.1	0.2	0.2
Barren Land	0.1	0.5	0	0	0
Perennial Snow or Ice	0	0	0	0	0

APPENDIX G
G. Development of Saskatchewan Regional Meteorological Data Sets

In Saskatchewan, the recommended air dispersion model to be used for most air quality assessments is AERMOD. To expedite modelling and to provide consistency, the Ministry of Environment in Saskatchewan prepared a series of fully processed AERMOD-ready meteorological data sets for the period of January 2012 to December 2016. The latest version of the Weather Research and Forecast (WRF) model was configured to produce representative meteorological output over the province of Saskatchewan. WRF is a prognostic mesoscale meteorological model that contains separate modules to compute different processes, such as surface energy budgets and soil interactions, turbulence, cloud microphysics and atmospheric radiation. The final WRF output was processed through the U.S. EPA's Mesoscale Model Interface Program (MMIF) to convert the meteorological fields into input formats that can be read directly by the AERMOD and CALPUFF dispersion models (Ramboll Environ, 2018).

OVERVIEW

Even though MMIF can write AERMOD input files (.sfc/.pfl) directly for use with AERMOD, current U.S. EPA Guidance requires that AERMET be run. Studies have shown that AERMOD performs better when AERMET is used for most situations. To have a better understanding of the strength and weaknesses of this data, sensitivity analyses were done on both data sets. The findings concluded to use only the AERMOD files generated using AERMET. Using only one set of data helps reduce the workload and makes it more manageable in maintaining the files. As well as applying consistency to the approach in running AERMOD in Saskatchewan.

The AERMOD-ready meteorological data sets were generated using a 12 km spaced grid data, resulting in an increase of five to over 3800 available AERMOD-ready meteorological data sets in Saskatchewan (Figure G-1). Considering the lack of complex terrain over most of Saskatchewan there should be little change in the wind pattern of most adjacent sites as shown in Figure G-2 for the Estevan area, which has more complex terrain based on the river valley. Having meteorological data every 12 km for most of Saskatchewan is not necessary for most regions, so the number of stations was reduced to a more manageable size with a resolution of about 100 km.

As a first step to setting up this new database, a select number of files were available for download. The number of files was kept to a manageable size to work with in case there are problems with the meteorological input files or if the files need to be adjusted using more recently available data. Twenty sets of data were used across the province at about 100 km separation (Figure G-3). These files were chosen so that nearby terrain would not have major influences on airflow and the radius of coverage for each site would cover most of the province without having an overlap of adjacent sites. Any sites located over or near water were replaced with an adjacent site if that site was not also affected by water or other obstructions. AERMET files over water are not representative of the airflow over a location intended to be modelled.

Each location has five files zipped for free download. The zipped files include the .sfc and .pfl files used in AERMOD as well as a .kml, .png and .dat files. The .png file shows the wind rose, stability distribution, monthly total precipitation amount, monthly average daily maximum mixing heights, sensible heat flux, monthly average wind speed, temperature, and cloud cover calculated at the site. The .dat file identifies the monthly average surface roughness, Bowen ratio and albedo files which were used to generate the AERMOD-ready input files. Depending on the exact location to be modelled, there may be times when

the albedo, surface roughness or Bowen ratio are not representative of the modelled area (i.e. urban vs rural or half the modelled domain is forest, and the other half is agricultural). If the modeller believes that more representative values should be used for the modelling location, they can contact the ministry and request all the input files used to generate the .sfc and .pfl files, and reproduce these .sfc and .pfl files for their modelling domain.

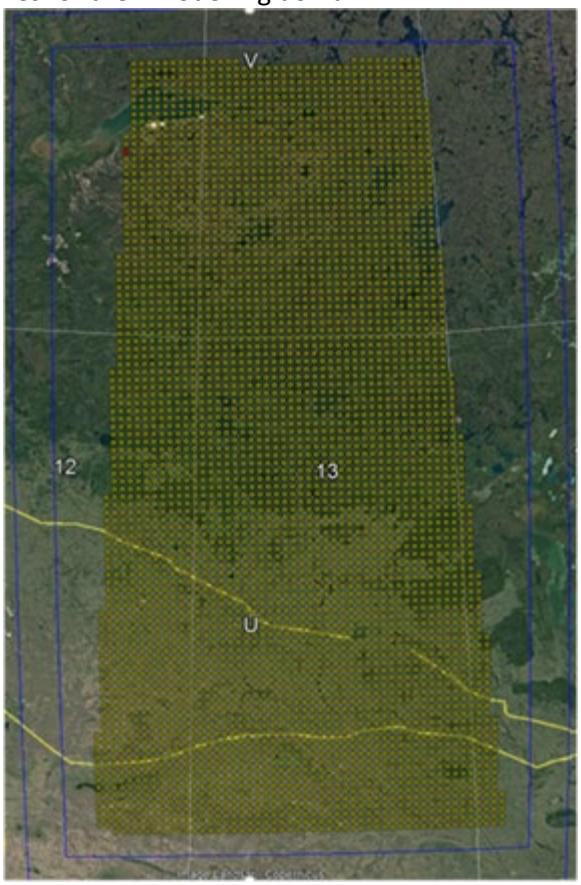


Figure G-1: AERMOD-ready meteorological files available in Saskatchewan

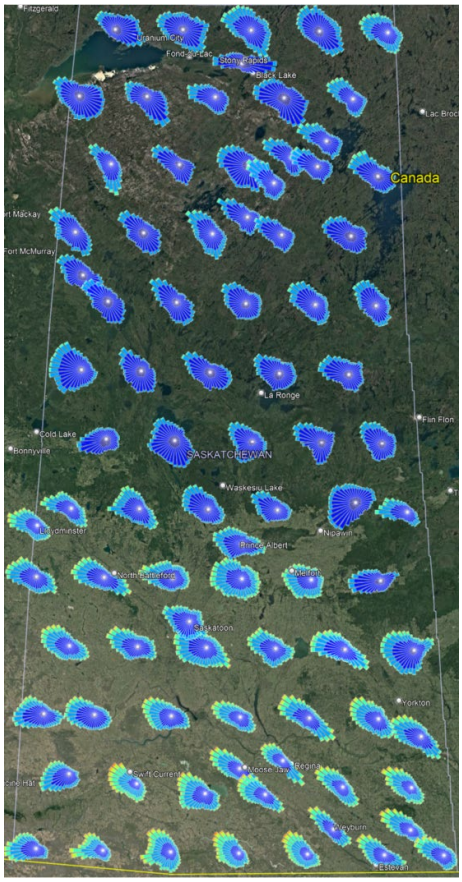


Figure G-2: AERMOD generated wind roses (2012-2016)

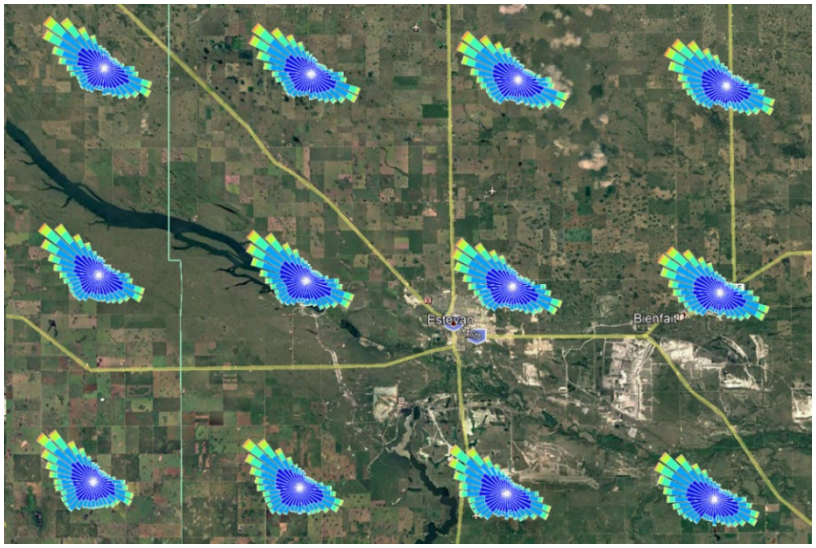


Figure G-3: AERMOD generated wind roses (2012-2016) at 12 km resolution near Estevan, Saskatchewan

There are two options to download data on the geohub.saskatchewan.ca web page. One option is to click on the "View Table" tab located in the top right of the map. The tab will display a list of all available sites to download. Click on the link next to the latitude and longitude that best represents the area to be modelled. The other option is the click on one of the dots displayed on the map. This will result in a small popup window providing additional information for that location. Click on the link labelled "Download File" to download the zipped file containing the relevant files.

Presently, there are 72 sites located approximately 100 km apart. The number of available sites will be increased depending on the complexity of the terrain, population (i.e. major urban locations) and the amount of industry activity (e.g. oil and gas activities in southeastern Saskatchewan).

The AERMOD-ready files were produced for the ministry by a third party. Several alterations were made to the files after they were received. These alterations included:

- The AERMOD-ready files were produced using the U.S. EPA regulatory default options. Before placing these files on the ministry's website, each file was reproduced using the latest version of the MMIF program, which enabled a beta option. This beta option allows for more deviation in the plume during light wind speeds and helps in the over-prediction in concentrations during these conditions.
- All light wind speeds (i.e. < 0.5 m/s), originally set to 0 m/s were changed to 0.5 m/s. Having wind speeds set to 0 m/s resulted in hours being ignored in modelling. The number of hours ignored in a year can range from 50 hours to 200 hours depending on the location and year. In most cases, the highest concentrations can occur under light wind conditions. By ignoring the hours with light winds, the model may miss some of the highest hourly concentrations and the 24-hour or annual averages will be lower than expected.
- Since the albedo of a surface can change hourly depending on the solar angle as well as the wavelength, the monthly albedo values used represent the noontime albedo in the visible spectrum. Monthly average albedo was calculated based on the amount of snow on ground predicted in the WRF files values but using data from the NASA Earth Observations website at neo.gsfc.nasa.gov/ was thought to provide more accurate results. It will also provide consistency, since monthly average albedo data for the province of Saskatchewan were taken from this web page and placed on the ministry's website at geohub.saskatchewan.ca/ to be used if the modeller believes that the existing land use data is not representative of the proposed modelling domain.
- The parameters in the .sfc file affected by changing the albedo value are only affected during the daytime when stability conditions become unstable (i.e. Monin-Obukhov Length < 0). Increasing the albedo would typically result in lower concentrations from stack source emission when considering averages longer than one hour, however, at times the maximum hourly concentrations may be higher depending on the stack parameters (Grosch and Lee, 1999). Albedo has little to no effect on maximum concentrations from sources emitted near the surface. This is due to the maximum impacts from low-level sources tend to occur at night whereas albedo only affects daytime parameters.
- The monthly average surface roughness values were calculated using the values provided in the MMMIF-generated AERMOD files, which were extracted from the WRF files. The maximum monthly average surface roughness recorded over forest areas was 0.5 m, which is much lower than the 1.3 m typically recommended for evergreen forests (U.S. EPA, 2020). Surface roughness values play a major role in the maximum predicted concentrations (Igri et al., 2011 and Meyers-Cook et al., 2010). Increasing the surface roughness usually results in higher daily and annual concentrations from stack sources, but lower concentrations from area or low-level sources (Grosch and Lee, 1999). Using the recommended value of 1.3 m as the maximum surface roughness resulted in unusual patterns in the

mixing heights, in which the maximum daytime mixing height during the winter was typically higher than those during the summer for areas in northern Saskatchewan. Therefore, the ministry recommends future modelling for forest areas to use a maximum default value of 0.5 m to be consistent with the meteorological data set available on the ministry's website.

- Bowen ratios were recalculated and readjusted, and some points with unexplained high values were removed from the database. The latest version of the MMIF program has the Bowen ratios calculated based on the daytime average rather than the daily average. However, daytime was defined as sunrise to sunset, and hourly Bowen ratios near sunrise and sunset can result in very high or low values for several hours as the latent heat flux approaches zero at those times (transitions from a negative to positive). Therefore, the Bowen ratios were recalculated to include the daytime period starting a few hours after sunrise and ending a few hours before sunset. Unfortunately, this results in using only three hours of values per day for northern sites during the winter. Another problem with the latest MMIF program is that all Bowen ratio values less than zero were converted to -1 rather than having all values <-1 converted to -1. However, this is expected to have only a minor effect on the daytime averages but may result in lower values for months when the average Bowen ratio is less than 0.5.
- Another problem with the Bowen ratio is the unexplained high values at selected grid locations. Figure G-4 shows the monthly average Bowen ratio at grid points across Saskatchewan near 51.3-degree latitude. There were several locations to the west in which the values for the Bowen ratio would increase considerably even though there was no indication of sudden changes in the vegetation. The receptor points with elevated values would have higher than average values for each month and all five years. These elevated levels occur at several latitudes but not at the same longitude and the problem appears to occur only in the southwest section of the province. The decrease in values around 105.3 degrees longitude in this figure occurred because that receptor point was located over a body of water where the dominant heat flux is the latent heat flux.

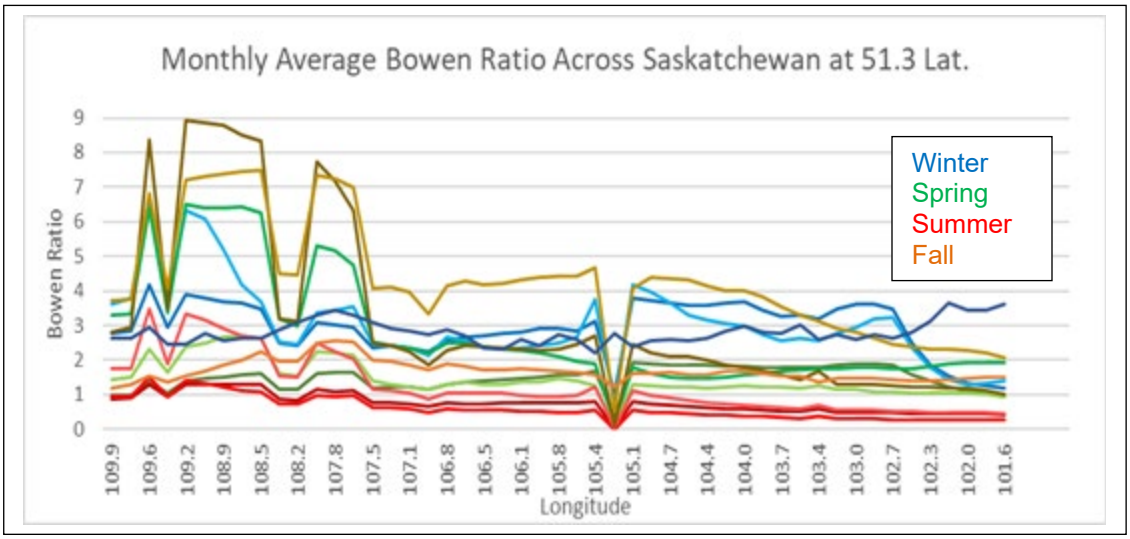


Figure G-4: Monthly Average Bowen Ratio Calculated for Receptors Across Saskatchewan at 51.3 Lat.

- Literature review as well as an examination of observational data was conducted to determine if the calculated Bowen ratio values were similar to what has been calculated based on ambient conditions (Lin et al., 2016) or observed over the Prairies. Over an agricultural area, the summer values for Bowen ratio can vary depending on the crop. Over southwestern Saskatchewan, the Bowen ratio over grasslands would range from 0.7 to 1.1 from May to October, whereas over a

wheat field, the Bowen ratio would be about 3.5 in May and drop to below 0.5 in June and July before increasing to 2.0 by mid-September (Raddatz, 1998). Another study showed areas located in the extreme southwest can have Bowen ratios as high as 2 in late May but increases to 3.5 by September, and near Saskatoon, levels can be about 1 in June and increase to 2 by September whereas agricultural regions just south of the Boreal Forest can have Bowen ratios around 0.4 in June and increasing to about 1 in September (Shrestha et al., 2012). The Bowen ratio over the Boreal Forest is also dependent on the type of vegetation. Near Prince Albert the vegetation can be mainly aspen whereas near Nipawin the forest could consist mainly of jack pine. At midday, during the summer, the aspen may have a lot of latent heat resulting in a Bowen ratio being as low as 0.13, whereas for jack pine the sensible heat tends to be to dominant heat flux and the Bowen ratio may be as high as 1.45 (Bonan, 2016). However, in other areas in the Boreal Forest over Prince Albert the Bowen ratio can range from about 0.75 in May and June to 0.85- 0.92 in July and August (Granger and Bussieres, 2005).

- The cloud cover fraction was calculated using a method which looks at the relative humidity at selected levels in the atmosphere (Angevine et al., 2012). AERMOD-ready files prepared using MIFF or AERMET did not provide representative cloud cover values when compared to surface data from airport observation sites. Since cloud cover plays an important role in the stability and hence the plume behaviour it is important to have the cloud cover represent the area as accurately as possible. The files were recompiled to read the hourly ERA5 cloud cover from the website cds.climate.copernicus.eu/cdsapp#!/search?type=dataset, which appears to be more representative of cloud cover conditions.
- The mixing heights were read from the MIFF-generated mixing heights. This resulted in over 4000 hours in five years being recorded with a mixing height between 8-10 m and the next lowest mixing height was 24 m. These low mixing heights occurred even when the wind speed was recorded up to 4 m/s. AERMET can calculate both the convective and mechanical mixing heights on its own. After the ministry received the data, the U.S. EPA shifted toward this as the best-performing option (Brashers, March 28, 2019). Using this approach and the beta option for adjustment for frictional velocity resulted in less than 200 hours with mixing heights <24 m, and less than 10 hours with mixing heights <10 m.
- For most locations in Saskatchewan, the monthly average maximum daytime mixing heights were typically less than 2200 m with, either similar mixing height throughout the summer or the highest mixing heights occurring during May and gradually decreasing throughout the summer. This height is similar to, or slightly higher than, those shown in other studies in the Prairies. More recent studies showed a similar pattern with the highest boundary layer heights for the Midwest US being slightly higher in May (1250 m) than in June (Lee and Pal, 2017). Other studies showed the Convective Boundary height to be higher ranging from 1300 m to 1900 m (Wang and Wang, 2014) or even higher, ranging from 1700 m to 2800 m (Lee and Pal, 2017 and McGrath-Spangler and Denning, 2012) depending on location.
- The Monin-Obukhov Length is used to determine the stability of the atmosphere which is used for plume behavior. The Monin-Obukhov Length originally had several minor issues. In some files, there were times in which the Monin-Obukhov Length was perfectly neutral (i.e., 8888) for 18 consecutive hours during the nighttime even when winds were less than 2 m/s. During summer, just after sunrise, the Monin-Obukhov Length would jump to 8888 at the same time the cloud cover jumped to 10-tenths. This was a bug in the program as the stability was changing from stable conditions at night to unstable conditions in the morning. No issues with the Monin-Obukhov Length were noticeable after alterations were made to the files and the updated MMIF program was used.

SUMMARY

As expected, when comparing adjacent sites most of the output parameters in the AERMOD-ready meteorological input files are consistent with little bias. There are three areas of concern when comparing adjacent sites: the cloud cover, the Bowen ratio, and the Monin-Obukhov Length. The effect those parameters have on the dispersion modelling output will depend on many factors such as the emissions parameters and the meteorological conditions. After testing two adjacent stations it was believed that the option to run AERMET to produce the meteorological data set provided better results than those produced by MMIF. To reduce confusion and issues in future modelling and to reduce the workload in preparing these files it was decided to only have one AERMOD set of files available for AERMOD modelling.

After reviewing this set of AERMOD meteorological data, it was decided to improve the accuracy when using these files by making several alterations to the data which included reading existing data like cloud cover and albedo rather than using calculated values. Readjusting the light winds help reduce the number of hours of missing data and recalculated the Bowen ratio for a shorter daytime period than what was used in the revised MMIF program.

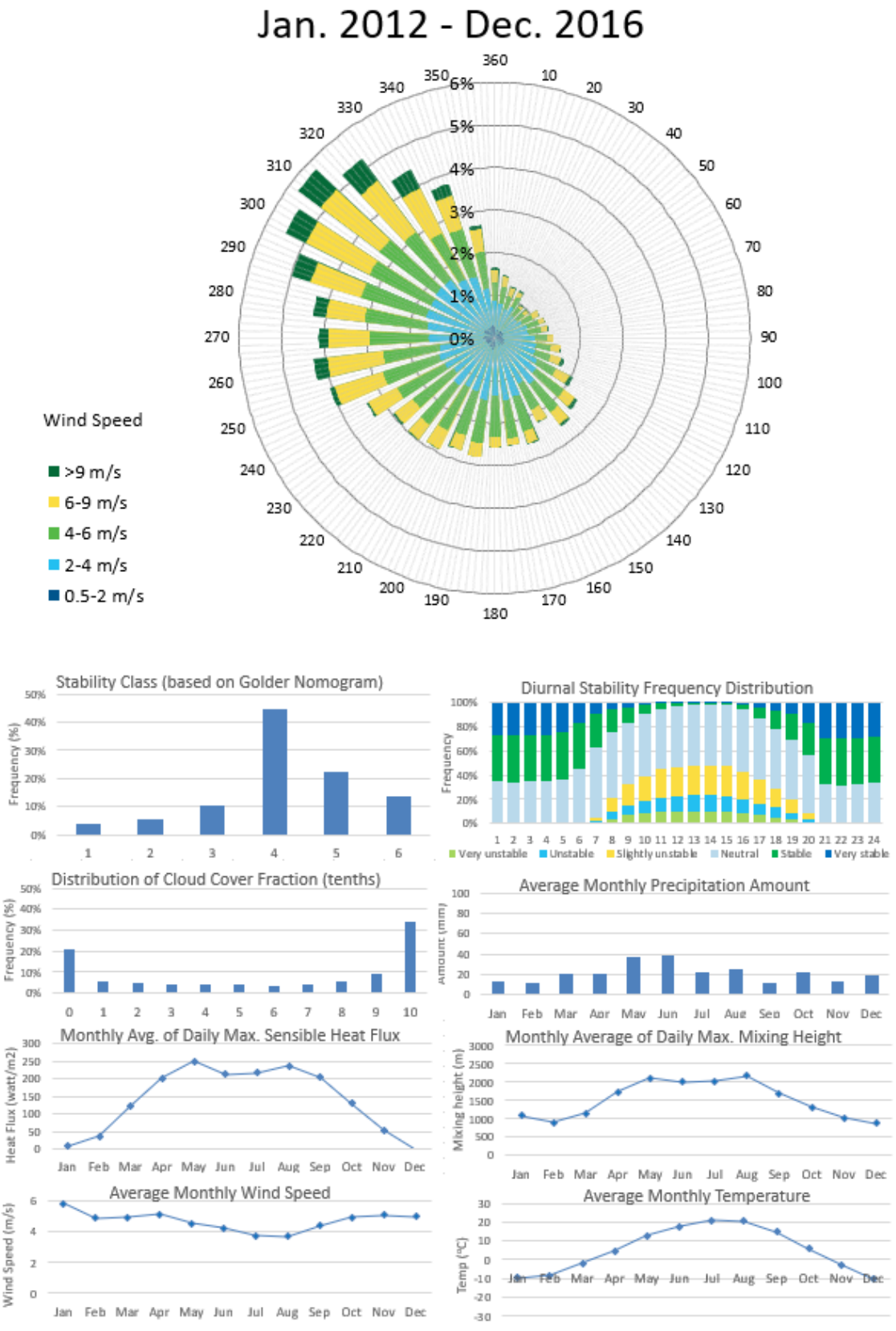


Figure G-5: Sample of the AERMOD .png input file

APPENDIX H
H. Alternate Surface Meteorological Data

If the purpose of the modelling is being undertaken to assess impact at specific receptors or to match modelled and monitored data, the choice of surface meteorological data becomes important. The choices for more representative surface data include:

- Use of on-site data from a meteorological tower; or
- Use of an existing nearby Environment and Climate Change Canada site, or similar monitoring station; or
- Use of numerically generated meteorological data for that specific location.

The following parameters are required by AERMET and CALMET to be collected at a surface meteorological station.

- Wind speed (m/s).
- Wind direction (degrees blowing from).
- Temperature (degrees Celsius).
- Relative humidity (per cent).
- Cloud cover (tens of per cent).
- Atmospheric Pressure (kPa) (only if a wet or dry deposition is modelled).
- Precipitation amount (mm) and type (only if a wet deposition is modelled).

Airport stations generally collect all these parameters, although smaller airports may collect some data during daylight hours only or collect certain parameters once every three hours. Typically, on-site stations collect only temperature, wind speed, wind direction, relative humidity and pressure. Data like cloud cover and precipitation are only available at selected stations. When using on-site data, it may be necessary to blend the meteorological data from the nearest airport for the exact time periods. If there are no representative data available for cloud cover, an equivalent cloud cover can be calculated by AERMET using the Bulk Richardson Number approach provided. Temperature measurements are available at two levels. Additional near-surface data such as net radiation, insolation and temperature difference may be included if available.

AERMET can read hourly meteorological data in varied formats. Some of the parameters in these formats have units different from what AERMOD requires (e.g. wind speeds in CD-144 are recorded as knots). A brief description of the formats accepted by AERMET is as follows.

- **CD-144 (National Climatic Data Center (NCDC) Surface Data)**: This file contains one record for each hour of data, with all weather elements reported in an 80-column card image.
- **SCRAM**: This is an older format specifically for use by air dispersion models. It does not include surface pressure and precipitation type and amount, which are required for particle deposition modelling.
- **SAMSON Surface Data**: This file contains all the required meteorological variables for both concentration and deposition modelling.
- **ISHD (Integrated Surface Hourly Data)**: This file is in the TD-3505 format and is available for download from the US National Oceanic and Atmospheric Administration (NOAA) website. This data is reported in Greenwich Mean Time (GMT) and contains many data sets which are not used by AERMET.

Table H-1 compares the format of the SCRAM data file with that of the CD-144 data file. Some Fortran programs require certain data to be in specific locations in each line when reading a data file. These specific locations, or character spaces in the line, are referred to as columns (i.e. Column 14-16 means the data is in the 14th, 15th, and 16th character space in that line)

Table H-1: Comparison between the CD-144 format and the SCRAM format

	Column	
Element	SCRAM	CD-144
Surface Station Number	1-5	1-5
Year	6-7	6-7
Month	8-9	8-9
Day	10-11	10-11
Hour	12-13	12-13
Ceiling Height (hundreds of feet)	14-16	14-16
Wind Direction (tens of degrees)	17-18	39-40
Wind Speed (knots)	19-21	40-42
Dry Bulb Temperature (°F)	22-24	47-49
Total Cloud Cover (tens of per cent)	25-26	-
Opaque Cloud Cover (tens of per cent)	27-28	79

All stations to be used as a source of meteorological data for air dispersion modelling should be representative and have similar geophysical conditions, have minimal missing data, have been Quality Assurance and Quality Controlled (QA/QC'd) for accuracy including calibration, and have been correctly sited (away from buildings and trees that mask certain wind directions). The purpose of the alternate meteorological site must meet the needs for dispersion modelling (U.S. EPA 2000) and the type of instruments are suitable (e.g. low wind speed thresholds and wind direction sensitivity). It is recommended that the exact site location in relation to any structures that may influence the data, as well as all QA/QC procedures, be included in all air quality assessments. A high percentage of missing data or calm winds which don't define a wind direction will result in the meteorological data being unreliable for modelling.

The height of all anemometers should be confirmed before any modelling. The standard height of the anemometer at a meteorological station is 10 m, however, 7 m towers are common. In urban areas, quite often the meteorological tower is located on top of a building, which may be as high as 25 m. In many cases, this height is not identified in the metadata when accessing this meteorological data. This height must be corrected in the input file of the air dispersion model since most models use a default height of 10 m for the meteorological tower.

Sites may record wind speed as scalar, vector or both. Occasionally the method of archiving the wind speed was not recorded. If possible, scalar wind speeds should be used in all dispersion modelling. The scalar wind direction should never be used. A sign of scalar wind direction being used is the lack of wind direction from the northwest to the northeast sector.

The anemometer height for most meteorological stations owned and operated by Environment and Climate Change Canada is 10 m without any surrounding obstacles. Even though this data has commonly been used for dispersion modelling, it is not the preferred data to use because this data is mainly

designed to generate long-term climate statistics and for NAV Canada. It is used for aviation safety. When using this data there are a few items worth noting.

- Most stations are located at airports surrounded by an open field.
- Wind information is not based on hourly averages. Wind data is mainly based on a two-minute average recorded a few minutes before each hour. This will increase the uncertainty in the hourly values.
- Wind directions are recorded to the nearest 10 degrees. Therefore, for AERMOD the option to randomize the wind speed in a 10-degree sector (RANDON) should be enabled.
- Wind speeds are recorded as knots and archived as an integer resulting in wind speeds, when converted to m/s, to be in intervals of about 0.5 m/s.
- The anemometer starting threshold may be as high as 2 knots (about 1 m/s), so all wind speeds less than 2 knots are archived as 0 m/s.
- Wind direction is assigned a zero when the wind speed is zero. Depending on the dispersion model being used, this may result in a problem. All wind directions should be reported as missing or changed to a representative wind direction based on the adjacent hours whenever wind speeds are recorded as zero. For CALMET, a zero-wind direction is interpreted as a northerly flow which may result in CALMET nudging the wind direction over that area to be more northerly even when wind speeds are 0 m/s.

A full assessment of all meteorological parameters and a comparison to the nearby ministry-approved meteorological AERMOD-ready file should be made. The comparison should include a full assessment, including scattered plots, frequencies analysis and wind roses. A description of any QA/QC should be provided, including a description of any obstruction that may affect the monitoring data.

APPENDIX H-2
H-2. Meteorological Data for CALMET

CALMET merges all available meteorological files, including a surface data file (SURF.DAT), upper air file (UP.DAT), precipitation file (PRECIP.DAT) and the NWP file (PROG.DAT) into one binary file. Quality assurance checks can be done either manually or by using a utility called METSCAN (for CD-144 formatted data) or other equivalent methods.

A pre-processing utility called SMERGE is used to combine all individual surface files into a singular SURF.DAT file to be used by CALMET. The SMERGE pre-processor can read data in a variety of U.S. data formats (including CD-144), as well as a comma delimited (.csv) format. This latter format is most convenient for on-site meteorology since that data are normally stored in a text file (.txt) or spreadsheet. A spreadsheet can easily be manipulated to SMERGE requirements (described as follows) and then saved in the .csv format.

1. Each parameter should be placed into a specific column in an Excel file as follows, with the proper units as listed.
   - Column 1 – month (mm, e.g. 1, 2, ..., 12).
   - Column 2 – day (dd, e.g. 1, 2, 3, ..., 31).
   - Column 3 – year (yyyy, e.g. 2010).
   - Column 4 – hour (hhmm, e.g. 0000, 0100, 0200, ..., 2300).
   - Column 5 – temperature (degrees Celsius).
   - Column 6 – precipitation amount (mm).
   - Column 7 – pressure (mb).
   - Column 8 – relative humidity (per cent).
   - Column 9 – wind direction (degrees).
   - Column 10 – wind speed (m/s).
   - Column 11 – cloud cover (tenths).
   - Column 12 – ceiling height (hundreds of feet).
2. A missing value of a real variable must be replaced with 9999.0 and for an integer variable: 9999 except for the station ID, month, day, year, and hour.
3. No blank cells are allowed.
4. Ceiling height and cloud cover are typically not available at most on-site meteorological stations. These parameters can be obtained elsewhere and combined with other parameters from the on-site measurement program if they apply to the site under consideration.
5. Use 888 for unlimited ceiling height (i.e. cloud opacity is less than 6/10ths).
6. Save the Excel file as a text file in a comma-delimited format (.csv file) with no spaces between the commas

The file must contain the following as the first three lines in the file exactly as shown except for the Station ID number. In this example, it is 1432 but could be any integer number.

```
GENERIC, Version,'2.0', Manually generated, Time as ending hour
Station, ID,=',1432,Temp,Precip,Pressure,RH,Wdir10m,Wspeed10m,Ccover,Cheight
Month, Day, Year, Hour, DegC, mm, mb, degrees, deg,ms-1, tenths, hundreds_of_feet
```

For each set of hourly data in the SURF.DAT file created by SMERGE, the first line is the date (i.e. 12 125 15 (year 2012, 125 Julian day, 15th hour in the day)), followed by each line representing meteorological

data from each surface station data in the order of wind speed, wind direction, cloud ceiling, cloud cover, temperature, relative humidity and pressure. The ceiling, cloud cover and relative humidity are recorded as integers. All meteorological data must be included for all hours in the SURF.DAT file. CALMET will only run if each hourly data is available for any of the available meteorological stations in the SURF.DAT file.

For wet deposition modelling, CALMET requires hourly precipitation and precipitation code (i.e. frozen vs. liquid precipitation). For hourly precipitation data, the pre-processors, PXEXTRACT are used for quality assurance of precipitation data and PMERGE is used to merge data from multiple stations into a PRECIP.DAT file. The hourly precipitation data must be in U.S. NWS TD-3240 format. Unfortunately, this format is not used in Canada. Therefore, to prepare precipitation data, users can select the free-formatted option by creating the PRECIP.DAT file directly in free format (Exponent, 2011).

NWP models can also generate data which can be used in CALMET. One issue with the NWP model is the limitations of the relatively coarse grid resolution which means some smaller terrain effects may only be partly resolved or completely ignore. Therefore, the coarse scale NWP output should be used as an initial guess field for the finer scale CALMET model.

The MMIF program can act as an alternative to CALMET to process NWP model output directly to a suitable format for CALPUFF. However, the terrain effects that CALMET applies to produce a final wind field will not be used and MMIF can only provide output with the same grid resolution provided with the NWP model. Therefore, it is recommended to use the CALMET program to generate the meteorological data file for CALPUFF.

There are three options in which CALMET can generate a meteorological data file for CALPUFF.

1. **No-Obs (no observations)**: CALMET relies solely on the NWP model output. Recommended only when there are no appropriate surface observations available, or the available surface observational data is unreliable or missing too much data.
2. **Obs-Only (Observations only)**: CALMET relies entirely on available observational data. Several observational sites can be used together, but there should be nearby upper-air data available. Should only be used if the expected area of impact is within a few kilometres from the emitting sources to simulate an incident. For this option, all required meteorological parameters must be available for every hour.
3. **Hybrid**: CALMET uses a combination of available observational data and the NWP model output. Data from a nearby upper air station is optional. The observational data used should be within 20 k of the emitting sources.

The Hybrid approach uses the strength of both NWP and observational data to produce better results and is the preferred option when modelling using CALPUFF. One common problem associated with using the Hybrid option is the doughnut pattern which may occur around a surface observation station during low wind speed conditions. This is due to a difference in the wind speed at the meteorological station being lower than the surrounding area as defined by the NWP model output. The NWP tends to predict wind speeds to be too high whereas the anemometer at the surface station may have high starting thresholds so low winds are reported as zero. The doughnut pattern can be eliminated or minimized by adjusting the R1 and RMAX1 switches in CALMET. An explanation of these switches is provided in the following Appendix I. For cases when there are several observation stations available and during periods when the wind speeds are reported as zero at one station the wind direction at that station should be reported as missing or replaced using procedures outlined in Sections 9.3 and 9.4.

APPENDIX I
I. CALPUFF/CALMET Recommended Model Options

There are numerous user-defined variables and options in CALMET and CALPUFF which require professional judgment. To provide consistency in Saskatchewan modeling the following guidance is provided on switches and options.

For switches or options in the CALMET or CALPUFF input files that are not included in this Appendix, the default values should be used. A justification should be provided for changing any of these switches/options and all changes should be identified in the assessment.

I.1 CALMET Recommended Options

There are several key wind field options and parameters in CALMET that should not be modified in the input file and the default values must be used. These input options and parameters are IWFCOD, IFRADJ, IKINE, IOBR, ISLOPE, and ISTEPPGS.

Option	Parameter	Value	Explanation & Justification
Extrapolate surface wind observations to upper levels	IEXTRP	-4	Use similarity theory. If <0: ignore layer 1 data of upper air stations
Min. distance (km) between upper air stn and surface stn for which extrapolation of surface winds will be allowed.	RMIN2	-1	(-1) when IEXTRP = ±4 to ensure extrapolation of all surface stations (i.e., unlimited distance). Option designed to avoid extrapolated surface data "competing" with upper air measurements when both surface and upper air measurements are co-located. Only considered when upper air data is used.
Use gridded prognostic wind field (NWP) model output as input to the diagnostic field	IPROG	14	Use winds from NWP output as the Initial Guess field.
Use varying radii of influence?.	LVARY	F	(F) the switch is off. The radius of influence is expanded when no stations are within the fixed radius of influence value. Caution: RMAX is effectively enlarged to incorporate the "nearest" station regardless of its suitability.
Min. radius of influence used in the wind field interpolation (km)	RMIN	0.1	Use a small value (0.1 km). Prevents a divide-by-zero error when a grid point and station are co-located.
The relative weighting of the prognostic wind field data.	RPROG	0	Used only if IPROG=1
Type of meteorological data used.	NOOBS	1 or 2	(1) a combination of observations and NWP output, (2) or just NWP output.
Cloud Data Option	MCLOUD	4	Compute the gridded cloud cover from prognostic relative humidity at all levels for the gridded NWP model.
Critical Froude number.	CRITFN	1	If Froude no. < CRITFN, the wind has an uphill component and direction is changed to be tangent to the terrain. If Froude no. > CRITFN, no adjustment is made.

Option	Parameter	Value	Explanation & Justification
The number of barriers to interpolation of the wind fields.	NBAR	0	Usually not used. Use barriers to block out certain station effects. Commonly used in complex terrain.
Level (1 to NZ) up to which barriers apply.	KBAR	varies	Used only if NBAR > 0. User-defined switch to control the vertical extent of barriers from the surface layer to user-defined upper layer limit. Requires careful examination of the resulting wind field at each level.
X and Y coordinates of barriers.	XBBAR YBBAR XEBAR YEBAR	varies	Use only if NBAR > 0 to define the coordinates of the barrier.
Depth (m) through which the domain-scale lapse rate is computed.	ZUPT	200	Units: Meters. Only used if IDIOPT2 = 0.
Upper air station to use for the initial guess winds.	IUPWND	-1	Use 3-D initial guess fields. Used only if IDIOPT3 = 0 and NOOBS = 0.

The following model options should use the default options recommended in the CALMET input file.
INPUT GROUP: 5 -- Wind Field Options and Parameters.
ICALM, IGFMET, LVARY, DIVLIM, NITER, NSMTH, NINTR2, ALPHA, FEXTR2, NBAR, IDIOPT (1,2,3,4 and 5), ISURFT, IUPT, ZUPT, IUPWND, ZUPWND, LLBREZE.

INPUT GROUP: 6 -- Mixing Height, Temperature and Precipitation Parameters.
CONSTB, CONSTE, CONSTN, CONSTW, IAVEZI, MNMDAV, HAFANG, ILEVZI, IMIXH, THRESHL, THRESHW, DPTMIN, DZZI, ZIMIN, ZIMAX, ZIMINW, ZIMAXW, ICOARE, DSHELF, IWARM, ICOOL, TRADKM, NUMTS, IAVET, TGDEFB, TGDEFA, NFLAGP, SIGMAP, CUTP.

When surface observations are used in CALMET, there are several user-defined parameters (BIAS, IEXTRP, RMAX1, RMAX2, R1, R2, and TERRAD) that require professional judgements. Due to their importance in creating a realistic CALMET wind field over the modelling domain, it is recommended that the user have attended the CALPUFF advanced training course or have a strong background in boundary latey meteorology.

The following is an explanation of critical user-defined, site-specific parameters when using observational data in CALMET (Barclay & Scire, 2011). These parameters have no default values (except for BIAS) and require skill and knowledge in boundary layer meteorology.

TERRAD - Terrain radius of influence (km)
The distance CALMET is considered when determining the terrain effects on the airflow. This distance will depend on the width of a valley. If TERRAD is too small, valley walls which contribute to the slope flow will not be considered. If TERRAD is too large, terrain on the lee side or hills may influence the airflow. TERRAD can be estimated as the typical ridge-to-ridge distance divided by two and usually rounded up. Typical values of TERRAD are between 5-15 km and should not exceed the modelling domain (TRC, 2010).

BIAS (NZ) Layer-dependent weighting factor of surface vs. upper air wind observations in defining the Initial Guess Field winds.
Default (NZ * 0) means the inverse distance squared (1/R2) weighting is given equally to the surface and upper air data. A BIAS value is applied to each vertical layer and ranges from -1 to +1. Where -1 means the surface station has 100 per cent weight for that layer, while +1 means the upper air station has 100 per cent weight for that layer. BIAS values are very important in complex terrain situations. In simple terrain situations, BIAS is often set to zero (0) for each vertical layer.

The values used in the BIAS will depend on how narrow and complex a valley may be or the distance the upper-air observation is from the receptor. For steep valleys, it is recommended to set the BIAS to -1 for all levels within the valley forcing surface data only to be used for the lowest layers, and gradually change the BIAS from -1 to near +1 from the top of the valley to the highest layer. BIAS is only used when using observations to develop an initial guess field. Not active when NO-OBS = 1 or 2.

R1 and R2 - Weighting parameter for Step 1 wind field vs. observations in Layer 1 (R1) and Layer 2 and above (R2).
The values used in R1 and R2 represent the distance from a surface observation station and the layer 2 aloft, respectively, at which the surface observation and the Step 1 wind field are weighted equally.
It is important to note that all the results of the diagnostic wind model (kinematics, slope and blocking effects) are contained in the Step 1 wind field, thus if too much weight is given to the observations, then all the information generated in creating the Step 1 winds may not be used. Typically, in flat terrain, values of R1 and R2 are larger than in mountainous terrain where a station's flow is limited by the valley segment, and that value may be as low as 0.1 km.
Only one value is used and that value represents all stations. This parameter is not used in the No-Obs mode.

RMAX - Maximum radius of influence for meteorological stations in layer 1 (RMAX1), layers aloft (RMAX2) and layers over water (RMAX3).
The values of RMAX determine the distance from the observation station where the observed winds are 'blended' in with the Step 1 winds. Any receptors from the observational station greater than RMAX1 in the surface layer or RMAX2 aloft are excluded from the 'blending' formula. RMAX1 and RMAX2 can be used to exclude observations from being inappropriately included (as they are in the next valley, on the other side of a mountain, etc.).
If RMAX1 and RMAX2 are used to exclude observations, then do not set LVARY to T, as CALMET will increase the values of RMAX1 and RMAX2 to at least capture the nearest observation. RMAX3 should be large enough so that all grid points over water are within the radius of influence of at least one observation. R1 and R2 values should always be smaller than RMAX1 and RMAX2, to prevent 'sharp' boundaries between the Step 1 wind field and the weighted observation station. Only one value is used and that value represents all stations. This parameter is not used in the No-Obs mode.

I.2 CALPUFF Recommended Options

Option	Parameter	Value	Explanation & Justification
Map projection	PMAP	UTM	Universal Transverse Mercator
UTM zone (1 to 60)	IUTMZN	11,12, or 13	UTM zones for Saskatchewan
Hemisphere for UTM projection	UTMHEM	N	Northern Hemisphere projection

Option	Parameter	Value	Explanation & Justification
Datum-Region for the coordinates	DATUM	NAR-C	NAD83 – North American 1983 GRS Spheroid
Near-field puffs modelled as elongated slugs	MSLUG	0	(0) No slug model except (1) for area sources with receptors in the very near field or for episodic time-varying emissions such as accidental releases.
Stack-tip downwash	MTIP	0 or 1	(1) Stack-tip downwash modelled, particularly if the ratio of stack gas exit velocity to wind speed is < 1.5. (0) No stack tip downwash for flares if pseudo-stack parameters are calculated using the AERflare/ABflare spreadsheet.
Method used to simulate building downwash	MBDW	1 or 2	(2) PRIME method. (1) ISC method if building aspect ratios of W/H are > 5
Puff splitting allowed	MSPLIT	0	No puff splitting for short-range modelling. In long-range transport, puff splitting may be necessary.
Chemical mechanism flag	MCHEM	0 or 6	(0) if no chemical transformation or (6) transformation calculated using RIVAD/ ISORROPIA scheme.
Aqueous phase transformation flag	MAQCHEM	1	Transformation rates and wet scavenging coefficients adjusted for in-cloud aqueous phase reactions. Used only if MCHEM = 6
Concentrations modelled	ICON	1	Output concentrations
Wet removal modelled	MWET	0 or 1	(0) no, (1) if wet deposition modeling. Important for long-range transport but may be used for near field if appropriate.
Dry deposition modelled	MDRY	0 or 1	(0) no, (1) if dry deposition modelled. Important for long range transport but may be used for near field if appropriate.
Relative Humidity	IVIS	1	Only if visibility analysis is required. Otherwise, 0
Gravitational settling (plume tilt)	MTILT	0 or 1	(0) recommended for small particles. (e.g. combustion size particles less than 10 µm). (1) recommended for very large particles with substantial gravitational settling effects.
Methods used to compute the dispersion coefficients.	MDISP	2	Dispersion coefficients from internally calculated sigma v and w using micrometeorological variables.
Probability Distribution Function used for dispersion under convective conditions	MPDF	0 or 1	(1) only if MDISP = 2 (turbulence-based dispersion coefficients).
Sub-grid TIBL module used for shoreline	MSGTIBL	0 or 1	(0) do not use, however, may be used for applications located along a coastline. If used, a coastline file (COASTLN.DAT) should be prepared to specify the location of the land-water boundary.

Option	Parameter	Value	Explanation & Justification
Configure for FOG Model output?	MFOG	0, 1 or 2	(1) PLUME mode format or (2) RECEPTOR mode format if visible plume assessment is required. Otherwise, 0
Test options specified to see if they conform to regulatory values.	MREG	0	No checks recommended, but still can be done.
Minimum turbulence velocities, sigma v for each stability class over land and water	SVMIN	σv =0.2 for A, B, C, D, E or F	For applications where calm wind and stagnation events are significant, set SVMIN = 0.2 to better represent lateral spread of the plume. Otherwise use default values.
When using RIVAD/ISOROPPIA Option			
Ozone data input option	MOZ	0	use a monthly background ozone value
Monthly ozone concentrations	BCKO3		specify an ozone value for each month (ppb) as provided in Appendix J
Monthly ammonia data input option	MNH3	0	use a monthly background ammonia value for all layers
Ammonia vertical averaging option	MAVGNH3	1	Average NH_3 values over vertical extent of puff.
Monthly ammonia concentrations	BCKNH3		used only if MCHEM = 1 or 3 and MNH3 = 0 specify a NH3 value for each month (ppb) as provided in Appendix J
H_2O_2 data input option	MH2O2	0	read monthly background H_2O_2 value. Used only if MCHEM = 6 or 7 and MAQCHEM = 1
Monthly H_2O_2 concentrations in ppb	BCKH2O2	12*1.0	Used only if MAQCHEM = 1 Specify H_2O_2 value (ppb) for each month.

The following model options should use the default options recommended in the CALPUFF input file.

- **INPUT GROUP: 2 -- Technical options:** MGAUSS, MCTADJ, MCTSG, MTRANS, MRISE, MTIP_FL, MRISE_FL, MLWC, MTURBVW, MSHEAR, MDISP2, MTAULY, MTAUADV, MCTURB, MROUGH, MPARTL, MPARTLBA, MTINV, MBCON, MSOURCE.
- **INPUT GROUP: 6 – Complex Terrain Input**: XHILL2M, ZHILL2M.
- **INPUT GROUP: 9 -- Miscellaneous dry deposition parameters**: RCUTR, RGR, REACTR, NINT, IVEG
- **INPUT GROUP: 11 – Chemistry Parameters:** RNITE1, RH_ISRP, SO2_ISRP, (RNITE2, RNITE3, BCKPMF, OFRAC, VCNX, NDECAY – Not used when using RIVAD/ISOROPPIA Option).
- **INPUT GROUP: 12 – Miscellaneous dispersion and computational parameters**: SYTDEP, MHFTSZ, JSUP, CONK1, CONK2, TBD, IURB1, IURB2, XSAMLEN, MXNEW, MXSAM, NCOUNT, SYMIN, SZMIN, SZCAP_M, SWMIN(12), CDIV(1), CDIV(2), NLUTIBL, WSCALM, XMAXZI, XMINZI, TKCAT(11), WSCAT(5), PLX0(6), PTG0(2), PPC(6), SL2PF, FCLIP, NSPLIT, IRESPLIT(24), ZISPLIT, ROLDMAX, NSPLITH, SYSPLITH, SHSPLITH, CNSPLITH, EPSSLUG, EPSAREA, DSRISE, HTMINBC, RSAMPBC, MDEPBC.

APPENDIX J
J. Saskatchewan Background/Baseline Concentrations

Baseline air quality includes substances from anthropogenic and biogenic sources that are not directly included in the dispersion model. The correct choice of a representative baseline value requires considerable professional judgement. When selecting the appropriate ambient monitoring station to use to derive the baseline values it is important to consider the nature of the missing emissions that will be represented by the baseline values and the similarity of baseline monitor location to the project, i.e., similar topography, climate normals and air quality regime.

For example, if a modelling assessment is conducted for a project in a heavily industrialized area and the modelling domain is quite extensive then a monitoring station that operates under similar climatological conditions that also captures similar traffic and residential/commercial heating emissions as well as biogenic emissions in the area, but not industrial emissions would be an appropriate choice. On the other hand, for an assessment in a relatively pristine area where all of the relevant industrial emissions associated with the project are included then the choice of a monitoring station from a small rural community under similar meteorological conditions would be appropriate.

When comparing to air quality standards, the background concentrations are to be added to all appropriate concentrations. Assessing the effects of the baseline component becomes more complex when short-term objectives (1-hour, 24-hour averages) are being considered.

The following method should be used to determine a baseline concentration:

1. All monitoring data should be subjected to validation and quality control to ensure its accuracy. Hourly, continuous ambient monitoring data is preferred over passive monitoring data where available.
2. The most recent three years of hourly ambient data should be averaged to form a baseline provided each year is at least 75% complete. If more than 25% of the hourly ambient data is missing (blanks) from a given year then it is acceptable to use the next most recent year of ambient data, provided it meets the 75% completeness criteria. Some additional considerations to the selection of the appropriate ambient data include:
    a. If less than three years of hourly ambient data is available, then average over the available data provided at least one complete year of data is available. If one complete year of data is not available, then the monitoring station cannot be used to construct a baseline.
    b. If an analyzer is changed during the period being used to construct a baseline the statistics of the monitoring data may change. This can be checked by visually comparing the mean and variance of monitoring data before and after the analyzer change. A noticeable step change in the mean value and/or a noticeable increase in the variance suggests the monitoring data statistics are different and the data from the two analyzers should not be combined. If there is a noticeable difference in analyzer performance and there is not sufficient data to form a baseline with the current analyzer (at least one full year) then a different station must be used to form the baseline.
3. Air assessments for all averaging periods should be based on average of the reduced hourly data set for each year, i.e., the top hourly values above the 90th percentile non-blank ambient baseline data are removed. This allows for some variability in the baseline due to anthropogenic or unusual local sources. Do not include blank data as zero values when determining the 90th

percentile. For all averaging periods greater than one hour, the maximum calculated average for each averaging period, to be used as the baseline value for modelling purposes, must then be based on the reduced hourly ambient data sets. No further removal of maximum values for other averaging time periods is allowed.

Example. An air monitor station is measuring NO_2 over a three-year period. The 90th percentile of valid hourly data for each year is as follows:

2020 – 15.4 ppb NO_2
2021 – 15.4 ppb NO_2
2022 – 16.2 ppb NO_2
Average – 15.7 ppb NO_2 (to be used for one-hour models)

In forming the 24-hour baseline value for the assessment, the hourly values above the 90th percentile should be set to blank. All 24-hour averages for each year must then be calculated using the reduced data set with the blank values in place as they occur. Once this is determined then each year's 24-hour averages may then be ranked separately with the 24-hour average baseline for the assessment being the average of the top ranked 24-hour average from each year. The highest 24-hour average per year and final average are as follows:

2020 – 13.5 ppb NO_2
2021 – 14.1 ppb NO_2
2022 – 14.3 ppb NO_2
Average – 14.0 ppb NO_2 (to be used for 24-hour models)

Similar to the 24-hour baseline, the annual average is taken from the same reduced data set. No further reduction is allowed. Annual concentrations are as follows:

2020 – 5.7 ppb NO_2
2021 – 5.3 ppb NO_2
2022 – 5.9 ppb NO_2
Average – 5.6 ppb NO_2 (to be used for annual models)

Note: Modelling assessments that include PM_{10} or TSP also require a baseline value to be added to the modelling results. Monitoring of PM_{10} or TSP is not widely available so baseline values should be derived from the most representative available $PM_{2.5}$ monitoring data based on a paper comparing ratios of $PM_{2.5}$:PM_{10}:TSP across Canada (Brook et. al. 1997). For models in Saskatchewan the following formula can be used:

$PM_{10} = PM_{2.5} * 2.56$
$TSP = PM_{10} * 2 = PM_{2.5} * 5.12$

If suitable PM_{10} or TSP monitoring data is available, it should be used to form a representative baseline rather than a derived baseline.

Note: For substances of concern modelled in an assessment that are not commonly monitored the proponent should apply a representative baseline value based on best available information from the literature.

Modelling reports must contain details, rational and data to support baseline concentrations used.

Where no appropriate monitoring stations are available, or for screening models, the following baseline concentrations in Table J-1 can be used.

Table J-1: Regional Background Air Contaminant Concentrations (all µg/m^3)

Pollutant	Period	Land Area	Concentration
CO	1-Hr	Urban	380
		Rural	300
	8-Hr	Urban	320
		Rural	290
NO_2	1-Hr	Urban	26.0
		Rural	6.2
	24-Hr	Urban	23.4
		Rural	6.2
	Annual	Urban	9.1
		Rural	2.0
SO_2	1-Hr	Urban	1.3
		Rural	0.8
	24-Hr	Urban	1.2
		Rural	1.0
	Annual	Urban	0.3
		Rural	0.2
$PM_{2.5}$	24-Hr	Urban	16.0
		Rural	12.1
	Annual	Urban	6.3
		Rural	4.0

Table J-2 is a summary of O_3 and NH_3 concentrations for each month that can be used in air dispersion modelling in Saskatchewan to represent background concentrations.

Table J-2: Regional One-hour Background Air Contaminant Concentrations (all µg/m^3)

Pollutant	Land Area	**Max**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
O_3	Urban	**59**	48	51	56	59	55	50	49	47	45	41	40	43
	Rural	**72**	60	65	73	72	56	48	45	45	44	52	54	56
NH_3		**2.3**	1	1	1	1.8	2	2.3	2.3	2	1.8	1.5	1	1

Where local areas have unique background concentrations, additional research will be required to produce background levels.

APPENDIX K
K. Flare Pseudo Parameters Calculations

AERMOD, CALPUFF and AERSCREEN contain a FLARE source option, which calculates stack pseudo-parameters (i.e. stack height and diameter and exit velocity) to appropriately characterize the flare in order to ensure that the resulting plume rise and spread are reasonably representative. Other models do not have the capability to model flares directly and most model them as point sources using the pseudo stack parameters should be calculated manually to compensate for the flame height, and initial dispersion from the flame. There are buoyancy flux reductions associated with radiative heat losses when estimating plume release height (U.S. EPA, 1992).

When determining pseudo parameters, the biggest unknown, which has been debated for years, is the radiative heat loss of a flare. Radiative heat loss has a large influence in determining the pseudo parameters to compensate for the flame height. Several studies have tried to develop a relationship between the burn conditions and the radiative heat loss. The 25 per cent radiative heat loss value used by Alberta Ministry of Environment and Protected Areas is more consistent with values published in literatures for flare gas streams (Alberta Environment, 2003).

Other papers published (Tan, 1967) considered the relationship between the molecular weight of the flare gas stream and the fraction of the heat loss due to radiation. Some jurisdictions like the state of Texas and the Ontario Ministry of Environment adopted this approach based on studies conducted and published. The Saskatchewan ministry of Environment is recommending the following equation the be used in determining the percent of radiative heat loss:

$$R = (MW)/3 + 21 \qquad \text{(eq M-1)}$$

Where:

R = radiative heat loss (per cent).
MW = Molecular weight of the gas stream.

The molecular weight of the flare gas stream should be calculated based on documented or measured composition including all components (i.e. combustible and inert components as well as any lift gas). The composition of the flare gas stream including any lift gas should be consistent with the scenario(s) being assessed. In the absence of sufficient information to calculate the molecular weight of the flare gas stream, a radiative heat loss values of 55 per cent should be used in the calculation to determine the net heat release value.

The effective stack height is the physical height of the flare plus the height of the tip of the flame. The tip of the flame is dependent on the flame length which depends on the amount of fuel burned and the net heat release rate, and the flame tilt which depends on the wind speed and exit velocity. For consistency in most models, it is assumed that the flame is tilted at a 45-degree angle. In CALPUFF, the angle of the flame can vary hourly depending on wind speeds (Exponent, 2019). The net heat release rate considers the total amount of heat available due to combustion minus the amount lost through radiation. The amount of heat loss through radiation can vary considerably depending on the gas composition burned and the plume behaviour. A very efficient flare would have no visible flame and no smoke, whereas an inefficient flare would have a yellow or orange flame and emit visible smoke.

Considering the 45-degree angle and using Milton Beychok best fit equation gives the following equation for the effective stack height.

$He = Hs + 0.00456\ (Q)^{0.478}$ (eq M-2)

Where:
He = Effective stack height above ground (m).
Hs = Physical stack height above ground (m).
Q = Total heat available for combustion (cal/s).

The effective diameter is much larger than the original inner diameter of the open flare or flare nozzle tip due to the combustion process and the air entrainment in the plume. The effective diameter, which is calculated at the flame tip, can be calculated knowing the actual buoyancy flux of the combusted gas. The buoyancy flux is a measure of the vertical momentum that the exhaust gas has due to the amount of heat released through combustion.

$F_b = (gQ(1-r))/(\pi c_p p\ T_a)$ (eq M-3).

Where:
F_b = Buoyancy flux
r = Fraction of heat lost through radiation (R/100)
g = Acceleration due to gravity (9.81 m/s^2)
c_p = Specific heat of dry air 0.24 cal/gK
p = Density (1205 g/m^3)
T_a = Ambient air temperature (K)

The buoyancy flux can also be estimated using the Briggs plume rise equation (Briggs, 1969) as follows.

$F_b = (gvd^2 / 4)[(T_s - T_a) / T_s]$ (eq M-4)

Where:
d = effective diameter (m)
v = effective exit velocity (m/s)
T_s = effective stack temperature (K)

Assuming both buoyancy fluxes are equal and merging both equations (M-3 and M-4) the effective diameter can be calculated as:

$d = [(4T_sQ(1-r))/(\pi c_p p T_a v(T_s - T_a)]^{0.5}$

or, assuming c_p and p are constant:

$d = 0.066[T_sQ(1-r)/(T_av(T_s - T_a))]^{0.5}$ (eq M-5)

Similar to the effective diameter, the effective velocity is calculated as a representative value at the flame tip.

To determine an effective velocity both the buoyancy flux and the momentum flux calculations need to assume they are conserved. The momentum flux is a measure of vertical momentum that a gas has due to the amount of physical momentum as it exits a stack, which is based on the exit velocity. Assuming the exhaust stream at the flare nozzle tip behaves similar to a traditional stack and this momentum is conserved, so that it is applicable at the flame tip, the effective velocity can be calculated as:

$V_{eff} = gF_m/F_b\ (T_s - T_a)/T_a$ (eq M-6)

Where:
V_{eff} = Effective velocity (m/s)
F_m = Momentum flux

Where the momentum flux of the exhaust stream at the nozzle tip prior to combustion can be calculated as:
$F_m = \rho_g(D_nV_n)^2/4p$ (eq M-7)

Where:
ρ_g = Density of the gas to be flared (g/m^3) at actual flare gas temperature and pressure at the nozzle.
D_n = Flare nozzle diameter (m)
V_n = Actual exit velocity of the gases at flare nozzle before combustion corrected to actual gas temperature and pressure (m/s).

Using the momentum flux equation (eq M-7) and the buoyancy flux equation (eq M-3), the effective velocity in eq. M-6 becomes:

$V_{eff} = \pi c_p \rho_g (T_s - T_a)(D_nV_n)^2/(4Q(1-r))$ (eq. M-8)

The pseudo parameters calculated account for stack tip downwash. Therefore, the modeller should disable this option when using either AERMOD or CALPUFF. To prevent stack tip downwash during low wind speed events, the minimum value for the effective velocity is set to 1.5 m/s.

Some flares are designed to handle both routine and non-routine flare events. Flows during non-routine flare events are much larger than those during routine flare events. This would lead to modelled plume rise being much higher for non routine flare events which may result in the locations of maximum impacts being at different locations. Therefore, it is important to model all scenarios expected for a particular flare.

APPENDIX L
L. Modelling Report Checklist

Modelling Report Checklist

A report describing the air quality analysis performed should be submitted. The purpose of the report is to provide the ministry with ample information to demonstrate that the new or modified source will not adversely affect ambient air quality. The content of the report should be adequate for the reviewer to establish that the analysis was accomplished in a manner consistent and defensible with respect to best practices and available modelling guidance.

At a minimum, applicants should refer to the following checklist to ensure the air quality analysis report is complete.

Table N-3: Modelling Report Check List

1	BACKGROUND AND SOURCE INFORMATION
1.a	Project background requirements. • General description of the plant processes. • Purpose of the modelling. • Proposed new sources or modification of existing sources including number and type of sources.
1.b	Project location requirements

1.b.i	Plot plan that includes the following.
	• UTMs on horizontal and vertical axis.
	• Property lines, including fence lines.
	• Roads and railroads that pass-through property line.
	• Location of all emission sources.
	• Buildings and structures (on or off property) which could cause downwash including:
	  • Location.
	  • Length/Width/Height.
	  • Building tiers and tier heights.

1.b.ii	Area map(s) that include the following. • Map of adjacent area (typically 10 km radius from plant). • UTMs on horizontal and vertical axis. • Location of all receptors used in the modelling. • Location of all sources that were modelled including nearby sources emitting same pollutant. • Location of all sensitive receptors including communities. • Topographic features. • Location of any existing or proposed meteorological or ambient monitoring stations. • Relevant roads and railroads.
1.c	Emissions of Proposed New / Modified Source Requirements.
1.c.i	Emission source descriptions and capacities (including proposed emission controls) Include fugitive, condensable and secondary emissions when applicable.
1.c.ii	Emission calculation.: • In stack ratio of NOx to NO_2 if applicable. • Describe how emissions were calculated / estimated. • Include sample supporting calculations. • Include references as needed.
1.c.iii	Discussion of potential operating scenarios for emission units. • Maximum emissions scenario. • Refined emissions scenario.

	• Start ups and shutdowns. • Upsets and Emergency situations.

1.c.iv	Include parameter table(s) for each operating scenario of each emission unit, which may include, but not be limited to the following.
	• Source type (Stack, Area, Volume, Line or Flare).
	• Location (UTM Coordinates).
	• Emission rate.
	• Exit height above ground.
	• Source parameters required for modelling.
	• If stack:
	  • Orientation (vertical, horizontal).
	  • Rain cap.

2	ANALYSIS.
2.a	List and discuss the model(s) chosen as well as supporting models and input programs.
2.b	Modelling procedure reporting requirements.
2.b.i	Description of the domain size. Source of terrain data. Flagpole height used. UTM zone.
2.b.ii	Identify all land use characteristic values used that were different from those recommend by the ministry. Justification for using different land use values.
2.b.iii	Meteorological data used. Identify which ministry prepared Regional Meteorological Data set was used. If regenerating the meteorological data discuss land use characterization include Bowen ratio, albedo, surface roughness values which were used. If using other sources of meteorological data. • Identified source and location of the data. • Comparison of meteorological site to modelling site. • Wind rose. • Graphs showing monthly patterns of other meteorological parameters. • Discussion of what quality assurance was done on the data.
2.b.iv	If applicable, a description of how each of the following were assessed. • Flares. • Odour. • Fogging. • Icing. • Acid deposition. • Lake effect. • Particle deposition. • Secondary PM and ozone.
2.b.v	Specify setting utilized within the model(s), which may include: • Default regulatory setting utilized within model. • Flat or elevated terrain. • Include discussion on non-default settings utilized and reasons.
2.c	Ambient condition requirements, including competing sources. Discuss the ambient background / baseline concentration. Data to support background / baseline concentrations. Conversion factor used for different averaging time (if applicable). Conversion factor utilized for converting NO_X to NO_2.
3	RESULTS DOCUMENTATION.

3.a	Identify all Standards and criteria to be used as indicator of potential impact (i.e. SAAQS or other jurisdictions criteria).
3.b	The model results to be documented as follows.
3.b.i	Table(s) of results including: • Source. • Contaminant(s). • Averaging time(s). • Operating scenario. • Receptor location and elevation of maximum impact (UTM coordinates). • Maximum impact from new / modified source. • Background concentration. • Maximum modelled cumulative concentration (all sources + background). • Applicable ambient air quality standards. • Number and frequency of concentrations exceeding the standards.
3.b.ii	Figure(s) showing ambient impacts of facility alone (and all sources). For each operating scenario and averaging time. • UTMs on horizontal and vertical axis. • Modelled facility. • Facility boundary. • Emission location (include non facility sources). • Topography features. • Isopleths of impact concentrations. • Location and value of maximum (cumulative) impact.
3.b.iii	All exceedances of the ambient air quality standards or criteria should be clearly identified.
4	SUPPORTING FILES.
4.a	Required electronic files to be submitted with report. • Input files for models. • Input & output files for pre-processors (if applicable.) • Input for post-processors (if applicable.) • Digital terrain files. • Plot files. • Threshold violation files. • Final report.