

# **GUIDANCE FOR NO<sub>2</sub> DISPERSION MODELLING IN BRITISH COLUMBIA**

**British Columbia Ministry of Environment & Climate Change Strategy  
Environmental Protection Division  
Environmental Standards Branch  
Clean Air**

**Victoria, British Columbia, Canada**

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### Contact Information

Comments or questions on the Guidance can be sent to: [bcdispersion.model@gov.bc.ca](mailto:bcdispersion.model@gov.bc.ca)

Users are encouraged to check the [Ministry website](#) for any Guidance updates.

Clean Air  
Environmental Standards Branch  
Environmental Protection Division  
British Columbia Ministry of Environment and Climate Change Strategy  
PO Box 9341, Stn Prov Govt  
Victoria, British Columbia, Canada  
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## **IMPORTANT NOTE**

Modelling practitioners are expected to read and follow the [BRITISH COLUMBIA AIR QUALITY DISPERSION MODELLING GUIDELINE](#) in addition to following the NO<sub>x</sub> and NO<sub>2</sub>-specific guidance in this document.

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## 1 INTRODUCTION

### 1.1 PURPOSE

The British Columbia (BC) Ministry of Environment and Climate Change Strategy (ENV or the Ministry) has prepared this document to provide guidance on the modelling of ambient nitrogen dioxide (NO<sub>2</sub>) concentrations from nitrogen oxides (NO<sub>x</sub>) emissions to supplement and replace aspects of the existing modelling guidance. For applications in the Metro Vancouver region, applicants should consult with the Metro Vancouver Regional District, which regulates air quality and makes air dispersion model decisions in the region.<sup>1</sup>

The primary goal in providing guidance specific to NO<sub>2</sub> modelling is to provide clarity for applicants on the assumptions and methods appropriate for NO<sub>2</sub> models in the province, which increases accuracy of modelling and leads to a streamlined model review process and consistency across projects.

### 1.2 NO<sub>x</sub> TO NO<sub>2</sub> CHEMISTRY

The term NO<sub>x</sub> generally refers to the mono-nitrogen oxides: nitric oxide (NO) and NO<sub>2</sub>. Other less common nitrogen species include nitrogen trioxide (NO<sub>3</sub>), nitrous oxide (N<sub>2</sub>O), dinitrogen dioxide (N<sub>2</sub>O<sub>2</sub>), dinitrogen tetroxide (N<sub>2</sub>O<sub>4</sub>), and dinitrogen pentoxide (N<sub>2</sub>O<sub>5</sub>).<sup>2</sup> NO and NO<sub>2</sub> account for the vast majority of directly emitted nitrogen species. Some NO<sub>x</sub> emission estimates also include nitrous acid (HONO) such as the U.S. EPA MOVES model for estimating vehicle emissions. It is possible for the NO<sub>x</sub> within a stack or tailpipe to form nitrous acid or nitric acid (HNO<sub>3</sub>) prior to being emitted to ambient air.

NO<sub>x</sub> concentrations reach equilibrium in ambient air, during daylight, and can be represented as a ratio of NO to NO<sub>2</sub>. The value of this ratio is dependent on the intensity of sunshine, concentration of ground-level ozone (O<sub>3</sub>), and concentrations of other reactive species.<sup>3</sup> The presence of excess molecular oxygen (O<sub>2</sub>) can also result in NO<sub>2</sub> formation, as the O<sub>2</sub> reacts with NO. Emissions of NO<sub>x</sub> from combustion occur when the nitrogen in combustion air converts to NO and NO<sub>2</sub> (thermal NO<sub>x</sub>) and when available nitrogen in the fuel oxidizes (fuel NO<sub>x</sub>); the majority of the NO<sub>x</sub> in combustion exhaust is in the form of NO.<sup>4</sup> The conversion of NO to NO<sub>2</sub> in the atmosphere must be considered in all air dispersion model NO<sub>2</sub> predictions. This document outlines the various assumptions and methods that can be used to model NO<sub>2</sub> concentrations from a given project or facility as accurately as possible.

### 1.3 INTRODUCTION TO CURRENT BC ENV MODELLING GUIDELINES

This document serves to supplement the [BC Air Quality Dispersion Modelling Guideline](#) (the Guideline). The Guideline outlines the levels of assessment available for various project scenarios, including descriptions of accepted methods for developing each model. Section 8.2 of the Guideline discusses NO to NO<sub>2</sub> conversion and associated modelling guidance, and Section 8.1.4 describes how to determine NO<sub>2</sub> baseline levels using monitoring data. Section 2 of this document outlines the changes in this NO<sub>2</sub> modelling guidance relative to the latest Guideline.

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<sup>1</sup> <http://www.metrovancouver.org/>

<sup>2</sup> All oxides of nitrogen species are referred to as NO<sub>z</sub> and non-NO<sub>x</sub> species referred to as NO<sub>y</sub>; i.e., NO<sub>x</sub> + NO<sub>y</sub> = NO<sub>z</sub>

<sup>3</sup> <https://www3.epa.gov/ttn/catc1/dir1/fnoxdoc.pdf>

<sup>4</sup> Many techniques and models apply an assumption that 90% of NO<sub>x</sub> in a typical combustion process is NO and 10% is NO<sub>2</sub>. See Appendix B for more details.

### 1.3.1 ASSESSMENT LEVELS

Air dispersion model analyses can be categorized by the associated complexity of the project's model requirements. Different model assessment levels may be appropriate depending on the site-specific conditions and project emissions considerations and the regulatory context related to a given model scenario. As described in Section 2 of the Guideline, Level 1 Assessments generally apply the AERSCREEN model, while Level 2 or Level 3 Assessments generally apply the AERMOD or CALPUFF model. The following sections provide the details as specified in Section 1.5 of the Guideline describing what conditions warrant a Level 1, Level 2, or Level 3 Assessment.

The latest Guideline states that advanced NO<sub>2</sub> modelling techniques are only acceptable for Level 3 Assessments. This updated guidance allows advanced NO<sub>2</sub> modelling techniques for any assessment level.

#### 1.3.1.1 LEVEL 1 – SCREENING MODELS

A Level 1 Assessment is appropriate when decisions can be made based only on an estimate of the possible worst-case air quality, independent of where or when they occur. Screening Assessments are appropriate for situations such as:

- ◆ “Go, no-go” evaluations (a critical acceptance/rejection criteria are exceeded or not exceeded: typically for low-risk sources).
- ◆ Permit/approval decisions for low-risk sources.
- ◆ Preliminary identification of air quality issues associated with proposed new sources or modifications to existing sources.
- ◆ Planning purposes (internal resources required to conduct assessment, need to consider other studies to support the decision-making process, need to contact other agencies).
- ◆ Identification of the need for more detailed modelling using Level 2 or 3 Assessment approaches (if exceedances of short-term objectives are predicted).
- ◆ Confirmation of refined model results that appear unusually high or low.

#### 1.3.1.2 LEVEL 2 – AIR DISPERSION MODELS

A Level 2 Assessment provides a more realistic and detailed determination of air quality dispersion than what is provided in a Level 1 Assessment. This level requires a refined model that uses a time series of hourly meteorological data and the geophysical conditions representative of the site. A Level 2 Assessment is appropriate when:

- ◆ A Screening (Level 1) Assessment indicates the potential for an exceedance of ambient objectives.
- ◆ There is a need to produce a maximum concentration for different time averages and distributions of the concentrations and/or depositions in time and space that reflect the actual meteorological conditions.
- ◆ The contaminant can be reasonably modelled by a straight-line, steady-state, Gaussian plume model with no chemical transformation. Although more complicated processes may be occurring (i.e., curved plume trajectory), a more complicated model that explicitly treats these processes is not necessary depending on the purposes of the modelling and the zone of interest. For example, if the area of interest is within 100 m, then curvilinear trajectories and chemical transformations are likely not critical.

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- ◆ The emissions are from small sources (e.g., a small compressor station stacks) where the greatest concentrations are in the order of 100 m downwind.
- ◆ The source is considered to be low risk.
- ◆ The purpose is for a standard/generic permit or amendment process (such as an emissions reduction).
- ◆ To define conditions under which well test flaring can occur.
- ◆ Supporting other air management related investigations such as:
  - identify potential contributing sources;
  - identify worst-case meteorological conditions;
  - identify areas of air quality concern;
  - analyze historical air quality trends; and
  - design monitoring networks (locations, contaminants, sampling period, frequency).

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### 1.3.1.3 LEVEL 3 – ADVANCED AIR DISPERSION MODELS

Level 3 Assessments require refined models and corresponding input data, resources and model operator expertise to properly account for these factors. These models require detailed meteorological, geophysical and source input that may include:

- ◆ representative meteorological data (e.g., wind speed, wind direction, temperature, turbulence, and mixing height) at a number of sites in the domain of interest.
- ◆ Detailed emission inventories for point, line, area and volume sources in an airshed that could vary in time and where there is a mix of urban, industrial and natural sources.
- ◆ The speciation, emissions and time variation of different contaminants.

In general, a Level 3 Assessment is recommended in situations where:

- ◆ A Level 1 or 2 Assessment indicates predicted exceedances of ambient objectives.
- ◆ The purpose of the assessment requires detailed time and space variation of the concentrations.
- ◆ It is important to account for multiple source types, chemical transformations and effects associated with complex topography such as causality, calms, curvilinear plume trajectories, spatial variations in turbulent mixing.
- ◆ A source is considered to be high risk.

More specifically, Level 3 Assessments are recommended in situations where there is a need to:

- ◆ Evaluate air quality consequences under a permitting or Environmental Assessment process for large industrial developments that have considerable social, economic and environmental consequences.
- ◆ Assess contaminants resulting from non-linear processes (e.g., deposition, ground-level ozone, particulate formation, visibility).
- ◆ Evaluate consequences of air quality management approaches that involve multi-source, multi-sector contributions from permitted and non-permitted sources in an airshed.

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- ◆ Provide information to support environmental, human and economic effects studies.
- ◆ Examine specific receptors that may be sensitive or of special interest such as individual residences, sensitive ecosystem areas.
- ◆ Assess contaminants in meteorologically complex situations (“complex flow” such as mountain valley flows, reversals, sea breeze, and fumigation).
- ◆ Assist in understanding of the underlying source and meteorological causes of episodes.

### 1.4 NO<sub>2</sub> MODELLING TECHNIQUES

In addition to determining the appropriate model used to estimate NO<sub>2</sub> by the complexity of the assessment (e.g., AERSCREEN for a Level 1 Assessment to the CALPUFF modelling system for a refined Level 3 Assessment), the techniques for predicting NO<sub>2</sub> can vary by complexity. At the conceptual centre of any NO<sub>2</sub> model analysis are the assumptions regarding the conversion of NO to NO<sub>2</sub> in the atmosphere. The following lists different conversion treatments recommended by various agencies:

- ◆ 100% of emitted NO<sub>x</sub> converts to NO<sub>2</sub>
- ◆ Ambient Ratio Method (ARM)
- ◆ Ozone Limiting Method (OLM) and Plume Volume Molar Ratio Method (PVMRM)

The OLM and PVMRM conversion techniques are considered most complex and require the most additional model inputs, but it is worth noting that a more complex methodology does not necessarily yield the most accurate or lowest NO<sub>2</sub> modelled concentration. Therefore, modellers should consider the contributing scientific factors behind a given NO<sub>2</sub> modelling technique and choose a method that is appropriate for the situation. In addition to those conversion treatments listed above, there are alternative NO<sub>2</sub> modelling techniques, such as RIVAD/ARM3, RIVAD/ISORROPIA chemical transformation schemes within CALPUFF. Section 3.2 below provides guidance on how to apply each technique.



## 2 SUMMARY OF CHANGES FROM THE LATEST GUIDELINE

The latest Guideline included guidance on approaches for selecting NO<sub>2</sub> baseline levels and methods for NO to NO<sub>2</sub> conversion. The following list summarizes differences (if any) between the new NO<sub>2</sub> modelling guidance presented in this document and each Guideline section related to NO<sub>2</sub> baseline and NO to NO<sub>2</sub> conversion.

- ◆ 8.1.4 Selecting a Baseline Level Using Monitoring Data – This new guidance includes a similar approach for selecting 1-hour NO<sub>2</sub> baseline. Consistent with the latest Guideline, use of a single value based on the 98<sup>th</sup> percentile of daily 1-hour maximum values is appropriate for Level 2 and 3 Assessments. However, this new guidance also provides further options for refinement including time-varying baseline NO<sub>2</sub> levels. This document also includes a detailed study of available NO<sub>2</sub> and NO<sub>x</sub> monitoring data in the province.
  - As a change from the latest Guideline, NO<sub>2</sub> baseline should be applied after applying ARM. This approach is consistent applying U.S. EPA Ambient Ratio Method 2 (ARM2) if using AERMOD's built-in ARM2 option.
  - Clarification is provided in this new guidance that NO<sub>2</sub> baseline should also be applied after applying OLM or PVMRM.
- ◆ 8.2.1 100% conversion – No substantive changes.
- ◆ 8.2.2 ARM – This new guidance applies the same general approach to use ambient NO<sub>2</sub> and NO<sub>x</sub> data to determine an NO<sub>2</sub> to NO<sub>x</sub> ratio curve. However, there are some key changes:
  - The form of the equation is updated to follow the U.S. EPA ARM2 approach (6th order polynomial rather than an exponential equation).
  - The updated method also yields a curve with a maximum ratio of 90% and a minimum ratio of 20%.
  - ARM2 curves are provided in Appendix A for different categories of areas (coastal, industrial, rural, and urban). Applicants may still develop a project-specific curve based on representative ambient NO<sub>2</sub> and NO<sub>x</sub> data on a case-by-case basis.
  - As a change from the latest Guideline, the NO<sub>2</sub> baseline level is applied after the application of the ARM2 equation.
- ◆ 8.2.3 OLM– This new guidance aligns with the latest Guideline with the following exceptions:
  - The OLM equation is changed to use the ISR, rather than use 0.1 as the minimum NO<sub>2</sub>/NO<sub>x</sub> ratio:

Equation from latest Guideline:  $NO_2 = 0.1 \times NO_x + \text{the lesser of } (O_3 \text{ or } 0.9 \times NO_x) + \text{baseline } NO_2$

Revised Equation:  $NO_2 = \text{ISR} \times NO_x + \text{the lesser of } (O_3 \text{ or } (ER\text{-ISR}) \times NO_x) + \text{baseline } NO_2$

Where:

- ISR stands for the in-stack ratio.
- Information is provided to determine ISRs for each source.
- ER stands for equilibrium ratio, and the default is 0.9. This is a change from the latest Guideline equation, which used an equilibrium ratio of 1.0.

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- More information, flexibility, and guidance are provided for using hourly O<sub>3</sub> datasets rather than “maximum hourly O<sub>3</sub> concentration measured from one year of representative monitoring data.”
- Note that OLM may be used within AERMOD or a separate post-processing step.
- ◆ 8.2.4 PVMRM (AERSCREEN and AERMOD Only) – This new guidance aligns with the latest Guideline with the following exceptions (similar to OLM):
  - For AERMOD and AERSCREEN, the latest Guideline recommended PVMRM. This document clarifies that OLM may be used in AERMOD.
  - Information is provided to determine ISRs for each source.
  - More information, flexibility, and guidance are provided for using hourly O<sub>3</sub> datasets rather than “maximum hourly O<sub>3</sub> concentration measured from one year of representative monitoring data.”
- ◆ 8.2.5 RIVAD/ARM3 and RIVAD/ISORROPIA Chemical Transformation – This new guidance maintains the same guidance as in the latest Guideline, not recommending the use of RIVAD/ARM3 and RIVAD/ISORROPIA for NO/NO<sub>2</sub> conversion.

The latest Guideline states that advanced NO<sub>2</sub> modelling techniques are only acceptable for Level 3 Assessments. This updated guidance allows advanced NO<sub>2</sub> modelling techniques for any assessment level.

The following table highlights the specific sections of this document that offer further detail and clarity regarding NO<sub>2</sub> model techniques as compared to the latest Guideline:

**Table 2-1: Summary of Sections Containing NO<sub>2</sub> Modelling Guidance Changes**

Section	Topic	Notes
3.2.1.2 & Appendix A	ARM2	This document provides additional clarity on both how and when to implement ARM2 for a Tier 2 NO <sub>2</sub> model project.
3.3.1	Post-processing tools for NO <sub>2</sub> conversion	Additional details for the available post-processing techniques for refining NO <sub>2</sub> model assumptions are provided.
3.3.2	Baseline NO <sub>2</sub> concentrations	This document offers a detailed study of available NO <sub>2</sub> baseline data in BC and provides guidance for obtaining and properly assessing available NO <sub>2</sub> baseline data for use in an NO <sub>2</sub> modelling project.
4	Materials for modelling project submissions	This document includes a comprehensive list of the files which applicants must include when submitting a modelling project to the Ministry.
Appendix C Appendix D	Ozone datasets	In addition to providing clarity for the use of ambient O <sub>3</sub> datasets, this document provides a detailed analysis of available O <sub>3</sub> monitoring data throughout the province, describes the O <sub>3</sub> datasets developed by the Ministry for use in regions lacking representative O <sub>3</sub> data, and provides applicants with appropriate methods for filling in gaps in O <sub>3</sub> data for representative datasets.
Appendix B	In-stack ratios	Appendix B offers ISR values for a variety of source types, which can be used by applicants to accurately take into account the characteristics of a given source type and the resulting effect on NO <sub>2</sub> conversion chemistry.

### 3 NO<sub>2</sub> MODELLING METHODS

#### 3.1 AIR DISPERSION MODELS

This section introduces the preferred models listed in Section 2 of the latest Guideline, provides brief descriptions of the models and underlying theories, and gives context to when each model would be most appropriate for a given project. For further information regarding the theory and implementation of these air dispersion models, applicants should refer to the latest Guideline.

##### 3.1.1 AERMOD AND AERSCREEN

###### 3.1.1.1 AERMOD

AERMOD is a regulatory straight-line, steady-state plume modelling system that consists of three components: AERMOD (calculates the concentrations), AERMET (prepares the meteorological input) and AERMAP (prepares the terrain input).

Recommended use:

- ◆ sources in an industrial complex (single or multiple point, area, line, volume sources)
- ◆ situations where a straight-line, steady state model applies (non-complex flow)
- ◆ single or multiple buildings with or without building downwash
- ◆ gas and particle depositions
- ◆ constant or time-varying emissions
- ◆ rural or urban areas
- ◆ transport distances less than 50 km (depends on terrain)
- ◆ concentration estimates for all terrain locations, except in areas located on the lee-side of the topographic features

###### 3.1.1.2 AERSCREEN

AERSCREEN is a screening version of the refined model AERMOD. AERSCREEN is a shell that runs AERMOD with an input matrix of meteorological conditions that represent a wide range of possible conditions.

Recommended use:

- ◆ maximum 1-hour, 3-hour, 8-hour, 24-hour and annual average concentrations
- ◆ single point, capped stack, horizontal stack, flare, area (circular or rectangular), volume sources
- ◆ building wake effects on point, capped stack, horizontal stack, and flare sources
- ◆ flat and elevated terrain
- ◆ urban and rural areas
- ◆ transport distances of less than 50 km (depends on terrain)

### 3.1.2 CALPUFF

#### 3.1.2.1 CALPUFF

CALPUFF is a curved trajectory, Gaussian puff model that can account for time and space-varying meteorological conditions, different source configurations and contaminants, and chemical transformations. The CALPUFF modelling system is comprised of three components: CALMET (meteorological model), CALPUFF (calculates concentration and deposition output), and CALPOST (analysis and display of output).

Recommended use:

- ◆ complex flow: non-steady-state meteorological conditions (calms, time and space variability in wind and turbulence fields) such as found in complex terrain and coastal situations
- ◆ local scale up to long range transport (>50 to 200 km)
- ◆ multiple sources, source types (point, area, volume) and building(s)
- ◆ gaseous and particulate deposition
- ◆ wet and dry Sulphur and Nitrogen deposition
- ◆ PM<sub>2.5</sub> secondary formation
- ◆ visibility assessments for regional (>10 km) and long-range transport distances (>50 km to 200 km)
- ◆ constant or time varying source conditions of gaseous and particulate contaminants
- ◆ fogging, icing and odour effects

### 3.2 NO<sub>2</sub> MODEL TECHNIQUES GUIDANCE

#### 3.2.1 RECOMMENDED NO TO NO<sub>2</sub> CONVERSION TECHNIQUES

The following subsections outline recommended model techniques for refining predictions of NO<sub>2</sub> concentrations from modelled NO<sub>x</sub> emissions. These techniques are provided in order of increasing complexity of implementation. While each subsequent technique requires more complex inputs or calculations, it is not necessarily a more refined model that will yield lower NO<sub>2</sub> concentrations. For example, a model that implements the ARM2 method will not necessarily yield higher modelled NO<sub>2</sub> concentrations than a model that implements OLM. Rather, specific scientific considerations and relative availability of data will determine the appropriate method of NO<sub>2</sub> model refinement for a given project. Modellers that are unsure about the appropriate NO<sub>2</sub> model technique for a given project are encouraged to consult with ENV regarding which modelling techniques are appropriate.

Tier 1, Tier 2, or Tier 3 NO<sub>x</sub> conversion techniques (described in the following subsections) may be used with any level of dispersion modeling (Level 1 to Level 3 described in Section 1.3.1).<sup>5</sup> However, Tier 1 for total conversion must be presented as part of all model reports so that reviewers can understand the upper-bound NO<sub>2</sub> model results.

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<sup>5</sup> See Section 4.2 for decision criteria for selecting the NO to NO<sub>2</sub> conversion technique.

### 3.2.1.1 TIER 1: TOTAL CONVERSION

The simplest technique for modelling NO<sub>2</sub> to implement is to assume that NO<sub>x</sub> emissions are converted entirely to NO<sub>2</sub> in the atmosphere. For this technique, models assume that 100% of NO<sub>x</sub> emissions resulting from a given project are converted to NO<sub>2</sub>. In reality, the quantity of NO<sub>x</sub> converted to NO<sub>2</sub> in an equilibrium state is dependent on numerous factors, including O<sub>3</sub> concentrations, NO<sub>2</sub> to NO<sub>x</sub> ISRs for a given source, baseline NO<sub>2</sub> concentrations, and more. Assuming complete conversion of NO<sub>x</sub> to NO<sub>2</sub> is a conservative screening technique to determine worst-case NO<sub>2</sub> concentrations from a source. This total conversion must be presented as part of all model reports so that reviewers can understand the upper-bound NO<sub>2</sub> model results.

This method, by nature, will provide a conservative estimate of NO<sub>2</sub> modelled concentrations and can therefore often serve as an appropriate initial screening assumption. Beyond initial, preliminary assessments this method is also appropriate for smaller sources with limited anticipated NO<sub>2</sub> model concentrations.

### 3.2.1.2 TIER 2: AMBIENT RATIO METHOD

The ARM method applies a ratio of NO<sub>2</sub> to total NO<sub>x</sub> in the atmosphere to calculate NO<sub>2</sub> concentrations based on modelled NO<sub>x</sub> concentrations. In 2013, RTP Environmental Associates, Inc. prepared the ARM2, a model refinement for NO<sub>2</sub> 1-hour modelling in AERMOD, for the American Petroleum Institute and the U.S. EPA.<sup>6</sup> The ARM2 methodology refines the U.S. EPA ARM approach by applying a varying ambient ratio of NO<sub>2</sub> to NO<sub>x</sub> as a function of the total NO<sub>x</sub> concentration in the atmosphere (the ratio decreases with increasing NO<sub>x</sub> concentrations). The U.S. EPA ARM2 curve was based on a 10-year dataset of monitoring data from the entire continental United States and is built into the U.S. EPA model, AERMOD. The U.S. EPA recommends ARM2 as the preferred NO<sub>2</sub> Tier 2 technique rather than its previous ARM, which used a fixed ambient ratio of NO<sub>2</sub> to total NO<sub>x</sub> (i.e., 0.75 for the annual averaging period and 0.8 for the 1 hour averaging period<sup>7,8</sup>). ARM2 represents a method of refinement that is often preferred when compared to Tier 3 methods (discussed in the next section) due to its shorter run times and fewer input data requirements (thereby requiring less case-by-case review and approval). A plot of the measured NO<sub>2</sub>/NO<sub>x</sub> ratios for all of the studied BC monitoring stations is provided in Figure 3-1 below, including the BC-specific ARM2 curve developed based on the data (see Appendix A for details).

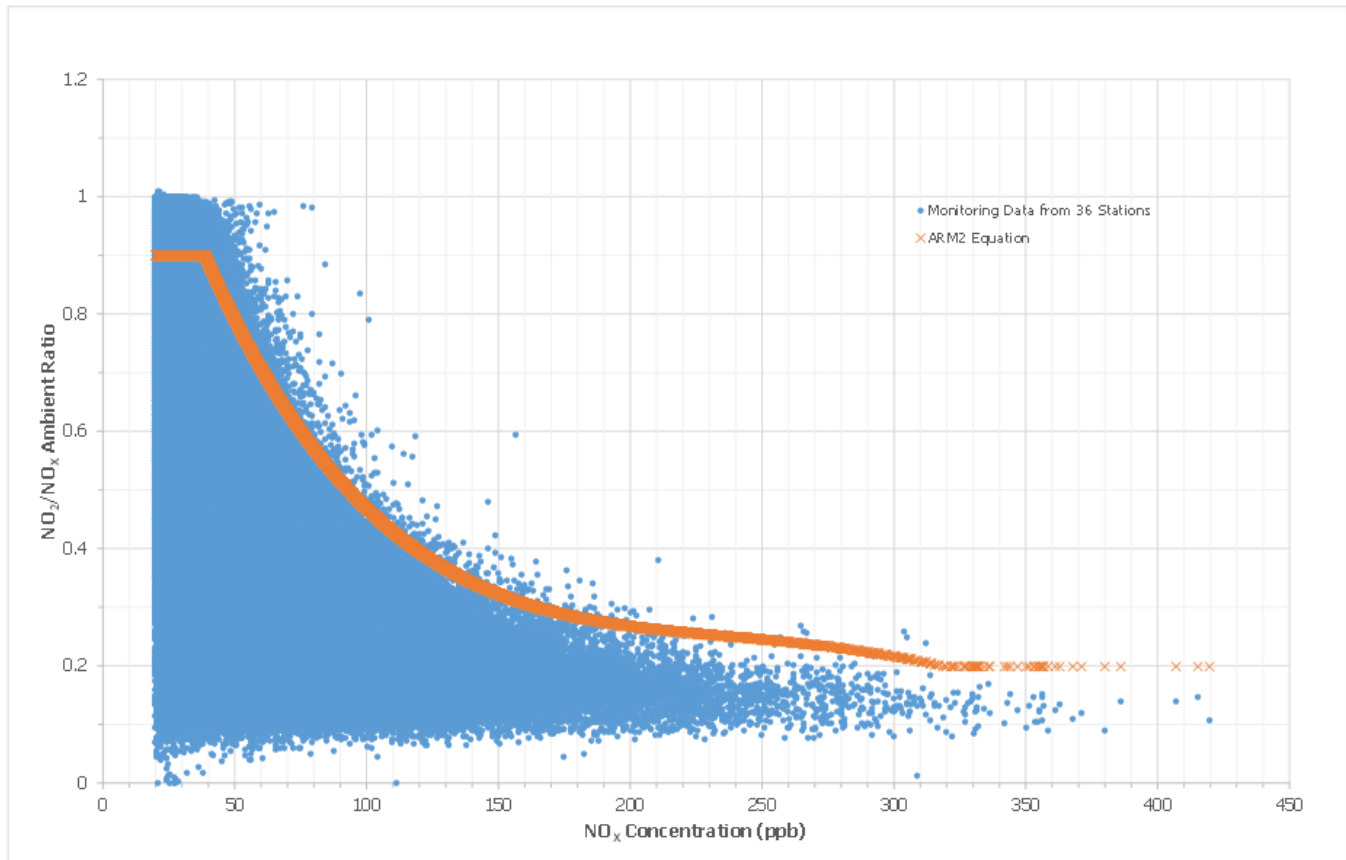
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<sup>6</sup> RTP Environmental Associates, Inc. "Ambient Ratio Method Version 2 (ARM2) for use with AERMOD for 1-hr NO<sub>2</sub> Modeling – Development and Evaluation Report." September 20, 2013.

[https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/ARM2\\_Development\\_and\\_Evaluation\\_Report-September\\_20\\_2013.pdf](https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/ARM2_Development_and_Evaluation_Report-September_20_2013.pdf)

<sup>7</sup> [https://www.epa.gov/sites/production/files/2020-10/documents/no2\\_clarification\\_memo-20140930.pdf](https://www.epa.gov/sites/production/files/2020-10/documents/no2_clarification_memo-20140930.pdf)

<sup>8</sup> Note that under the existing guidelines, applicants may alternatively use a single conversion factor based on a range of expected concentrations with ENV approval.



**Figure 3-1: British Columbia ARM2 Curve with Associated Monitoring Data**

The data included in the figure above represents 10 years of monitoring data from a total of 36 monitoring stations in BC. A summary of the data is provided in Appendix A.

Trinity Consultants Inc. (Trinity) developed province-specific ARM2 curves using monitoring data obtained from the BC Air Data Archive Website<sup>9</sup> based on the methodology used by RTP Environmental Associates, Inc.<sup>10</sup> Details of the equations used to determine NO<sub>2</sub> concentrations based on NO<sub>x</sub> concentrations, including specific datasets and ARM2 curves developed for different site categories (coastal, industrial, rural, and urban) for BC are included in Appendix A of this document.

An applicant can apply the appropriate BC ARM2 curve provided in Appendix A based on the category that best fits the facility location. In addition to those ARM2 curves provided in Appendix A, site-specific ARM2 curves can be developed if adequate hourly NO<sub>x</sub> measurements are available (e.g., ten complete calendar years representative of current conditions). However, the province-wide curves are generally preferred. An applicant will need to justify why a site-specific curve is needed and consult with ENV to ensure an adequate dataset is used. Applicants should also consider anticipated future changes affecting conditions

<sup>9</sup> British Columbia Ministry of Environment Air Data Archive Website, Station Reports. <https://envistaweb.env.gov.bc.ca/>

<sup>10</sup> RTP Environmental Associates, Inc. "Ambient Ratio Method Version 2 (ARM2) for use with AERMOD for 1-hr NO<sub>2</sub> Modeling – Development and Evaluation Report." September 20, 2013. [https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/ARM2\\_Development\\_and\\_Evaluation\\_Report-September\\_20\\_2013.pdf](https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/ARM2_Development_and_Evaluation_Report-September_20_2013.pdf)

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(e.g., new NO<sub>x</sub> sources in the airshed). Applicants should consult with ENV before taking this approach and should review the curves with ENV through the Dispersion Modelling Plan.

The NO<sub>2</sub> baseline concentration (see Section 3.3.2) should be added to modelled NO<sub>2</sub> concentrations after applying the ARM2 equation for consistency with the NO<sub>2</sub> monitoring values used for comparing to the ambient objectives or standards. If AERMOD is used, the ARM2 option in AERMOD may be selected as a screening approach because the U.S. EPA ARM2 curve is more conservative (higher NO<sub>2</sub>/NO<sub>x</sub> ratio) at all NO<sub>x</sub> concentrations (see Figure A-1). The approach and curve selection with justification should be outlined in the Dispersion Modelling Plan and approved by ENV.

Note that when applying ARM2 to determine 1-hour NO<sub>2</sub> values, the same ARM2 approach should be used to determine annual average values (by applying ARM2 to all 1-hour model results and calculating or outputting the annual average after ARM2 is applied).

### 3.2.1.2.1 CONVERSION BETWEEN PPB AND MG/M<sup>3</sup>

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Ambient monitoring data is usually measured and recorded in units of parts per billion (ppb) by volume, while models typically provide output in concentrations in micrograms per cubic metre (µg/m<sup>3</sup>). As such, it is important to appropriately convert ambient monitoring data to units that are consistent with model output or vice-versa, using consistent conversion assumptions. The ARM2 curves provided in Appendix A are in units of ppb. Therefore, model output should be converted or vice versa, so that both are in the same units before applying the ARM2 equation.

When developing the AERMOD ARM2 curve, the following equation was used to convert from ppb to µg/m<sup>3</sup>:<sup>11</sup>

$$C [\mu\text{g}/\text{m}^3] = (\text{ppb}/1000) \times \text{MW} \times 40.8727$$

Where MW is the molecular weight of the pollutant in grams/mole.

In the case of NO<sub>x</sub> and NO<sub>2</sub> specifically, the molecular weight of 46 g/mole<sup>12</sup> is used, and this equation is therefore simplified to the following:

$$C [\mu\text{g}/\text{m}^3] = \text{ppb} \times 1.880$$

Applicants should also use the above conversion when converting from ppb to µg/m<sup>3</sup> or vice versa to maintain consistency.

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### 3.2.1.3 TIER 3: OZONE LIMITING METHOD AND PLUME VOLUME MOLAR RATIO METHOD

Tier 3 NO<sub>2</sub> modelling techniques, including OLM and PVMRM, incorporate ambient O<sub>3</sub> concentrations when determining the level of conversion of NO to NO<sub>2</sub>. The U.S. EPA states that “PVMRM is most appropriate with relatively isolated and

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<sup>11</sup> [https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/ARM2\\_Development\\_and\\_Evaluation\\_Report-September\\_20\\_2013.pdf](https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/ARM2_Development_and_Evaluation_Report-September_20_2013.pdf)

These factors are developed for standard conditions using a standard temperature and pressure of 25 degrees C and 760 millimeters of mercury.

<sup>12</sup> For NO<sub>x</sub>, even though NO and NO<sub>2</sub> have different molecular weights, the convention for NO<sub>x</sub> mass emission rate input to dispersion models and source testing is to represent NO<sub>x</sub> “as NO<sub>2</sub>” (using the molecular weight of NO<sub>2</sub> of 46 g/mole).

elevated sources, while OLM is more appropriate for area sources, near-surface releases, or scenarios with multiple sources where plume overlap is likely to occur.”<sup>13</sup>

### 3.2.1.3.1 OZONE LIMITING METHOD

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The OLM assumes that O<sub>3</sub> is the limiting reagent in the photochemical reaction of O<sub>3</sub> and NO to form NO<sub>2</sub>. As a result of this assumption, at all receptor locations or any given model hour, the ambient concentration of O<sub>3</sub> along with an equilibrium constant determines the amount of NO<sub>2</sub> formed by the reaction of NO and O<sub>3</sub> in the atmosphere. The amount of NO emitted from a modelled source is determined using the NO<sub>2</sub> to NO<sub>x</sub> ISR, with the remaining percentage of NO<sub>x</sub> emissions assumed to be NO.

The OLM can be applied with the approval of the Ministry. The NO<sub>2</sub> concentration can be determined using the following equation:<sup>14</sup>

$$\text{NO}_2 = \text{ISR} \times \text{NO}_x + \text{the lesser of (O}_3 \text{ or (ER-ISR) } \times \text{NO}_x) + \text{baseline NO}_2$$

Where:

“ISR” refers to the in-stack ratio of NO<sub>2</sub> to NO<sub>x</sub>. This value varies by source type, and the value should be identified with suitable justification in the Dispersion Modelling Plan. ISRs are described in further detail, along with a table of ISR values for various source types provided in Appendix B of this document. The NO<sub>2</sub> baseline concentration (see Section 3.3.2) should be added to modelled NO<sub>2</sub> concentrations after applying the OLM equation because the OLM equation is based the concentrations of NO<sub>x</sub> within the plume. When applying the equation above for multiple sources, ISR should be based on the source with the highest ISR. Alternative methods (e.g., weighted average based on contribution to ambient concentrations of NO<sub>x</sub> by source at receptors used for decision-making)<sup>15</sup> may be acceptable with approval from ENV.

“ER” refers to the equilibrium ratio. The default ER is 0.9. Applicants should contact ENV if proposing to use an alternative value.

The above equation assumes the concentrations for all constituents are in vol/vol units (e.g., ppmv). If there are multiple plumes that have merged, OLM is applied to the combined plume NO<sub>x</sub> concentration (OLMGROUP ALL option in AERMOD). If use of the maximum ISR among each individual source is believed to be too conservative for a given model, applicants may calculate the weighted average ISR based on contribution to ambient concentrations of NO<sub>x</sub> by source at receptors used for decision-making. Applicants should contact ENV if they wish to pursue an alternative other than using of the maximum ISR among individual sources.

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<sup>13</sup> U.S. EPA’s memo on Clarification on the Use of AERMOD Dispersion Modeling for Demonstrating Compliance with the NO<sub>2</sub> National Ambient Air Quality Standard (2014)).

<sup>14</sup> Cole, H. S., & Summerhays, J. E. (1979). A Review of Techniques Available for Estimation of Short-Term NO<sub>2</sub> Concentrations. *Journal of the Air Pollution Control Association*, 29(8), 812-817.

<sup>15</sup> Different ISRs may be entered in AERMOD and the weighted average of concentration is used to determine the hour and receptor-specific NO<sub>2</sub>/NO<sub>x</sub> ratio and NO<sub>2</sub> concentration. For CALPUFF modelling, when there are overlapping plumes, apply OLM based on the weighted average of concentrations of NO<sub>x</sub> by source at receptors. An OLM post-processor for CALPUFF will be available from ENV in the near future that can be used to assess NO<sub>2</sub> concentrations from sources with different ISRs.



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For plumes that do not merge, OLM is applied to each plume separately. For AERSCREEN and AERMOD applications, OLM can be applied by selecting the OLM option within the model. In most cases the OLMGROUP ALL option in AERMOD should be specified to allow for competition for O<sub>3</sub> in overlapping plumes. Sources at a single facility within a typical footprint (e.g., within 1 km in length) may have overlapping plumes, and the OLMGROUP ALL option is appropriate.<sup>16</sup>

The required additional inputs are:

- ◆ Background O<sub>3</sub> concentrations – site-specific. See Appendix C.
- ◆ NO<sub>2</sub> to NO<sub>x</sub> ISR – source-specific (can apply different ISR for each source). See Appendix B. If a source type is not listed in Appendix B and site-specific data are not available, a default ISR of 0.5 should be applied.
- ◆ NO<sub>2</sub>/NO<sub>x</sub> ambient ER – should be kept at the default of 0.9.

Detailed descriptions of how to select appropriate O<sub>3</sub> datasets, ISRs, and filling in missing data gaps for those O<sub>3</sub> datasets are provided in the Appendices of this document. If selected, the OLM approach, O<sub>3</sub> background, and ISR for each source with justification should be outlined in the Dispersion Modelling Plan and approved by the Ministry.

### 3.2.1.3.2 PLUME VOLUME MOLAR RATIO METHOD

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The PVMRM method builds on the same reaction chemistry used in OLM, calculating the ratio of NO<sub>2</sub> to NO<sub>x</sub> based on the moles of emitted NO<sub>x</sub> and ambient O<sub>3</sub> contained in the volume of plume located between the receptor and the source. PVMRM estimates the amount of O<sub>3</sub> entrained in the dispersion plume of a source to determine the amount of O<sub>3</sub> that is available for oxidation of NO to form NO<sub>2</sub>, then applies a limiting factor approach.<sup>17</sup>

For AERSCREEN and AERMOD applications, use of the PVMRM for NO<sub>x</sub> conversion represents another potential Tier 3 NO<sub>2</sub> modelling technique.<sup>18</sup> This method limits the conversion of NO to NO<sub>2</sub> based on the amount of O<sub>3</sub> available in the plume and accounts for the changing plume volume due to dispersion. The method also accounts for merging plumes in multi-source modelling scenarios. The three additional inputs are the same as needed for OLM within AERMOD:

- ◆ Background O<sub>3</sub> concentrations – site-specific. See Appendix C.
- ◆ NO<sub>2</sub> to NO<sub>x</sub> ISR – source-specific (can apply different ISR for each source). See Appendix B. If a source type is not listed in Appendix B and site-specific data are not available, a default ISR of 0.5 should be applied.
- ◆ NO<sub>2</sub>/NO<sub>x</sub> ambient ER – should be kept at the default of 0.9.

Detailed descriptions of how to select appropriate O<sub>3</sub> datasets, ISRs, and filling in missing data gaps for those O<sub>3</sub> datasets are provided in the Appendices of this report. If selected, the PVMRM approach, O<sub>3</sub> background, and ISR for each source with justification should be outlined in the Dispersion Modelling Plan and approved by the Ministry.

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<sup>16</sup> [https://www.epa.gov/sites/production/files/2015-07/documents/appwno2\\_2.pdf](https://www.epa.gov/sites/production/files/2015-07/documents/appwno2_2.pdf)

<sup>17</sup> [https://www.epa.gov/sites/production/files/2021-01/documents/no2\\_modeling\\_techniques\\_white\\_paper.pdf](https://www.epa.gov/sites/production/files/2021-01/documents/no2_modeling_techniques_white_paper.pdf)

<sup>18</sup> Hanrahan, P. L. (1999). The Plume Volume Molar Ratio Method for Determining NO<sub>2</sub>/NO<sub>x</sub> Ratios in Modelling. Part II: Evaluation Studies. *Journal of the Air and Waste Management Association*, 49, 1332-1338.

### 3.2.2 ALTERNATIVE NO<sub>2</sub> MODELLING TECHNIQUES

Additional modelling techniques include:

- ♦ The RIVAD/ARM3 and RIVAD/ISORROPIA chemical transformation schemes within CALPUFF are able to provide predicted NO<sub>2</sub> concentrations as part of the output suite of parameters. However, consistent with the latest Guideline, the use of these modules directly for local and regional scale NO<sub>2</sub> estimates has not been evaluated. Until more evidence emerges on the use of CALPUFF for this specific purpose, ENV does not recommend the use of RIVAD/ARM3 and RIVAD/ISORROPIA for NO/NO<sub>2</sub> conversion.
- ♦ Photochemical grid models (e.g., the Community Multiscale Air Quality Model (CMAQ) or the Comprehensive Air Quality Model with Extensions (CAMx)) and photochemical puff models (e.g., SCICHEM) estimate concentrations of NO<sub>2</sub> and other pollutants by simulating complex atmospheric photochemical transformations. These models are generally used for estimating O<sub>3</sub> or secondary particulate matter during episodic events. While photochemical models may include reactions that more accurately represent actual conditions, the photochemical models' sophistication, data requirements and cost are generally not warranted for model predictions of NO<sub>2</sub>.
- ♦ The Atmospheric Dispersion Model System (ADMS)<sup>19</sup> Method applies a similar approach as PVMRM including plume entrainment.<sup>20</sup> It also adds a reaction rate based on solar radiation and travel time from source to receptor. While this method has shown better performance in at least one study,<sup>21</sup> this approach is an alternative approach that must be approved by the Ministry because ADMS is not an approved model listed in Section 2 of the Guideline.

This document does not provide detailed guidance on these techniques. Applicants should contact ENV prior to use of alternative models if proposing that alternative model techniques are necessary to adequately demonstrate expected NO<sub>2</sub> concentrations for a given modelled source.

### 3.3 MODEL POST-PROCESSING

The following sections provide descriptions of post-processing methods for model outputs.

#### 3.3.1 CONVERSION OF NO TO NO<sub>2</sub> USING POST-PROCESSING TOOLS

The Tier 2 and Tier 3 techniques described in the previous section can be used by selecting the appropriate options in AERMOD. CALPUFF does not include built-in algorithms for these same techniques, but CALPOST includes an option to specify short-term and long-term ambient NO<sub>2</sub>/NO<sub>x</sub> ratio conversion tables with key words CNOX\_S, TNO2NOX\_S, CNOX\_L, and TNO2NOX\_L. The tables include 24 values, so they can be used to specify a step function that corresponds to the province-specific curves. Applicants must specify these 24 values based on the representative ARM2 curve to use CALPOST's ARM-related option. Care should be taken to ensure the step functions fall to the right of the province-specific curves. The 24 values should be listed in the Dispersion Modelling Plan. The NO<sub>2</sub> baseline should be added to the model result after applying the ARM2 equation. The ARM2 equations can also be applied to the model output using other post-processing methods such as running post-processing scripts.

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<sup>19</sup> <http://www.cerc.co.uk/environmental-software/ADMS-model.html>

<sup>20</sup> [https://www.cerc.co.uk/environmental-software/assets/data/doc\\_techspeg/P18\\_02.pdf](https://www.cerc.co.uk/environmental-software/assets/data/doc_techspeg/P18_02.pdf)

<sup>21</sup> Carruthers, D.J., Stocker, J.R., Ellis, A., Seaton, M.D. and Smith, S.E. (2017). Evaluation of an explicit NO<sub>x</sub> chemistry method in AERMOD. *Journal of the Air & Waste Management Association*, 67(6), pp.702- 712.

It is important to note that for 1-hour NO<sub>2</sub> results, the ARM2 equation should be applied to each hour and receptor rather than only to the summary result because the hour and location of the 98<sup>th</sup> percentile result can change depending on the outcome of the ARM2 equation.

CALPOST does not include a specific option to apply Tier 3 techniques like OLM or PVMRM; however, applying the OLM equation can be achieved using POSUTIL or another post-processing tool. The NO<sub>2</sub> baseline should be added to the model result after the OLM equation is applied. The OLM equation could also be applied using simpler tools such as Excel. Again, it is important to note that for 1-hour NO<sub>2</sub> results, the OLM equation should be applied to each hour and receptor rather than only to the summary result because the hour and location of the 98<sup>th</sup> percentile result can change depending on the outcome of the OLM equation.

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### 3.3.2 BASELINE NO<sub>2</sub> CONCENTRATIONS

The baseline concentration is the concentration added to model results to account for sources not explicitly modelled (usually existing during the baseline period). The baseline concentration is typically applied as a single constant value throughout the spatial and temporal model domain. Section 8.1 of the latest Guideline provides general baseline-related recommendations (e.g., the baseline should be based on the most recent years of representative hourly monitoring data with 75% completion in each quarter; the monitoring data can be pre-screened to exclude any periods when an intermittent source has a significant influence on the monitor.). When modelling NO<sub>2</sub> for a given facility, the baseline concentrations of NO<sub>2</sub> selected for an analysis can have a substantial effect on the resulting combined NO<sub>2</sub> concentrations at a given location.

- ◆ For Tier 2 (ARM2), NO<sub>2</sub> baseline concentrations should be applied after applying the ambient NO<sub>2</sub>/NO<sub>x</sub> ratio to modelled total NO<sub>x</sub> concentrations in order to produce results consistent with monitored NO<sub>2</sub> concentrations.
- ◆ For Tier 3 (OLM and PVMRM), NO<sub>2</sub> baseline concentrations should be applied after OLM or PVMRM is implemented.

The temporal variability of NO<sub>2</sub> baseline datasets is an important consideration when selecting an appropriate NO<sub>2</sub> baseline for a model. While an NO<sub>2</sub> baseline is often represented as a single value applied to the entirety of the model's time domain, temporally varying NO<sub>2</sub> baselines can offer a more refined approach for 1-hour averaging period NO<sub>2</sub> models. This refinement can range in complexity from using annual hour-of-day values (which take into account fluctuations in NO<sub>2</sub> over the course of a day) to datasets that vary by both hour-of-day and by month.

1-hour NO<sub>2</sub> baseline datasets can vary widely in format. The following methods are presented in order of increasing refinement. Applicants should progress sequentially through the following list as necessary to develop a refined 1-hour NO<sub>2</sub> modeling baseline that is representative of the conditions at the modelled facility.<sup>22</sup>

- ◆ Level 1 Assessments should use the most conservative approach for consistency with the latest Guideline, requiring use of the maximum monitored concentration (100<sup>th</sup> percentile).
- ◆ For Level 2 and 3 Assessments, the total concentration (baseline + modelled concentration) sequential calculation options are provided below:

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<sup>22</sup> Considerations to determine whether conditions are representative of the conditions at the modelled facility are included in Section 4.2.

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- 98<sup>th</sup> Percentile of Daily 1-Hour Maximum (D1HM) Baseline from Monitoring Data  
+ 98<sup>th</sup> Percentile of D1HM Modelled Concentration  
[For complete years, the 8<sup>th</sup> highest D1HM from monitor + the 8<sup>th</sup> highest D1HM model.]
- 98<sup>th</sup> Percentile of D1HM of:  
(Baseline 98<sup>th</sup> Percentile of Annual Hour-of-Day from Monitoring Data  
+ Hourly Modelled Concentration)  
[For complete years, the 98<sup>th</sup> percentile baseline dataset is based on the 8<sup>th</sup> highest of each hour of day over year from monitor, each hour-of-day averaged over each year of a multi-year monitor dataset.]
- 98<sup>th</sup> Percentile of D1HM of:  
(Baseline 98<sup>th</sup> Percentile of Monthly or Seasonal Hour-of-Day from Monitoring Data  
+ Hourly Modelled Concentration)  
[For complete years, the 98<sup>th</sup> percentile baseline dataset is based on the 1<sup>st</sup> highest of each hour of day over month or the 3<sup>rd</sup> highest of each hour of day over season, averaged over each year of a multi-year monitor dataset.<sup>23</sup> Note that the winter season is defined to include January and February of the year under review and December of the previous year.]

The annual average baseline concentration is the annual mean calculated from screened or unscreened hourly data over a year.

For sites without NO<sub>2</sub> monitoring data, applicants should select a representative monitor based on the monitor categories below. These categories provide a straight-forward approach to identify the most similar baseline concentrations based on the types of NO<sub>x</sub> sources that may exist in the surrounding area.

- ◆ Rural Sites
- ◆ Coastal Sites
- ◆ Urban Sites
- ◆ Industrial Sites

The baseline NO<sub>2</sub> concentration should reflect the NO<sub>2</sub> concentrations in the area from existing emission sources. Additionally, the ambient NO<sub>2</sub> concentration is also heavily affected by the local climatology, including background O<sub>3</sub> concentration and terrain, which could affect how quickly NO emitted from combustion sources converts to NO<sub>2</sub>. If a proposed site is located in a remote area without a monitor, the applicant should evaluate whether the location is considered coastal (with nearby marine activity), industrial (with nearby industrial operations emitting NO<sub>x</sub>), or rural (with no nearby notable NO<sub>x</sub> sources). If a proposed site will be located in an area that fits multiple categories, the applicant should discuss the most representative baseline with ENV when preparing the Dispersion Modelling Plan. See Appendix A for further explanation of how monitoring stations are categorized.

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<sup>23</sup> The use of the 3<sup>rd</sup> highest to represent the seasonal 98<sup>th</sup> percentile is consistent with the California Air Pollution Control Officers Association (CAPCOA) guidance on modelling compliance with the U.S. Federal 1-hour NO<sub>2</sub> air quality standard. When assessing values for seasonal hour-of-day datasets, use of the 2<sup>nd</sup> highest would effectively “ignore” only four total values for the entire year, rather than the seven total values “ignored” when determining the 98<sup>th</sup> percentile (8<sup>th</sup> highest) for a yearly dataset. Therefore, use of the 2<sup>nd</sup> highest from a given season would be more conservative, and the 3<sup>rd</sup> highest should therefore represent the 98<sup>th</sup> percentile for seasonal hour-of-day.

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Once the category of the proposed site is determined, the most representative monitor can be selected based on commonly applied considerations, such as proximity, land cover similarity, and population similarity. After the representative monitor is selected, the baseline value(s) can be determined.

For example, oil and gas facilities in BC are primarily located in northeast of the province. Urban areas are not present for most of the locations where the oil and gas facilities are situated. Based on the proximity of the continuous NO<sub>x</sub> monitoring stations, Fort St. John Key Learning Centre, Farmington Community Hall, and Taylor Townsite are available options.

- ♦ The Fort St. John Key Learning Centre station represents a small urbanized residential area which is not influenced by point sources.<sup>24</sup> The NO<sub>2</sub> monitor data from this station could be used to estimate the NO<sub>2</sub> baseline condition in areas further away from NO<sub>2</sub> emitting sources but with human activities (e.g., Fort Nelson).
- ♦ The Farmington Community Hall station is an industrial-owned monitoring station located in a rural area. No nearby notable NO<sub>x</sub> sources are present. The closest NO<sub>x</sub> emission source is an oil and gas extraction site owned by Tourmaline Oil Corp. (approximately 3 km away). The NO<sub>2</sub> monitor data from this station could be used to estimate the NO<sub>2</sub> baseline condition in rural areas without notable NO<sub>x</sub> sources.
- ♦ The Taylor Townsite station is located approximately 1 km from Spectra Energy's natural pipeline station, which reported over 1000 tonnes of NO<sub>x</sub> emissions in 2017. The NO<sub>2</sub> monitor data from this station could be used to estimate the NO<sub>2</sub> baseline condition in areas with notable NO<sub>x</sub> sources (e.g., areas close to Ikkuma Resource Corp's Sierra Gas Plant which reported 1,200 tpy in 2017).

The baseline approach and dataset selection with justification should be outlined in the Dispersion Modelling Plan and approved by the Ministry.

### 3.3.2.1 MONTE CARLO METHOD FOR BASELINE

The Monte Carlo method of analysis further refines baseline by using a statistical analysis to address variability in monitored concentrations and how the concentrations are paired with model results. Prior approval from ENV is required to use this approach, and the simpler baseline approaches described in the previous section should be applied first. A Monte Carlo approach can be used for NO<sub>2</sub> baseline by following the steps in the list below.

- ♦ Daily 1-hour maximum NO<sub>2</sub> concentrations based on appropriate monitoring dataset are entered as inputs for this method. The monitoring dataset should cover 3 years in order to match the form of BC's 1-hour NO<sub>2</sub> Ambient Air Quality Objective (AAQO).
- ♦ For each receptor, the daily 1-hour maximum modelled NO<sub>2</sub> concentration and ambient NO<sub>2</sub> concentrations are randomly combined so that a combined value is generated for each day of the year (365 values). For a 5-year AERMOD modelling example, the sampling process first randomly selects thirty-one daily 1-hour maximum modelled NO<sub>2</sub> concentrations from all modelled January days (155 in total for 5 years of modelled results). The sampling process then randomly select thirty-one daily 1-hour maximum monitored NO<sub>2</sub> values from all monitored January days (93 in total for 3 years of monitoring data). The randomly-selected modelled NO<sub>2</sub> concentrations and the monitored NO<sub>2</sub> values are then combined to represent the thirty-one daily total January NO<sub>2</sub> results. This

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<sup>24</sup> Based on the NAPS Classification for Fort St. John Key Learning Centre monitoring station, provided by Li Huang (BC ENV) on October 21, 2019 to Hui Cheng (Trinity).

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process is performed for each month and 365 values are generated. The 98<sup>th</sup> percentile of the 365 resulting values for a given year is then taken as the output of the random sampling process.

- The number of years of monitoring data can be different than the number of years of model data without making any adjustments to use the datasets.
- ◆ The above random sampling process is repeated 1,000 times, and the median of those 98<sup>th</sup> percentile values is taken to be the most likely total concentration in the form of BC's 1-hour NO<sub>2</sub> AAQO for each modelled receptor.

This method is applied using the Monte Carlo script, which was developed using the software “R” by the Washington State Department of Ecology and adapted in conjunction with Idaho Department of Environmental Quality's Pao Baylon and Kevin Schilling for use with background concentrations.<sup>25</sup> CALPOST outputs should be reformatted into AERMOD-output format to allow the Monte Carlo R script to read the outputs.

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<sup>25</sup> Baylon, P. and Schilling, K (Idaho Department of Environmental Quality). “Revisiting the Monte Carlo method for combining modeled pollutant concentrations with monitored values: Case study in Idaho.” *Guideline on Air Quality Models: Planning Ahead, Paper #MO23*. Durham, NC. March 19-21, 2019.

### 4 MATERIALS REQUIRED FOR A MODEL PROJECT APPLICATION

#### 4.1 FILES INCLUDED IN SUBMITTAL

The following list outlines the files that applicants should include in an application package when submitting a model project. A project application will not be considered complete unless the following materials are provided:

- ◆ Input files
  - Meteorological input and output files including prognostic data files (e.g., WRF .m3d files) if applicable
  - Model control input files
  - Building downwash files
  - O<sub>3</sub> data files (as applicable)
  - NO<sub>2</sub> baseline data files (as applicable)
- ◆ Output files
  - Model output files
  - Relevant plot files
  - CALPOST or other post-processing files
  - Data used to assess model quality (as applicable)

#### 4.2 DISPERSION MODELLING PLAN

Each modelling project that incorporates NO<sub>2</sub> techniques must submit a completed Dispersion Modelling Plan that provides justification for model parameters, assumptions made regarding NO<sub>2</sub>/NO<sub>x</sub> chemistry, and selection of any needed ambient monitoring datasets for O<sub>3</sub> or NO<sub>2</sub>. The Dispersion Modelling Plan should address the following specific to NO<sub>2</sub> techniques:

- ◆ NO<sub>2</sub> model technique/Tier
  - Which NO<sub>2</sub> modelling technique was selected and why? Factors considered may include availability of representative data.
  - What considerations were given to ambient concentrations in the model location, characteristics of the modelled sources, and availability of relevant monitoring data?
- ◆ For Tier 2 ARM, what dataset is used for the ARM2 curve and why?
  - If CALPOST is used, provide the 24 values used for the step function.
- ◆ For Tier 3 OLM and PVMRM, what ISR was used for each source and why?
  - If multiple NO<sub>x</sub> sources are modelled using an OLM post-processing tool, applicants should provide justification for how the single ISR is selected.
- ◆ For Tier 3 OLM and PVMRM, what O<sub>3</sub> dataset is selected and why?

## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

- Applicants should provide justification for O<sub>3</sub> datasets used in the model, taking into account NO<sub>2</sub> chemistry, location and proximity of urban regions relative to the modelled source, proximity of nearby large industrial or transportation sources of NO<sub>x</sub>, etc.
- For representative hourly O<sub>3</sub> datasets corresponding to meteorological data, the Dispersion Modelling Plan also needs to describe the data substitution methods followed.
- ◆ NO<sub>2</sub> baseline
  - Applicants should specify the NO<sub>2</sub> monitoring dataset used and why the dataset is representative of the facility site considering NO<sub>2</sub> chemistry, location and proximity of urban regions relative to the modelled source, proximity of nearby large industrial or transportation sources of NO<sub>x</sub>, etc.
  - Applicants should also specify the approach used to determine a single or time-varying baseline level based on the dataset (see Section 3.3.2).
- ◆ If any of the advanced processing methods (e.g., the Monte Carlo method) are applied, the computer code used to generate results must be included in the submittal.

### 4.3 QUALITY ASSURANCE AND MODEL PERFORMANCE

Good modelling practice involves the examination of the input files to ensure that specific data treatments have been applied properly (missing data, calms, formats, and units). Section 9.1 of the Guideline provides guidance on the application of QA/QC for CALPUFF as this model can involve more professional judgment for its proper application than the other recommended models. Model output should also be reviewed to identify unexpected model behavior.

If sufficient historical emissions data and corresponding ambient monitoring data are available for a site conducting Level 3 Assessments, applicants are encouraged to conduct an assessment of model performance as quality assurance for the model project. As detailed in Section 9.2 of the latest Guideline, demonstrations of model performance can vary in form, each providing a different perspective on model performance. A robust model performance evaluation will provide added confidence in the ability of the selected model to provide accurate predictions. Examples of model performance assessments comparing modelled concentrations to monitored concentrations include but are not limited to the following:

- ◆ Comparison of summary concentrations
  - Maximum 1-hour, 98<sup>th</sup> percentile of daily 1-hour maximum, annual average, etc.
  - Paired in space, not time other than annual average
- ◆ Comparison of frequency statistics
  - Number of exceedances of a certain level such as ½ the air quality objective
  - Paired in space, not time
- ◆ Comparison of robust highest concentrations (RHC)
  - RHC represents a smoothed estimate of the highest concentrations, based on a tail exponential fit to the upper end of the concentration distribution.<sup>26</sup>

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<sup>26</sup> [https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/aermod\\_mep.pdf](https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/aermod_mep.pdf) (pp. 13-14)



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- Paired in space, not time
- ◆ Quantile-Quantile (Q-Q) plots
  - Q-Q plots are created by sorting by rank the predicted and the observed concentrations from a set of predictions initially paired in time and space. The sorted list of predicted concentrations is then plotted by rank against the observed concentrations also sorted by rank.
  - These concentration pairs are no longer paired in time or location. However, the plot is useful for answering the question, “Over a period of time and over a variety of locations, does the distribution of the model predictions match those of observations?”<sup>15</sup>
  - A similar Q-Q plot approach can be used by maintaining pairing in space (separate datasets for each monitor) and plotting each monitor’s dataset separately.
- ◆ Timeseries plots
  - Paired in time and space to visualize the variation in concentrations over time.
- ◆ Bias, error, and correlation
  - Bias, error, and correlation compare model concentrations to monitor concentrations for each hour modelled (paired in time and space).
  - These comparisons often show high error and weak correlations because air dispersion models “are reasonably reliable in estimating the magnitude of highest concentrations occurring sometime, somewhere in the area” but “much less reliable” when looking at “estimates of concentrations that occur at a specific time and site.”<sup>27</sup>
  - That said, the bias and error statistics can be helpful when comparing performance of two or more similar models.

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<sup>27</sup> [https://www.epa.gov/sites/production/files/2020-09/documents/appw\\_05.pdf](https://www.epa.gov/sites/production/files/2020-09/documents/appw_05.pdf) (pp. 66246)

### APPENDIX A: NO<sub>2</sub> AND NO<sub>x</sub> DATA FOR ARM2 IMPLEMENTATION

In 2013, RTP Environmental Associates, Inc. prepared the ARM2, a model refinement for NO<sub>2</sub> 1-hour modelling in AERMOD, for the American Petroleum Institute and the U.S. EPA.<sup>28</sup> This method expands on the previously used ARM, for a Tier 2 model for NO<sub>2</sub> concentrations with a 1-hour averaging period. While ARM previously used a fixed ambient ratio of NO<sub>2</sub> to total NO<sub>x</sub> of 0.8 for the 1 hour averaging period, the ARM2 methodology refines the ARM approach by applying a varying ambient ratio of NO<sub>2</sub> to NO<sub>x</sub> as a function of the total NO<sub>x</sub> concentration in the atmosphere. In other words, ambient monitoring data demonstrate that the ratio of NO<sub>2</sub> to NO<sub>x</sub> changes as a function of total NO<sub>x</sub> concentration in the atmosphere (the ratio decreases with increasing NO<sub>x</sub> concentrations). ARM2 represents a method of refinement that is often preferred when compared to Tier 3 methods such as OLM and PVMRM due to its shorter run times and fewer input data requirements (thereby requiring less case-by-case review and approval). Note that when applying ARM2 to determine 1-hour NO<sub>2</sub> values, the same ARM2 approach should be used to determine annual average values (by applying ARM2 to all 1-hour model results and calculating or outputting the annual average after ARM2 is applied).

Trinity developed province-specific ARM2 curves using monitoring data obtained from the BC Air Data Archive Website<sup>29</sup> based on the methodology used by RTP Environmental Associates, Inc. for the following specific categories:

- ◆ Industrial Sites
  - Monitoring stations are considered industrial when they are located within 5 km of a large industrial source that emits 500 tonnes per year or more of NO<sub>x</sub>.
- ◆ Urban Sites
  - Urban sites are located in or near urban centres that influence the baseline NO<sub>x</sub> concentrations in the ambient air.
- ◆ Rural Sites
  - Rural sites are not located in or near urban centres or industrial areas (defined above).
- ◆ Coastal Sites
  - These sites are near the Pacific Coast, and the NO<sub>x</sub> concentrations are not primarily driven by urban centres or large industrial sources.
- ◆ All Sites

Each of the categories and their associated monitoring sites can be found in Table A-1, below. If a site is classified under multiple categories, the data from the site are included in both sub-sets of data used to develop the category-specific curves.

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<sup>28</sup> RTP Environmental Associates, Inc. "Ambient Ratio Method Version 2 (ARM2) for use with AERMOD for 1-hr NO<sub>2</sub> Modeling – Development and Evaluation Report." September 20, 2013.  
[https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/ARM2\\_Development\\_and\\_Evaluation\\_Report-September\\_20\\_2013.pdf](https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/ARM2_Development_and_Evaluation_Report-September_20_2013.pdf)

<sup>29</sup> British Columbia Ministry of Environment Air Data Archive Website, Station Reports.  
<https://envistaweb.env.gov.bc.ca/>

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Based on the curves developed for the province, the AERMOD default ARM2 equation is an appropriate and conservative equation for use with the ARM2 option:

$$y = -5.176E-16x^6 + 1.005E-12x^5 - 7.288E-10x^4 + 2.296E-07x^3 - 1.981E-05x^2 - 5.148E-03x + 1.244$$

(Where x is the NO<sub>x</sub> concentration in ppb, and y is the calculated ambient ratio)

Applicants wishing to further refine assumptions for NO<sub>2</sub> conversion while using this Tier 2 method may consider using the province- and category-specific equations developed by Trinity and provided in detail below. A comparison of the equations and the corresponding curves for the province-specific and U.S. EPA AERMOD default ARM2 equations is provided in Figure A-1 below.

## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

**Table A-1: Summary of Monitoring Site Categories**

Site	Category/Categories	Monitoring Period
Abbotsford Central	Urban	2009-2018
Burnaby Kensington Park	Urban	2009-2018
Burnaby Mountain	Urban	2009-2018
Burnaby South	Urban	2009-2018
Chilliwack Airport	Urban	2009-2018
Colwood City Hall	Urban	2009-2018
Coquitlam Douglas College	Urban	2009-2018
Duncan Cairnsmore	Urban	2009-2018
Fort St. John Key Learning Centre	Industrial	2015-2018
Hope Airport	Rural	2009-2018
Kamloops Federal Building	Urban	2009-2018
Kelowna College	Urban	2009-2018
Langdale Elementary	Rural/Coastal	2009-2018
Langley Central	Urban	2009-2018
Maple Ridge Golden Ears School	Urban	2009-2018
Nanaimo Labieux Road	Urban	2009-2018
North Delta	Urban	2009-2018
North Vancouver Mahon Park	Urban	2009-2018
North Vancouver Second Narrows	Urban/Industrial	2009-2018
Pitt Meadows Meadowlands School	Urban	2009-2018
Port Moody Rocky Point Park	Urban	2009-2018
Powell River Cranberry Lake	Rural	2009-2018
Prince George Plaza 400	Urban	2009-2018
Quesnel Senior Secondary	Industrial	2009-2018
Richmond South	Urban	2009-2018
Rolla 213 Road	Industrial	2016 <sup>a</sup> - 2017
Smithers St Josephs	Rural	2009-2018
Surrey East	Urban	2009-2018
Taylor Townsite	Industrial	2018
Tsawwassen	Coastal	2009-2018
Vancouver Intl Airport 2	Urban	2009-2018
Vancouver Robson Square	Urban	2009-2018
Vernon Science Centre	Urban	2009-2018
Victoria Topaz	Urban/Coastal	2009-2018
Whistler Meadow Park	Rural	2009-2018
Williams Lk Columneetza School	Industrial	2009-2018

<sup>a</sup>. Rolla 213 Road data began in December 2015. Listing 2016 as start year because less than one month of data were recorded in 2015.

These curves, with their associated equations, can be used to refine NO<sub>2</sub> model concentrations based on the characteristics of the area where a given facility or project is located. These curves are provided in Figure A-1 for comparison, with the coefficients of the 6<sup>th</sup> order equations provided in Table A-2. The following list summarizes a few key notes regarding the development of the curves:

- ♦ In order to address noise in data at low concentrations, a lower-bound NO<sub>x</sub> threshold of 20 ppb was used to filter data.

## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

- ◆ Based on a study conducted by Chu and Meyers, the ARM2 equation is constrained to a maximum value of 0.9 and a minimum value of 0.2.<sup>30</sup>
- ◆ The NO<sub>2</sub>/NO<sub>x</sub> ratio at a given NO<sub>x</sub> concentration is calculated as the 98<sup>th</sup> percentile value of all NO<sub>2</sub>/NO<sub>x</sub> values for a given “bin” of measurements. “Bins” of 10 ppb in range (or 20 ppb for measurements greater than 200 ppb) are used to divide the data. This method results in a curve that is conservative relative to the data obtained from the site(s).<sup>31</sup>
- ◆ A valid data point for these curves is any data point with non-negative NO<sub>2</sub> and NO measurements and a calculated total NO<sub>x</sub> concentration of 20 ppb or greater.
  - For data obtained later than 2017, a measured total NO<sub>x</sub> value is given preference over the sum of the measured NO and NO<sub>2</sub> concentrations, otherwise the sum is used for the total NO<sub>x</sub>.<sup>32</sup>

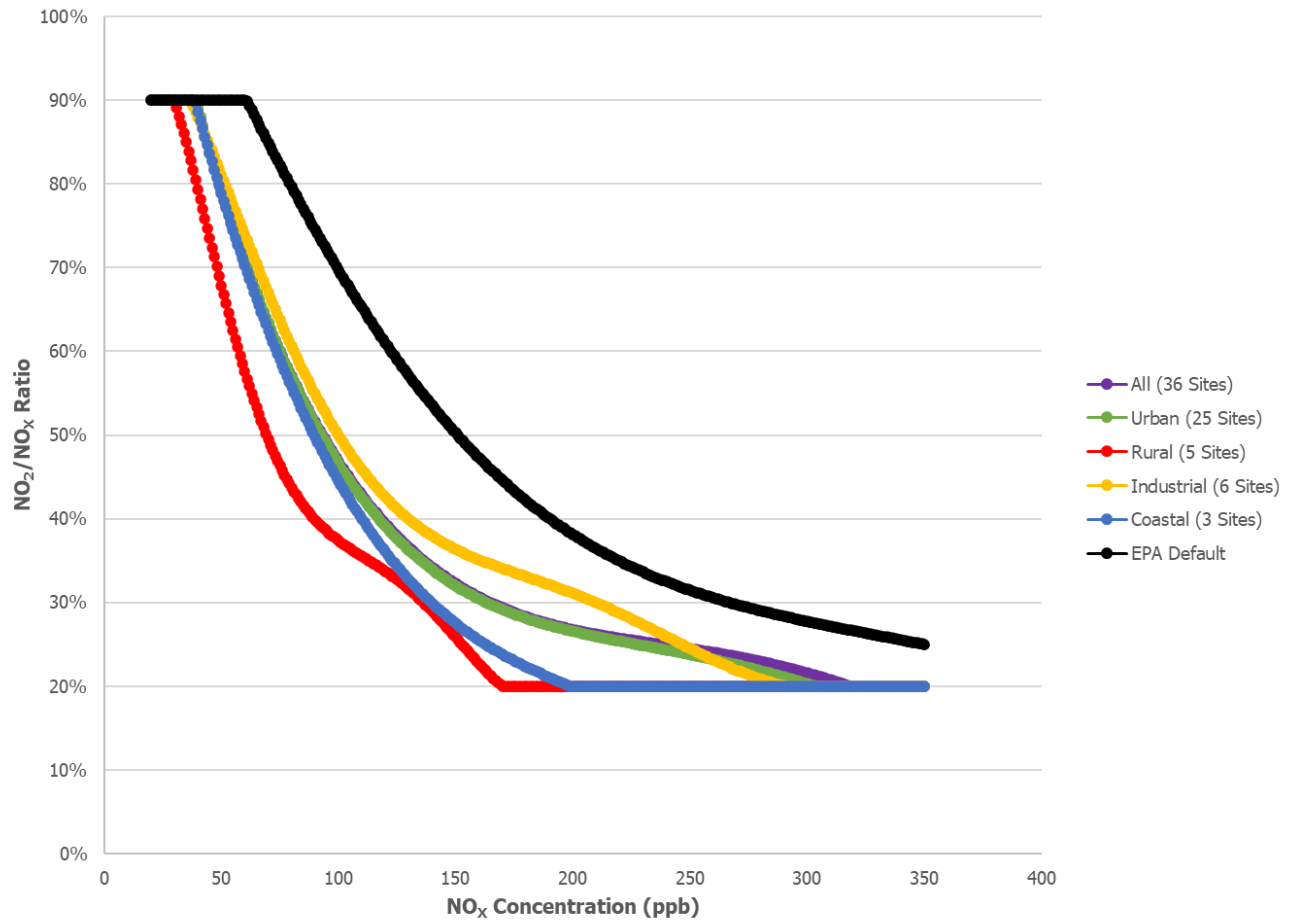
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<sup>30</sup> RTP Environmental Associates, Inc. “Ambient Ratio Method Version 2 (ARM2) for use with AERMOD for 1-hr NO<sub>2</sub> Modeling – Development and Evaluation Report.” September 20, 2013.  
[https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/ARM2\\_Development\\_and\\_Evaluation\\_Report-September\\_20\\_2013.pdf](https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/ARM2_Development_and_Evaluation_Report-September_20_2013.pdf)

<sup>31</sup> Ibid.

<sup>32</sup> Total NO<sub>x</sub> measurements prior to January 2017 are not validated, per email correspondence between Trinity and Li Huang on Wednesday, October 9, 2019.

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**Figure A-1: Comparison of ARM2 Curves Developed for Various Monitoring Station Categories**

\* Note that there are some monitoring stations that are included in multiple categories for the purposes of the ARM2 curve development, hence the discrepancy in site count between groups.

## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

**Table A-2: ARM2 Curve 6th Order Polynomial Equation Coefficients (µg/m<sup>3</sup>)**

Polynomial Order	BC-Specific ARM2 Curves					U.S. EPA Default
	All	Urban	Rural	Industrial	Coastal	
0	1.4217E+00	1.4081E+00	7.0908E-01	9.7054E-01	1.4097E+00	1.2441E+00
1	-9.0043E-03	-8.4309E-03	1.8014E-02	2.7563E-03	-8.6617E-03	-2.7383E-03
2	2.8689E-05	2.2008E-05	-4.0219E-04	-8.0316E-05	2.6443E-05	-5.6062E-06
3	-5.1310E-08	-1.8692E-08	3.1248E-06	4.4204E-07	-5.9049E-08	3.4555E-08
4	6.2556E-11	-1.4082E-11	-1.1639E-08	-1.0885E-09	1.3159E-10	-5.8345E-11
5	-5.5299E-14	2.9761E-14	2.0910E-11	1.2663E-12	-2.0684E-13	4.2795E-14
6	2.4169E-17	-1.1526E-17	-1.4534E-14	-5.6578E-16	1.3132E-16	-1.1723E-17

### APPENDIX B: IN-STACK RATIOS OF NO<sub>2</sub> AND NO<sub>x</sub>

The in-stack NO<sub>2</sub>/NO<sub>x</sub> ratio or ISR is one of two critical inputs required for refined NO<sub>2</sub> modelling using the OLM or PVMRM options (the other is background O<sub>3</sub> levels). These OLM and PVMRM options are available in the U.S. EPA AERMOD model. OLM may also be used with CALPUFF or any other model output data in a post-processing step. The ISR defines the ratio of NO<sub>2</sub> to total NO<sub>x</sub> within the stack. Many combustion sources have a low ISR of approximately 0.1, meaning approximately 10% of the NO<sub>x</sub> in the exhaust within the stack is in the form of NO<sub>2</sub>, with the remainder in the form of NO. The OLM and PVMRM options estimate the ratio of NO<sub>2</sub> in the plume at the modelled receptor and use the ISR as the minimum ratio (i.e., the minimum fraction of NO<sub>2</sub> begins at the stack and increases as more NO converts to NO<sub>2</sub> in the atmosphere).

ISR data have been collected formally by the U.S. EPA for several years, and the Alaska Department of Environmental Conservation provides a dataset<sup>33</sup> last updated in August of 2013. The U.S. EPA ISR webpage provides two different datasets;<sup>34</sup> a beta dataset with complete information collected as part of the formal collection effort and an alpha dataset which contains NO<sub>2</sub> ISR values collected by various Regional, State, and Local air permitting offices prior to the formal collection initiated by U.S. EPA. Additionally, the U.S. EPA MOVES model includes several ISRs for different categories of vehicles based on a dataset of 292 tests on a variety of vehicles.<sup>35</sup> The available ISR data from these datasets are used to develop the recommended ISR values summarized in Table B-1 below.

The MOVES vehicle ISR dataset was reviewed for the most meaningful source categories. Based on the review, the fuel type rather than equipment class (e.g., light duty vs heavy duty vehicles) plays a more important role in determining the appropriate ISR. Therefore, the vehicle categories are differentiated by fuel type rather than vehicle class.

The recommended ISR is the 75<sup>th</sup> percentile of each category. The 75<sup>th</sup> percentile is chosen rather than the average, maximum or a higher percentile, to avoid a small number of high values skewing the value. ENV is collecting additional source-specific ISRs through permitting applications and/or volunteering program. Source-specific ISR data provided to ENV for use in NO<sub>2</sub> models should include the following:

- ◆ Site details and contact information
- ◆ Equipment information, including:
  - Equipment class
  - Equipment descriptions
  - Fuel type
  - Manufacturer and model

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<sup>33</sup> Alaska Department of Environmental Conservation, "NO<sub>2</sub>/NO<sub>x</sub> In-Stack Summaries." <https://dec.alaska.gov/media/10228/no2-nox-instack-ratios-from-source-tests-082313.xlsx>

<sup>34</sup> U.S. EPA Support Center for Regulatory Atmospheric Modeling (SCRAM), "NO<sub>2</sub>/NO<sub>x</sub> In-Stack Ratio (ISR) Database." [https://www3.epa.gov/scram001/no2\\_isr\\_database.htm](https://www3.epa.gov/scram001/no2_isr_database.htm)  
Accessed October 2020. Current (October 2021) database available at: <https://www.epa.gov/scram/nitrogen-dioxidenitrogen-oxide-stack-ratio-isr-database>

<sup>35</sup> Data extracted from the U.S. EPA Motor Vehicle Emission Simulator (MOVES2014b). <https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves>



## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

- Equipment capacity
- Any control devices installed on the equipment
- ◆ Test information, including:
  - Equipment load (% of total capacity)
  - Exhaust flow rate
  - Operating temperature
  - Average NO<sub>2</sub> and NO concentrations
  - % O<sub>2</sub> from sample gas
- ◆ Any additional comments that may impact the resulting ISRs.

The recommendations on ISR values will be updated once additional ISR data are available and reviewed.

## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

**Table B-1: Summary of ISR Values for Various Source Types**

Equipment Class <sup>c</sup>	Fuel Type	Number of Data Points	Standard Deviation	Recommended ISR <sup>a</sup>
Turbine	All	886	0.053	0.065
	Natural Gas	876	0.050	0.065
	Diesel/Kerosene	3	0.112	0.242
	Fuel Oil Combustion	5	0.088	0.177
Reciprocating IC Engine	All	3349	0.162	0.182
	Biogas	96	0.003	0.004
	Process Gas <sup>b</sup>	9	0.147	0.314
	Natural Gas	3099	0.165	0.187
	Diesel/Kerosene	139	0.119	0.083
Boiler/Heater	All	137	0.154	0.304
	Fish Oil and Diesel (70:30)	12	0.005	0.013
	Process Gas <sup>b</sup>	58	0.109	0.407
	Natural Gas	53	0.042	0.100
	Diesel/Kerosene	10	0.016	0.035
	Coal, unspecified	4	0.006	0.015
Marine Vessels	All	85	0.083	0.113
Vehicles	All	292	0.113	0.156
	Gasoline	105	0.043	0.041
	Ethanol (E-85)	105	0.043	0.041
	Diesel Fuel	80	0.142	0.398
	Compressed Natural Gas	2	NA	0.127

- a. The ISR is the in-stack-ratio of NO<sub>2</sub>/NO<sub>x</sub> and can vary from 0 to 1. A value of 1 indicates 100% of NO<sub>x</sub> is NO<sub>2</sub>.
- b. For equipment firing process gas, applicants may propose an alternative ISR based on the U.S. EPA database or other reference information, subject to approval as part of the Dispersion Modelling Plan.
- c. If a category is not listed in Table B-1, proposing an ISR based on the U.S. EPA database can be accepted on a case-by-case basis.

## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

The ISR source categories in the previous section were also selected based on the industry or source sectors' contribution to NO<sub>x</sub> based on the latest copy of the province-wide NO<sub>x</sub> emission levels extracted from Canada's 2019 Air Pollutant Emission Inventory.<sup>36</sup> The following list, ordered by which sectors contribute NO<sub>x</sub> from the most to the least, provides cross references for which ISR source categories would be appropriate for each emission inventory industry/source sector.

- ♦ Marine transportation – covered under marine vessels.
- ♦ Upstream oil and gas industry – most sources are covered under reciprocating engines and combustion turbines.
- ♦ Heavy-duty vehicles – covered under diesel fuel vehicles.
- ♦ Air transportation – representative data unavailable.
- ♦ Light-duty vehicles – covered under diesel or gasoline vehicles.
- ♦ Off-road vehicles and equipment - most sources are covered under reciprocating engines.
- ♦ Rail transportation – covered under reciprocating engines.
- ♦ Pulp and paper industry – some covered under wood fired boilers.
  - Process specific units (e.g., recovery furnaces, lime kilns) should be based on site-specific data.
  - NOTE: ISR data for this category is not currently available in the U.S. EPA datasets.
- ♦ Commercial/residential/institutional – covered under boilers/heaters.
- ♦ Mining and rock quarrying – some covered under reciprocating engines.
  - Process-specific units should be based on site-specific data.
- ♦ Cement and concrete industry – some covered under heaters/boilers.
  - Process-specific units (e.g., cement kilns) should be based on site-specific data.
- ♦ Wood products – some covered under wood fired boilers.
  - Process-specific units (e.g., direct fired dryers) should be based on site-specific data.
  - NOTE: ISR data for this category is not currently available in the U.S. EPA datasets.
- ♦ Electric power generation (utilities) – covered under boilers and combustion turbines.
- ♦ Downstream oil and gas industry – some covered under boilers/heaters, reciprocating engines, combustion turbines, and incinerators/thermal oxidizers.
  - Process-specific units (e.g., refinery catalytic crackers, reformers, process heaters)<sup>37</sup> should be based on site-specific data.
  - NOTE: ISR data for thermal oxidizers is not currently available in the U.S. EPA datasets.

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<sup>36</sup> The emission inventory is developed by Environment Canada and Climate Change Strategy (ECCC), and it is available on ECCC's website (<https://www.canada.ca/en/environment-climate-change/services/air-pollution/publications/emissions-inventory-report-2019.html>).

<sup>37</sup> Note many process heaters, particularly indirect-fired heaters could justify using a default ISR for heaters.

### APPENDIX C: OZONE DATA

Modellers have two options for developing and using O<sub>3</sub> datasets:

- ◆ Option 1: Hourly representative data can be used, as long as hourly O<sub>3</sub> data (with appropriate data gap filling methods described in this report) correspond to the complete meteorological data being used in the model. The applicant must also verify the O<sub>3</sub> dataset is representative of the facility location.
- ◆ Option 2: A dataset developed by BC ENV or a dataset developed by the applicant using the methods outlined in this appendix.<sup>38</sup>

### OZONE DATA AVAILABLE IN BRITISH COLUMBIA

BC and Metro Vancouver operate 43 O<sub>3</sub> monitoring stations able to measure compliance against the O<sub>3</sub> air quality standard for the 2015-2017 period, which requires three years of complete data.<sup>39</sup> As shown in Figure C-1, majority of the monitors (23) are located in the lower Fraser Valley Air Zone, where O<sub>3</sub> concentrations are highest.<sup>40</sup> Extending the dataset period to 10 years (2010 – 2019), 49 stations recorded three or more years of data. The map in Figure C-1 below obtained from ENV's website shows divisions of each air zone within the province, and the following list summarizes the O<sub>3</sub> data in each air zone.

- ◆ The **Northwest Air Zone** does not include any O<sub>3</sub> monitoring stations; however, minimal industrial activity that would require O<sub>3</sub> data for refined NO<sub>2</sub> modelling takes place in this air zone.
- ◆ While the **Coastal Air Zone** contains only one O<sub>3</sub> monitoring station, the coastal zone contains lots of industrial activity, with the most activity located relatively near the established Terrace monitor and the newer or shorter-term monitors in Kitimat and Prince Rupert.
- ◆ The **Southern Interior** and **Central Interior** air zones do have industrial activity that may require O<sub>3</sub> data for refined NO<sub>2</sub> modelling. Each of these air zones has four O<sub>3</sub> monitors spread across the zone; as such, a representative O<sub>3</sub> monitoring dataset is expected to be available for most or all applicant projects within these air zones.
- ◆ Representative O<sub>3</sub> monitoring data are also expected to be available for any location within the **Lower Fraser Valley** and **Georgia Strait** air zones with their higher density of monitors (23 and 7 for 2015-2017, respectively).
- ◆ In contrast to the Southern and Central Interior air zones, the three O<sub>3</sub> monitors in the Northeast Air Zone are clustered near Fort St. John, while much of the industrial activity is removed from urban areas (100 km away or further).

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<sup>38</sup> ENV has developed an O<sub>3</sub> dataset for use in rural sites located in Northeast BC. Additional O<sub>3</sub> datasets may be developed in the future.

<sup>39</sup> The statistical form of the Canadian Ambient Air Quality Standard O<sub>3</sub> metric is the 3-year average of the annual 4<sup>th</sup>-highest daily maximum 8-hour rolling average concentration.

<http://www.env.gov.bc.ca/soe/indicators/air/ozone.html>

<sup>40</sup> The highest measured concentration in the form of the standard for the 2015-2017 period was 64 ppb at the Hope station.

<http://www.env.gov.bc.ca/soe/indicators/air/ozone.html>

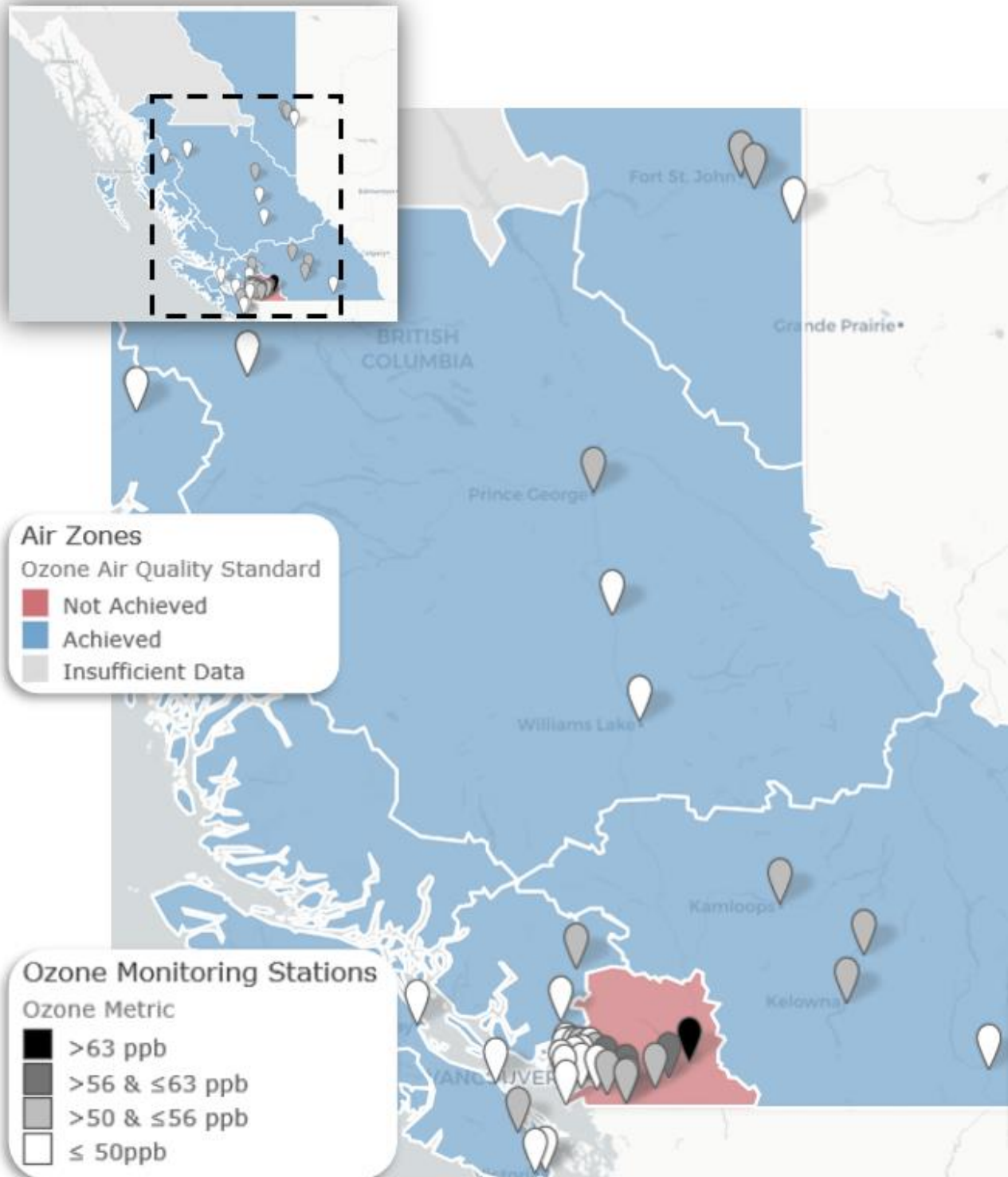


Figure C-1: BC Ozone Monitors, 2015-2017

### OZONE DATA IN NORTHEAST BRITISH COLUMBIA

Based on the available representative O<sub>3</sub> monitoring data in relation to existing and potential industrial sites, the Northeast Air Zone requires further review to evaluate O<sub>3</sub> monitoring data alternatives to using a nearby representative hourly O<sub>3</sub> monitoring data, including:

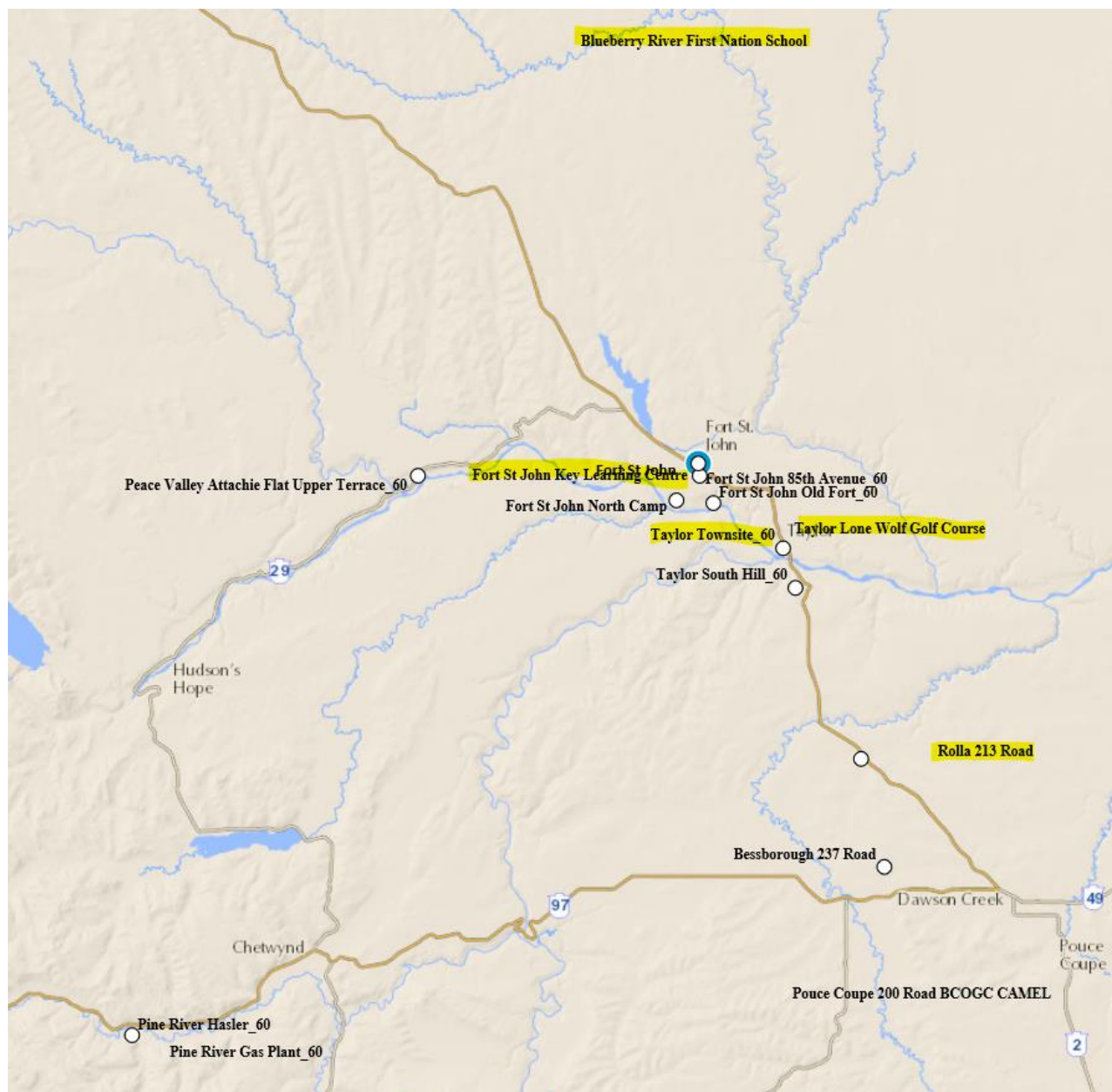
- ♦ Analyzing the data quality and representativeness of all O<sub>3</sub> monitors in the zone (even those with less than three years of data);
- ♦ Evaluating whether data from Fort St. John or other Northeast monitors can be used to represent all regions within the Northeast Air Zone; and
- ♦ Assessing whether a dataset should be developed that applies some conservative assumptions to represent the regions of the air zone without monitoring data and if so, how the dataset should be developed and whether wildfire years should be excluded.

Figure C-2 below shows the air quality monitors in Northeast BC.<sup>41</sup> The monitors that measure O<sub>3</sub> are highlighted in yellow. The Blueberry River monitor only operated from June 2016 to November 2017, but this monitor provides a helpful indication of the amount of variation at sites north of Fort St. John. Based on the summary data, the site measured similar O<sub>3</sub> compared to the other northeast stations:

- ♦ Rolla 213 Road: 65 ppb (1-hour maximum) and 28.2 ppb (average December 2015–June 2017)
- ♦ Taylor Lone Wolf Golf Course: 67.2 ppb (1-hour maximum) and 24.9 ppb (average January 2016–June 2017)
- ♦ Blueberry River First Nation School: 60.7 ppb (1-hour maximum) and 26.5 ppb (average June 2016–June 2017)

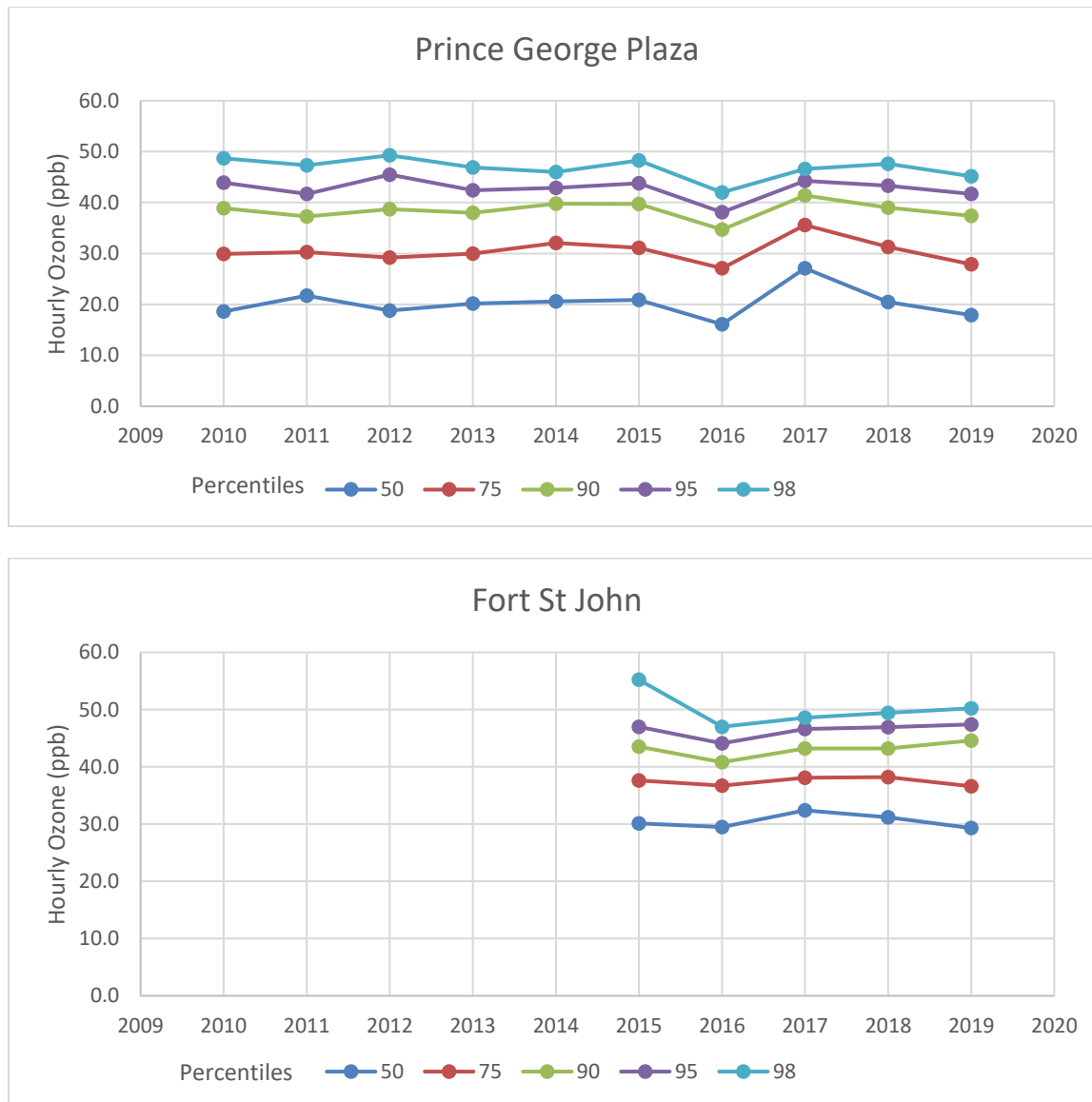
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<sup>41</sup> <http://www.env.gov.bc.ca/epd/bcairquality/readings/ne-stations-map.html>



**Figure C-2: Northeast British Columbia Ozone Monitors**

In order to evaluate whether some years should be excluded due to wildfire influence, annual charts were developed. Figure C-3 below shows the annual trends of the summary statistics at the two northern sites with the longest history. While some influence of the intense wildfire seasons in 2017 and 2018 may be seen at Prince George Plaza (Central Interior), minimal influence is observed at Fort St. John in the Northeast. Therefore, excluding O<sub>3</sub> data due to wildfire influence is not warranted for the 2017-2018 period in the Northeast Air Zone.



**Figure C-3: Annual Trends for the 50<sup>th</sup>, 75<sup>th</sup>, 90<sup>th</sup>, 95<sup>th</sup>, and 98<sup>th</sup> Percentiles of Hourly Ozone Data**

### OZONE DATASETS FOR USE IN NO<sub>2</sub> MODELS

Identification of an appropriate and representative O<sub>3</sub> monitoring station should consider the following, among any other factors that may impact O<sub>3</sub> concentrations at a given location:

- ◆ Proximity to urban areas of the province.
- ◆ Proximity to large sources of NO<sub>x</sub> emissions.
- ◆ Proximity to major roadways with frequent traffic.



## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

Rural areas tend to have higher O<sub>3</sub> than urban areas because NO from vehicle traffic can reduce O<sub>3</sub>. In addition, O<sub>3</sub> takes time to form, so it tends to be highest in rural areas 30+ km from the largest metropolitan areas. In order for a site to be considered urban, it must be located within 10 km of any city or town with a population of 5,000 or more. All other sites should be considered rural, but urban can be considered on a case by-case basis if the site is 10 km to 20 km from a larger city.

If a representative hourly O<sub>3</sub> monitoring dataset is not available for a specific facility (Option 1), applicants should contact the Ministry to discuss use of a BC ENV-prepared O<sub>3</sub> dataset for the model's region or development of a new dataset. An example of a rural dataset is provided below for the Northeast Air Zone. Datasets for both rural and urban O<sub>3</sub> can be developed based on either the 1<sup>st</sup> or the 2<sup>nd</sup> highest O<sub>3</sub> concentration for each hour of the day by month, depending on the amount of data available. If fewer than 3 years of monitoring data are used to develop the O<sub>3</sub> dataset for use in an NO<sub>2</sub> model, then the 1<sup>st</sup> highest value for each hour of the day by month should be used. For example, the January noon hours (31 total) are ranked, and the 1<sup>st</sup> highest January noon value represents the noon hour for the month of January. If 3 or more years of monitoring data are used, then the 2<sup>nd</sup> highest value for each hour of the day by month should be used. Therefore, one data point will exist for each hour of the day for a given month (i.e., the ENV-developed datasets include 24 values for each month, 288 values for the year).

## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

**Table C-1: Rural Ozone Dataset (ppb) for Northeast British Columbia**

Hour	Month											
	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
24:00 AM	43.9	46.7	55.0	51.8	54.0	50.5	39.0	36.0	39.3	42.0	41.0	43.1
1:00 AM	43.3	46.9	57.0	52.2	51.0	49.1	39.0	36.8	41.2	41.9	41.1	43.6
2:00 AM	44.0	46.7	54.5	53.8	50.0	45.0	37.0	34.1	38.1	41.3	41.1	43.9
3:00 AM	45.0	46.7	52.0	53.7	48.0	46.0	34.0	37.0	36.7	44.0	42.0	43.5
4:00 AM	44.9	47.3	51.0	51.0	47.0	45.0	33.4	36.0	35.7	45.0	42.0	43.6
5:00 AM	46.2	47.4	47.5	49.3	40.5	41.8	29.5	31.4	34.6	39.7	40.2	42.3
6:00 AM	45.0	48.2	49.0	50.0	44.1	44.9	35.0	34.0	35.0	47.4	42.0	42.6
7:00 AM	46.1	47.9	49.0	51.0	45.4	45.8	34.0	32.0	35.0	45.0	41.5	42.5
8:00 AM	45.9	46.9	46.8	54.1	48.6	47.0	35.2	34.4	34.9	42.0	42.0	42.6
9:00 AM	45.0	48.1	47.1	56.0	51.8	48.4	38.0	36.0	36.7	42.0	41.6	42.4
10:00 AM	45.0	48.2	47.3	54.9	54.1	61.0	41.0	43.2	38.0	42.0	41.7	42.3
11:00 AM	44.9	48.4	49.0	55.1	60.8	61.0	42.9	45.6	40.7	41.3	41.6	43.0
12:00 PM	44.9	48.5	51.7	59.0	64.0	63.0	43.0	47.0	42.4	46.0	42.2	43.5
1:00 PM	45.0	48.7	55.8	57.3	71.0	60.3	45.0	47.0	48.1	48.0	42.3	44.1
2:00 PM	45.2	48.5	59.0	59.0	69.0	61.0	49.0	46.3	50.5	46.0	42.4	42.6
3:00 PM	44.5	47.8	60.0	59.0	69.0	62.0	50.0	47.0	49.4	44.8	42.6	43.7
4:00 PM	45.0	47.4	62.0	60.0	67.0	65.0	50.0	48.2	53.0	44.0	42.4	43.8
5:00 PM	44.0	47.0	62.1	60.0	66.0	62.0	46.0	53.3	51.0	46.0	42.3	43.4
6:00 PM	44.9	46.5	60.0	60.0	65.0	60.0	50.0	47.0	52.0	45.0	41.4	44.8
7:00 PM	44.0	46.2	58.0	58.3	62.4	57.0	51.0	45.0	46.0	45.0	41.0	43.3
8:00 PM	43.9	47.0	56.8	57.8	60.0	56.0	46.4	43.0	46.7	43.3	41.0	43.4
9:00 PM	43.9	47.0	58.3	55.7	56.0	53.5	46.6	40.0	46.0	42.0	41.0	42.6
10:00 PM	43.5	47.1	58.4	53.9	55.0	52.0	47.0	38.4	41.0	41.0	41.5	42.3
11:00 PM	44.0	46.2	55.1	52.8	54.0	51.9	49.0	39.0	39.7	41.4	41.5	42.8

The dataset above is intended for use in NO<sub>2</sub> models located in the Northeast region of BC, where O<sub>3</sub> monitoring data availability is limited. The O<sub>3</sub> values represent the 2<sup>nd</sup> highest value among all O<sub>3</sub> data points for each given hour and month. The monitoring stations used to develop this dataset are the following, which are considered rural stations based on the qualifications detailed above:

- ◆ Blueberry Hill
- ◆ Farmington Community Hall
- ◆ Rolla 213 Road
- ◆ Beaverlodge<sup>42</sup>

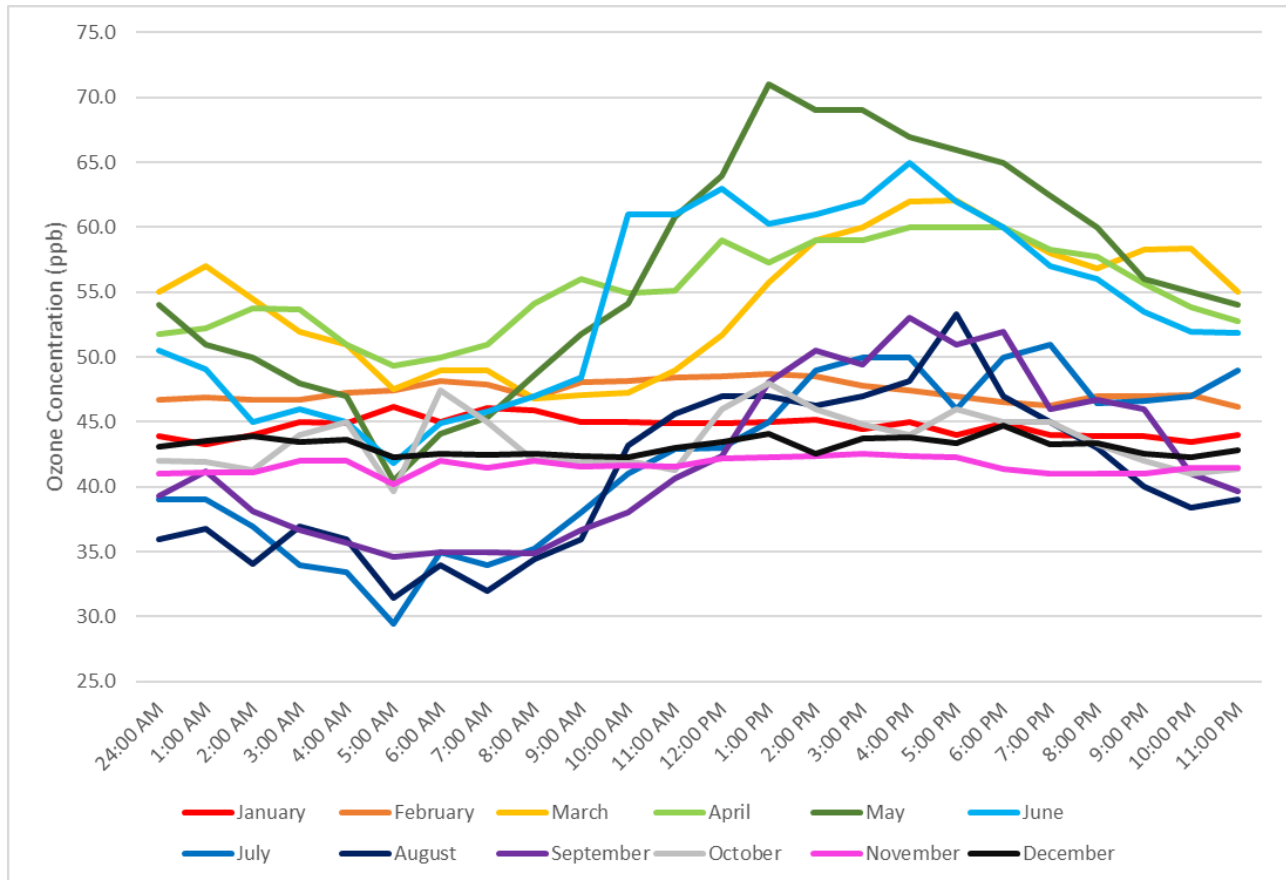
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<sup>42</sup> The Beaverlodge monitoring station is located in Alberta but is considered appropriate for inclusion in this rural dataset for the Northeast Air Zone on the basis of its proximity to Northeast British Columbia and its similarities with other rural datasets in the region.

## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

Two to five years of data are available from each of the four stations, resulting in approximately 150 datapoints per value at each station and 600 datapoints total per value. Since more than 3 years of data are available, the 2<sup>nd</sup> highest value for each given hour and month is used. Using the 2<sup>nd</sup> highest value in this instance excludes only the top 0.16%.

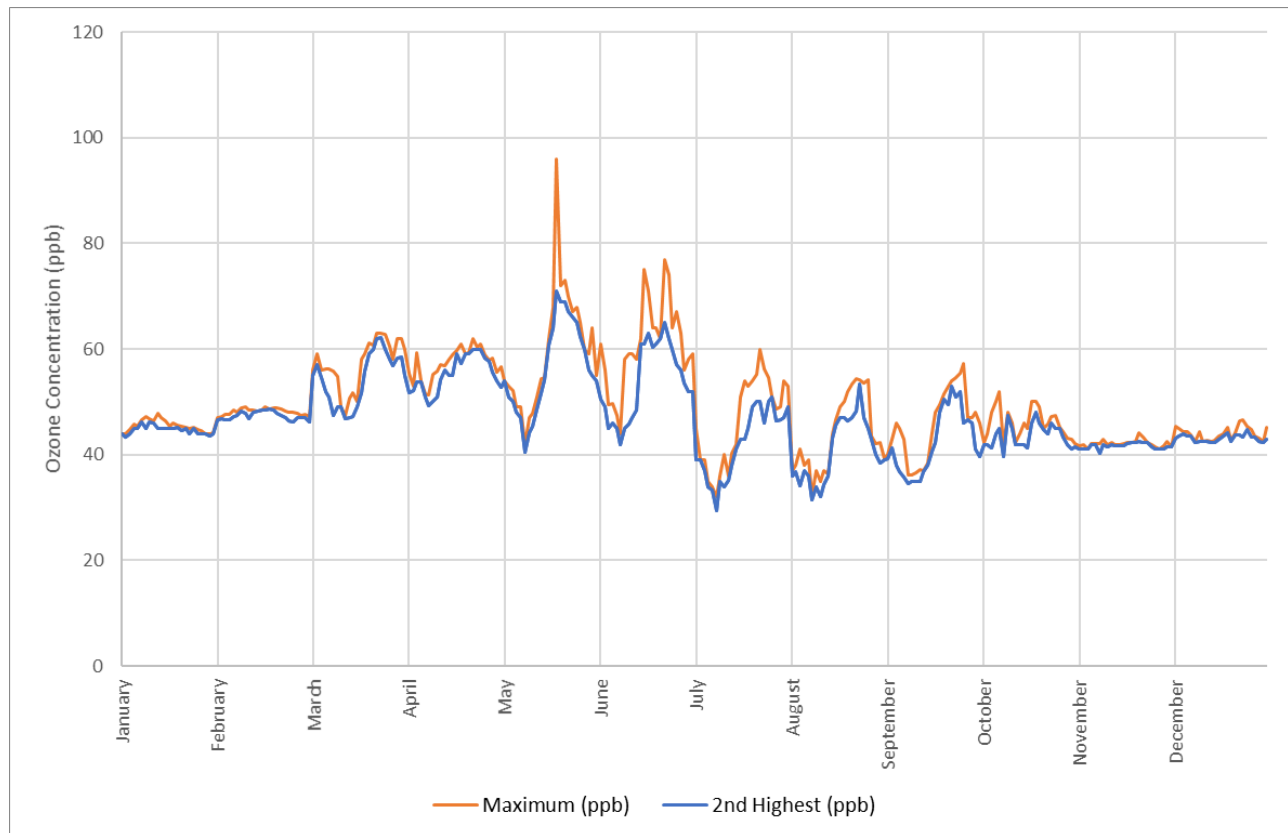
The rural dataset is displayed in the plot below.



**Figure C-4: Rural Ozone Dataset for Northeast British Columbia** <sup>43</sup>

The 2<sup>nd</sup> highest value for a given hour and month is selected for use in the O<sub>3</sub> background dataset to avoid outliers that would otherwise overestimate typical O<sub>3</sub> concentrations throughout the year. When comparing the 2<sup>nd</sup> highest O<sub>3</sub> value to the maximum for a given hour and month, there are hours when the difference is substantial, indicating the maximum values could represent an overestimate. Additionally, the 2<sup>nd</sup> highest values follow the maximum concentrations closely during periods of lower O<sub>3</sub> concentrations, indicating the use of the 2<sup>nd</sup> highest values is likely not an underestimate of typical O<sub>3</sub> concentrations. Figure C-5 below illustrates the differences in the two possible values for each given hour and month, for comparison.

<sup>43</sup> Data presented in this figure represents the 2<sup>nd</sup> highest value for a given hour and month to exclude any outliers.



**Figure C-5: Comparison Between Maximum and 2<sup>nd</sup> Highest Ozone Concentrations for the Rural Northeast British Columbia Background Ozone Dataset**

Note that some remote rural locations may have so little influence from O<sub>3</sub> precursors that their O<sub>3</sub> levels could be considerably lower than a typical rural location. For example, Trinity examined the O<sub>3</sub> monitoring data available at three remote monitoring stations located in the Northwest Territories. Table C-2 below compares summary data at these remote locations with the summary data for stations used in the rural dataset developed above. While this comparison indicates that O<sub>3</sub> levels are lower for more remote rural locations, it is important to note that the stations are considerably farther north of the comparison rural sites in Northeast BC, and the higher latitude may contribute to the lower O<sub>3</sub> concentrations. Therefore, use of these remote monitoring stations should be considered on a case-by-case basis for locations in the far north of BC.

## Guidance on NO<sub>2</sub> Dispersion Modelling in British Columbia

**Table C-2: Ozone Data Comparison – Rural and Remote Monitoring Stations**

Site	Minimum	Maximum	Average	Median	75 <sup>th</sup> Percentile	98 <sup>th</sup> Percentile
<b>Remote Monitoring Stations, Northwest Territories</b>						
Fort Smith	0.00	71.00	24.01	24.60	30.10	41.00
Inuvik	0.00	68.40	24.03	24.50	30.50	40.50
Norman Wells	0.50	53.50	21.91	21.60	28.50	41.40
<b>Monitoring Stations Used in Rural Dataset</b>						
Blueberry Hill	0.00	60.70	25.83	26.40	34.90	48.30
Farmington Community Hall	0.00	63.90	27.87	28.70	36.90	50.20
Beaverlodge	0.00	96.00	28.29	29.00	36.44	50.00
Rolla 213 Road	0.00	65.00	27.47	27.70	35.10	47.00

### APPENDIX D: SUBSTITUTION METHODS FOR MISSING OZONE DATA

O<sub>3</sub> datasets for Tier 3 NO<sub>2</sub> methods (OLM and PVMRM) require a complete dataset with no missing hours. However, O<sub>3</sub> datasets have the potential to include gaps where data are missing for individual hours or groups of hours. These gaps can result from the absence of monitoring activity, temporary equipment malfunction, or from QA/QC procedures where requirements are not met. In the event that data are missing from O<sub>3</sub> datasets, the following methods should be used to fill in gaps in available data.

If single hour values are missing, missing O<sub>3</sub> concentrations should be filled using linear interpolation between the concentrations for the hour before and the hour after. The values for the hours before and after are added, and the sum is divided by two.

In the event that multiple hours are missing, there are a variety of methods that may be appropriate for a given dataset. Provided that sufficient data are available (75% data completeness for each quarter), the preferred method of filling data would be to use the monthly maximum hourly concentration to fill in any remaining data gaps. For example, for every multi-hour block of missing data in January, the data would be filled with the maximum O<sub>3</sub> concentration among all monitored values in January across all years of the model domain.

In the event that the data completeness is not sufficient, the following list represents available gap-filling options that are relatively simple to implement and result in a conservative estimate of the O<sub>3</sub> concentrations:

- ◆ Maximum Hourly Concentration
  - Select the highest hourly concentration over the entirety of the modelled period and use this value to fill in all remaining missing hours.
- ◆ Maximum Annual Hourly Concentration
  - Select the highest hourly concentration over each individual year of the modelled period and use this value to fill in all remaining missing hours for the corresponding year in the model.
- ◆ Maximum Annual Average Hourly Concentration
  - Select the highest hourly concentration over each individual year of the modelled period and use the *average* of those values to fill in all remaining missing hours.

Applicants are encouraged to contact the Ministry if there is uncertainty about the quality of a background O<sub>3</sub> dataset, particularly if the use of a Ministry-prepared O<sub>3</sub> dataset may be more appropriate for a given model.