Final Report

ESSA 35 YEARS

Kitimat Airshed Emissions Effects Assessment

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Prepared for
British Columbia Ministry of Environment
Environmental Protection Program
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BRITISH COLUMBIA

Kitimat Airshed Emissions Effects Assessment

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ABBREVIATIONS AND TERMS

List of Symbols and Abbreviations

Δ	delta, meaning quantitative change (e.g. ΔANC or Δ pH)
<	is less than what follows
≤	is less than or equal to what follows
>	is greater than what follows
≥	is greater than or equal to what follows
Al	aluminum
ANC	acid neutralizing capacity
ASC	acid sensitivity class
B_C	base cations
BC	British Columbia
CAAQS	Canadian Ambient Air Quality Standards
CCME	Canadian Council of the Ministers of Environment
CL	critical load
CO	carbon monoxide
CO_2	carbon dioxide
COPD	chronic obstructive pulmonary disease
DEM	digital elevation model
DFO	Fisheries and Oceans Canada
DM	dry moderate weather type
DOC	dissolved organic carbon
DP	dry polar weather type
DT	dry tropical weather type
ED	emergency department
ESSA	ESSA Technologies Ltd.
FEV1	forced expiratory volume in 1 second
FVC	forced vital capacity
GAQM	Guideline on Air Quality Models
GIS	geographic information system
H_2SO_4	sulphuric acid
HRV	a measure of cardiovascular autonomic control
KMP	Kitimat Modernization Project

LFH	litter-fibric-humic soil layer
LNG	liquefied natural gas
LOI	loss-on-ignition
MDISP	dispersion coefficients switch setting
MM5	5^{th} generation mesoscale model (data from this model used in sensitivity analyses of CALPUFF model output)
MOE	British Columbia Ministry of Environment
MM	moist moderate weather type
MP	moist polar weather type
n	number (sample size, e.g. “n=6”)
N	nitrogen
NAAQS	US EPA National Ambient Air Quality Standards
NO_2	nitrogen dioxide
NO_3	nitrate
NO_X	nitrogen oxides
O_2	oxygen
O_3	ozone
ORs	odds ratios
PCO	Pollution Control Objectives (of BC)
PM	particulate matter
$PM_{2.5}$	particulate matter up to 2.5 micrometers in diameter
PM_{10}	particulate matter up to 10 micrometers in diameter
QA/QC	quality assurance/quality control
QP	qualified professional
RR	relative risk
RTA	Rio Tinto Alcan
S	sulphur
SCR	selective catalytic reduction
SD	standard deviation
SO_2	sulphur dioxide
SO_3	sulphur trioxide
SO_4	sulphate, a salt of sulphuric acid
SO_X	sulphur oxides
sRaw	specific airway resistance
SMB	Simple Mass Balance model

SSC	spatial synoptic classification
SSWC	steady state water chemistry (model)
TFL	tree farm license
TR	transitional weather type
US	United States (of America)
US EPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator

List of Measurement Units

ha	hectares
km	kilometre
kg/ha	kilograms per hectare
kg/ha/yr	kilograms per hectare per year (units of deposition flux)
m	metres
m/s	metres per second
mg/L	milligrams per litre
meq/m^2/yr	milliequivalents per square metre per year
ppb	parts per billion
ppm	parts per million
t/d	tonnes per day
µeq/L	microequivalents per litre (µ can also be shown as u)
µg/m^3	micrograms per cubic metre (µ can also be shown as u)
µm	micrometres (µ can also be shown as u)

Glossary of Terms

A2M	Analysis to Mineralogy; a matrix-based model that estimates relative mineral content of soils
acid deposition	Transfer of acids and acidifying compounds from the atmosphere to terrestrial and aquatic environments via rain, snow, sleet, hail, cloud droplets, particles, and gas exchange
acidic episode	An event in a water body in which acidification of surface waters results in an acid neutralizing capacity of less than or equal to 0
acidification	The decrease of acid neutralizing capacity in water, or base saturation in soil, by natural or anthropogenic processes
acid neutralizing capacity	The equivalent capacity of a solution to neutralize strong acids; ANC and alkalinity are often used interchangeably; ANC includes alkalinity plus additional buffering from dissociated organic acids and other compounds

alkalinity	Measures the ability of a solution to neutralize acids; the terms acid neutralizing capacity and alkalinity are sometimes used interchangeably
ambient	Of the surrounding area or environment
anion	An ion with more electrons than protons, giving it a negative charge, e.g., SO_4^{2-}
anthropogenic	Of, relating to, derived from, or caused by humans or related to human activities or actions
base cations	An alkali or alkaline earth metal (Ca2+, Mg2+, K+, Na+)
base saturation	The proportion of total soil cation exchange capacity that is occupied by exchangeable base cations (i.e., by Ca^{2+}, Mg^{2+}, K^{+}, Na^{+})
CALMET	A diagnostic 3-dimensional meteorological model that forms a component of the CALPUFF system
CALPOST	A post-processing package that forms a component of the CALPUFF system
CALPUFF	An air quality dispersion model that forms part of an advanced non-steady-state meteorological and air quality modelling system of the same name
catchment	See “watershed”
cation	An ion with fewer electrons than protons, giving it a positive charge, e.g., Ca^{2+}
climate	The average weather of a location over a long period of time
critical load	A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge
dissolved organic carbon	Organic carbon that is dissolved or unfilterable in a water sample (0.45 µm pore size in the National Surface Water Survey)
dry deposition	Transfer of substances from the atmosphere to terrestrial and aquatic environments via gravitational settling of large particles and turbulent transfer of trace gases and small particles
empirical	Derived from or guided by experience or experiment
epidemiology	The study of the patterns, causes, and effects of health and disease conditions in defined populations
eutrophication	The enrichment of an ecosystem with chemical nutrients, typically compounds containing nitrogen, phosphorus, or both
glaciofluvial	Pertaining to streams fed by melting glaciers, or to the deposits
Gran ANC	The capacity of a solution to neutralize strong acids, determined by titration to the inflection point of the pH-alkalinity titration curve
hydrology / hydrologic	Pertaining to the movement, distribution, and quality of water
interquartile range	A measure of statistical dispersion; also called the midspread or middle fifty
ion	An atom or molecule in which the total number of electrons is not equal to the total number of protons, giving it a positive or negative electrical charge

isopleth	Contour line on a map connecting places with the same value of some parameter, e.g., total sulphate deposition
leaching	The extraction of materials from a carrier into a liquid
morbidity	Refers to the disease state of an individual, or the incidence of illness in a population
mortality	Refers to the state of being mortal, or the incidence of death (number of deaths) in a population
myocardial infarction	Heart attack
neonatal	Of, relating to, or affecting the newborn and especially the human infant during the first month after birth
organic acids	Acids possessing a carboxyl (-COOH) group or phenolic (C-OH) group; includes fulvic and humic acids
peak exposure	The highest average exposure over a short time period, generally in the range of 5 to 15 minutes, as compared to the average exposure over a longer period that contains the peak exposure (e.g., over the corresponding hour, or day)
pH	A measure of how acidic or basic a solution is, on a scale of 0-14; the lower the pH value, the more acidic the solution; pH 7 is neutral; a difference of 1 pH unit indicates a tenfold change in hydrogen ion activity
physiology	The scientific study of function in living systems; includes how organisms, organ systems, organs, cells, and bio-molecules carry out the chemical or physical functions that exist in a living system
PROFILE	A steady-state soil chemistry model
salt effect	The process by which hydrogen ions are displaced from the soil exchange complex by base cations (from neutral salts); the result is a short-term increase in the acidity of associated water; also referred to as the “sea salt effect”
saturation	The point at which a solution of a substance can dissolve no more of that substance
spirometry	The measuring of breath
strong acids	Acids having a high tendency to donate protons or to completely dissociate in natural waters (e.g., H_2SO_4, HNO_3, HCl, and some organic acids)
toxicology	The study of the adverse effects of chemicals on living organisms, of symptoms, mechanisms, treatments and detection of poisoning, especially the poisoning of people
turbidity	The cloudiness of a fluid caused by suspended particles
watershed	The geographic area from which surface water drains into a particular lake or point along a stream
wet deposition	Transfer of substances from the atmosphere to terrestrial and aquatic environments via precipitation (e.g., rain, snow, sleet, hail, and cloud droplets); droplet deposition is sometimes referred to as occult deposition

1 INTRODUCTION

1.1 Background

Kitimat's location at the head of Douglas Channel in northwestern British Columbia (BC) makes it an attractive location for industries seeking a marine terminal along BC's Pacific Coast in order to access foreign markets. Numerous liquefied natural gas (LNG) facilities as well as an oil refinery and a crude oil export terminal have been proposed for the Kitimat area, which is placing new and urgent demands upon regulatory decision-making processes. The ESSA team was contracted by the BC Ministry of Environment (MOE) to conduct a rapid scoping-level assessment of the potential combined effects on the environment and human health from nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) emissions from a collection of alternative future scenarios representing a range of existing and proposed industrial facilities in the Kitimat area. The objective was to provide information that would help decision-makers understand and compare the potential risks under different scenarios with a view to ultimately determining how many industrial facilities could be added to the Kitimat airshed without causing unacceptable impacts to human health and the environment.

The study area is shown in Figure 1-1 and comprises an area of 6,772 km^2. This is only one corridor of interest regarding the potential combined effects from multiple sources of NO_2 and SO_2. Results from this assessment are also intended to help inform decisions in the Prince Rupert and Grassy Point areas where LNG terminals have also been proposed. The Kitimat area was chosen for this study because regulatory decisions regarding LNG development will likely be needed there sooner than elsewhere.

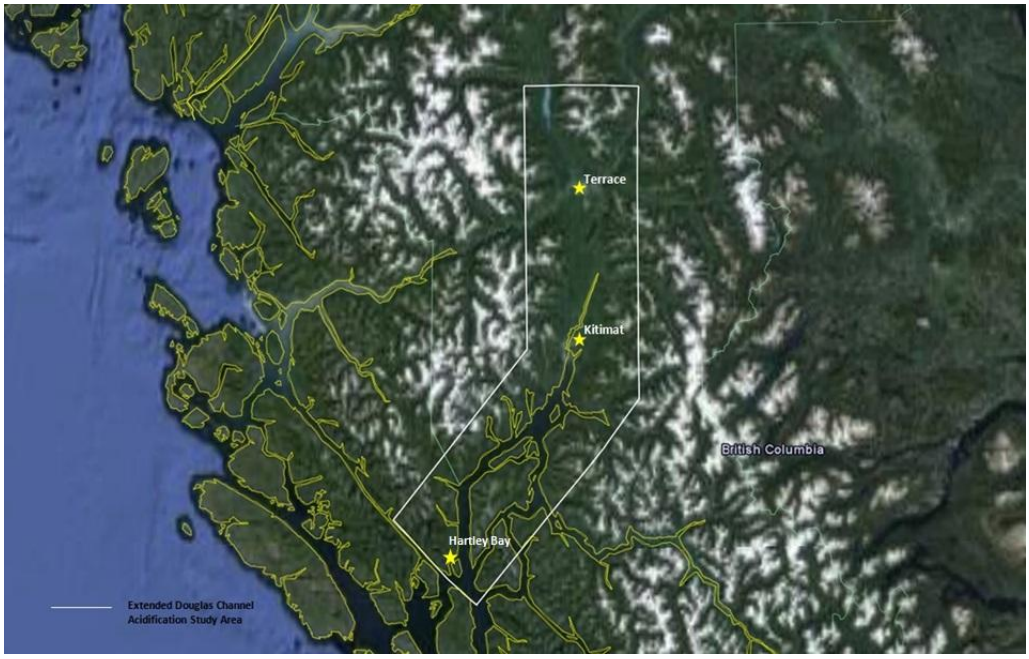


Figure 1-1. Map of the study area.

The industrial facilities explored in the assessment included an existing aluminum smelter, four proposed LNG terminals, a proposed oil refinery, and gas turbine powered electrical generation

facilities, as well as related marine transportation sources. Their locations are shown in Figure 1-2. The assessment also included emissions from shipping related to these facilities, along a route in Douglas Channel show in Figure 1-3.

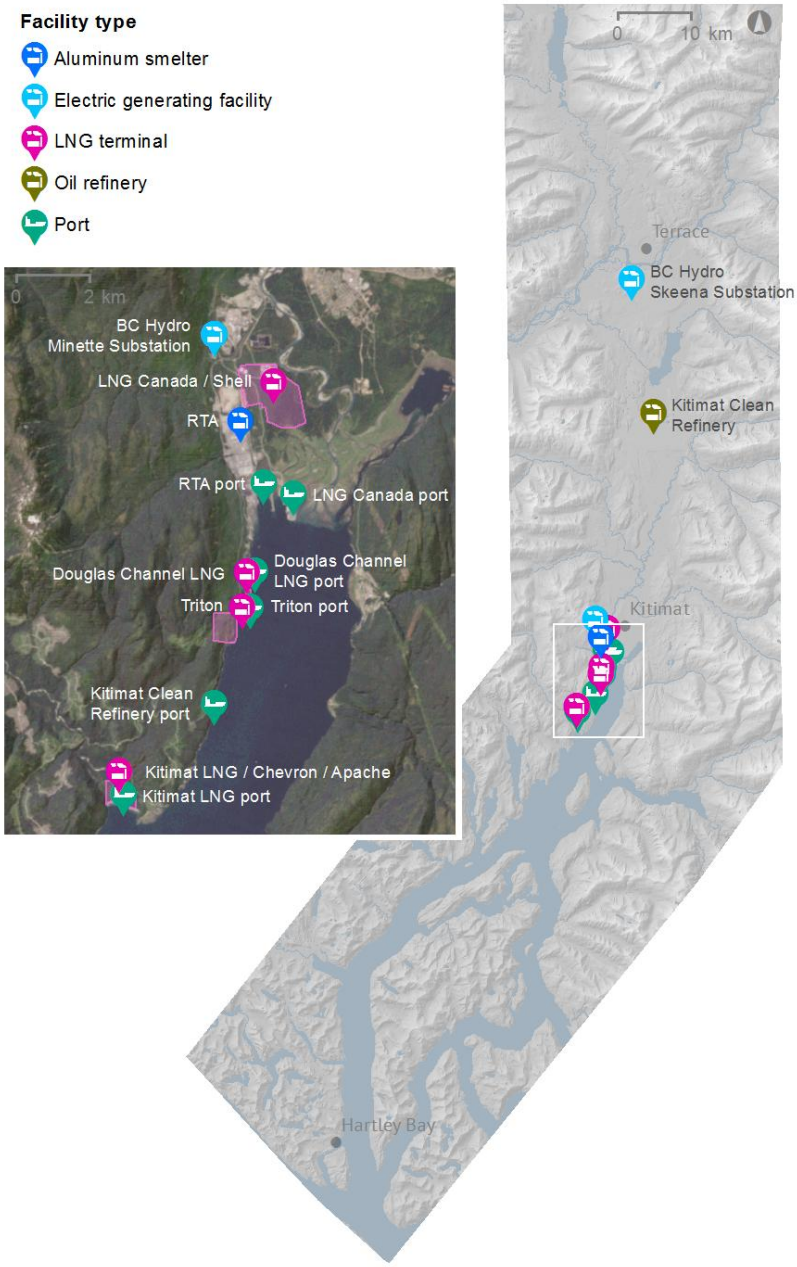


Figure 1-2. Locations of the stationary emissions sources modelled in the scenarios. The inset zooms in on the facilities at the head of Douglas Channel.

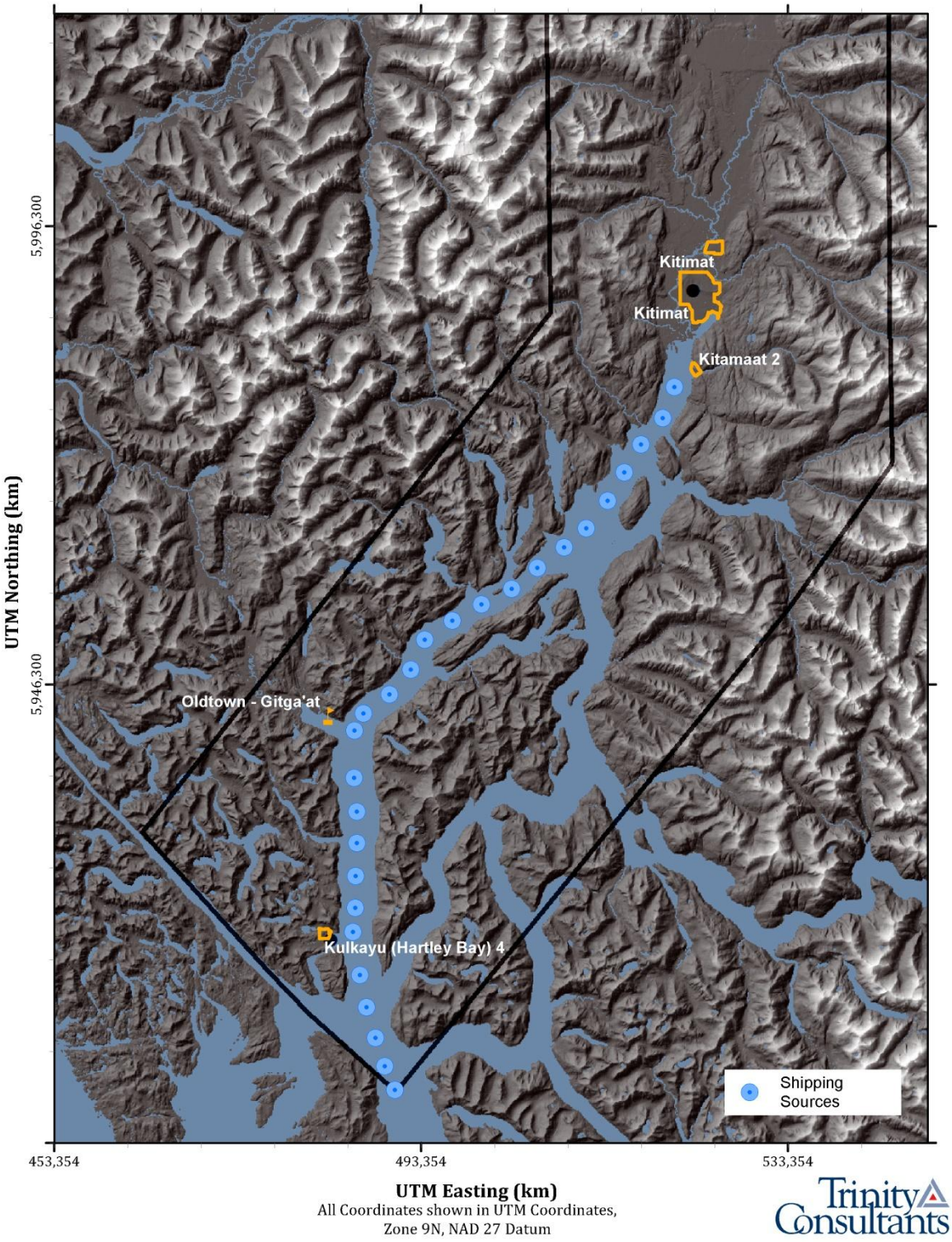


Figure 1-3. Locations of the shipping emissions sources modelled in the scenarios.

1.2 Approach

The study was designed using the source-pathway-receptor framework illustrated in Figure 1-4. The BC Ministry of Environment was interested in learning about the potential effects on human health and vegetation from *direct exposure* to SO_2 and NO_2 concentrations in the air, and the potential effects on soils and lakes from *deposition* of sulphur (S) and nitrogen (N) – which includes the potential for acidification of soils and lakes as well as the potential for eutrophication of soils.

The work for each pathway and receptor was undertaken by qualified professionals (QPs) in each field:

- Air Dispersion and Deposition – Trinity Consultants Inc.
- Human Health – Risk Sciences International Inc.
- Vegetation – Dr. John Laurence
- Terrestrial Ecosystems (acidification and eutrophication) – Trent University
- Aquatic Ecosystems (acidification) – ESSA Technologies Ltd.

Detailed methods and results for each of these pathways and receptors are presented in Section 2 through Section 6 of this report.

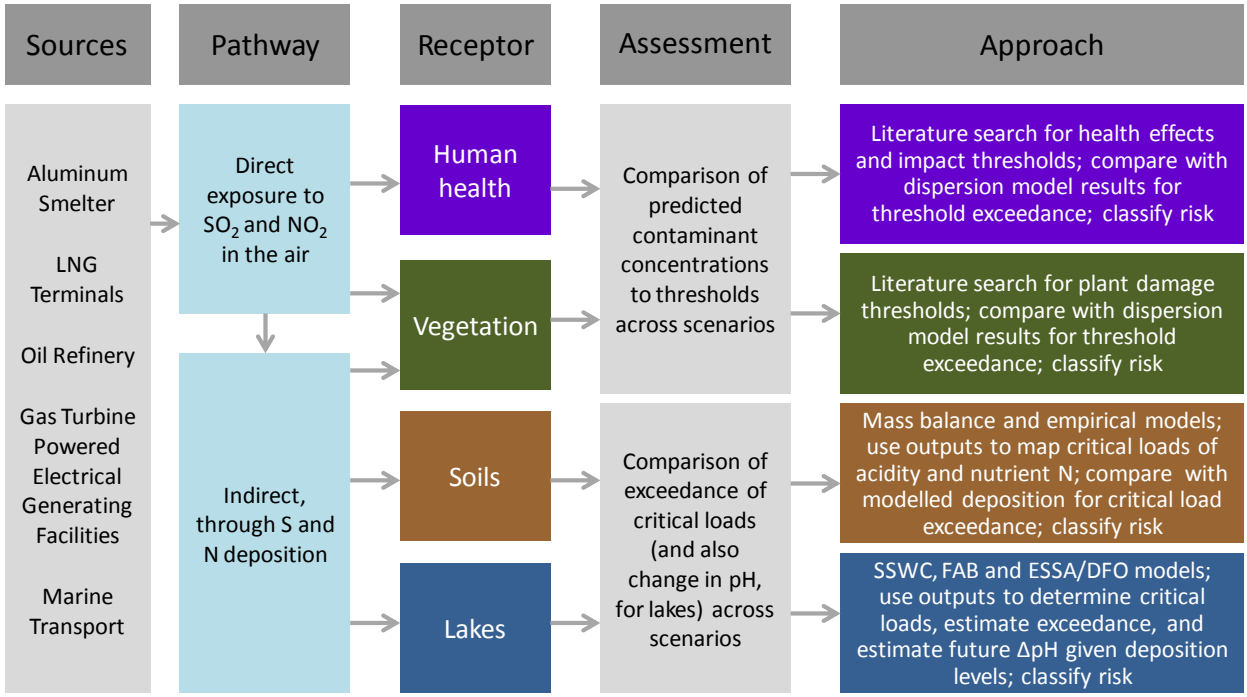


Figure 1-4. High-level overview of the study design.

Assessment results are organized into four colour-coded risk categories: green, yellow, orange and red. Table 1-1 defines these categories for the environmental receptors (vegetation, soils and lakes). The risk categories for human health are very different, and are further explained in Section 3.

Table 1-1. Risk categories and definitions for the environmental receptors: vegetation, soils and lakes.

Low	Scenarios expected to have no, or negligible, impact
Moderate	Scenarios expected to have an impact, but of a magnitude, frequency, and spatial distribution considered to be acceptable [a]
High	Scenarios expected to have an impact of a magnitude, frequency or spatial extent, or spatial distribution, considered to be unacceptable [a]; further investigation is needed into the implications of the assumptions in this scoping-level assessment to determine if reducing uncertainties and refining assessment inputs lowers the risk category
Critical	Scenarios expected to have an impact of a magnitude, frequency or spatial distribution, considered to be extremely unacceptable [a]; further investigation could be made into the implications of the assumptions in this scoping-level assessment to determine if reducing uncertainties and refining assessment inputs lowers the risk category, but would be unlikely to reduce the risk rating sufficiently to be considered acceptable

[a] The quantitative boundaries of these categories used for the assessments of vegetation, soils and lakes are presented in Sections 4, 5 and 6 respectively. It is important to note that "acceptability" of impacts depends on one's values, and is ultimately a policy decision that will be *informed* by this assessment.

1.3 Scenarios

MOE was interested in many scenarios encompassing different combinations of emission sources and emissions treatment. Eight of these were selected collaboratively by MOE and the assessment team for inclusion in this study, and are listed in Table 1-2 and Table 1-3. The longer list of scenarios considered for the study is provided in Appendix 1. Each scenario modelled in this assessment has a label that includes a letter (alphabetically, i.e., A through H) as well as a number representing the total SO_2+NO_X emissions across all sources as configured for that scenario. Scenarios A_28.2 and H_82.6 represent the "bookend" scenarios, having the lowest and highest total combined concentrations of SO_2+NO_X, respectively. The remaining six scenarios were selected to represent a range of emission source and treatment combinations between these two bookends. The emissions characteristics are listed in Table 1-2, and also presented visually in Figure 1-5.

Four additional scenarios modelled the incremental impacts of locating a BC Hydro electric generating facility at one of two candidate sites. These sites were selected by BC Hydro to co-locate with existing substations: the Skeena Substation and Minette Substation. The air dispersion and deposition model results for each of these two generating facility locations have been added to Scenario H_82.6, allowing for a comparison of receptor impacts between these two candidate locations with all other scenario characteristics remaining unchanged. Two of the BC Hydro scenarios represent NO_X control and are labelled Is_83.3 and Im_83.3, for the Skeena and Minette locations, respectively. The remaining two scenarios represent no NO_X control and are labeled Js_86.1 and Jm_86.1. Their emissions characteristics are presented in Table 1-3.

The characteristics for each facility have been modelled as separate "layers", as explained further in Section 2.1. This layered approach was designed to allow MOE the flexibility to later explore additional scenarios through different layer combinations, without having to re-do the air dispersion and deposition modelling. MOE will retain ownership of all of the model results and outputs.

Table 1-2. Emissions from the eight scenarios assessed in the study. Emission numbers are *estimates* based on the available design information for these sources.

Scenario	Smelter	SO_2 t/d	NO_X t/d	LNG	SO_2 t/d	NO_X t/d	Refinery	SO_2 t/d	NO_X t/d	Shipping	SO_2 t/d	NO_X t/d	**Total SO_2** t/d	**Total NO_X** t/d	**Total SO_2+NO_X** t/d
A_28.2	Full Treatment	6.5	1.0	All Electric Drive	9.6	3.2	Off	-	-	Smelter +LNG	0.2	7.8	16.3	11.9	28.2
B_51.8	Partial Treatment	27.5	1.0	Base Case-NO_X treatment	10.8	4.4	Off	-	-	Smelter +LNG	0.2	7.8	38.6	13.2	51.8
C_57.5	Partial Treatment	27.5	1.0	Mixed 60/40	10.3	10.7	Off	-	-	Smelter +LNG	0.2	7.8	38.1	19.4	57.5
D_61.8	Partial Treatment	27.5	1.0	Base Case	10.8	14.5	Off	-	-	Smelter +LNG	0.2	7.8	38.6	23.2	61.8
E_66.1	Base Case	41.8	1.0	Base Case-NO_X treatment	10.8	4.4	Off	-	-	Smelter +LNG	0.2	7.8	52.9	13.2	66.1
F_72.6	Base Case	41.8	1.0	Base Case-NO_X treatment	10.8	4.4	On	2.9	1.1	Smelter +LNG + Refinery	0.3	10.2	55.8	16.8	72.6
G_76.2	Base Case	41.8	1.0	Base Case	10.8	14.5	Off	-	-	Smelter +LNG	0.2	7.8	52.9	23.2	76.12
H_82.6	Base Case	41.8	1.0	Base Case	10.8	14.5	On	2.9	1.1	Smelter +LNG + Refinery	0.3	10.2	55.8	26.8	82.6

Table 1-3. Emissions from the BC Hydro scenarios assessed in the study. Emission numbers are *estimates* based on the available information for the sources.

Scenario	Smelter, LNG, Refinery and Shipping	SO_2 t/d	NO_X t/d	BC Hydro	SO_2 t/d	NO_X t/d	Total SO_2 t/d	Total NO_X t/d	Total SO_2+NO_X t/d
Is_83.3	As for Scenario H_82.6	55.8	26.8	Skeena	3.84E-06	0.69	55.81	27.49	83.30
Im_83.3	As for Scenario H_82.6	55.8	26.8	Minette	3.84E-06	0.69	55.81	27.49	83.30
Js_86.1	As for Scenario H_82.6	55.8	26.8	Skeena	3.84E-06	3.46	55.81	30.25	86.06
Jm_86.1	As for Scenario H_82.6	55.8	26.8	Minette	3.84E-06	3.46	55.81	30.25	86.06

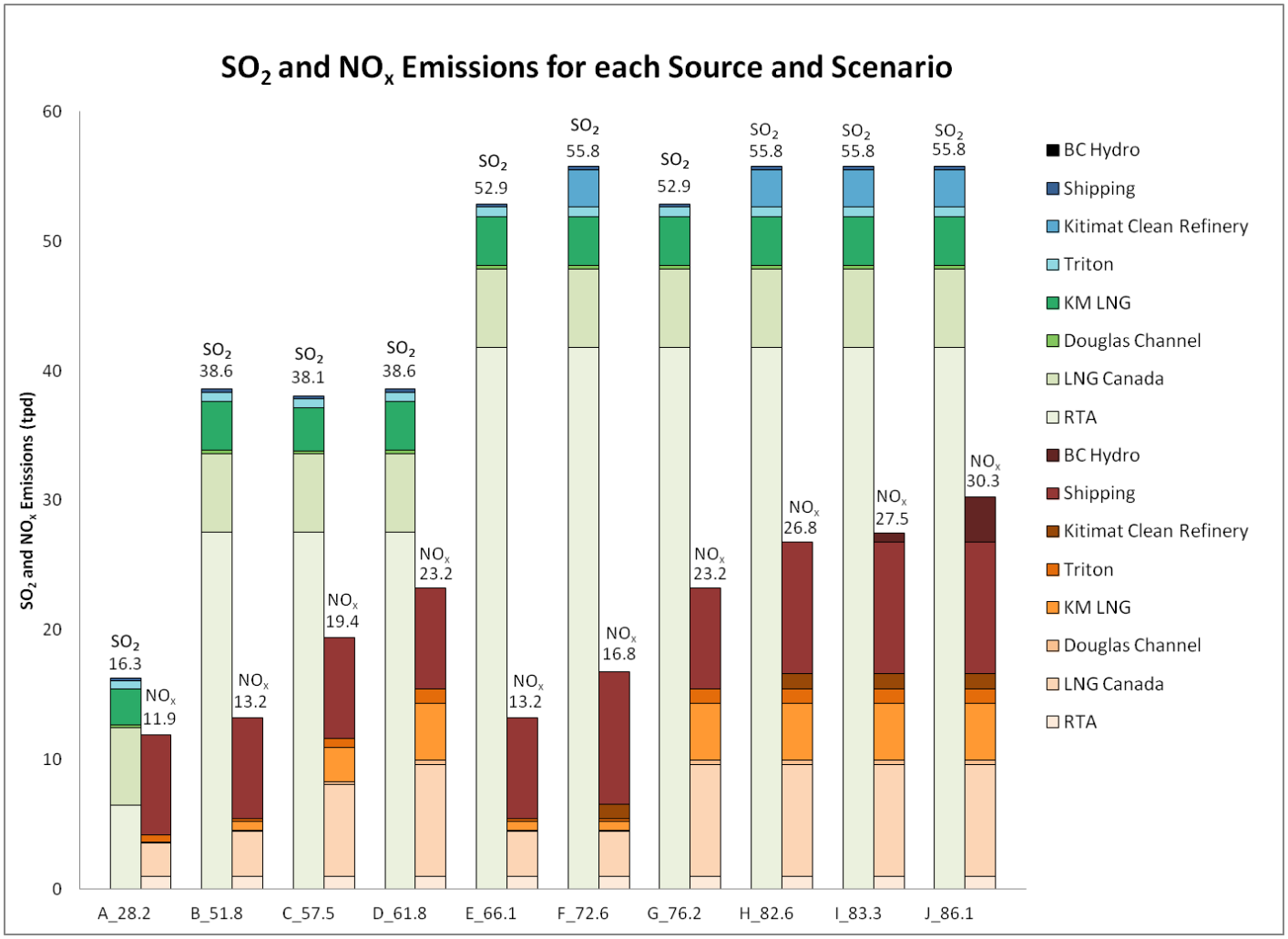


Figure 1-5. Bar chart illustrating relative emissions and sources by scenario. The bar labeled "I_83.3" applies to Scenarios Is_83.3 and Im_83.3, as their emission characteristics are identical. Similarly, the bar labeled "J_86.1" applies to Scenarios Js_86.1 and Jm_86.1.

2 AIR DISPERSION AND DEPOSITION MODELLING

2.1 Methods

The CALPUFF dispersion modelling analysis follows the modelling methods and procedures detailed in a modelling protocol developed during a recent SO_2 technical assessment of the Kitimat Modernization Project (KMP) in cooperation with and approved by the BC Ministry of Environment (MOE).[1] A copy of the final modelling protocol is included in Appendix 7.6-1 of Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b).

2.1.1 Layering Method

As discussed in Section 1.3, modelling outputs were developed for eight separate scenarios for the analysis of potential impacts on human health, vegetation, soils and lakes. Rather than preparing a scenario-specific CALPUFF input file and conducting the associated model run, each facility was modelled individually for the one to four cases under which each facility may operate:

- Smelter – three options modelled
  - Base case using the same emissions as modelled in the KMP SO_2 Technical Assessment (ESSA et al. 2013a)
  - Partial Control
  - Full Control
- LNG Facilities – four options modelled
  - Base case assuming direct drive technology
  - 60/40 electricity from grid
  - Full NO_X control
  - 100% electric
- Refinery – two options modelled
  - With the refinery included
  - Without the refinery included
- Shipping – two options modelled
  - Shipping associated with the smelter, 4 LNG facilities, and the refinery
  - Shipping associated with the smelter and the 4 LNG facilities

Once each facility was modelled individually, results were then combined in the post-processing phase of the CALPUFF modelling analysis (i.e., using CALSUM for concentrations and POSTUTIL for deposition). Using this CALSUM, or "layer", method will allow MOE to request additional combination scenarios for a fraction of the time and cost required for a scenario-specific CALPUFF run. This layering approach may result in some overestimation or underestimation of combined results for SO_2. However, the difference is expected to be small, as detailed in Section 2.3.

[1] Trinity Consultants submitted a final modelling protocol on September 4, 2012 for approval by the MOE. As documented in the response letter provided by Mr. Ben Weinstein, MOE, to Ms. Anna Henson, Trinity Consultants, email communication, November 4, 2012, the Ministry accepted and agreed to the approach outlined in the September modelling protocol, with consideration of sensitivity study results presented on November 1, 2012. The modelling protocol and response from MOE are provided in Appendix 7.6-1 in ESSA et al. (2013b).

BC Hydro Siting Method

Four scenarios are included to assess the incremental impacts of locating a BC Hydro electric generating facility at the site of either the Minette Substation or the Skeena Substation. The modelled emissions for each option are compared to assess the meteorological and terrain advantages and disadvantages of each candidate location. The BC Hydro model results are added to Scenario H_82.6 for each location and the resulting changes to the end-receptor impacts between the two stations are compared. The following list describes the four BC Hydro scenarios:

- Scenario Is_83.3 for the Skeena Substation location with Selective Catalytic Reduction (SCR) NO_X control
- Scenario Im_83.3 for the Minette Substation location with SCR NO_X control
- Scenario Js_86.1 for the Skeena Substation location without add-on NO_X control
- Scenario Jm_86.1 for the Minette Substation location without add-on NO_X control

The emissions in each scenario are estimates based on the operation of four 100 megawatt power turbines at one of the two candidate sites.

2.1.2 About Dispersion Models

Dispersion models serve as a tool to predict or estimate ambient air concentrations and deposition rates due to industrial or other sources of emissions. Dispersion models are most commonly used to predict air concentrations from industrial sources that have not yet been constructed. Predictions available from dispersion models allow stakeholders to gain an understanding of the changes to ambient air due to emissions changes from a project *before* the project begins operation. Dispersion models are designed to be conservative, because their most common purpose is to provide a worst case estimate of the air quality after a project to ensure the project will not result in violations of air quality requirements or detrimental impacts to human health or the environment. Typical levels of conservatism range from 50 percent over-prediction, up to over-predicting by a factor of four (400 percent over-prediction).

Once a project is in operation, air monitoring programs are often implemented to verify that the ambient concentrations are below levels of concern. However, dispersion models are also increasingly being used now to estimate air pollutant concentrations from existing sources, as a reliable and more cost effective option than ambient air monitoring. Most notably, the United States Environmental Protection Agency (US EPA) recently proposed using dispersion modelling to determine the attainment status of regions within each state with respect to a new SO_2 ambient air quality standard. The most commonly-used dispersion models for predicting air pollutant concentrations from industrial sources are AERSCREEN, AERMOD, and CALPUFF.

2.1.2.1 About the CALPUFF Dispersion Model

While the CALPUFF model is more complex and technically challenging than its relatives, it offers several advantages. The modelling analysis presented in this report applies the CALPUFF dispersion model for a number of reasons, including the need to:

- determine long-range impacts (AERSCREEN and AERMOD are not recommended for distances over 50 kilometres),
- represent complex terrain conditions in the Kitimat area (AERMOD assumes winds do not change direction across the entire domain for each time step, while AERSCREEN does not consider wind direction at all), and

- represent the buoyant plume rise typical of aluminum smelter potroom roof vents (AERSCREEN\AERMOD does not include a buoyant line source type, while CALPUFF does).

The CALPUFF model is a useful tool to inform decisions and generally errs on the conservative side. For this analysis, the CALPUFF model was expected to perform similarly to its performance for the recent KMP SO_2 technical assessment (ESSA et al. 2013a,b). As part of this previous modelling effort, a study was conducted comparing pre-project CALPUFF results to SO_2 monitoring data during the corresponding period (2006, 2008, and 2009). The monitoring data study demonstrated that the CALPUFF model predicts concentrations that are approximately double the measured concentrations (227%), averaged over the three years, three sites, and averaging periods of interest (1-hour, 3-hour, 24-hour, and annual).[2]

2.1.3 CALPUFF Dispersion Modelling Methods Summary

The main components of the CALPUFF modelling system are the CALMET, CALPUFF, and CALPOST models. CALMET is the meteorological model that generates hourly three-dimensional meteorological fields such as wind and temperature. CALPUFF simulates the non-steady state transport, dispersion, and chemical transformation of air pollutants emitted from a source in "puffs". CALPUFF calculates hourly concentrations of specified pollutants at specified receptors in a modelling domain. CALPOST is the post-processor for CALPUFF that computes concentration and deposition from emissions sources based on the pollutant concentrations and deposition that are output by CALPUFF.

2.1.3.1 Modelling Domain

The CALPUFF modelling system utilizes three modelling grids: the meteorological grid; the computational grid; and the sampling grid (or receptor grid). The meteorological grid is the system of grids within which meteorological fields are developed with CALMET. The computational grid defines the computational area for a CALPUFF run (i.e., where the puffs are tracked), and is defined identically to the meteorological grid. The sampling grid defines the locations where the ground level concentration and/or deposition results are calculated and stored within the CALPUFF output files. This particular study also uses two separate model domains: a local-scale domain and a regional scale domain. The meteorological and CALPUFF computational grid spacing is 4 kilometres (km) across the entire domain for long range regional modelling. For local scale modelling, the analysis applies a more refined meteorological and CALPUFF computational grid spacing of 500 metres.

The three regional scale modelling grids have been updated for the current effort to accommodate the larger study area (and are different from those shown in the modelling protocol provided in Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b). The regional domain was extended to the south and west and somewhat to the north to accommodate the study domain specified by MOE and presented in Section 1.2. The local-scale domain remains identical to that used in the KMP SO_2 Technical Assessment.[3] Figure 2-1 presents the updated regional scale meteorological and computational domains.

[2] See Section 7.6.2.1.1 of Volume 2 (ESSA et al. 2013a), and Appendix 7.6-3 of Volume 3 (ESSA et al. 2013b), of the KMP SO_2 Technical Assessment for more details regarding the "Pre-KMP SO_2 monitoring data study".

[3] This modelling analysis uses two separate domains: one at the local-scale to assess the near-field impacts from the aluminum smelter, LNG facilities, and marine ports on the immediate areas surrounding the facilities, on the town of Kitimat, and on Kitamaat Village; and one at the regional-scale to assess the impacts on sensitive lakes, soils, vegetation, and residential areas that are farther from the highest model results, but may be affected due to greater sensitivity to increases in concentrations or deposition.

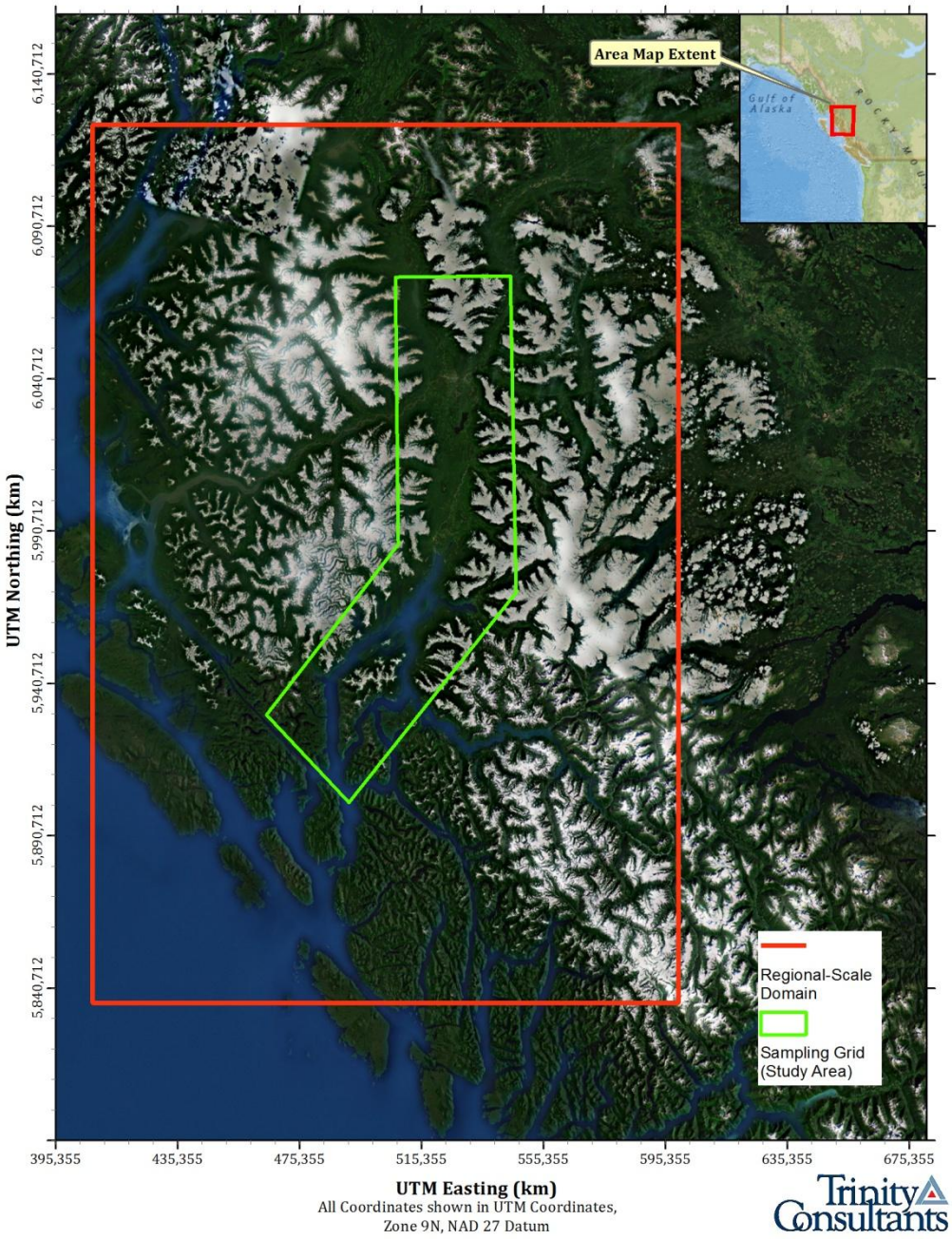


Figure 2-1. Regional scale meteorological/computational modelling domain and sampling grid (study area).

2.1.3.2 CALMET Meteorological Processor

We used the CALMET meteorological processor to generate the meteorological data for CALPUFF. CALMET is the meteorological processor that compiles meteorological data from raw observations of surface and upper air conditions, precipitation measurements, mesoscale model output, and geophysical parameters into a single hourly, gridded data set for input into CALPUFF. CALMET uses the same methodology as described in Section 3 of Appendix 7.6-1 of the KMP SO_2 Technical Assessment, Volume 3 (ESSA et al. 2013b), with the exception of MM5 data (Section 3.2.2, Appendix 7.6-1) and the range of meteorological data (Section 3.2.1, Appendix 7.6-1). Details regarding the meteorological year selection and the MM5 data processing are provided below (see about *Meteorological data*). Full details regarding the CALMET meteorological processor are provided in the modelling protocol in Appendix 7.6-1 of Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b).

Geographical Data

CALMET requires geophysical data to characterize the terrain and land use parameters that potentially affect dispersion. Terrain features affect flows, create turbulence in the atmosphere, and are potentially subjected to higher concentrations of elevated puffs. Different land use types exhibit variable characteristics such as surface roughness, albedo, Bowen ratio, and leaf-area index that also affect turbulence and dispersion. The methodology for geophysical parameters, described in Section 3.1, Appendix 7.6-1 of Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b), was used without modification with the exception of the same datasets covering the larger domain.

Meteorological Data

This scoping assessment used one meteorological year in order to focus on comparisons between scenarios. Three years of meteorological data were readily available from the KMP SO_2 technical assessment: 2006, 2008, and 2009. The 2008 meteorological year was selected because it produced the highest sulphur deposition results from the KMP SO_2 assessment.[4] As such, 2008 is expected to produce the most conservative results (of the three years) for the assessment of acidification and eutrophication impacts to soils and water. To learn whether this was also the most conservative year for human health impacts, we conducted a study comparing the variation of air concentration results between 2006 or 2009 versus 2008 for one scenario. The results are presented in Section 2.3.3. Additionally, Section 2.3.1 summarizes an analysis comparing meteorological conditions during 2008 to a 10-year period from 2003 to 2012.

CALMET was used to assimilate data for 2008 using 5th generation mesoscale model output (MM5 data), surface station observations, upper air station observations, and National Oceanic and Atmosphere Administration's buoy station observations to develop the meteorological field.[5] The MM5 domain was set for the modelling analysis to cover the study area. CALMET and CALPUFF domains (meteorological grid and computational grid) need to extend 50 kilometres beyond the study area (sampling domain) to account for puff recirculation. The MM5 domain extends six grid cells beyond the CALMET domain in order to avoid meteorological noise effects resulting from boundary conditions coming into dynamic balance with the MM5 algorithms. Full details regarding the meteorological data are provided in the

[4] To further describe the differences between 2006, 2008, and 2009, Trinity calculated the total deposition in the KMP study area, compared to the total mass of emissions released, to gain an understanding of the variation in the fraction of emissions exiting the modelling domain. The percentage deposited compared to emitted in 2006, 2008, and 2009 for the SO_2 technical assessment (ESSA et al. 2013a,b) was 10%, 14%, and 13%, respectively.

[5] Note that precipitation data are not available on an hourly scale in the meteorological domain. Therefore, the MM5 dataset was used for precipitation information.

modelling protocol described in Appendix 7.6-1 of Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b). The expanded regional domain does not reach any new surface, upper air, or buoy meteorological stations; therefore, the modelling protocol methods outlined in Sections 3.2.3 through 3.2.5, Appendix 7.6-1 of the KMP SO_2 Technical Assessment Report (ESSA et al. 2013b), were used without modification.

The upper air stations included in the CALMET processing were limited to Annette Island and Port Hardy, near the edge of the regional CALMET domain. Only these two stations were included, because no other upper air stations operate within the regional domain boundary (meaning zero operate within the study area). Since these two stations are near the edge of the regional CALMET domain boundary, they have limited influence on the three dimensional meteorological fields generated by CALMET within the study area. However, the lack of upper air stations means that more of the three dimensional MM5 wind fields are preserved, and that discontinuities in the upper wind fields are avoided.

Control Parameters

The CALMET processing applied the recommended CALMET control parameters presented in Table 9.6 of the *Guidelines for Air Quality Dispersion Modelling in British Columbia* (BC Air Quality 2008). For switch settings that have multiple or variable recommended settings, the appropriate settings were based on expert judgment, discussed and agreed upon between Trinity Consultants and MOE. The CALMET switch settings used in this CALMET modelling analysis are provided in Table 3-3 of the modelling protocol in Appendix 7.6-1 of Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b).

QA Procedures

The Quality Assurance (QA) procedures for the CALMET processing were performed as specified in Sections 10.2.1 of the BC dispersion modelling guidelines (BC Air Quality 2008). Further details regarding the QA procedure are provided in the modelling protocol outlined in Appendix 7.6-1 of Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b).

2.1.3.3 Sampling Grid

MOE specified the study area within which modelling receptors should be placed. Additionally, individual points are included for locations of specific interest in order to evaluate impacts on lakes, soils, and vegetation, and finely-spaced receptors are included for residential areas of interest for potential human health impacts.[6] Terrain elevations for receptors are determined from digital elevation models (DEMs) referenced in Section 3.1.1 of the modelling protocol in Appendix 7.6-1, Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b), with additional DEM datasets obtained from the same source to cover the new domain. Figure 2-2 shows the residential receptors and individual receptors within the near grid, and Figure 2-3 shows all other receptors within the study area.[7]

[6] The list of individual points of interest and residential areas has been expanded from what was specified in Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b). Additional points are included at the center of each lake and soil sample within the study area. Residential receptors have also been added for the Gitga'at and Hartely Bay areas.

[7] Note that receptors in addition to those shown in green in each of the figures were included in the human health impact study, as presented in Figure 3-1.

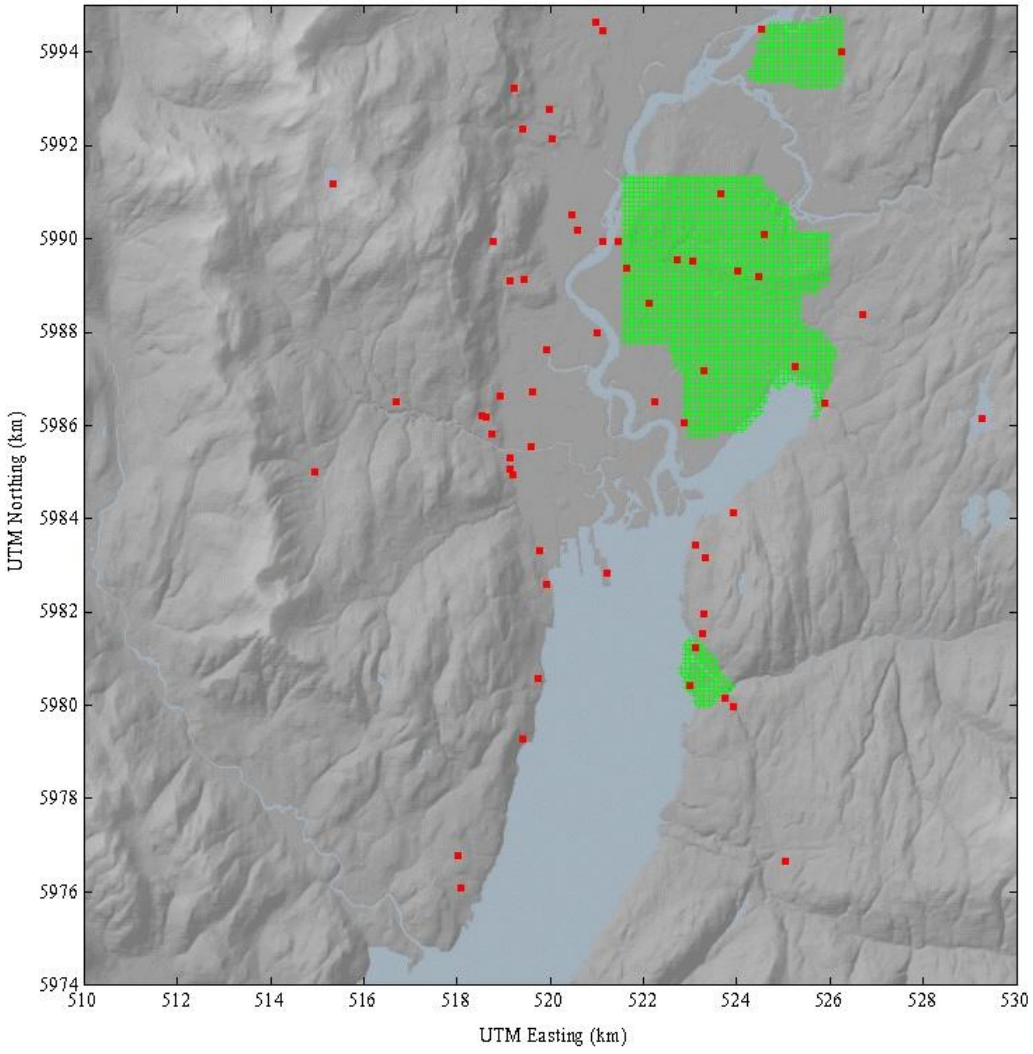


Figure 2-2. Residential and individual receptors in near grid. All residential receptors are marked in green, and all individual receptors (soils, lakes, points of interest) are marked in red.[8]

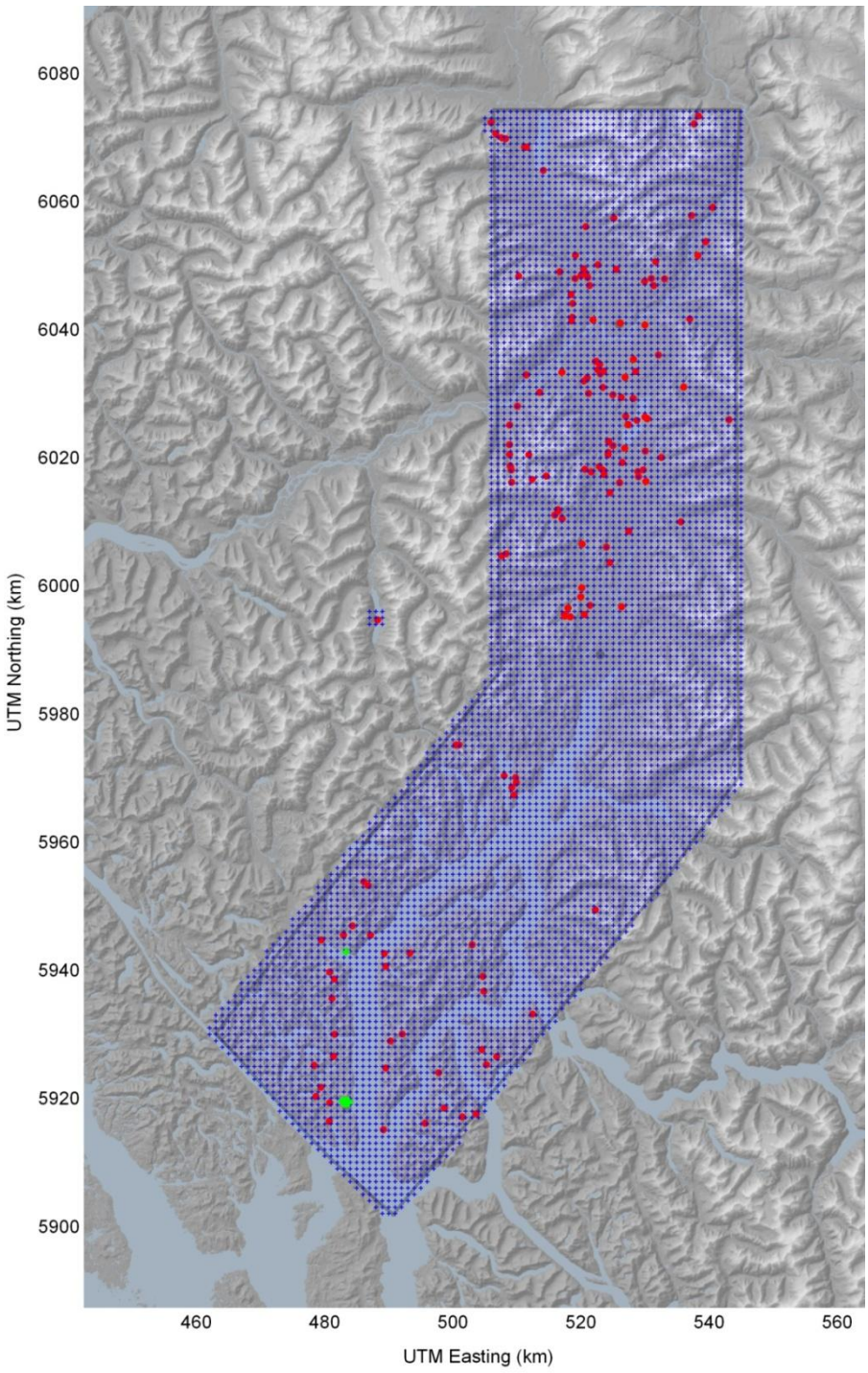


Figure 2-3. All other receptors within study area. All individual receptors (soils, lakes, and points of interest) are marked in red, residential receptors are marked in green, and all grid receptors are marked in blue.[8]

The study area extends to Douglas Channel in the southwest which required additional receptors to be generated over and above those used in the KMP SO_2 assessment, to cover the new extended area. To complete the study within the timeline, but still achieve the resolution needed for the vegetation, water and soil assessments, the coarse grid receptors were set to 1 km by 1 km in non-residential areas, rather

than the 500 metre spacing used for the KMP SO_2 assessment (i.e., this represents a departure from the protocol used for the KMP SO_2 assessment described in Appendix 7.6-1 of Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b)).

Residential and commercial area receptor spacing remains at 100 metres. In addition to Kitimat and Kitamaat Village, there are two more residential areas within the study area: Hartley Bay and Gitga'at Old Town (Laxgal'tsap). A 100 metre grid was added to cover the Hartley Bay residential area. Since the populated area of the Gitga'at Old Town is smaller than 100 meters, only a single receptor was added at the centre of the town to represent the area.

To predict the impacts on the ecosystem and assist with the analysis, additional receptors to represent the centre of lakes and soils of interest were added to this modelling effort. A complete list of individual receptors is provided in Appendix 2. All individual receptors listed in Table 4-7 of the modelling protocol in Appendix 7.6-1, Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b), were included in the modelling analysis.

2.1.3.4 CALPUFF Dispersion Model

The CALPUFF model uses the output file from CALMET together with source, receptor, and chemical reaction information to predict hourly concentrations. We conducted a CALPUFF analysis using data and model settings as described below.

Emissions sources

The modelling analysis included emissions of particulate matter less than 10 microns (µm) in diameter (PM_{10}), particulate matter less than 2.5 µm in diameter ($PM_{2.5}$), SO_2, and nitrogen oxides (NO_X).[8] However, this report focuses on only SO_2 and NO_X. A summary of estimated emissions from each scenario modelled are described in Section 1.3. Locations, parameters, and emission rates for the refinery and LNG sources were provided by MOE based on communications with proponents regarding their preliminary design *estimates* in December 2013. Modelled inputs for the aluminum smelter were consistent with the KMP SO_2 assessment with the exception of minor updates to NO_X and PM emissions provided by Rio Tinto Alcan (RTA). Smelter emissions and parameters for this study also differ from the KMP SO_2 assessment with respect to the SO_2 emissions, PM emissions, and parameters from stacks assumed to be controlled with a seawater scrubber. The seawater scrubber emissions and parameters are based on preliminary estimates by Rio Tinto Alcan based on similar scrubbers at a similar plant. We determined marine transportation emissions and parameters, and these are further described in Section 2.1.3.8 and Section 2.1.5. Appendix 3 provides tabulated inputs for each source's modelling parameters.

2.1.3.5 Control Parameters

We applied the recommended CALPUFF control parameters presented in Table 9.7 of the *Guidelines for Air Quality Dispersion Modelling in British Columbia* (BC Air Quality 2008). The only CALPUFF switch setting for which a required or recommended setting was not provided was the "dispersion coefficients switch setting" (MDISP). The dispersion coefficients switch setting was set to MDISP 2, as recommended for near-field impacts by the *Guidelines for Air Quality Dispersion Modelling in British Columbia* (BC Air

[8] Emissions data were collected and CALPUFF models run for PM_{10} and $PM_{2.5}$, however processing PM_{10} and $PM_{2.5}$ results was not within the scope of this assessment.

Quality 2008).[9] Chemical transformation, wet removal, and dry deposition pollutant removal were modelled, as recommended in the BC air dispersion modelling guidelines. The mass of a pollutant in a given puff decreases as the puff travels through time and space. This decrease in mass is a result of that pollutant being chemically transformed, removed due to wet deposition, or removed due to dry deposition.

In addition to the CALPUFF control parameters presented in Table 9.7 of the BC guidelines, CALPUFF Version 6.42 includes several new control parameters (not included in CALPUFF Version 5.8) that must be specified. These new control parameters and the corresponding values used in this analysis are presented in Table 4-8 of the modelling protocol in Appendix 7.6-1, Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b).

2.1.3.6 Atmospheric Transformation and Transport

This CALPUFF modelling analysis applies the MESOPUFF-II chemical transformation algorithms, where the concentrations of NO_2, SO_2, ammonium sulphate, ammonium nitrate, nitric acid, and PM_{10} may be tracked.[10] There are two user-selected input parameters that affect the MESOPUFF II chemical transformation: ammonia and ozone background concentrations. We applied a constant background ammonia concentration of 0.5 ppb, based on the recommended background for a forested area as described in the modelling protocol in Appendix 7.6-1, Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b). A constant background ozone concentration was also applied, using the CALPUFF default of 80 ppb.

The high ozone concentration of 80 ppb is the recommended CALPUFF default, as a conservative assumption to avoid the situation where limited ozone results in a slower reaction rate of SO_2 to SO_4, or NO_X to NO_3. This assumption results in potentially higher reaction rates and total sulphur deposition rates than would occur when using site-specific ozone data; thus, the assumption is conservative when considering total sulphur deposition rates, but it could be less conservative when considering SO_2 air concentrations. Based on a sensitivity study performed as part of the KMP SO_2 assessment, CALPUFF SO_2 air concentrations are not noticeably affected when a site-specific regional ozone background concentration is used. Specifically, a 0% change in SO_2 concentrations and a 2% to 5% change in SO_4 concentrations were detected between the study results and the original CALPUFF results.

2.1.3.7 Deposition Analysis

Gas-phase dry deposition fluxes were modelled for SO_2, NO_X, and HNO_3. Particulate-phase dry deposition was modelled for SO_4, NO_3, and PM_{10}. Wet deposition was modeled for all pollutants, using the liquid and frozen precipitation scavenging coefficients in the CALPUFF modelling system chemical species library. For dry deposition of gases, the dry deposition resistance model handles land use in multiple equations. The atmospheric resistance equation includes surface roughness based on predominant land use in grid cell (4 km spaced grid cells for regional domain). The canopy resistance equation also considers land use by including the leaf area index in each grid cell. In this way, and by using spatially varying precipitation in CALMET, the CALPUFF model accounts for variations from location to location within the domain when predicting deposition flux, aside from the deposition variation due to

[9] All CALPUFF control settings were also consistent with those applied for the KMP SO_2 Technical Assessment (ESSA et al. 2013a,b), with the exception of the vertical wind shear option (MSHEAR), which was updated to turn the vertical shear function off, to be consistent with the *Guidelines for Air Quality Dispersion Modelling in British Columbia* (BC Air Quality 2008).

[10] Although these other concentrations are tracked, this report focuses only on the results of SO_2 and NO_X modelling.

distribution of modelled concentrations. The sum of wet and dry deposition fluxes for SO_2 and SO_4 represent the total sulphur deposition as follows:

$$Sulfur\ Deposition\ (kg/ha/yr) = \left(flux_{SO2} + flux_{SO4} \right)_{wet} + \left(flux_{SO2} + flux_{SO4} \right)_{dry}$$

Similarly, total nitrogen deposition is the sum of wet and dry deposition fluxes for NO_X and NO_3. Additionally, deposition of nitrates and sulphate was assumed to be in the form of ammonium nitrate (NH_3NO_3) and ammonium sulphate ($(NH_3)_2SO_4$), resulting in a small fraction of additional nitrogen being deposited from these secondary pollutants.

2.1.3.8 QA Procedures

The Quality Assurance (QA) procedures for the CALPUFF processing were performed as specified in Section 10.2.1 of the *Guidelines for Air Quality Dispersion Modelling in British Columbia* (BC Air Quality 2008). Further details regarding the QA procedure are provided in the modelling protocol in Appendix 7.6-1, Volume 3 of the KMP SO_2 Technical Assessment (ESSA et al. 2013b). A QA log documenting checks for each scenario's modelling input and results files can be found in Appendix 4 of this report.

2.1.4 Marine Vessel Emissions Calculation Methodology

Emissions from marine vessels were calculated for travel in Douglas Channel and for activity at the piers for the four LNG facilities, the smelter, and the oil refinery. All marine vessel emissions are determined based on annual production capacities of the facilities. The sections below detail which vessel types were evaluated for each facility. For all facilities, emissions from main engines and auxiliary engines were based on emission factors provide by MOE and Environment Canada (email from Kyle Beauliua, Environment Canada transportation division, December 11, 2013) for the closest related vessel type. Emission factors from projections for 2015 were used as a basis for estimating the 2015 fuel sulphur content to most accurately represent the fuel expected to be in use for these vessels (i.e., by the time the LNG, crude, or petroleum product begins shipping, the marine vessels will be subject to the more stringent fuel sulphur content standards that take effect in 2015). For hoteling boilers,[11] emission factors were taken from US EPA's (2009) *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*. Emissions in Douglas Channel were based on an estimated travel distance of 57 nautical miles to the boundary of the study area. Emissions included in the modelling analysis represent annual average emission rates. Appendix 5 presents the detailed emission calculations.

2.1.4.1 LNG Facilities

For each LNG facility, emissions were calculated for LNG carriers and tugboats. Emissions from each LNG carrier were calculated based on the main engine during travel to and from the pier, during berthing at the pier, and for departure from the pier. Additionally, emissions from a boiler hoteling at the pier plus emissions from auxiliary engines used for loading/unloading LNG were included. Emissions from tugboats were calculated for travel to and from the pier, for berthing at the pier, and for departure from the pier, assuming two tugboats would accompany each LNG carrier.

Emissions were calculated for each LNG facility based on assumed engine operating parameters which were deemed to represent an average LNG carrier of the capacity stated in the *LNG Canada Project* –

[11] Hoteling boilers operate to maintain power and heat functions on marine vessels while they are stationary at dock.

Project Description (Stantec 2013). The number of LNG carriers traveling to each facility annually was calculated based on the production capacity of the facility and the average carrier capacity as stated in (Stantec 2013). Duration of time spent in each operating mode (i.e., travel in channel, berthing, hoteling, and departure) was based on engineering estimates provided by MOE from discussions with proponents and an assumed travel speed of 10 knots.

2.1.4.2 Smelter

For the RTA aluminum smelter, emissions were calculated for cargo vessels and tugboats. Emissions from each cargo vessel were calculated based on the main engine and auxiliary engines during travel to and from the pier, during berthing at the pier, and for departure from the pier. Additionally, emissions from a boiler hoteling at the pier were included. Emissions from tugboats were calculated for travel to and from the pier, for berthing at the pier, and for departure from the pier, assuming two tugboats would accompany each cargo vessel.

Characteristics of the main engine and auxiliary engines for the cargo vessels were estimated based on information in *Current Methodologies in Preparing Mobile Source Port-Related Emissions Inventories* (US EPA 2009). The number of vessels traveling to RTA each year was determined based on the annual production capacity and vessel capacity from data provided by MOE from communications with RTA for aluminum export, alumina import, petcoke, and liquid pitch. Duration of time spent in each operating mode was based on data provided by MOE from communications with RTA and an assumed travel speed of 12 knots.

2.1.4.3 Oil Refinery

For the Kitimat Clean Refinery, emissions were calculated from three different types of tankers and tugboats. Emissions from VLCC, Suezmax, and Aframax tankers were calculated based on the main engine during travel to and from the pier and for manoeuvring at the pier. Additionally, emissions from auxiliary engines were calculated for travel to and from the pier, for manoeuvring at the pier, and for hoteling at the pier. Emissions from tugboats were calculated based on a main engine and auxiliary engines for travel to and from the pier and for manoeuvring at the pier, based on three tugboats accompanying each tanker as stated in the *Enbridge 2010 Technical Data Report* (Jacques Whitford Axys Ltd. 2010).

Engine parameters, number of tankers, and time spent at the pier were based on information in the Enbridge report. Duration of travel to the pier was based on an assumed travel speed of 12 knots.

2.1.5 Marine Vessel Stack Parameters

Marine vessel emissions were included in the modelling analysis at each pier and along Douglas Channel.

2.1.5.1 Vessels at the Pier

One stack for each facility located at the facility's pier was included in the modelling analysis to represent emissions during berthing, hoteling and departure from the pier. Marine vessel emissions from the sources outlined above were combined and modelled as a single emission point.

For the LNG facilities, stack parameters were based on values presented in the *Enbridge 2010 Technical Data Report* (Jacques Whitford Axys Ltd. 2010). All four LNG facilities were assumed to use similar carriers and therefore the same stack parameters were used for each.

For the Kitimat Clean Refinery, stack parameters were based on data from the Enbridge report. Stack parameters for the Suezmax tanker were used in the modelling analysis. These stack parameters represent the middle-range of the three types of tankers used for the refinery and Suezmax tankers account for more than half of the total tankers calling at the pier.

No stack parameter information was readily available for RTA marine vessels, and RTA marine emissions are a fraction of those from the LNG and refinery ports. As such, the stack parameters for the cargo vessels were assumed to be the same as those for the tankers traveling to the Kitimat Clean Refinery.

2.1.5.2 Travel in Douglas Channel

Emissions from all marine vessels traveling in Douglas Channel were included in the modelling analysis as a series of 27 point sources. These sources were spaced two nautical miles apart due to travel constraints on the channel. Average annual emissions from all LNG carriers, cargo vessels, tankers and tugboats during travel to and from the piers were added together and divided evenly along the 27 sources.

The stack parameters used for all emissions sources in Douglas Channel were the same as those used for the LNG carriers modelled at the piers. LNG carriers account for the majority of vessels traveling on the pier. Additionally, the exhaust flow rate of the LNG carriers is significantly lower than that of the tankers, which results in less favourable dispersion from decreased velocity-driven plume rise. Therefore, using the LNG carrier stack parameters for all marine vessels traveling in Douglas Channel was deemed to be representative and conservative.

One of the 27 marine emissions sources was specifically placed directly near Hartley Bay and another directly near Gitga'at Old Town. This placement of marine vessel sources ensures that the modelled location of Douglas Channel marine vessels appropriately represents the maximum impacts possible to these two areas of concern.

2.2 Results

This section presents modelling results for SO_2 and NO_2 concentrations, and for sulphur (as sulphate) and nitrogen deposition for the two bookend scenarios: Scenario A_28.2 (lowest emissions) and Scenario H_82.6 (highest emissions). Each scenario is described in Section 1.3. Modelling results for the intermediate scenarios are provided in Appendix 6.

2.2.1 Modelling Background Concentrations based on Monitoring Data

For comparison of maximum air concentrations to established thresholds, standard procedure (and that applied for the KMP SO_2 Technical Assessment (ESSA et al. 2013a,b)) is to add a modelling background concentration to modelled air concentrations to predict the total maximum air concentrations after the new/modified sources begin operation (i.e., total air concentrations = modelled concentrations due to new and existing emissions sources plus modelling background concentration from non-modelled emissions).

The 1-hour NO_2 concentration results presented in this report apply a modelling background concentration of 30.6 ppb (57.53 µg/m^3). The SO_2 modelling background concentration applied for the 1-hour averaging period is 1.5 ppb (3.92 µg/m^3). The modelling background concentration for SO_2 is

determined based on the Kitamaat Village monitoring station, and all SO_2 modelling background concentrations are consistent with those applied for the KMP SO_2 Technical Assessment (ESSA et al. 2013a,b).

The modelling background concentration for NO_2 is determined based on the Quesnel monitoring station. The form of the modelling background added for NO_2 is consistent with the KMP SO_2 assessment (for the 1-hour averaging period, based on 98th percentile, averaged over 3 years). However, unlike for SO_2, for NO_2, the modelling background is intended to represent the regional sources of NO_X that are not included as model input, such as NO_2 concentrations from commercial, industrial, and personal vehicle and train traffic that may increase as an indirect effect of the proposed industrial activity. For SO_2, the vast majority of emissions come from industrial sources included in this assessment. As such, the selected NO_2 modelling background is considerably greater than the SO_2 modelling background.

The NO_2 modelling background value is based on one of the closest NO_2 monitors with a population similar to that projected for Kitimat - namely Quesnel, which had a 2011 population of 13,566. Kitimat's population has been projected to reach about 15,000 by 2021 and 17,000 by 2031 if all projects move forward (includes oil refinery; unclear how many LNG facilities included).[12] Squamish was also considered (2011 population 15,501) as well as several other locations with NO_2 monitors, but Quesnel appears to best represent a similar population with a transportation corridor. We reviewed population, proximity, similarity in geography, and annual average NO_2 at BC NO_2 monitoring stations. All non-metropolitan locations were included in the review. Quesnel was determined to be the most representative based on all three categories (population, proximity, and geography). Additionally, NO_2 concentrations at Quesnel are higher than most others reviewed (e.g., Squamish, Williams Lake, Gibsons), so provide a more conservative basis for analysis.

Over the period 2011 to 2013, Quesnel's 98th percentile 1-hour monitored NO_2 concentration was 26.1-34.2 ppb, compared to 15-18 ppb for Squamish, 14 ppb for Gibsons, and 37 ppb for Prince George. Additionally, hourly NO_2 data were collected at a temporary monitoring site at Kitimat City Centre using MOE's mobile monitoring unit from 13 Sept 2010 to 21 Nov 2011. Reported values ranged from 0 to 34.3 ppb, with an average of 2.3 ppb and median of 1.6 ppb. The overall 98th percentile concentration was 9.4 ppb (~18 $\mu g/m^3$). Compared to the Kitimat City Centre monitoring data and the other stations evaluated, the Quesnel modelling background of 30.6 ppb (or 57.5 $\mu g/m^3$) used in this analysis, provides a measure of conservatism. By applying the highest NO_2 modelling background concentration from areas with populations similar to Kitimat's projected population, this indirect increase in NO_2 concentrations due to road and rail traffic is expected to be conservatively captured within the background concentration adjustment.

A constant modelling background value is applied to all locations. While applying the same background concentration for all locations is the most common approach used in modelling analyses, the approach could result in overly-conservative predictions of NO_2 in more remote, low traffic areas such as Kitamaat Village and Hartley Bay. This conservatism applies primarily for NO_2 rather than SO_2, because the NO_2 modelling background is intended to also capture background concentrations from non-modelled regional sources (e.g., rail and road transportation emissions). One option to provide more accurate (less conservative) total predicted NO_2 concentrations would be to apply spatially varying modelling background NO_2 concentrations based on a land use regression model.

[12] http://www.kitimatdaily.ca/go6664a/KITIMAT_TO_GROW_OR_STAY_THE_SAME__OR_DWINDLE

2.2.1.1 NO_2 / NO_X Ratio

Approximately 90% of NO_X emissions from typical combustion sources are in the form of NO in the exhaust exiting the smoke stack. However, most of this NO converts to NO_2 in the atmosphere within a relatively short time and distance. This study applies an ambient NO_2/NO_X ratio of 80% for the 1-hour averaging period.[13] In other words, this assessment assumes 80% of predicted 1-hour concentrations of NO_X are in the form of NO_2 by the time the plume reaches ground level. This assumption is sometimes considered overly conservative for concentrations near the emissions source, but for most locations, the ratio appropriately represents the highest expected NO_2 percentage, accounting for the daily and annual variation in NO_2/NO_X ambient equilibrium. For the annual averaging period, the maximum NO_X concentration is scaled to assume 75% of NO_X is in the form of NO_2 based on US EPA's national default value.[14] For the Kitimat, Service Centre, and possibly Kitamaat Village human health area, the 80% and 75% equilibrium ratios are most likely overly conservative, based on the proximity of these regions to NO_X emission sources.

2.2.2 Modelled NO_2 Concentrations

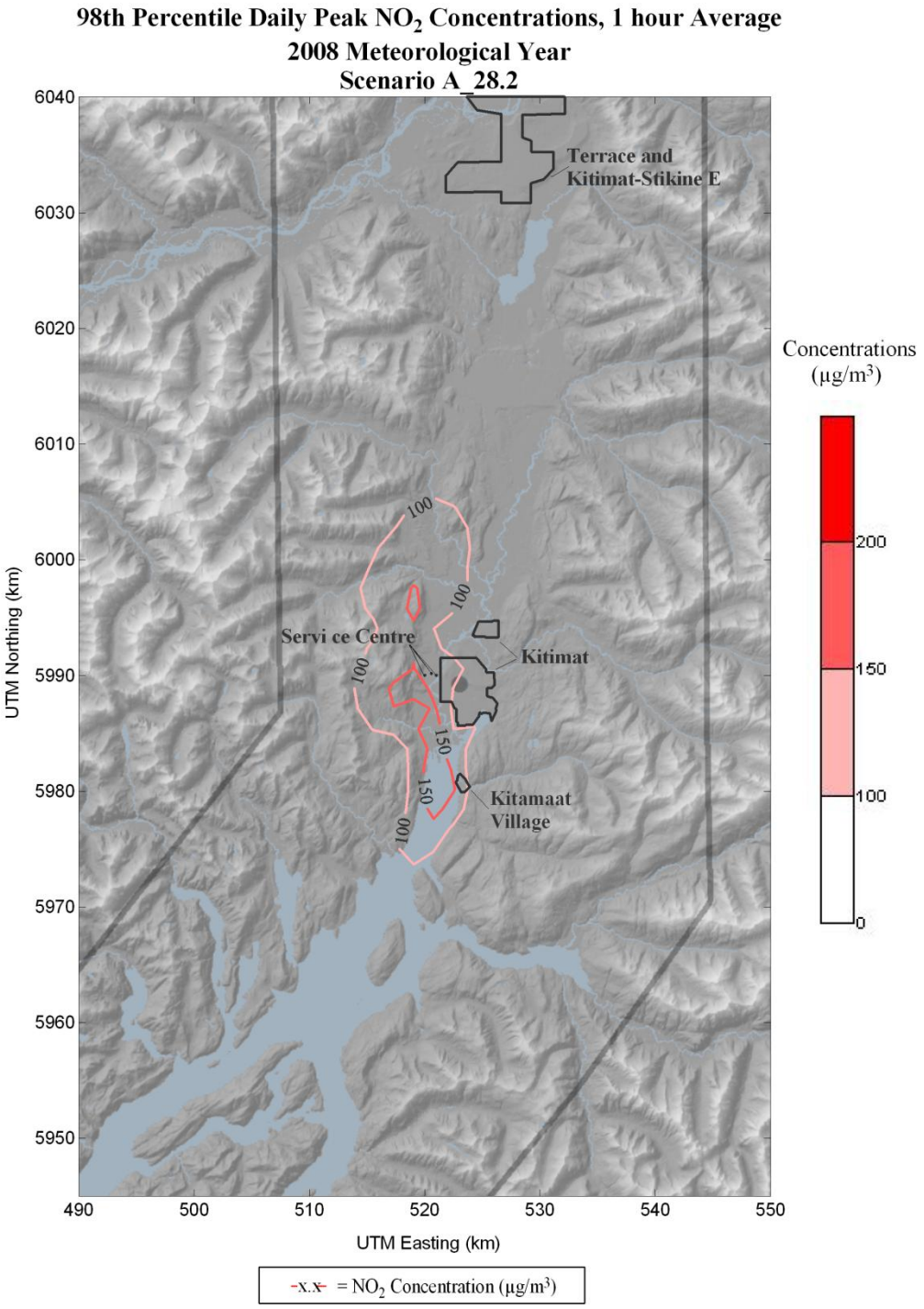
Figure 2-4 and Figure 2-5 show the 98th percentile of the daily peak 1-hour NO_2 concentrations (8th highest daily peak at each location) for Scenario A_28.2 and Scenario H_82.6, respectively. The 98th percentile NO_2 concentration for the 1-hour averaging period has been identified by Risk Sciences International Inc. (the authors of Section 3) as a primary focus for human health review. Between Scenario A_28.2 and Scenario H_82.6, there is an increase in the maximum NO_2 value as well as an increase in the area encompassed within the lowest concentration contour (100 µg/m^3).

As presented in the figures in Appendix 6, the NO_2 concentration results do not vary substantially among scenarios, but they do show some small differences as summarized in the following list.

- Comparing the two lower NO_X emission scenarios – the all-electric LNG design under Scenario A_28.2 versus the NO_X treatment design under Scenario B_51.8 – showed an almost indiscernibly small increase in NO_2 concentrations for Scenario B_51.8 derived exclusively from the LNG sources. The small magnitude of the change in NO_2 concentrations between the two scenarios was due to an effective treatment regime resulting in a small change in NO_X emission rates between the two scenarios (1.3 tpd).[15]
- Comparing Scenario B_51.8 (the NO_X treatment design) and Scenario C_57.5 (the mixed 60/40 grid) shows a small increase in the NO_2 concentrations for Scenario C_57.5. This increase in concentrations is expected due to the higher NO_X emission under Scenario C_57.5 (19.4 tpd versus 13.2 tpd). The LNG facilities are the only contributor to the NO_2 increase (6.3 tpd) between these scenarios. The increase in modelled concentrations is slightly greater between B_51.8 and C_57.5 than between A_28.2 and B_51.8.
- Scenario D_61.8 for the base case LNG facility emissions shows a small increase in concentrations to the south of the port near the LNG facilities compared to Scenario C_57.5 (60/40 grid LNG facility emissions).

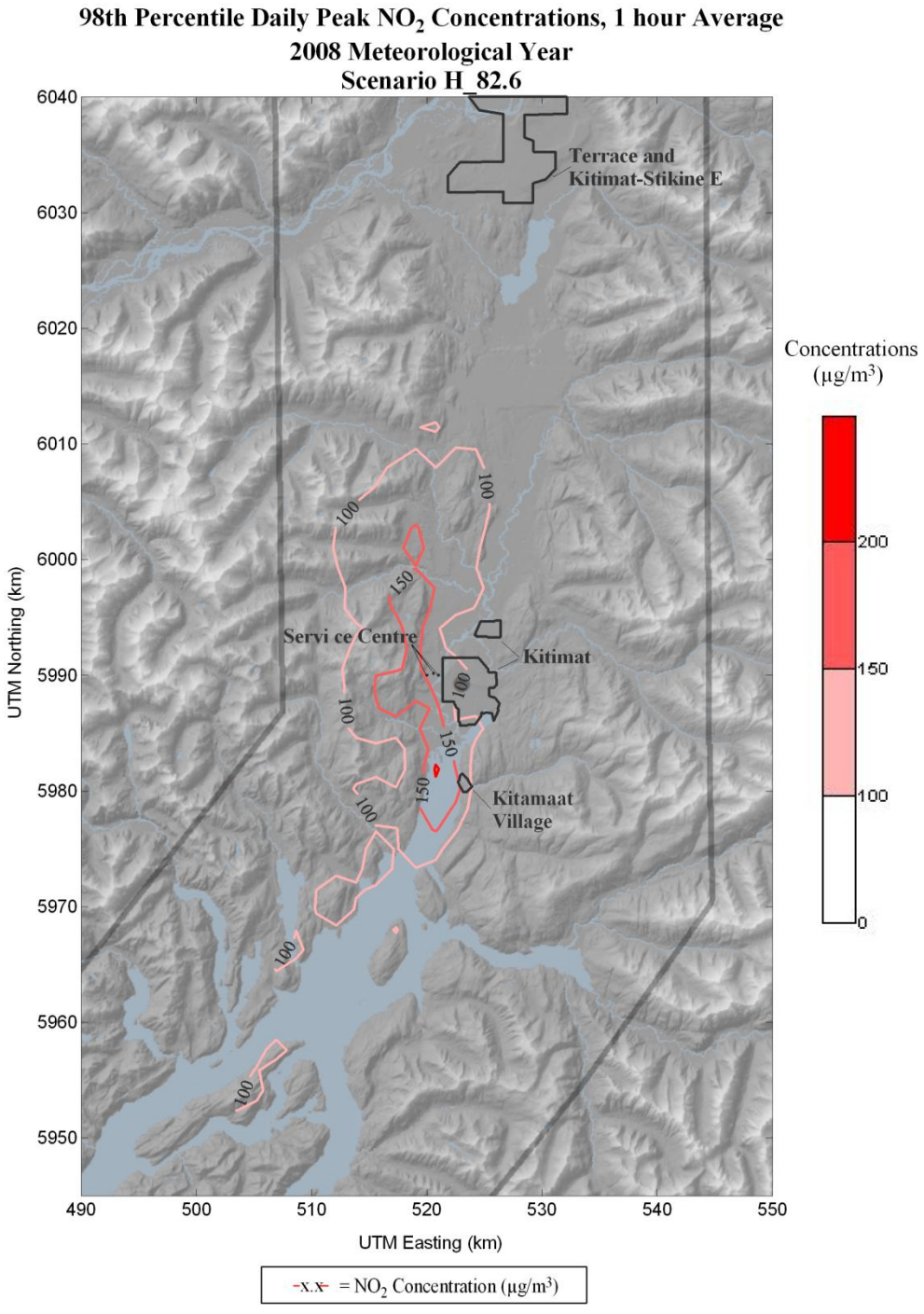
[13] Per US EPA guidance (March 1, 2011 memorandum from Tyler Fox), an ambient NO_2/NO_X ratio of 80% can be assumed as the default value for the 1-hour averaging period.
[14] US EPA's prescribed method for modelling NO_X emissions can be found in Section 6.2.3 of the *Guideline on Air Quality Models* (GAQM). The GAQM is codified as Appendix W to 40 CFR Part 51.
[15] While RTA has a different design between Scenario A_28.2 and Scenario B_51.8, this difference does not affect NO_X emissions.

- While separate plots are shown for each scenario, for all practical purposes for NO_2, Scenario E_66.1 is identical to B_51.8, and Scenario G_76.2 is identical to D_61.8.
- Scenario F_72.6 includes the refinery and NO_X treatment for LNG. As such, the NO_2 concentration profile is similar to the profile for Scenario H_82.6 along the shipping channel (though with lower overall concentrations than Scenario H_82.6 due to the lower LNG facility NO_X emissions), and similar to the profile for Scenario B_51.8 near the LNG facilities.
- Comparing the two higher NO_X emission scenarios – the base case under Scenario H_82.6 versus the base case without the refinery under Scenario G_76.2 – isolates the effects of the addition of the refinery. The increase in NO_2 concentrations under Scenario H_82.6 is noticeable along the channel due to increased shipping (the same would be seen for a crude export terminal); however, the small increase in NO_2 concentrations from the well-controlled refinery NO_X emissions (1.14 tpd) is almost indiscernible for annual average concentrations and results in only a small change for 1 hour average concentrations.



* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m³.

Figure 2-4. Scenario A_28.2, 98th percentile NO_2 concentrations, 1-hour average.



* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m³.

Figure 2-5. Scenario H_82.6, 98th percentile NO_2 concentration, 1-hour average.

2.2.3 Modelled SO_2 Concentrations

Figure 2-6 and Figure 2-7 show the 99th percentile daily peak 1-hour SO_2 concentration (4th highest daily peak at each location) for Scenario A_28.2 and Scenario H_82.6, respectively. The 99th percentile SO_2 concentration for the 1-hour averaging period has been identified by Risk Sciences International Inc. (the authors of Section 3) as a primary focus for human health review. The SO_2 concentrations and distribution are different than for NO_2, both because the exhaust emission composition is different (level of NO_X compared to level of SO_2 in a given stack and level of NO_X versus level of SO_2 at each facility), but also because the majority of SO_2 emissions are from a small number of larger, hotter stacks versus several smaller stacks emitting NO_X. Between Scenario A_28.2 and Scenario H_82.6, there is an increase in the maximum SO_2 value as well as an increase in the extent of modelled concentrations.

As presented in the figures in Appendix 6, the SO_2 concentration results show changes as summarized in the following list.

- Comparing the two lower SO_2 emission scenarios – full SO_2 treatment for RTA under Scenario A_28.2 versus partial SO_2 treatment for RTA under Scenario B_51.8 – a clear increase in SO_2 concentrations is apparent under the partial treatment scenario. Scenario B_51.8 also includes SO_2 emissions from LNG combustion sources; however, the SO_2 levels from combustion at LNG facilities are insignificant compared to the SO_2 change realized by treating two Gas Treatment Centre stacks and the Calciner Pyroscrubber stack at the aluminum smelter (full treatment) versus treating one Gas Treatment Centre stack (partial treatment).
- While separate plots are shown for each scenario, for all practical purposes for SO_2, Scenario C_57.5 and Scenario D_61.8 are essentially identical to Scenario B_51.8, and Scenario E_66.1, Scenario F_72.6, and Scenario G_76.2 are essentially identical to Scenario H_82.6.[16]
- Comparing Scenario E_66.1, Scenario F_72.6, Scenario G_76.2, and Scenario H_82.6 (no SO_2 treatment) to Scenario B_51.8, Scenario C_57.5, and Scenario D_61.8 (partial SO_2 treatment) shows clearly higher SO_2 ambient concentrations associated with no treatment at KMP (base case).

[16] Note that there are some small SO_2 changes between Scenario G_76.1 and Scenario H_82.6 due to the addition of the refinery, but the difference is small (2.9 tpd, compared to a total of 55.8 tpd). Additionally, Scenario C_57.5 has slightly lower SO_2 emissions than Scenario B_51.8 and Scenario D_61.8 due to less power combustion at the LNG facilities, but this difference is even smaller (0.5 tpd).

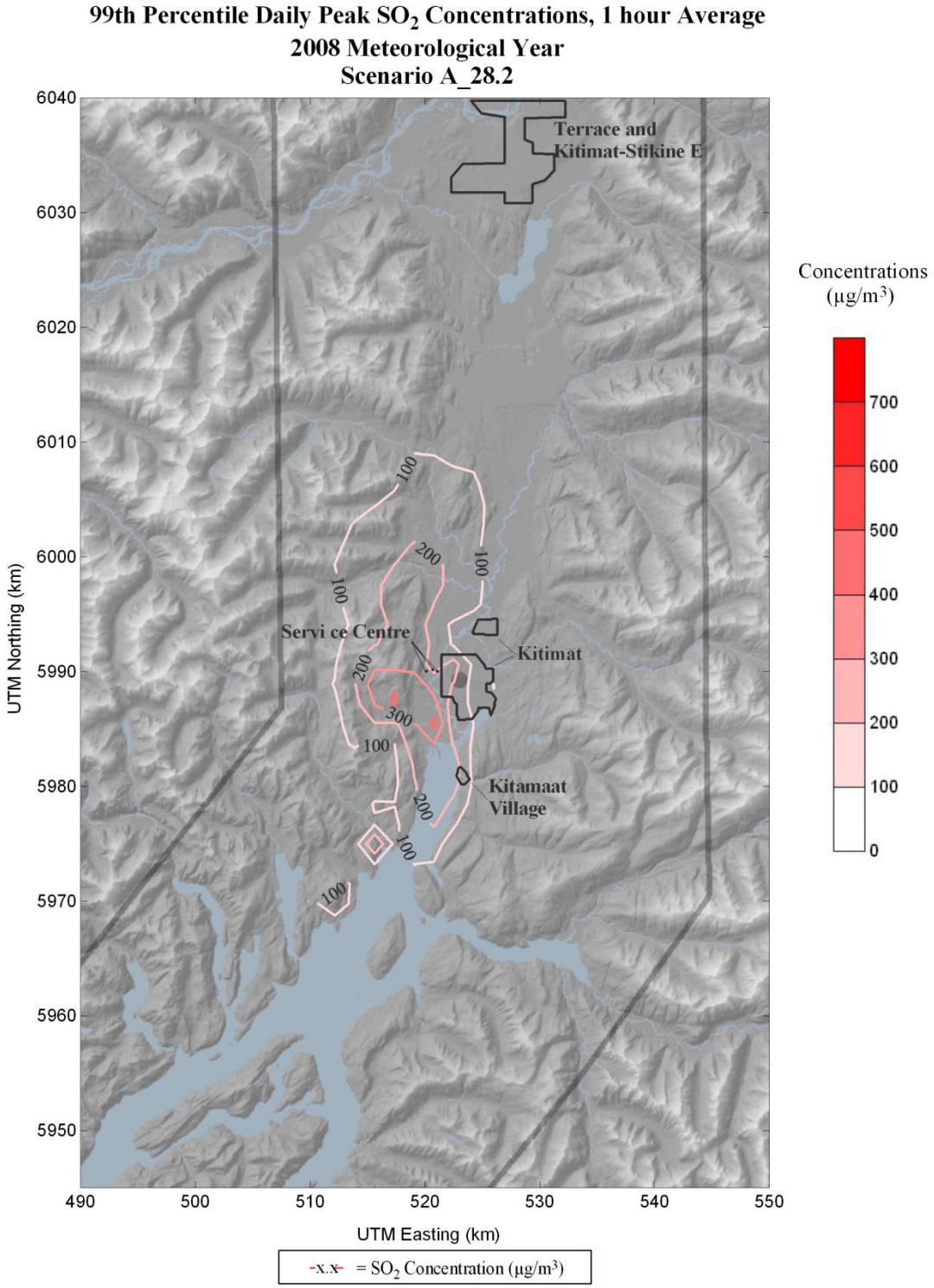


Figure 2-6. Scenario A_28.2, 99th percentile SO_2 concentration, 1-hour average.

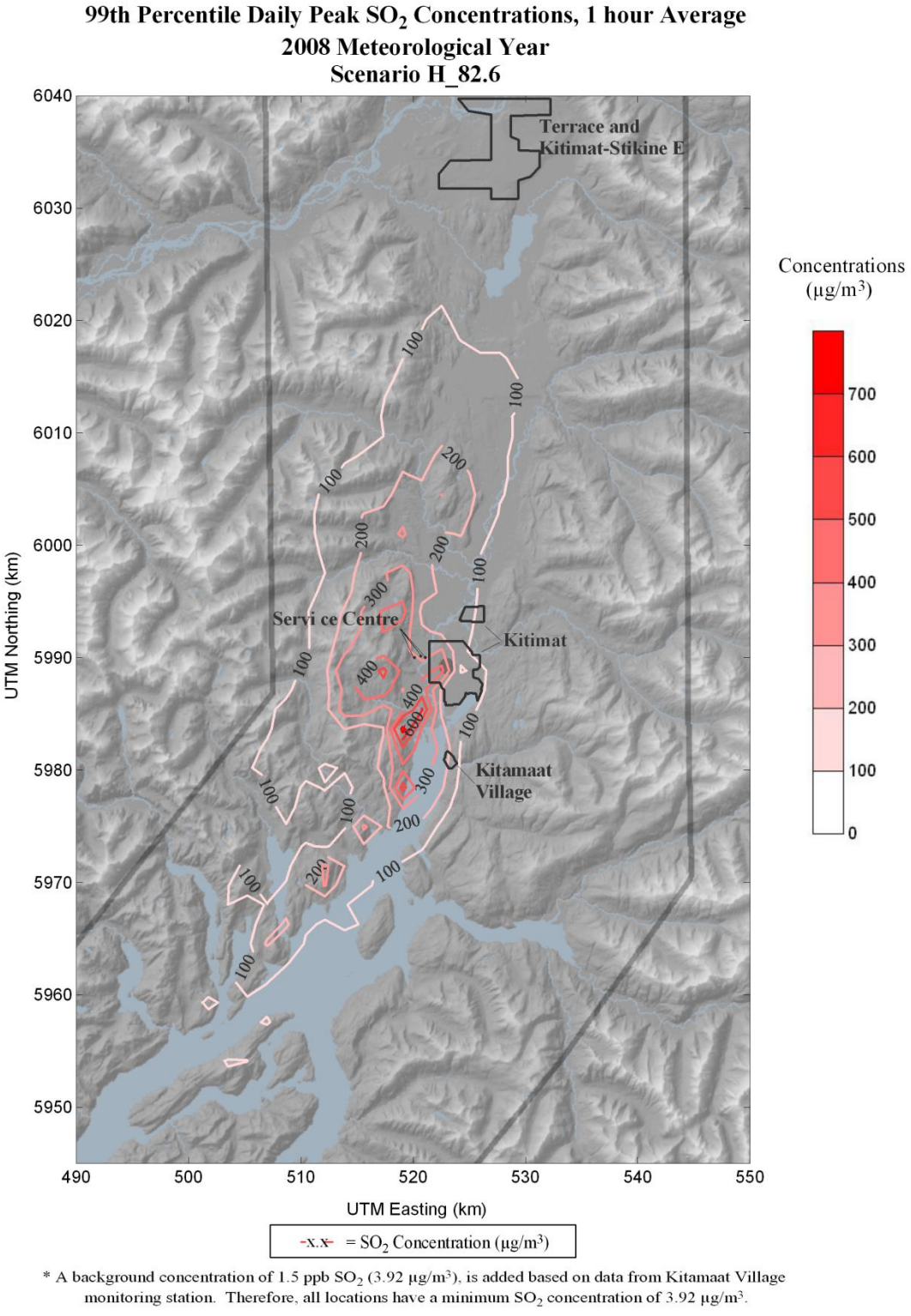


Figure 2-7. Scenario H_82.6, 99th percentile SO_2 concentrations, 1-hour average.

2.2.4 Modelled Nitrogen Deposition

Figure 2-8 shows the annual average nitrogen deposition for Scenario A_28.2.[17] There is no background deposition applied to these data. Figure 2-9 shows annual average nitrogen deposition for Scenario H_82.6. Between Scenario A_28.2 and Scenario H_82.6 there is an increase in the maximum value as well as an increase in the extent of deposition. As presented in the figures in Appendix 6, the trends from scenario to scenario for nitrogen deposition are consistent with the changes observed for NO_2 concentrations.

As expected, the nitrogen deposition distribution is similar to the annual NO_2 concentration distribution. In fact, while orographic effects due to higher precipitation and land use factors often result in higher deposition in steep terrain, by far, the dominating factor in this study is the distribution of air concentrations.

[17] Note that while it is common practice to apply background concentrations to air concentration results, it is not common to apply background concentrations to deposition results. Therefore, no background nitrogen deposition is applied.

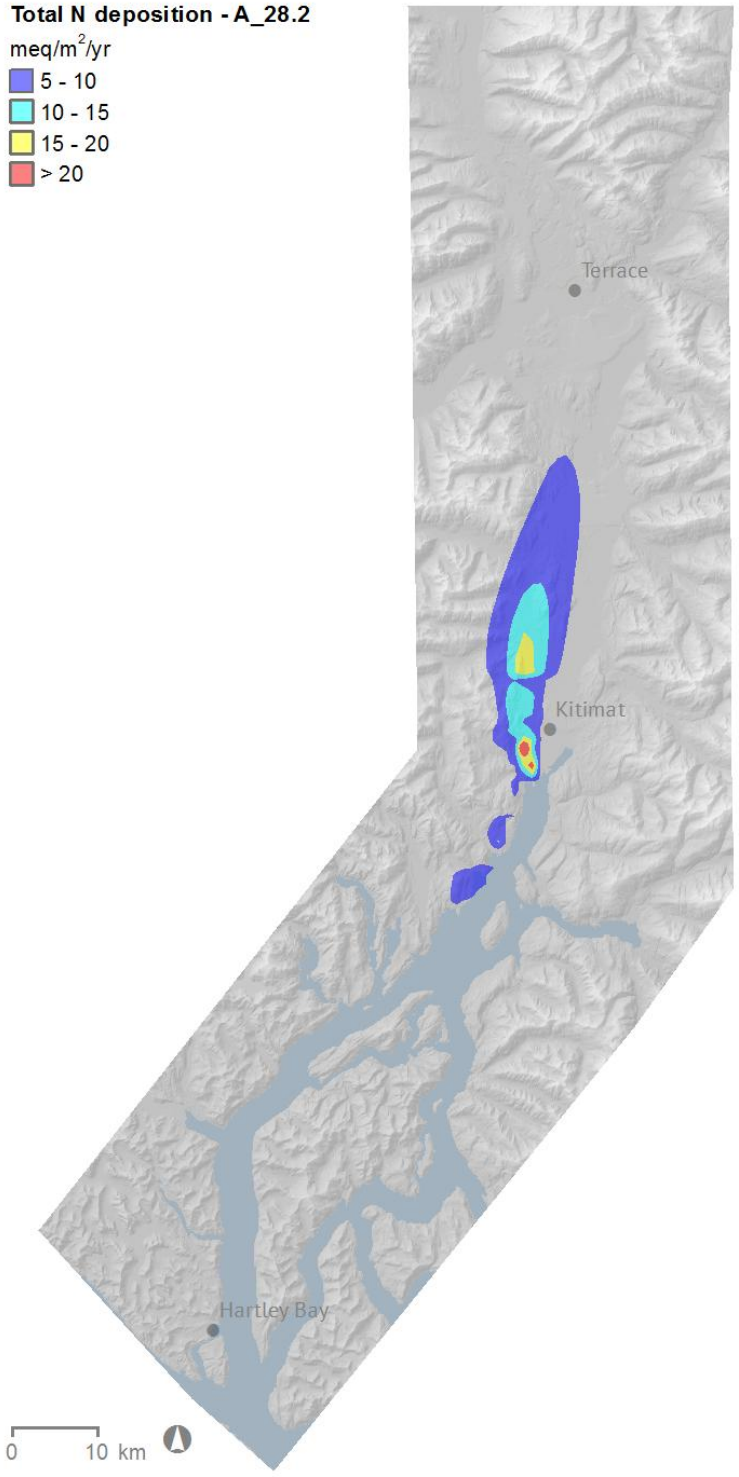


Figure 2-8. Scenario A_28.2 total nitrogen deposition, annual averaging period. This map shows incremental deposition associated with this emission scenario *without* background deposition; however background levels of S and N deposition *are* considered in the analyses of exceedance for soils and lakes.

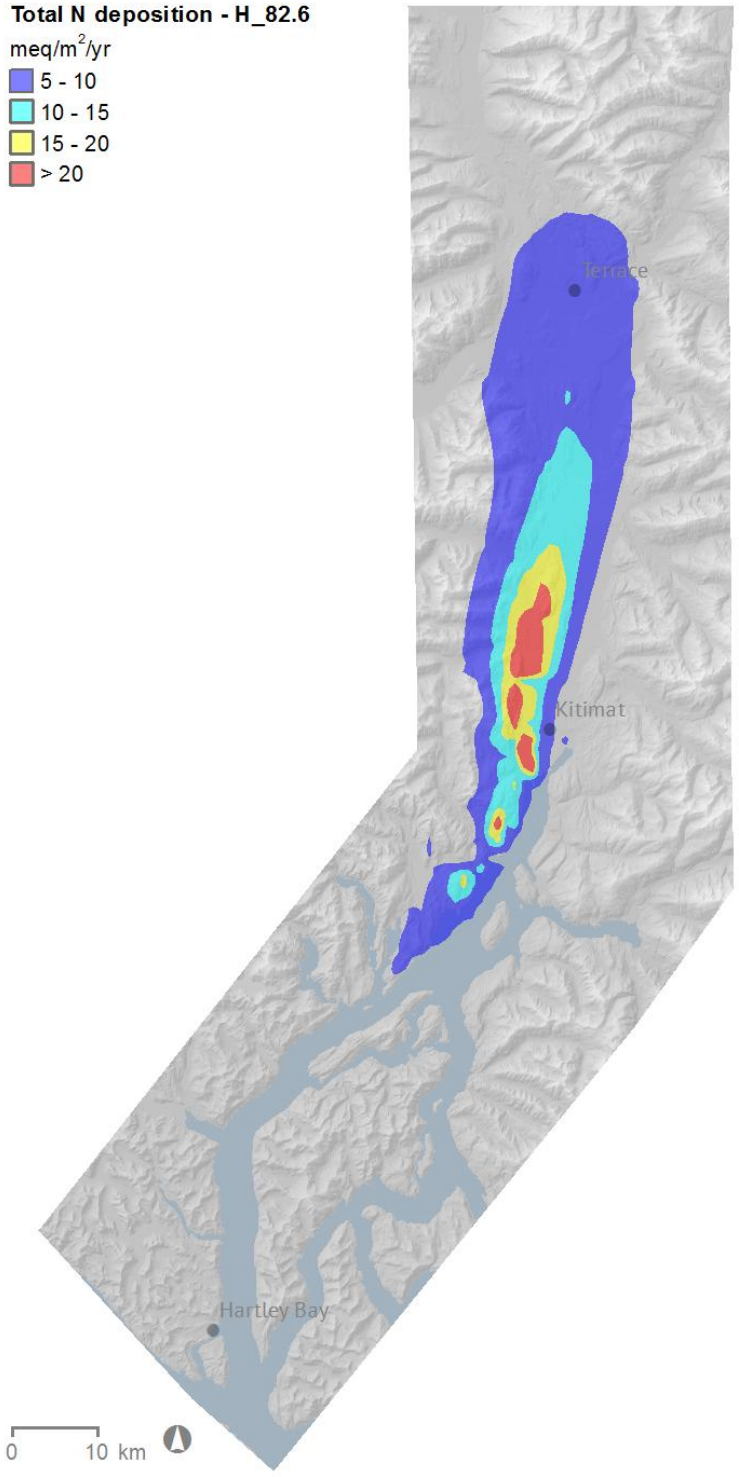


Figure 2-9. Scenario H_82.6, total nitrogen deposition, annual averaging period. This map shows incremental deposition associated with this emission scenario *without* background deposition; however background levels of S and N deposition *are* considered in the analyses of exceedance for soils and lakes.

2.2.5 Modelled Sulphur Deposition

Figure 2-10 shows the annual average sulphur deposition for Scenario A_28.2.[13] There is no background deposition applied to these data. Figure 2-11 shows annual average sulphur deposition for Scenario H_82.6. Between Scenario A_28.2 and Scenario H_82.6 there is an increase in the maximum value as well as an increase in the extent of deposition. As presented in the figures in Appendix 6, the trends from scenario to scenario for sulphur deposition are consistent with the changes observed for SO_2 concentrations.

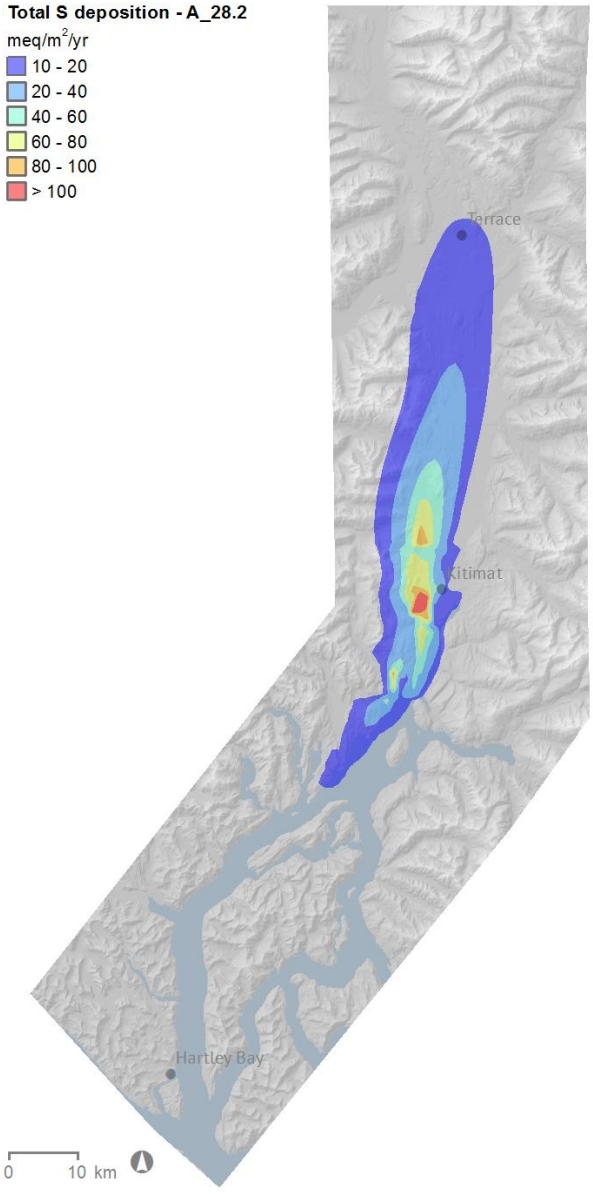


Figure 2-10. Scenario A_28.2, total sulphur deposition, annual averaging period. This map shows incremental deposition associated with this emission scenario *without* background deposition; however background levels of S and N deposition *are* considered in the analyses of exceedance for soils and lakes.

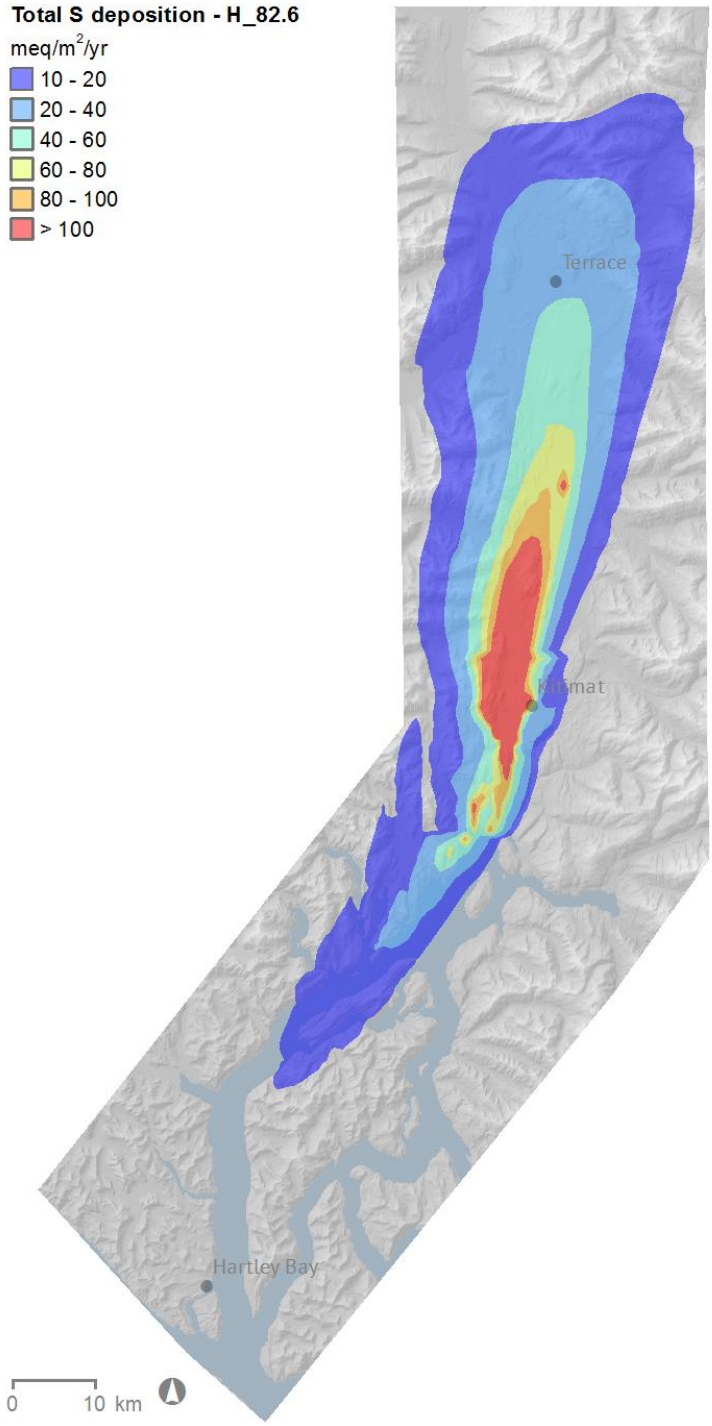


Figure 2-11. Scenario H_82.6, total sulphur deposition, annual averaging period. This map shows incremental deposition associated with this emission scenario *without* background deposition; however background levels of S and N deposition *are* considered in the analyses of exceedance for soils and lakes.

2.2.6 BC Hydro Siting Results

As described in Section 2.1.1, the modelling results for the BC Hydro siting assessment are compared between two possible locations: Skeena Substation and Minette Substation. Figure 2-12 and Figure 2-13 compare the BC Hydro 98th percentile NO_2 concentration for the 1-hour averaging period by themselves to assess the meteorological and terrain advantages and disadvantages of each location. As indicated by the figures, the Skeena Substation location appears to provide an advantage due to lack of nearby terrain effects (plumes impinging on hillsides), in addition to the more obvious advantage of greater distance from compounding effects from existing and proposed industrial sources in Kitimat. The increase in concentrations due to the BC Hydro facility Skeena Substation location within the Terrace residential areas is small, below the US EPA significance level of 7.52 µg/m^3. Likewise, the increase of NO_2 concentrations due to the BC Hydro facility Minette Substation location is also small, below the US EPA significance level in the Kitimat residential areas.

Figure 2-14 and Figure 2-15 present the 98th percentile NO_2 concentration for the 1-hour averaging period for the BC Hydro SCR model results added to Scenario H_82.6 for each location, i.e., for Scenarios Is_83.3 and Im_83.3. SO_2 concentration plots are not presented for Scenarios Is_83.3 and Im_83.3 in this section, because the SO_2 emissions from the BC Hydro electric generation facility are minimal; however, SO_2 concentration plots are presented in Appendix 6. The resulting changes to the total NO_2 concentrations are indiscernible for the Skeena Substation location, and show a small increase for the Minette Substation location to the north of Kitimat. As presented in Appendix 6, results for all other averaging periods also show minimal or negligible differences between H_82.6 and Scenario Im_83.3 or Scenario Is_83.3.

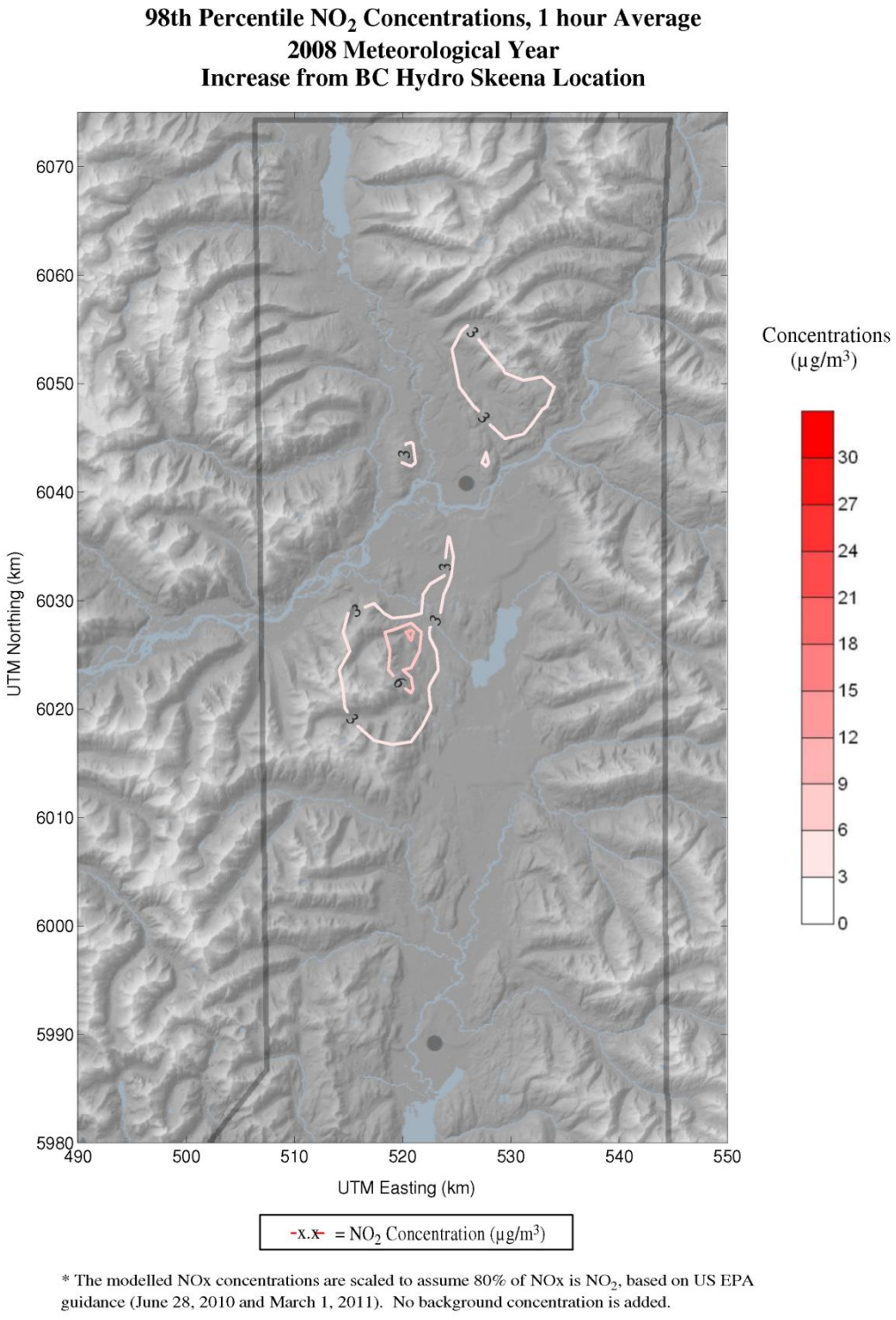


Figure 2-12. BC Hydro Skeena location, 98th percentile NO_2 concentrations, 1-hour average.

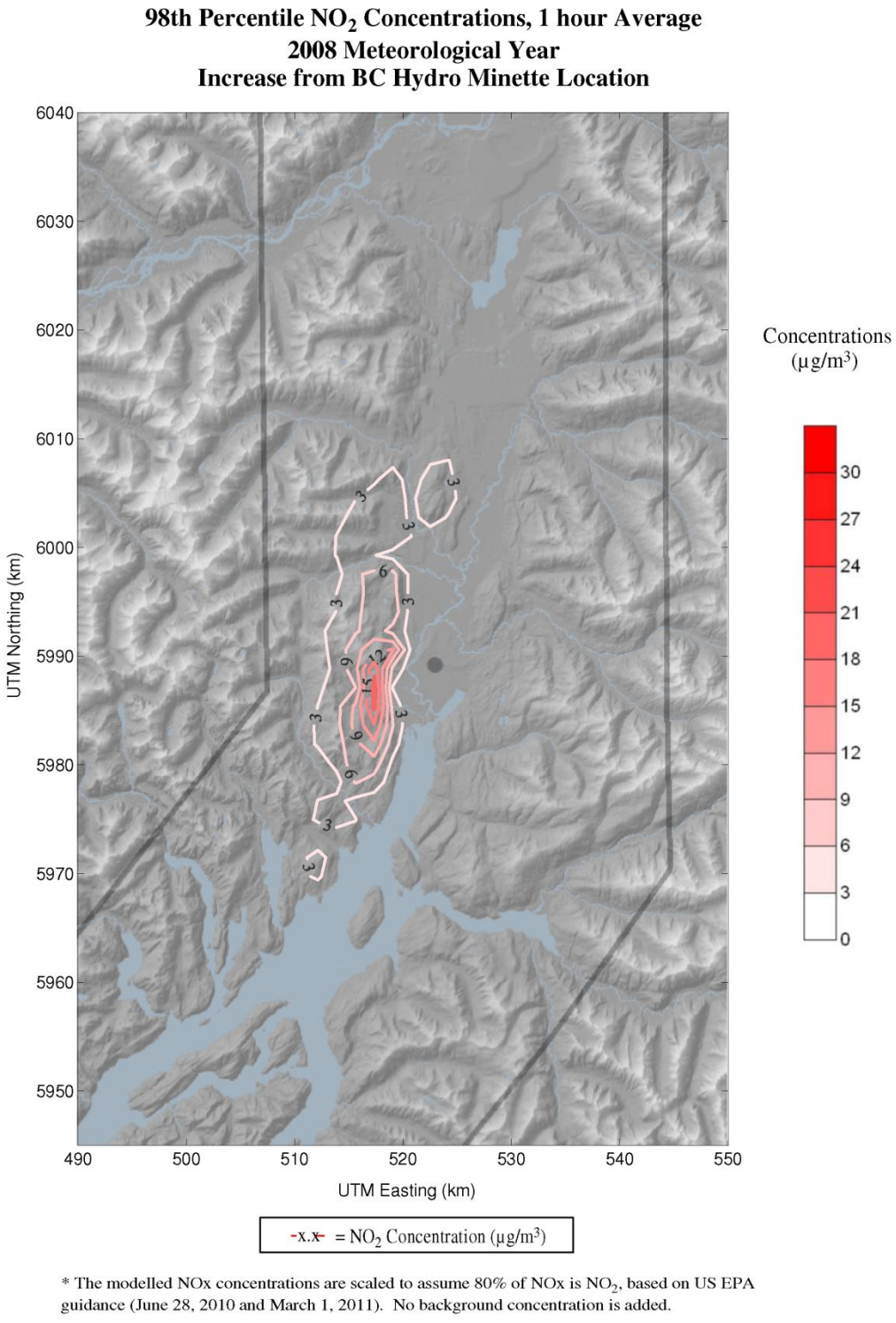
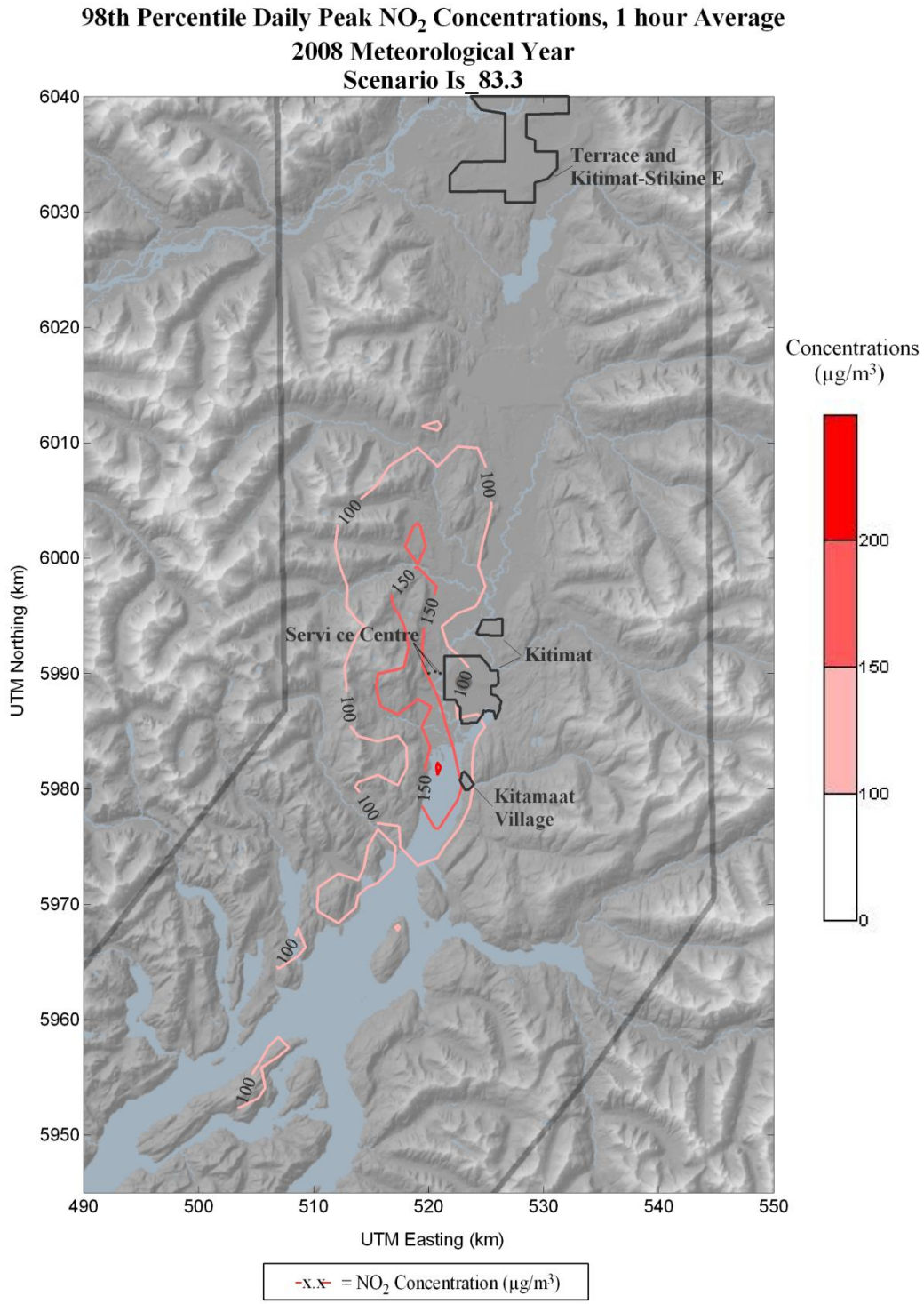
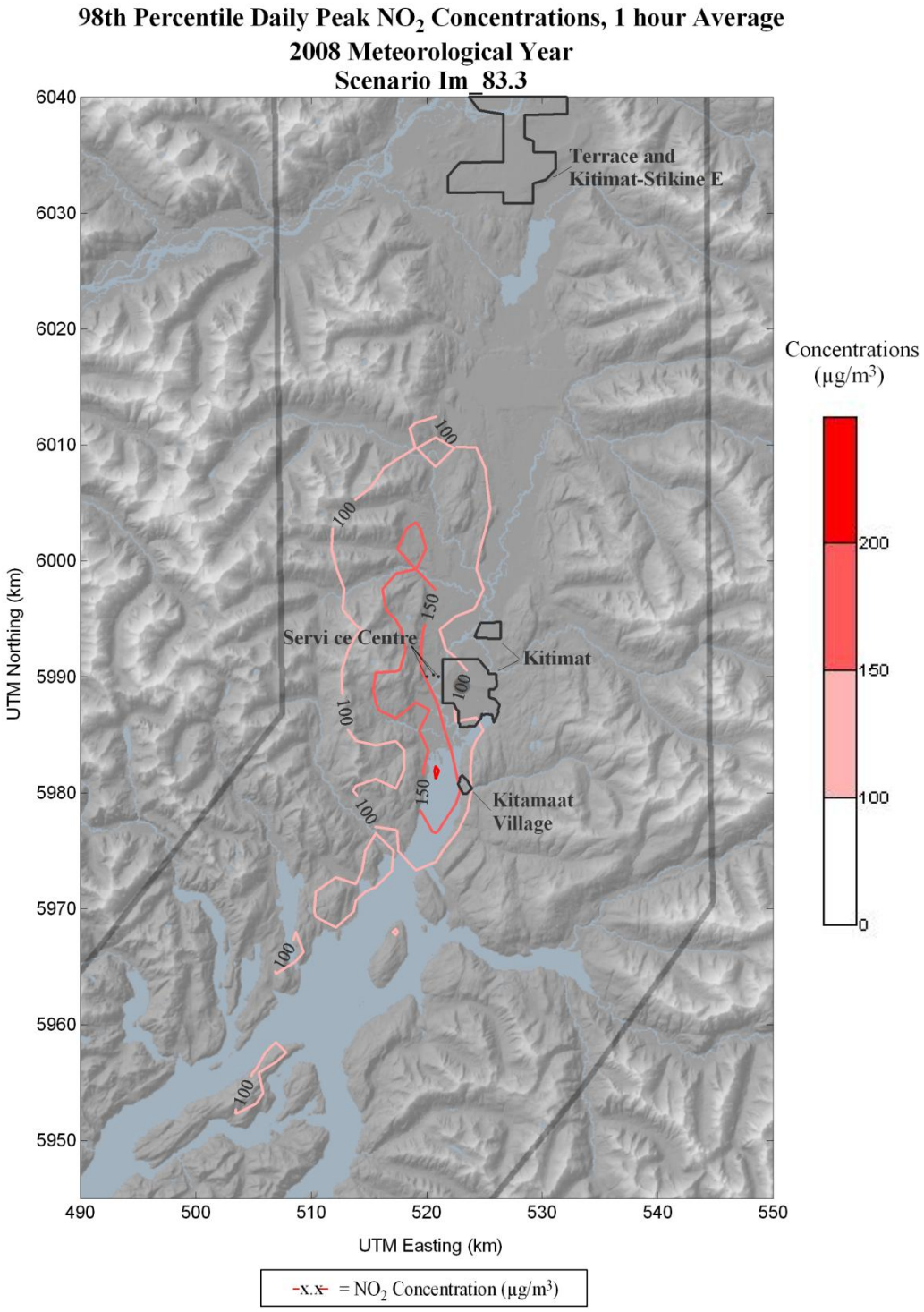


Figure 2-13. BC Hydro Minette location, 98th percentile NO_2 concentrations, 1-hour average.



* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m^3), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m^3.

Figure 2-14. Scenario Is_83.3, 98th percentile NO_2 concentrations, 1-hour average.

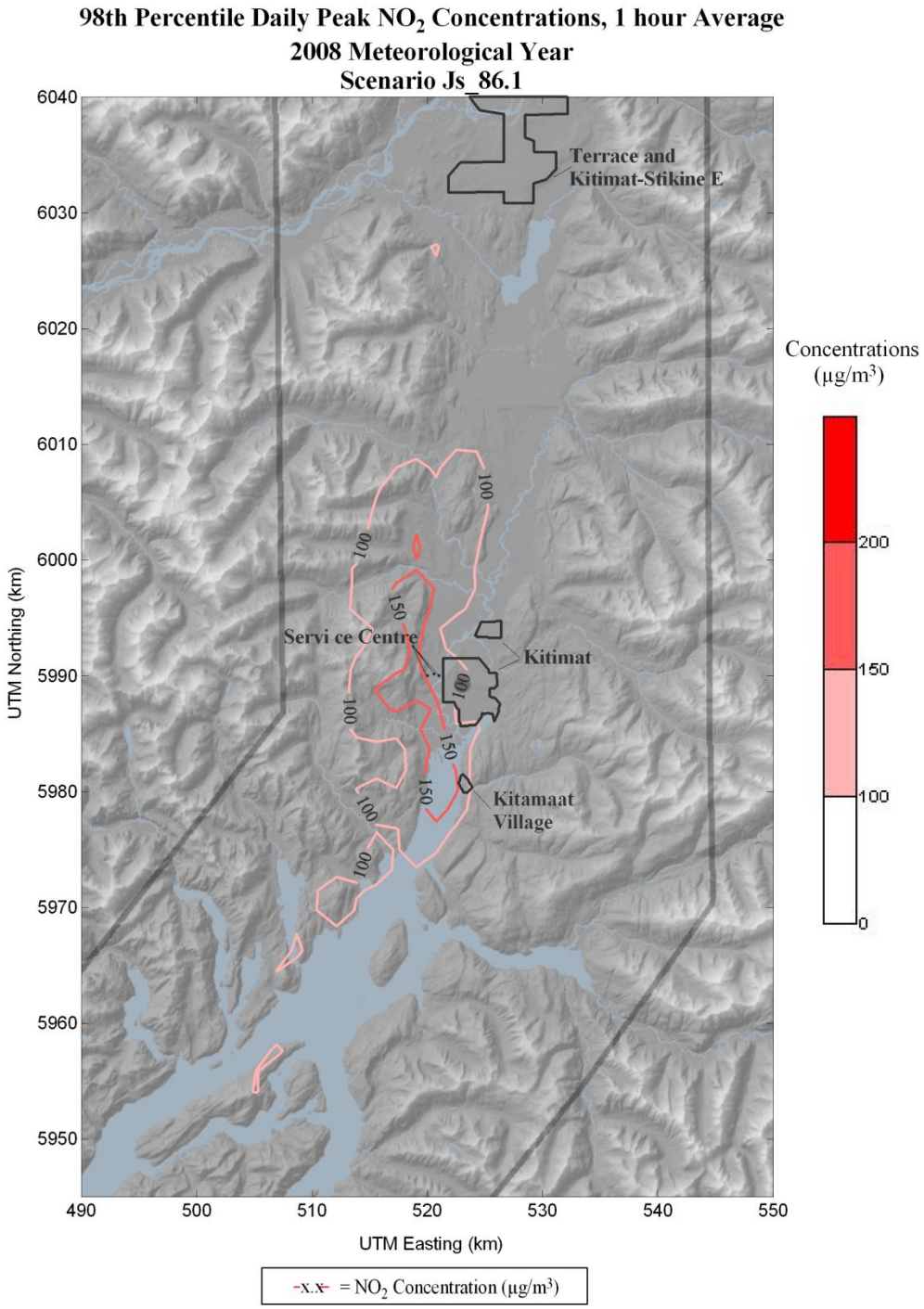


* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m^3), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m^3.

Figure 2-15. Scenario Im_83.3, 98th percentile NO_2 concentrations, 1-hour average.

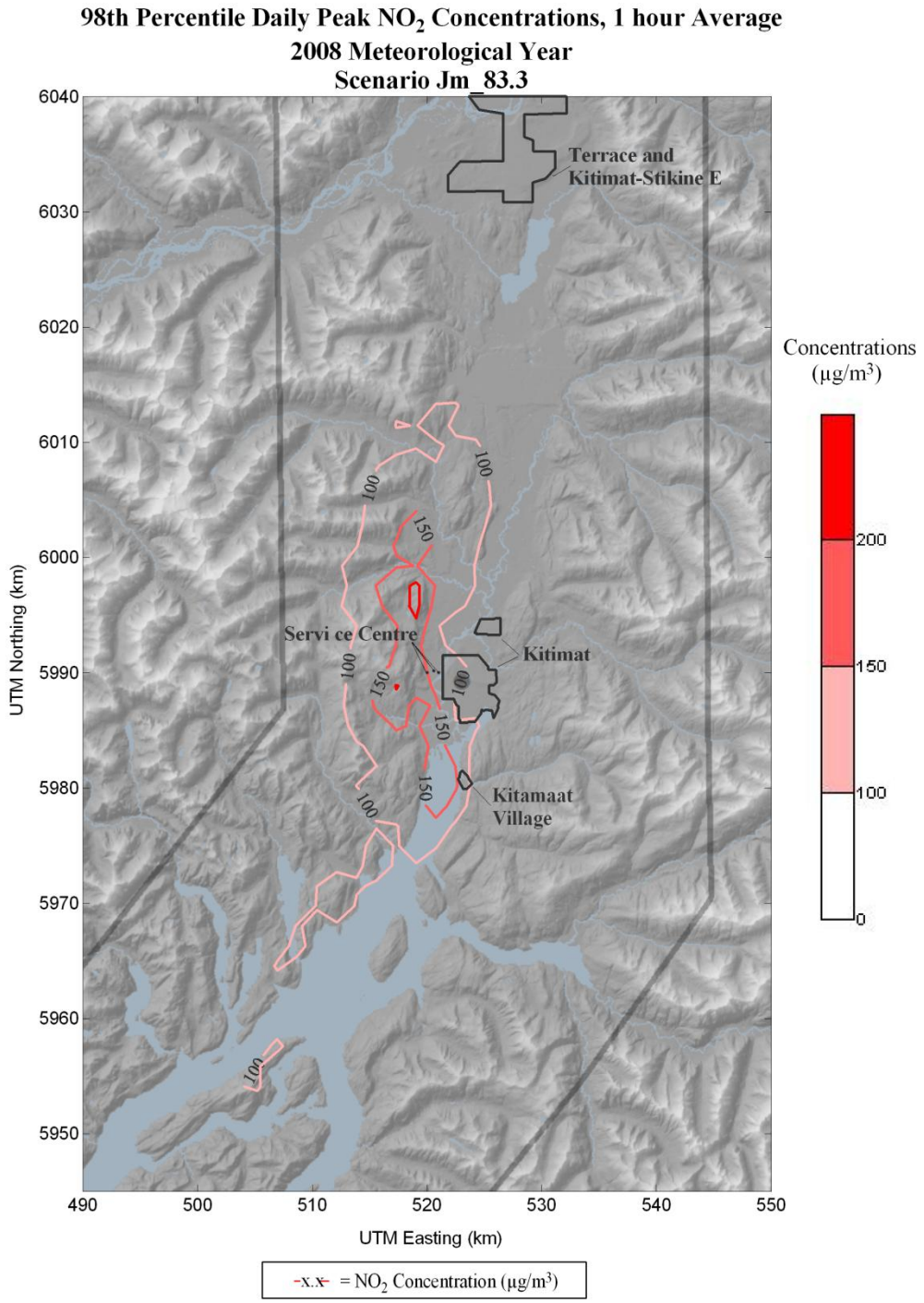
In addition to Scenario Is_83.3 and Scenario Im_83.3 results presented above for the BC Hydro electric generating stations operating under Selective Catalyic Reduction control, concentration results were also compared for a scenario where the BC Hydro electric generating stations are operating without NO_X control: Scenario Js_85.1 and Scenario Jm_86.1. The results distribution for the generators alone looks nearly identical with and without SCR, because the concentrations change almost linearly with the emission rate. However, the total concentrations showing the generators in addition to the other sources do change.

Figure 2-16 and Figure 2-17 present the 98th percentile NO_2 concentration for the 1-hour averaging period for the BC Hydro uncontrolled model results added to Scenario H_82.6 for each location, i.e., for Scenarios Js_86.1 and Jm_86.1. SO_2 concentration plots are not presented for Scenarios Js_86.1 and Jm_86.1 in this report, because the SO_2 emissions from the BC Hydro electric generation facility for these scenarios are identical to BC Hydro SO_2 emissions for Scenarios Is_83.3 and Im_83.3. The resulting increases from Skeena Substation location to the total NO_2 concentrations show a slight increase near the source, but do not overlap noticeably with Scenario H_82.6 concentrations. Conversely, the resulting increases from Minette Substation location to the total NO_2 concentrations show a noticeable increase to the west and northwest of the smelter, resulting in maximum concentrations above 200 $\mu g/m^3$ on the uninhabited hillsides. As presented in Appendix 6, results for all other averaging periods also show similar differences between H_82.6 and Scenario Js_86.1 or Scenario Jm_86.1.



* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m³.

Figure 2-16. Scenario Js_86.1, uncontrolled, 98th percentile NO_2 concentrations, 1-hour average.



* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m³.

Figure 2-17. Scenario Jm_86.1, uncontrolled, 98th percentile NO_2 concentrations, 1-hour average.

2.3 Main Sources and Implications of Quantitative Scientific Uncertainty

The primary source of uncertainty in the air dispersion and deposition modelling is the preliminary nature of the emission rates and stack parameters for the LNG facilities, oil refinery, and marine transportation emissions. While we made several conservative assumptions with respect to transportation emissions, little information is available regarding the level of uncertainty or extent of assumptions from proponent data. With respect to local scale results in the town of Kitimat and near the facilities, the absence of building data needed to predict building downwash effects is also expected to result in uncertainty to varying extents. In general, it is expected that the absence of building downwash results in under-prediction in locations near the facility. This under-prediction from building downwash is not expected to be significant at distances approaching the nearest residential areas in Kitimat and Kitamaat Village.

Meteorological data uncertainty is typically and consistently the key source of uncertainty in any predictive air dispersion modelling analysis, because it is not possible to know with any certainty what the weather will be in future years and how well the modelled meteorological year represents future years. However, comparing the modelled year used in this study (2008) to recent years can provide good insight into how much conditions vary year to year in the airshed and where the modelled year falls within the variable range. Therefore, we conducted an analysis comparing the meteorological data in 2008 to a 10-year period from 2003 to 2012, as presented in Appendix 7 and summarized in Section 2.3.1. In addition to comparing meteorological data across a 10-year period, understanding the sensitivity of the CALPUFF model results to variation in meteorological data also aids in providing insight into the model uncertainty. As such, we summarized a previous sensitivity study and conducted two new sensitivity studies as part of the current assessment: a precipitation sensitivity study, and a study comparing near-field concentrations for one scenario for three years using previously prepared 2006 and 2009 CALMET data in addition to the 2008 data used for all scenarios.

2.3.1 Ten Year Meteorological Data Analysis Summary

Kitimat airshed meteorological data from years 2006, 2008, and 2009 were compared to conditions over the 2003-2012 period in the airshed. The years were compared based on wind patterns (speed and direction), atmospheric stability, and occurrence of conditions likely to indicate a daytime atmospheric temperature inversion situation. Appendix 7 presents the detailed analysis. The 2008 year of meteorological data appeared to be broadly representative of an average year in the 2003-2012 period considered and may reasonably be assumed to be representative of a typical year in the near future. Years 2006 and 2009 showed more deviation from the 10-year norm.

The average nature of 2008 appeared to be consistent across all metrics as well as when comparing results from two different sites in the airshed (Kitimat Haul Road and Terrace Airport meteorological stations). 2006 and 2009 showed a less consistent pattern, with 2006 having a higher-than-average frequency of low wind speed and stable atmosphere conditions, but a lower-than-average frequency of inversion-like events. 2009 showed the opposite general tendency: below-average occurrences of low wind speed and stable atmosphere conditions, but above-average occurrences of inversion-like conditions.

Because low wind speeds are associated with lower dilution of pollutants, the findings for 2008 indicate that that year likely included a slightly higher number of low-dilution (high-concentration) events than an average year in the region, but is generally close to the average.

2.3.2 MM5 Sensitivity Study Summary

The CALPUFF modelling system's sensitivity to altering some meteorological input data and CALMET settings was evaluated as part of the KMP SO_2 assessment (ESSA et al. 2013a,b). Model sensitivity related to processing without the MM5 data resulted in modelled SO_2 concentrations that averaged 17% lower than the full CALMET results in residential areas and 12% higher in offsite areas.

2.3.3 Sensitivity Study of 2006 and 2009 CALPUFF Concentration Results

As described in Section 2.1.3.2, the scope of the current assessment includes one meteorological year (2008) in order to focus the comparison between scenarios. During the KMP SO_2 technical assessment, three meteorological years were used for assessment: 2006, 2008, and 2009. The CALMET datasets are prepared using actual measured meteorological data, and therefore vary from year to year. A study was conducted for Scenario G_76.2 for the local scale (near-field) domain to show how different meteorological data from year to year can affect modelled concentrations. The local scale domain, and not the long range domain, was included in this comparison study, because local scale CALMET datasets were readily available, whereas long range CALMET datasets were not available for the study area used in the Kitimat Airshed Effects Assessment. Deposition results are not included in the study comparisons, because the local scale domain represents only a small fraction of the area important for assessing deposition effects, whereas the concentration results of most concern for human health and vegetation effects are located in the local scale domain. The local scale (near-field) models were run for Scenario G_76.2 with only the meteorological data changed from 2008 to 2006 or 2009.

2.3.3.1 2006 vs 2008

As detailed in the tables and figures presented in Appendix 8, the annual average modelled SO_2 concentrations range from less than 0.1% different to 91% lower (and 81% higher) and are, on average across all near-field locations, 53% higher in 2006 than in 2008. The maximum hourly SO_2 concentration at any location is 2% lower in 2006 than in 2008 (1,713 µg/m^3 for 2006 versus 1,745 µg/m^3 for 2008).

The differences in NO_X modelling results are similar to those for SO_2. The annual average modelled NO_X concentrations range from less than 0.1% different to 104% lower (and 80% higher) and are, on average across all near-field locations, 47% higher in 2006 than in 2008. The maximum hourly NO_2 concentration at any location is 6% higher in 2006 than in 2008 (328 µg/m^3 for 2006 versus 308 µg/m^3 for 2008).[18]

The annual average modelled SO_2 concentrations at near-field receptors included in the human health study (Kitimat and Kitamaat Village residential areas and the Service Centre commercial area) range from 0% different to 81% higher (and 18% lower) and are, on average, 62% higher in 2006 than 2008. The maximum hourly SO_2 concentration at any residential near-field location is 42% higher in 2006 than in 2008 (1,713 µg/m^3 for 2006 versus 990 µg/m^3 for 2008).

[18] The NO_2 concentrations presented in this section apply the same 80% NO_2/NO_X ratio and 57.5 µg/m^3 background concentrations as all other 1-hour results. The differences in NO_X model results specifically refer to the modelled NO_X concentrations; therefore, the NO_2/NO_X ratio and background concentration is not considered when the term "NO_x concentration" is used.

The annual average modelled NO_X concentrations at near-field receptors included in the human health study range from 0% different to 80% higher (and 57% lower) and are, on average, 57% higher in 2006 than in 2008. The maximum hourly NO_2 concentration at any human health near-field location is 27% higher in 2006 than in 2008 (328 µg/m^3 for 2006 versus 241 µg/m^3 for 2008). Additionally, the highest 98th percentile daily peak NO_2 concentration at human health near-field receptors is 200 µg/m^3 compared to 147 µg/m^3 for 2008.

Based on the results of the 10-year meteorological analysis summarized in Section 2.3.1, the higher results in 2006 may be surprising, because fewer days with low wind speeds occurred in 2006 versus 2008 and 2009. However, as stated in the detailed meteorological analysis in Appendix 7, wind direction is also important to consider when understanding modelled concentrations in a specific area (such as the limited set of receptors included in the human health assessment). The wind direction also plays a key role in the frequency of high concentrations that occur from impingement of plumes on the steep terrain to the northwest, west, and southwest of the smelter, as can be seen occurring in the 2006 concentration plots presented in Appendix 8.

2.3.3.2 2009 vs 2008

As detailed in the tables and figures presented in Appendix 8, the annual average modelled SO_2 concentrations range from less than 0.1% different to 76% higher (and 52% lower) and are, on average across all near-field locations, 1% higher in 2009 than in 2008. The maximum hourly SO_2 concentration at any location is 9% higher than in 2008 (1,925 µg/m^3 for 2009 versus 1,745 µg/m^3 for 2008).

The differences in NO_X modelling results are similar to those for SO_2. The annual average modelled NO_X concentrations range from less than 0.1% different to 78% higher (and 59% lower) and are, on average across all near-field locations, 6.3% lower in 2009 than in 2008. The maximum hourly NO_2 concentration at any location is 5% lower than in 2008 (293 µg/m^3 for 2009 versus 308 µg/m^3 for 2008).

The annual average modelled SO_2 concentrations at near field receptors included in the human health study ranges from 0% to 61% higher (and 52% lower) and are, on average, 0.3% lower in 2009 than 2008. The maximum hourly SO_2 concentration at any human health nearfield location is 49% higher in 2009 than in 2008 (1,925 µg/m^3 for 2009 versus 990 µg/m^3 for 2008).

The annual average modelled NO_X concentrations at near field receptors included in the human health study ranges from 0% to 59% lower (and 58% higher) and are, on average, 7% lower in 2009 than in 2008. The maximum hourly NO_2 concentration at any human health near-field location is 11% higher (271 µg/m^3 for 2009 versus 241 µg/m^3 for 2008).[19] Additionally, the highest 98th percentile daily peak NO_2 concentration at human health near-field receptors in 2009 is 154 µg/m^3 compared to 147 µg/m^3 for 2008.

2.3.3.3 Conclusions

Of 2006, 2008 and 2009, the worst-case year for potential human health effects at near-field locations appears to be 2006. However, the overall health conclusions would not necessarily change significantly when considering three years together. The annual average concentrations at human health receptors are higher for 2006, but slightly lower for 2009.

Additionally, as can be seen in the 99th percentile SO_2 plots presented in Appendix 8, the 99th percentile daily peak modelled SO_2 concentrations in Kitimat and Kitimaat Village are above the 1-hour SO_2 US EPA National Ambient Air Quality Standards (NAAQS) for 2008, and also above the 1-hour SO_2 NAAQS for 2006 and 2009.

The 98th percentile daily peak modelled NO_2 concentrations in Kitimat and Kitimaat Village are below the 1-hour NO_2 NAAQS for 2008 and 2009, and above the 1-hour NO_2 NAAQS for 2006. However, the form of the US EPA NO_2 NAAQS calls for all modelled years to be averaged, on a receptor by receptor basis. Applying the three year average form, the resulting highest 3-year average 98th percentile daily peak modelled NO_2 concentration is below the 1-hour NO_2 NAAQS.

2.3.4 Precipitation Sensitivity Study

A detailed sensitivity study of precipitation on deposition in CALPUFF modeling system was conducted by changing precipitation data but keeping all other parameters in the CALPUFF-ready meteorological file. The study included two months: one "dry" month (June 2008), and one "wet" month (November 2008) Appendix 9 presents the detailed analysis. As noted in Section 2.1.3.2, the precipitation data in the CALPUFF modelling in this study were predicted by MM5. Two factors are therefore of concern: 1) studies (such as Box et. al. 2006) show that MM5 tends to overestimate precipitation in coastal areas, which may cause overestimation of wet deposition; and 2) the MM5 modelling domain has a 4 km by 4 km resolution that may not fully resolve terrain features in the region. As such, the sub-grid precipitation variation may not be reflected by the CALPUFF modelling system. Figure 2-15 presents the MM5 derived 4 km by 4 km precipitation field.

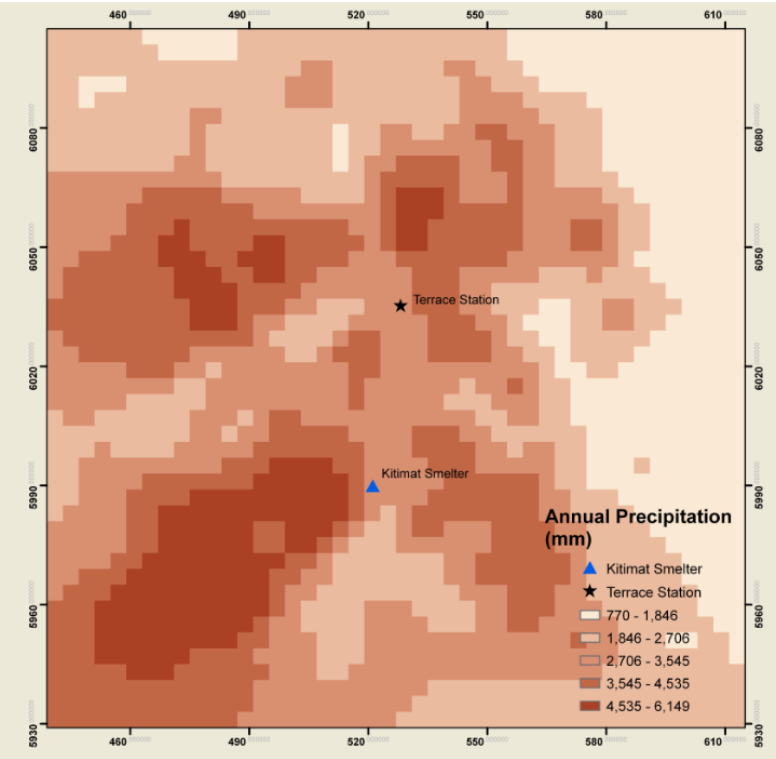


Figure 2-18. 2008 precipitation in 4 km by 4 km resolution predicted by MM5.

The results of the precipitation study confirm that precipitation has nearly no impact on dry deposition all season long. For wet deposition, however, the precipitation clearly impacts predicted wet deposition fluxes, especially when the wet deposition is high: the wet deposition tends to be proportional to the precipitation under such a circumstance.

The CALPUFF model (as applied for this Kitimat Airshed Emissions Effects Assessment) includes depletion, meaning any mass deposited on the ground from wet or dry deposition is removed from the mass of the plume's air concentrations. Therefore, any increase in deposition would result in a corresponding decrease in air concentrations and vice versa. However, as detailed in Appendix 9, the changes to air concentrations as a result of the changes to wet deposition, are minimal.

2.3.5 Layering Approach Study

The layering approach described in Section 2.1.1 is also a source of uncertainty, though less significant and more readily quantifiable than the sources described above. There may be differences in the results between the two approaches (modelling each facility separately and adding results in a post-processing step versus including all sources in a single CALPUFF input file), because the CALPUFF dispersion model includes chemical interactions between plumes (as SO_2 converts to SO_4 and NO_X converts to NO_3). In order to assess the effect of the layering approach, we modelled one scenario as a "scenario-specific" run with all emissions sources in a single input file, and compared the results from this run with the results from the same scenario using the layered approach. We selected Scenario G_76.2 for the layering approach study in order to assess a scenario with high total emissions levels of both SO_2 and NO_X.[19]

As detailed in the tables and figures presented in Appendix 10, the modelling results change less than 0.3% on average for SO_2 concentration and sulphur deposition. In this case, "on average" means the average, across all receptors, of the absolute difference (between layered versus scenario-specific for each receptor) of annual average concentrations or deposition. The differences in NO_X modelling results are similarly minimal, with the NO_X concentrations changing less than 0.1% on average. While the average nitrogen deposition changes approximately 6.5%, the average change is less than 0.02 kg/ha/yr, indicating the higher percent changes in nitrogen deposition are an artifact of the large number of receptors with extremely low model results. Additionally, for SO_2 concentrations and sulphur deposition, less than 4% of receptors see a difference greater than 1%. Overall, the layered approach shows a slight negative bias (e.g., average of 0.02% under prediction for sulphur deposition), but the differences for sulphur deposition range from 6% under prediction to 5% over prediction.

In summary, biases associated with applying the layering method for the Kitimat Airshed Emissions Effects Assessment are inconsequential.

[19] Scenario G_76.2 was selected over Scenario H_82.6 because the inclusion of the refinery facility outside the local scale domain required for Scenario H_82.6 (the only difference between the two scenarios) was problematic for the scenario-specific single input file configuration.

3 HUMAN HEALTH

The human health assessment component of the Kitimat Airshed Emissions Effects Assessment is reported below in four main sections. In the first section, the overall approach to the health assessment is described. The second section provides a review of the evidence for, and expected health effects due to, exposure from both SO_2 and NO_2. In the third section, an approach to risk characterization is proposed, with a conceptual basis similar to that of the Canadian Council of Ministers of the Environment (CCME) in the establishment of air quality management criteria (and associated "bands" of air quality) for particulate matter and ozone. In the fourth section, the results of the air dispersion modelling are reviewed in light of this health risk characterization scheme.

3.1 Methods

The human health assessment was conducted through the following sequence of tasks:

1. Residential and commercial areas for which human health effects should be assessed were identified, in addition to those already identified in past work for SO_2 in the KMP SO_2 Technical Assessment Report (ESSA et al. 2013).
2. The US EPA (2008) conducted an extensive literature review of evidence for health effects of SO_2; this was then updated to late 2012 during development of the KMP SO_2 Technical Assessment Report (ESSA et al. 2013), so a further review of new evidence for health effects of SO_2 (2013-2014) was not done, except as described below (4).
3. At the onset of the literature review for NO_2, it was determined that a very recent, authoritative and comprehensive review of the scientific literature was available (note: this report was released after contract award). This report was reviewed (878 pages, including appendices), and used as the basis for evaluating the evidence for health effects of short-term and long-term exposures to NO_2.
4. A separate, specific literature review was conducted focusing on studies of the relationship between health effects and exposures to SO_2 and NO_2 involving Canadian populations. The description of the literature review search and a description of these studies are available in Appendix 11.
5. A classification scheme was derived to characterize the risks for NO_2 and SO_2.
6. Dispersion model results (consisting of one year of hourly average ambient air concentrations for the identified residential and commercial human health receptor locations) were processed to allow for comparison with the ambient concentration thresholds, for different residential and commercial locations identified in Task 1.
7. An assessment of the relative risk associated with alternate emissions scenarios was conducted for SO_2, to describe the differences in public health impacts that are not apparent from consideration of the thresholds and extreme percentiles of concentrations. A comparison of the percentage increase in the annual average concentration of NO_2 among the scenarios is provided as a potential surrogate for relative risk estimates for NO_2.

3.2 Review of Evidence for Health Effects for SO_2 and NO_2

Oxides of sulphur (SO_X) include sulphur dioxide (SO_2), sulphur trioxide (SO_3), and gas-phase sulphuric acid (H_2SO_4). Only SO_2 is present in the atmosphere in concentrations significant for human exposure, and it serves as the indicator for SO_X (US EPA 2008a). Oxides of nitrogen (NO_X) are complex mixtures of many oxides including NO_2, nitric oxide (NO), and all other oxidized nitrogen-containing compounds formed from NO_2 and NO. NO_2 is the most important of the gaseous NO_X and serves as the indicator (US EPA 2008b). Most studies on health effects of gaseous SO_X and NO_X focus on SO_2 and NO_2, respectively.

Four sources of information were used to identify health outcomes causally linked with environmental exposure to SO_X and NO_X:

1. US EPA *Integrated Science Assessment for Sulfur Oxides* – Health Criteria (US EPA 2008a).
2. US EPA *Integrated Science Assessment for Oxides of Nitrogen* – Health Criteria (US EPA 2008b). These two documents represent the most recent authoritative reviews of scientific literature on health effects of exposures to ambient oxides of sulphur and nitrogen.
3. To update the literature on health effects of sulphur oxides (particularly SO_2), a search was conducted using the US National Library of Medicine (PubMed) database. The search took place on October 25, 2012 and identified literature published between 2008 and that date. This work is described in detail as part of the KMP SO_2 Technical Assessment Report (ESSA et al. 2013). A summary of this review is provided below.
4. In November 2013, the Clean Air Scientific Advisory Committee of the US EPA issued an updated *First External Review Draft of the Integrated Science Assessment for Oxides of Nitrogen – Health Criteria* (US EPA 2013). This document updates the literature on health effects of nitrogen oxides.

The Scientific Advisory Committee of the US EPA considered scientific evidence for health effects of short-term and long-term exposures to SO_2 and NO_2. Exposure durations from several minutes to a month were considered to be short-term, and exposures averaged over months or years were considered long-term (US EPA 2008a,b). Evidence was integrated across scientific disciplines: epidemiology; controlled human exposure experiments; and toxicology. Causal determinations were based on consistency of findings (as opposed to reliance on a single study) from a large number of independent studies, coherence of evidence from various fields, and the biological plausibility of observed effects.

3.2.1 Health Effects with a Causal Association to Sulphur Dioxide (SO_2)

In 2008, the US EPA Committee concluded that the scientific evidence was sufficient to infer a causal relationship between short-term exposure to SO_2 and respiratory morbidity. Inhaled SO_2 and its reaction products can stimulate chemosensitive receptors in the tracheobronchial tree and initiate a reflexive contraction of smooth muscles in the bronchi (bronchoconstriction). The key evidence for the US EPA (2008a) conclusion came from human clinical studies. Volunteers were exposed to SO_2 under controlled conditions in the absence of other pollutants. These studies consistently demonstrated decreased lung function accompanied by respiratory symptoms (e.g., wheeze and chest tightness) in exercising mild to moderate asthmatics following peak exposures (5-10 min duration) to SO_2 at concentrations ~1,050 to ~1,570 µg/m^3. Physical exercise was used in these experiments to increase lung ventilation rate and, as a result, SO_2 uptake. Some asthmatic subjects experienced decreases in lung function at SO_2 concentrations of ~520 to ~790 µg/m^3. In clinical studies of exercising individuals without asthma,

decreases in lung function were observed only at SO_2 concentrations greater than ~2,620 µg/m^3. Supporting evidence for a causal relationship between short-term exposure to SO_2 and respiratory morbidity came from epidemiologic studies reporting increases in respiratory symptoms, emergency department visits and hospitalizations for respiratory diseases, and decreases in lung function associated with increased SO_2 levels (US EPA 2008a).

Studies published from 2008 to 2012 generally supported the US EPA conclusion regarding a causal relationship between short-term SO_2 and respiratory morbidity. Most of the identified epidemiological studies demonstrated a link between increased SO_2 concentrations in the air and respiratory effects. In clinical studies among non-smoking healthy volunteers (Raulf-Heimsoth et al. 2010; van Thriel et al. 2010), exposure to SO_2 for four hours at concentrations up to ~5,240 µg/m^3 had no effect on lung function and did not cause an increase in biochemical markers of airway irritation or inflammation. Data from recent studies and those reviewed by the US EPA in 2008 suggest that ambient SO_2 does not induce respiratory diseases in healthy people but rather exacerbates existing diseases. It was clearly demonstrated that individuals with asthma represented a population susceptible to the effects of short-term exposures to SO_2.

Thus, decreased lung function and respiratory symptoms were health outcomes for which a causal relationship with SO_2 was unequivocally established. The Scientific Advisory Committee of the US EPA (US EPA 2008a) defined populations susceptible to the adverse effects of a pollutant as populations that "might exhibit an adverse health effect to a pollutant at concentrations lower than those needed to elicit the same response in the general population, or exhibit a more severe adverse effect than the general population when exposed to the same pollutant concentrations". The Advisory Committee concluded that subjects with asthma were a population particularly susceptible to the respiratory effects of SO_2. Physical exercise increased the sensitivity of individuals with asthma to the effects of SO_2.

The Advisory Committee characterized the evidence as suggestive but not sufficient to infer a causal relationship between short-term exposure to SO_2 and mortality (USEPA 2008a). This "suggestive" evidence came from epidemiological studies that reported associations between increased ambient SO_2 concentrations and mortality from all causes and from specific causes. The US EPA pointed out that interpretation of findings from epidemiological studies was complicated, in particular due to difficulties in differentiating the effects of SO_2 from the effects of other air pollutants.

Studies published from 2008 to 2012 that examined associations between ambient SO_2 concentrations and mortality from all causes, from all non-accidental causes, and from cause-specific mortality, support the US EPA conclusion. When pollutants other than SO_2 were not accounted for in the statistical analyses, positive and statistically significant associations between SO_2 concentrations in the air and mortality were reported in 20 studies. No significant association was seen in five studies and a significant negative association was reported in one study. Since SO_2 was only one of many air pollutants, such analyses could not rule out the possibility that SO_2 was only a marker of other pollutants but not a "causal" factor. An attempt to differentiate between the effects of different air pollutants by including them in a statistical model simultaneously was made in seven studies (two- or multi-pollutant analyses). In six of these studies, the positive association seen in the single-pollutant analysis was reduced and lost statistical significance. Overall, despite many positive associations reported between ambient SO_2 concentrations and mortality, the data suggest that these may not be "true" associations but a reflection of the effects of other air pollutants (more commonly, the causal association is attributed to particulate matter and ozone).

The Advisory Committee (US EPA 2008a) concluded that the evidence was inadequate to infer the presence or absence of a causal relationship for:

- short-term SO_2 exposure and cardiovascular morbidity;
- long-term SO_2 exposure and respiratory morbidity;
- long-term SO_2 exposure and non-respiratory morbidity; and
- long-term SO_2 exposure and mortality.

Studies published from 2008 to 2012 investigated the possible relationship between short-term SO_2 exposure and indices of cardiovascular health, such as electrocardiographic parameters, pulse rate, blood pressure, biochemical markers of cardiovascular risk, hospitalizations and emergency department visits for cardiovascular diseases. The results do not show a consistent pattern that would suggest a causal link between SO_2 and cardiovascular morbidity.

Studies published from 2008 to 2012 examined possible associations between long-term exposure to SO_2 and respiratory diseases and non-respiratory outcomes including indices of cardiovascular health, cancer, prenatal/neonatal outcomes (e.g., low birth weight, preterm births, birth defects, stillbirths) as well as total, cardiovascular and respiratory mortality. Due to lack of consistency across studies and inability in many studies to discriminate between the effects of SO_2 and the effects of other air pollutants, the recent literature does not substantially deviate from the US EPA (US EPA 2008a) finding regarding inadequacy of the existing data for a conclusion about causality.

3.2.2 Exposure-Response Relationship for Sulphur Dioxide (SO_2)

The US EPA (US EPA 2009) used a combined dataset from controlled human exposure studies of mild-to-moderate asthmatic individuals engaged in physical exercise, and a Bayesian Markov Chain Monte Carlo approach, to estimate probabilistic exposure-response relationships for lung function decrements associated with 5-min daily peak exposures to SO_2. The US EPA Advisory Committee selected two-parameter logistic and probit models.

A respiratory response was defined using two measures of lung function, forced expiratory volume in 1 s (FEV1) and specific airway resistance (sRaw), and two levels of changes in these measures. Four definitions of a respiratory response by the US EPA were: (1) an increase in sRaw ≥100%; (2) an increase in sRaw ≥200%; (3) a decrease in FEV1 ≥15%; and (4) a decrease in FEV1 ≥20%. These responses represent "moderate or greater lung function decrements" and were considered adverse to the health of individuals with asthma. The Advisory Committee noted that risk estimates using sRaw as the measure of lung function response were based on a larger set of data, and the US EPA placed more confidence in the exposure-response relationship for sRaw than for FEV1. However, the pattern of exposure-response for sRaw and FEV1 were similar. These exposure-response patterns are intended for application to predict responses in susceptible populations (those with pre-existing restrictive airway disease such as asthma and chronic obstructive pulmonary disease (COPD)) during exercise.

The free-breathing controlled human exposure studies included in the exposure-response analysis by the US EPA (2009) were conducted at SO_2 concentrations ≥200 ppb (~520 µg/m^3). Following exposures to 200-300 ppb (~520 to ~790 µg/m^3), between 5% and 30% of exercising asthmatics were expected to experience the respiratory responses. The US EPA noted "greater uncertainty in responses below 200 ppb because of the lack of comparable experimental data." Most controlled human exposure studies were conducted using adult subjects; the uncertainty in risk estimates was greater for asthmatic

children. The US EPA also noted that small decrements in lung function were seen in two mouthpiece exposure studies at 100 ppb, although the results from these studies were "not comparable to free-breathing chamber studies." The US EPA (2009) concluded that there was "no evidence to indicate that exposure to 200-300 ppb SO_2 for 5-10 minutes represents a threshold below which no respiratory effects occur."

3.2.3 Health Effects with a Causal Association to Nitrous Dioxide (NO_2)

At the time that this health effects assessment was proposed (October 2013), there was no recent, authoritative report on the health impacts of NO_2. As such, the work plan included a literature review for NO_2 which would update the understanding of health effects from what was reviewed by US EPA in 2008(b). Since the time of contract award, the US EPA issued a new report (November 2013, currently labelled as an External Review Draft). This document served as the primary reference for our current analysis of health effects of NO_2.

In 2008, the Scientific Advisory Committee of the US EPA issued a report (US EPA 2008b) which concluded that there was sufficient scientific evidence to infer a likely causal relationship between short-term exposure to NO_2 and respiratory effects. Epidemiologic, controlled human exposure studies, and animal toxicological studies demonstrated that exposure to NO_2 could affect lung host-defense and immune systems and increase the risk of susceptibility to viral and bacterial infections, increase airway inflammation, airway responsiveness to specific allergen challenges and to nonspecific challenges, such as cold air, histamine, methaholine, or SO_2. These are potential mechanisms by which exposure to NO_2 may exacerbate upper and lower airway symptoms (US EPA 2008b). In its more recent November 2013 draft report (US EPA 2013), the US EPA strengthened the causal determination from a likely causal relationship to a more certain causal relationship mainly because recent epidemiological studies reduced uncertainty regarding confounding by co-pollutants; associations between short-term NO_2 exposure and respiratory effects remained positive after adjustments for air pollutants such as particulate matter, ozone, sulphur dioxide.

Scientific evidence for other combinations of exposure duration and health effects was classified by the US EPA (2008b) as either suggestive of a causal relationship (short-term exposure and total mortality, long-term exposure and respiratory effects) or inadequate for making any conclusion regarding causality (long-term exposure and cardiovascular, reproductive, developmental effects, total mortality and cancer). Based on recent literature, the US EPA (2013) upgraded causal determinations for several outcomes for which scientific evidence was previously classified as inadequate, and changed it to suggestive of a causal relationship or likely to be a causal relationship. In some cases, recent studies demonstrated health effects where previous findings were inconsistent or negative. In other cases, recent studies reduced the uncertainty regarding potential confounding from co-pollutants. New data added to understanding of biological mechanisms by which health effects may occur (US EPA 2013).

Pre-existing asthma, COPD, genetic factors for oxidant and inflammatory damage, and low socio-economic status, may result in greater susceptibility to the effects of NO_2 exposure (US EPA 2008b, 2013). The evidence that children (0-14 years) and older individuals (≥65 years) represent populations susceptible to the effects of NO_2 was stronger and was classified by the US EPA (2013) as "adequate."

3.2.4 Exposure-Response Relationship for Nitrous Dioxide (NO_2)

Individual-level data from controlled human exposure studies were inconsistent and provided inadequate evidence to derive a concentration-response relationship (US EPA 2008b). Population-level

data from epidemiological studies that examined a concentration-response were scarce at the time of the 2008 US EPA review. The outcomes of interest in most available studies of short-term NO_2 exposure were hospitalizations, emergency department visits for respiratory diseases, and mortality. The studies were "generally consistent with a linear or log-linear relationship between ambient NO_2 concentration and the health outcome." Epidemiological studies that attempted to explore exposure-response at NO_2 concentrations below 50 ppb did not provide adequate evidence to suggest departures from linearity along any part of this range of NO_2 concentrations (US EPA 2008b). More recent data (US EPA 2013) provide additional evidence that respiratory hospital admissions, emergency department visits and mortality are linearly related with short-term NO_2 exposure; no thresholds for these effects have been identified. Potential exposure-response relationships for long-term NO_2 exposures were not well characterized (US EPA 2013).

3.2.5 Summary of Causal Determinations for SO_2 and NO_2

A summary of the status of current causal determinations for the linkage between various categories of health effects and exposure to both short-term and long-term exposure to SO_2 and NO_2 is provided in Table 3-1. The determinations for SO_2 are based on the 2008 US EPA Integrated Assessment (US EPA 2008a), and a previously conducted literature review covering 2008 to late October 2012, previously described (ESSA et al. 2013). The determinations for NO_2 are based on the recent US EPA *Integrated Science Assessment for Oxides of Nitrogen (External Review Draft)* report (US EPA 2013). The conclusions have not been adjusted from this source.

Table 3-1. Weight of evidence in support of causation for different health effects and durations of exposure to oxides of sulphur and nitrogen.

Health effect	Evidence for causality	
	SO_X/SO_2	NO_X/NO_2
Short-term exposure		
Respiratory effects	Sufficient to infer a causal relationship	Causal relationship
Mortality	Suggestive but not sufficient to infer a causal relationship	Likely to be a causal relationship
Cardiovascular effects	Inadequate to infer the presence or absence of a causal relationship	Likely to be a causal relationship
Long-term exposure		
Respiratory effects	Inadequate to infer the presence or absence of a causal relationship	Likely to be a causal relationship
Cardiovascular effects	Inadequate to infer the presence or absence of a causal relationship	Suggestive of a causal relationship
Reproductive and developmental effects	Inadequate to infer the presence or absence of a causal relationship	Suggestive of a causal relationship
Mortality	Inadequate to infer the presence or absence of a causal relationship	Suggestive of a causal relationship
Cancer	Inadequate to infer the presence or absence of a causal relationship	Suggestive of a causal relationship

The status of the causal relationships between SO_2 and NO_2 are subject to change, and tend to include more health endpoints over time in the higher categories (causal, likely to be causal). This is due to the accumulation of evidence over time needed to meet the requirement for consistency in findings, and

the gradual removal of sources of uncertainty such as exposure estimates and confounding. This suggests that the potential for additional short-term and long-term health outcomes could be considered in a subsequent assessment. This is consistent with some current practice (e.g., in the Canadian Air Quality Health Index, which links short-term exposure to combinations of $PM_{2.5}$, Ozone, and NO_2 with short-term risk of mortality).

3.3 Derivation of a Proposed Risk Characterization Scheme for SO_2 and NO_2

In order to provide a characterization of the potential health risk associated with exposures to SO_2 and NO_2, a risk characterization scheme was developed to assign different levels of exposure (i.e., in the form of ambient concentrations) to a series of categories describing increasing indicators of public health risk. This was based on a review of regulatory ambient concentration thresholds derived by other regulatory authorities, and the existing air quality management framework developed by the Canadian Council of Ministers of the Environment (CCME) which provides a relevant categorization scheme, but is currently limited to providing categories based on numerical thresholds for particulate matter and ozone.

3.3.1 Review of Regulatory Ambient Concentration Thresholds for SO_2 and NO_2

Regulatory exposure threshold values were reviewed for SO_2 and NO_2. Table 3-2 provides threshold values for SO_2, while Table 3-3 provides threshold values for NO_2.

Table 3-2. Selected regulatory ambient concentration threshold values for SO_2 and SO_X.

	Concentration						Source	Comments
	1-h average		24-h average		Annual average			
	µg/m^3	ppb	µg/m^3	ppb	µg/m^3	ppb		
WHO	A 10-min average is used (500).		125 (interim target 1) 50 (interim target 2) 20 (guideline)	48 19 7.6			***Air quality guidelines - global update 2005*** http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf?ua=1	10-min mean: 500 µg/m^3 (190 ppb)
European Union	350	134	125	48	--	--	***Air Quality Standards*** http://ec.europa.eu/environment/air/quality/standards.htm	1-h average: 24 permitted exceedences each year 24-h average: 3 permitted exceedences each year
USA	197	75	--	--	--	--	***National Ambient Air Quality Standards*** http://www.epa.gov/air/criteria.html	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years Secondary standard: 0.5 ppm (1,310 µg/m^3) averaged over 3-h; not to be exceeded more than once per year. "Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings."
Canada Manitoba	900	343	300	114	60	23	***Canadian National Ambient Air Quality Objectives*** http://ceqg-rcqe.ccme.ca/download/en/133/ ***Ambient Air Quality Criteria (Manitoba)*** http://www.gov.mb.ca/conservation/envpr	These are maximum acceptable levels. Maximum tolerable level: 800 µg/m^3 (305 ppb) averaged over 24-h Maximum desirable levels: 1-h: 450 µg/m^3 (172 ppb); 24-

	Concentration						Source	Comments
	1-h average		24-h average		Annual average			
	µg/m^3	ppb	µg/m^3	ppb	µg/m^3	ppb		
							ograms/airquality/pdf/criteria_table_update_july_2005.pdf	h: 150 µg/m^3 (57 ppb), annual: 30 µg/m^3 (11 ppb)
New Brunswick Nova Scotia Prince Edward Island	900	340	300	110	60	20	***New Brunswick Ambient Air Quality Objectives*** ***See table 1 in:*** http://www.gnb.ca/legis/business/currentsession/57/57-2/LegDocs/2/en/AirQuality2010.pdf ***Maximum Permissible Ground Level Concentrations*** http://www.novascotia.ca/just/regulations/regs/envairqt.htm ***Environment Protection Act Air Quality Regulations*** http://www.gov.pe.ca/law/regulations/pdf/E&09-02.pdf	
British Columbia	A or lower: 450 B or upper: 900 C: 900	A or lower: 170 B or upper: 340 C: 340	A or lower: 160 B or upper: 260 C: 360	A or lower: 60 B or upper: 100 C: 140	A or lower: 25 B: 50 C: 80	A or lower: 10 B: 20 C: 30	***British Columbia Ambient Air Quality Objectives*** http://www.bcairquality.ca/reports/pdfs/aqotable.pdf	Note that some of the British Columbia Pollution Control Objectives have been rescinded, though they continue to be used for reference purposes in some situations. Level A generally applies to all new and proposed discharges as a desirable goal; Level B generally applies to existing discharges as an interim objective; Level C: immediate objective (See British Columbia Ambient Air Quality Objectives for

	Concentration						Source	Comments
	1-h average		24-h average		Annual average			
	µg/m^3	ppb	µg/m^3	ppb	µg/m^3	ppb		
								further details). 3-h average: lower – 375 µg/m^3 (140 ppb), upper – 665 µg/m^3 (250 ppb)
Alberta	450	172	125	48	20	8	***Alberta Ambient Air Quality Objectives*** http://environment.gov.ab.ca/info/library/5726.pdf	30-day average: 30 µg/m^3 (11 ppb)
Saskatchewan	450	170	150	60	30	10	***Ambient Air Quality Standards (Saskatchewan)*** http://www.environment.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=6b1f40c1-7d4a-499b-a366-e5ffa76324d5&MediaID=1539&Filename=Saskatchewan+Ambient+Air+Quality+Standards.pdf&l=English	
Ontario	690	250	275	100	55	20	***Ontario's Ambient Air Quality Criteria*** http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079182.pdf	See also http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_078657.pdf
Quebec	A 4-min average is used (1050).	400	288	110	52	20	***Normes et critères québécois de qualité de l'atmosphère*** *http://www.mddefp.gouv.qc.ca/air/criteres/Normes-criteres-qc-qualite-atmosphere.pdf*	Soufre, dioxyde de CAS # 7446-09-5 4-min average: 1,050 µg/m^3 (400 ppb)

	Concentration						Source	Comments
	1-h average		24-h average		Annual average			
	µg/m^3	ppb	µg/m^3	ppb	µg/m^3	ppb		
Newfoundland and Labrador	900	343	300	114	60	23	***Air Pollution Control Regulations under the Environmental Protection Act (O.C. 2004-232) Amended by 94/10 (Newfoundland and Labrador)*** http://www.assembly.nl.ca/legislation/sr/regulations/Rc040039.pdf	3-h average: 600 µg/m^3 (230 ppb)

Table 3-3. Selected regulatory exposure threshold values for NO_2 and NO_X.

	Concentration						Source	Comments
	1-h average		24-h average		Annual average			
	µg/m^3	ppb	µg/m^3	ppb	µg/m^3	ppb		
WHO	200	106	--	--	40	21	***Air quality guidelines - global update 2005*** http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf?ua=1	
European Union	200	106	--	--	40	21	***Air Quality Standards*** http://ec.europa.eu/environment/air/quality/standards.htm	18 permitted exceedences of the 1-h average limit per year
USA	188	100	--	--	100	53	***National Ambient Air Quality Standards*** http://www.epa.gov/air/criteria.html	1-h average: 98th percentile, averaged over 3 years
Canada British Columbia Manitoba	400	213	200	106	100	53	***Canadian National Ambient Air Quality Objectives*** http://ceqg-rcqe.ccme.ca/download/en/133/ ***British Columbia Ambient Air Quality Objectives*** http://www.bcairquality.ca/reports/pdfs/aqotable.pdf ***Ambient Air Quality Criteria (Manitoba)*** http://www.gov.mb.ca/conservation/envpr	These are maximum acceptable levels. Maximum tolerable levels: 1-h 1,000 µg/m^3 (532 ppb); 24-h 300 µg/m^3 (160 ppb) Maximum desirable annual average level: 60 µg/m^3 (32 ppb)

	Concentration						Source	Comments
	1-h average		24-h average		Annual average			
	µg/m^3	ppb	µg/m^3	ppb	µg/m^3	ppb		
							ograms/airquality/pdf/criteria_table_update_july_2005.pdf	
New Brunswick Newfoundland and Labrador	400	210	200	105	100	52	***New Brunswick Ambient Air Quality Objectives*** ***See table 1 in:*** http://www.gnb.ca/legis/business/currentsession/57/57-2/LegDocs/2/en/AirQuality2010.pdf ***Air Pollution Control Regulations under the Environmental Protection Act (O.C. 2004-232) Amended by 94/10*** http://www.assembly.nl.ca/legislation/sr/regulations/Rc040039.pdf	
Alberta	300	159	--	--	45	24	***Alberta Ambient Air Quality Objectives*** http://environment.gov.ab.ca/info/library/5726.pdf	
Saskatchewan	400	200	--	--	100	50	***Ambient Air Quality Standards (Saskatchewan)*** http://www.environment.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=6b1f40c1-7d4a-499b-a366-e5ffa76324d5&MediaID=1539&Filename=Saskatchewan+Ambient+Air+Quality+Standards.pdf&l=English	
Ontario	400	200	200	100	--	--	***Ontario's Ambient Air Quality Criteria*** http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079182.pdf	See also http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_078657.pdf
Quebec	414	220	207	110	103	55	***Normes et critères québécois de qualité de***	Azote, dioxyde d' (CAS # 10102-44-0)

	Concentration						Source	Comments
	1-h average		24-h average		Annual average			
	µg/m^3	ppb	µg/m^3	ppb	µg/m^3	ppb		
							l'atmosphère ***http://www.mddefp.gouv.qc.ca/air/criteres/Normes-criteres-qc-qualite-atmosphere.pdf***	
Nova Scotia	400	210	--	--	100	50	***Maximum Permissible Ground Level Concentrations*** http://www.novascotia.ca/just/regulations/regs/envairqt.htm	
Prince Edward Island	400	213	--	--	100	53	***Environment Protection Act Air Quality Regulations*** http://www.gov.pe.ca/law/regulations/pdf/E&09-02.pdf	

3.3.2 Derivation of CCME-Compatible Thresholds for SO_2 and NO_2

The CCME has recently published Proposed Air Management Threshold Values for Ozone and Particulate Matter ($PM_{2.5}$) (CCME 2012). These are illustrated in Figure 3-1. The key properties of this categorization scheme are the provision of three thresholds for ambient concentrations (specifically, thresholds for various statistics of the ambient concentrations, such as the annual mean or a percentile value of hourly concentrations). These three thresholds divide potential concentrations into four categories that are associated with colours.

These four categories are:

- Green: the lowest category associated with very low exposures. A threshold value separates the Green and Yellow category, and is associated with the upper end of a range of ambient concentrations associated with "clean" environments.
- Red: the highest category is associated with concentrations above the threshold set at the level of the Canadian Ambient Air Quality Standards (CAAQS).
- Yellow: a third threshold lies midway between the "background" levels that separate Green and Yellow, and the CAAQS levels. Concentration values below this level, but higher than Green, are assigned Yellow.
- Orange: above the midway threshold, but below the Red category, the concentration values are assigned to the category labelled Orange.

Management Level	Management Actions	Proposed Air Management Threshold Values					
		Ozone (ppb)		$PM_{2.5}$ Annual ($\mu g/m^3$)		$PM_{2.5}$ 24h ($\mu g/m^3$)	
		2015	2020	2015	2020	2015	2020
RED	**Actions for Achieving Air Zone CAAQS**						
Threshold		63 ppb	62 ppb	10.0 µg/m3	8.8 µg/m3	28 µg/m3	27 µg/m3
ORANGE	**Actions for Preventing CAAQS Exceedance**						
Threshold		56 ppb		6.4 µg/m3		19 µg/m3	
YELLOW	**Actions for Preventing AQ Deterioration**						
Threshold		50 ppb		4.0 µg/m3		10 µg/m3	
GREEN	**Actions for Keeping Clean Areas Clean**						

Figure 3-1. Illustration of the CCME Air Management Categorization Scheme (extracted from CCME 2012).

The risk categorization scheme used for this health assessment is derived from the CCME approach and adapted for SO_2 and NO_2. Table 3-4 illustrates this scheme, with threshold values provided for NO_2 and SO_2, followed by an explanation of how these values were derived.

Table 3-4. Adaptation of the CCME Air Management Categorization Scheme for SO_2 and NO_2.

SO_2 Annual Average	SO_2 Hourly (99th %ile)	NO_2 Annual Average	NO_2 Hourly (98th %ile)
30 µg/m^3	196 µg/m^3	94 µg/m^3	188 µg/m^3
15 µg/m^3	100 µg/m^3	49 µg/m^3	105 µg/m^3
1 µg/m^3	5 µg/m^3	5 µg/m^3	22 µg/m^3

To date, CAAQS have not been established for SO_2 and NO_2. Based on discussions with the BC Ministry of the Environment (MOE), we have employed the use of thresholds based on the US EPA Primary National Ambient Air Quality Standards (NAAQS) values for both SO_2 and NO_2 to serve in place of values that may in the future be included in the CCME standard. It should be noted that these threshold values are not scientifically derived from known thresholds for the onset of human health effects. The US EPA does not employ a criterion for the annual average concentration of SO_2, however there is a Canadian National Ambient Air Quality Objective of 30 µg/m^3 (CCME 1998). It may be argued that establishing a criterion for the annual average (applicable to both NO_2 and SO_2) provides a preventative approach by focusing on the full range of concentrations rather than a specific high percentile value. A focus on high percentile values tends to distort the understanding of the principal source of public health risks due to air pollution which have been estimated to be derived more from high frequency ("everyday") exposures to low and moderate concentrations rather than infrequent extreme values. Additionally, to the extent that long-term exposures become more clearly linked to health outcomes (i.e., were the causality categories become "upgraded" due to accumulating evidence or reductions in uncertainties), a criterion based on the annual average would constitute an appropriate reference value to protect against such potential effects.

Table 3-4 also includes other threshold values consistent with the CCME approach. Values to define the lower or Green threshold were provided by MOE, based on observed levels in more than 35 communities in British Columbia in the years 2010-2012 that are not affected by significant local sources of these pollutants, and using the 10th percentile values (to be consistent with the CCME characterization of this category as being akin to levels expected in "a clean location on a good day"). By extension, the midway points are calculated as halfway between the derived Red thresholds, and the Green values. Accordingly, the midway thresholds for purposes of comparison with the air dispersion model results are calculated from the Red and Green thresholds.

Given that only 1 year of meteorological data was used in the air dispersion modelling, for present purposes the 99th and 98th percentile values are derived from a single year of modelled data (rather than averaged over 3 years as prescribed by the US EPA scheme).

IMPORTANT: The colour categories used in the human health effects assessment component of this study have the meanings intended by the CCME (CCME 2012) and do not have the same interpretation as the risk categories for the environmental receptors in this report (vegetation, soils, lakes).

3.4 Results

3.4.1 Locations Considered for Human Health

For purposes of human health effects assessment, 10 locations were identified in the airshed. The comparison of modelled concentrations to the thresholds described above was performed for each location. Figure 3-2 shows the locations. For communication purposes, they have been grouped and labelled Near and Far. The calculations are conducted in the same way for both categories. The industrial area designated in Figure 3-2 is not equivalent to the industrial sites themselves, rather it is the commercial area commonly referred to in Kitimat (and in the KMP SO_2 Technical Assessment Report (ESSA et al. 2013)) as the "Service Centre."

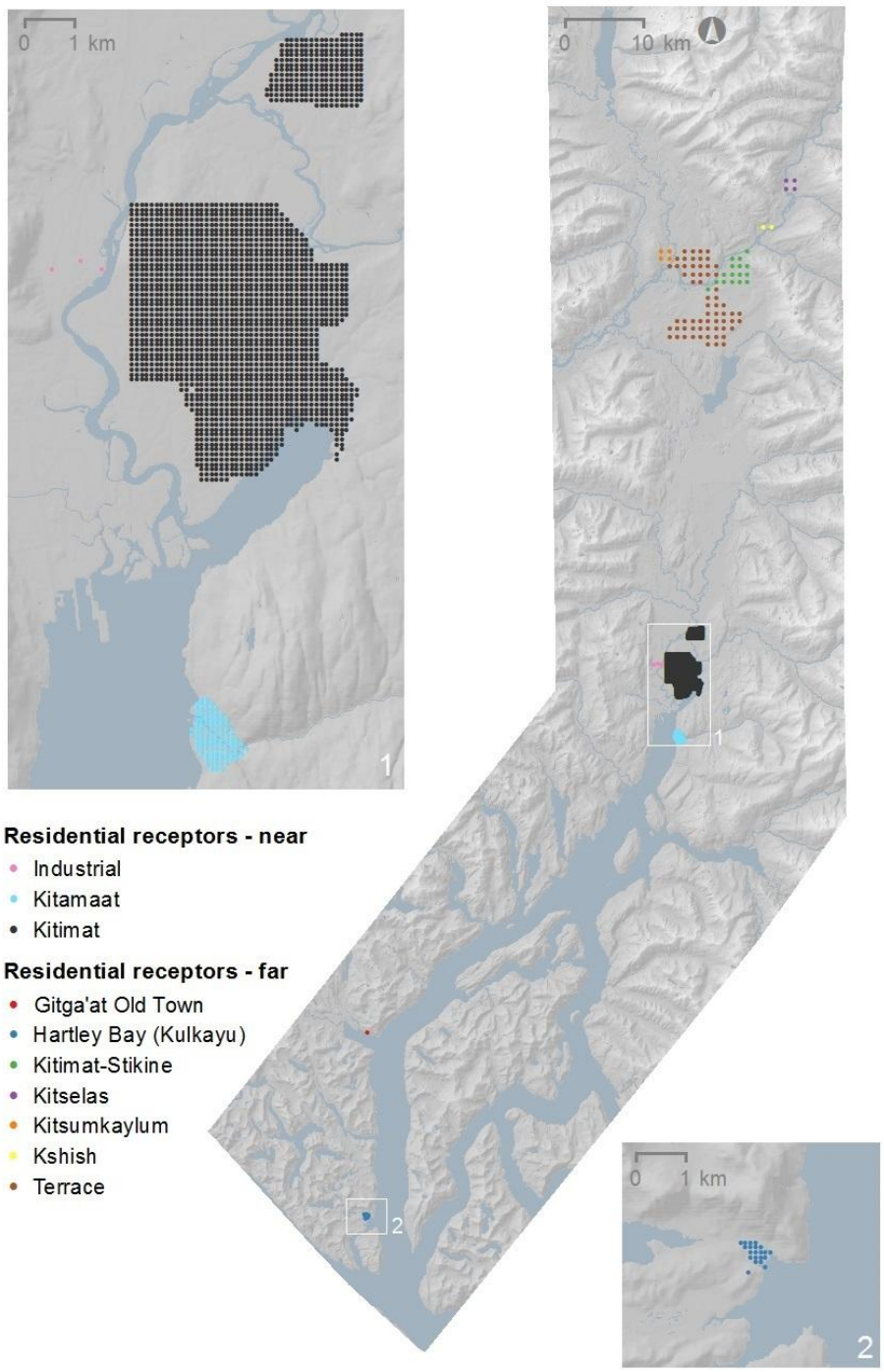


Figure 3-2. Locations considered for the human health effects assessment.

3.4.2 Overview of Modelled Concentrations of SO_2 (Hourly)

Hourly average concentrations for both the *Near* and *Far* locations are typically well below the thresholds described above. The relative frequency of hourly average concentrations is illustrated below in a series of histograms. The histograms show only the concentrations contributed by the modelled sources of SO_2 and do not include background levels of SO_2, which are included later when the exposures are compared to thresholds.

Figure 3-3 shows a histogram depicting the relative frequency of hourly averaged concentrations of SO_2 for the three Near locations (Kitimat, Kitamaat Village, and the Service Centre) for the lowest emission scenario (A_28.2). Figure 3-4 provides the same illustration for Scenario H_82.6. These histograms look quite similar, but some difference can be seen in the frequency of the lowest SO_2 concentrations, and differences across the three locations can also be seen.

Due to the relatively high frequency of very low concentrations (more than 70% of the hours in Scenario H_82.6 for the most affected area, the Service Centre, are below 10 µg/m^3), it is difficult to illustrate the frequency of higher concentrations on a single histogram view. Therefore, the histograms in Figure 3-5 and Figure 3-6 have been given a modified vertical scale to better illustrate the relative frequency of higher concentration values (the vertical axis is "zoomed in" to show the range from 0 to 5%).

The same sets of histograms are shown for the seven Far locations in Figure 3-7 through Figure 3-10. These show, as expected, a much smaller range of concentrations, with higher concentrations occurring much less frequently in these locations when compared to the Near locations.

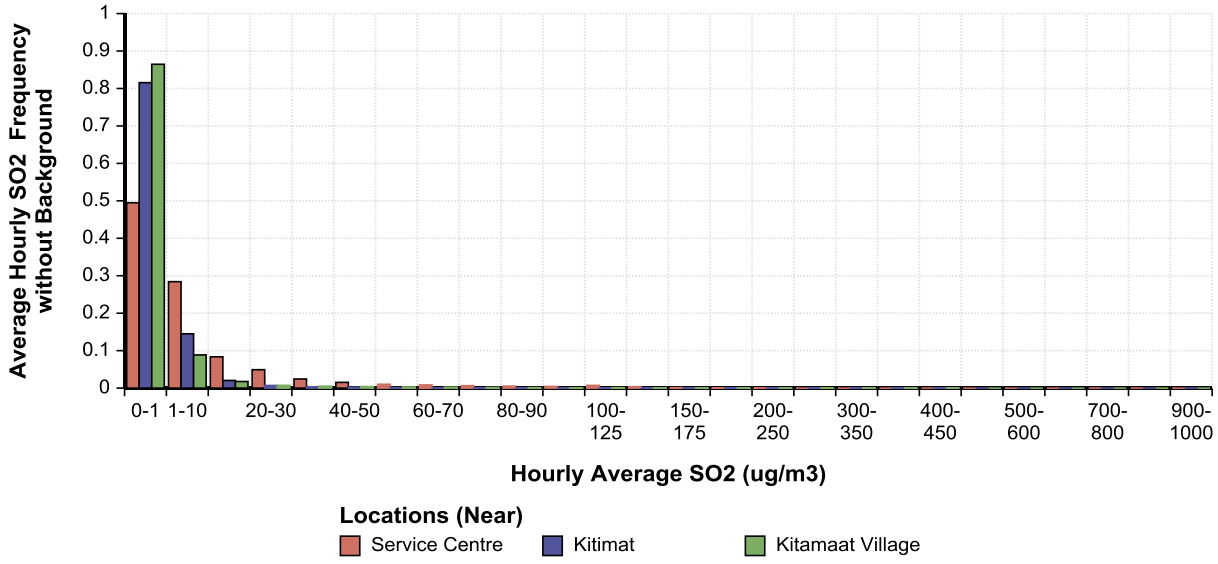


Figure 3-3. Histogram of SO_2 hourly average concentrations derived from modelled emissions for the three Near locations, for Scenario A_28.2.

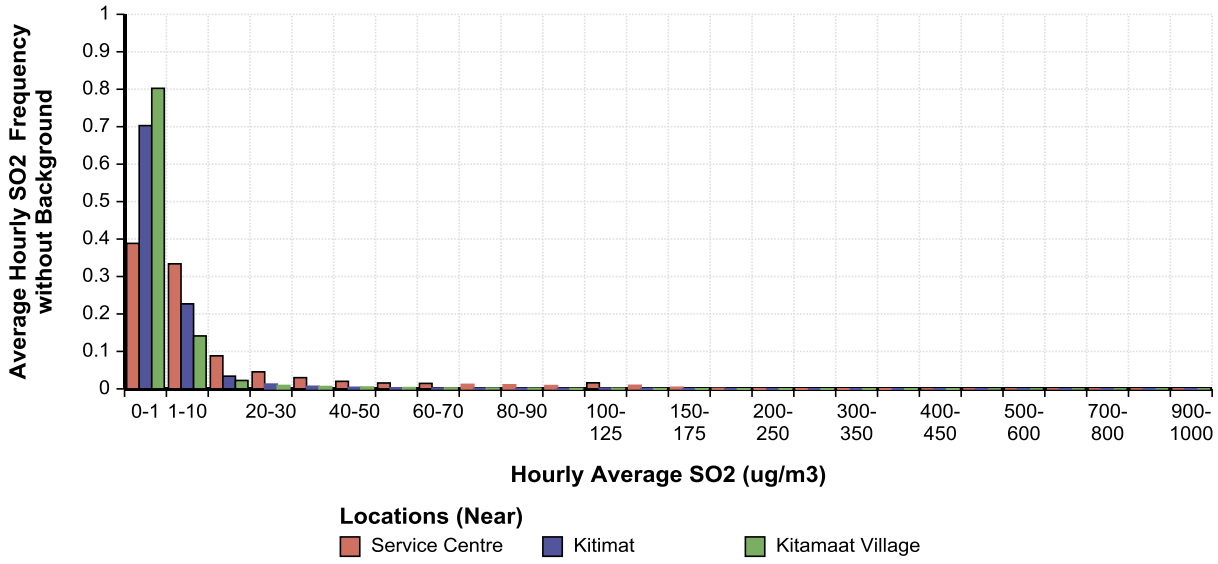


Figure 3-4. Histogram of SO_2 hourly average concentrations derived from modelled emissions for the three Near locations, for Scenario H_82.6.

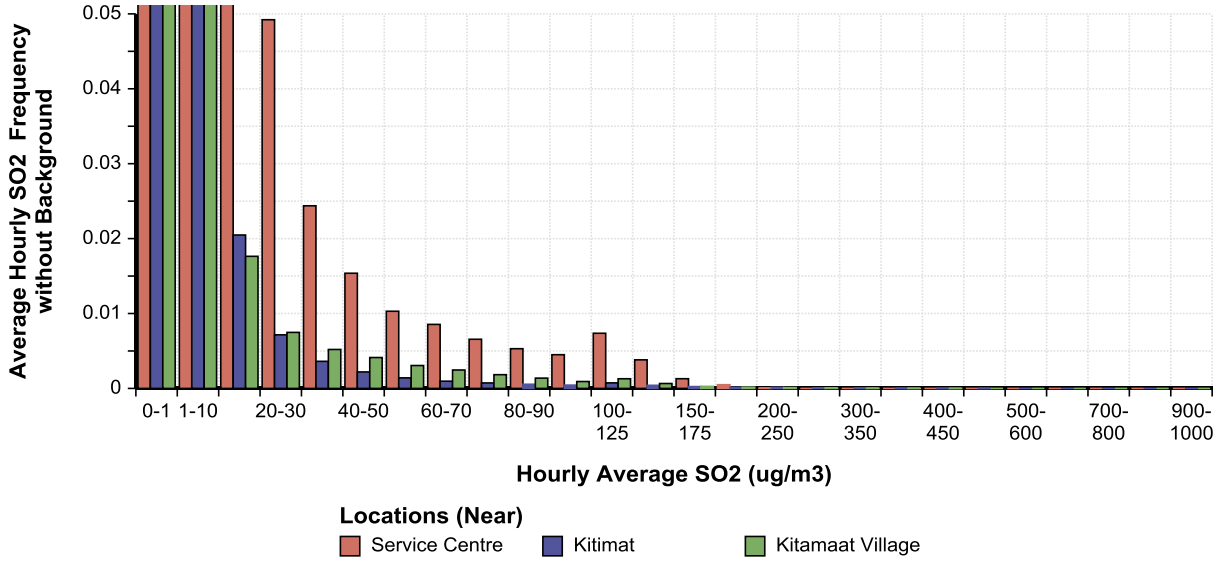


Figure 3-5. Histogram of Hourly SO_2 concentrations for the Near locations for Scenario A_28.2 "zoomed in" to show only frequencies in the range of 0 to 5%. (Same data as shown in Figure 3-3, with modified scale on vertical axis.)

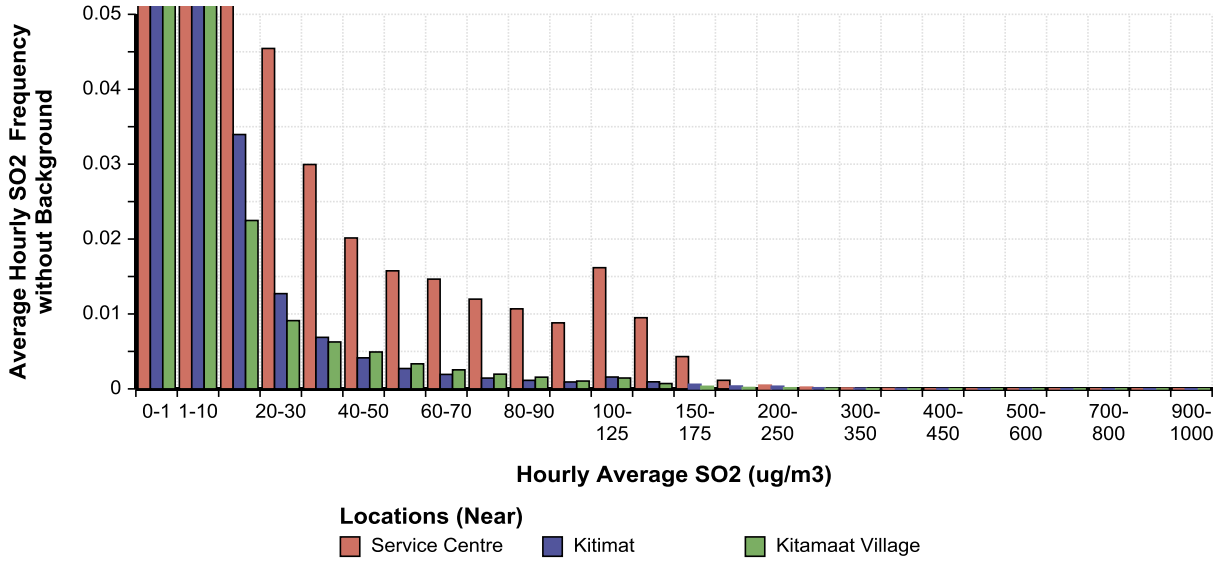


Figure 3-6. Histogram of Hourly SO_2 concentrations for the Near locations for Scenario H_82.6 "zoomed in" to show only frequencies in the range of 0 to 5%. (Same data as shown in Figure 3-4, with modified scale on vertical axis.)

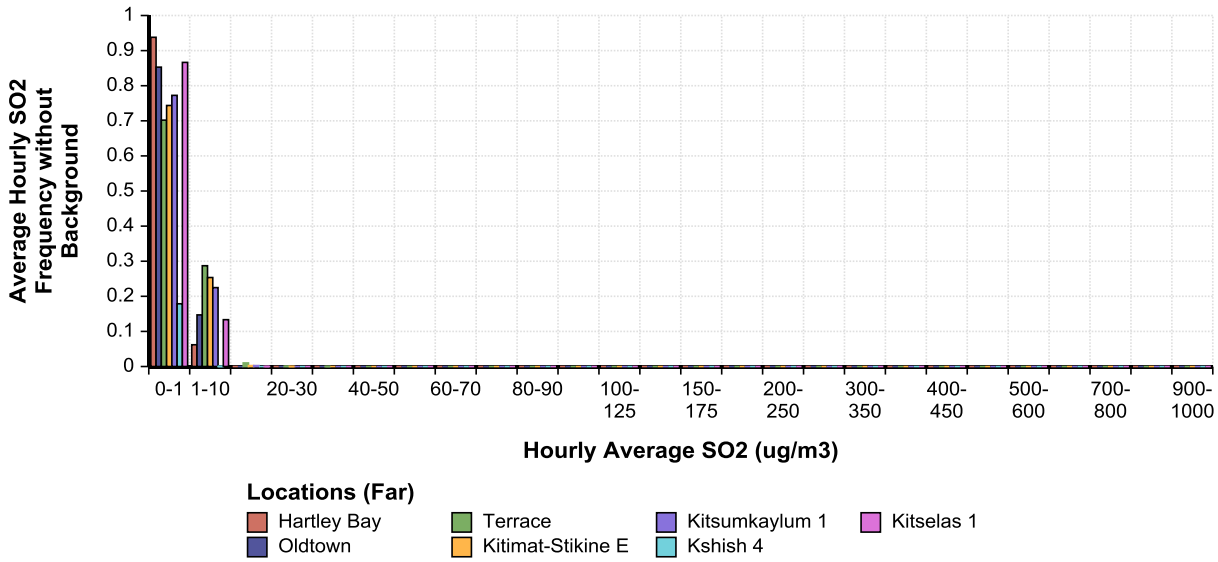


Figure 3-7. Histogram of SO_2 hourly average concentrations derived from modelled emissions for the seven Far locations, for Scenario A_28.2.

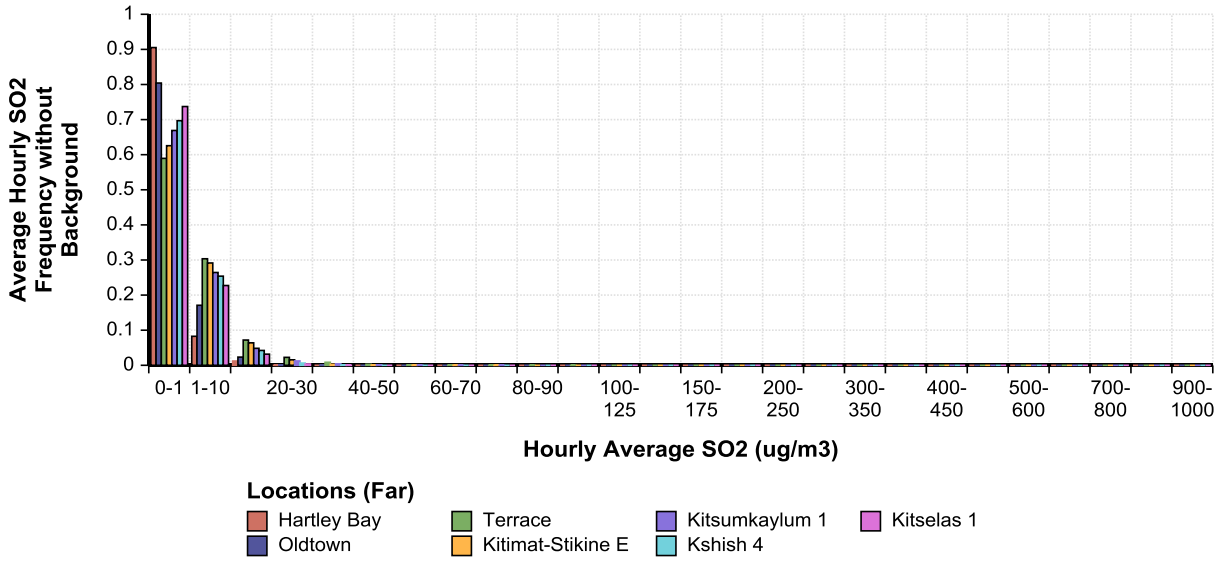


Figure 3-8. Histogram of SO_2 hourly average concentrations derived from modelled emissions for the seven Far locations, for Scenario H_82.6.

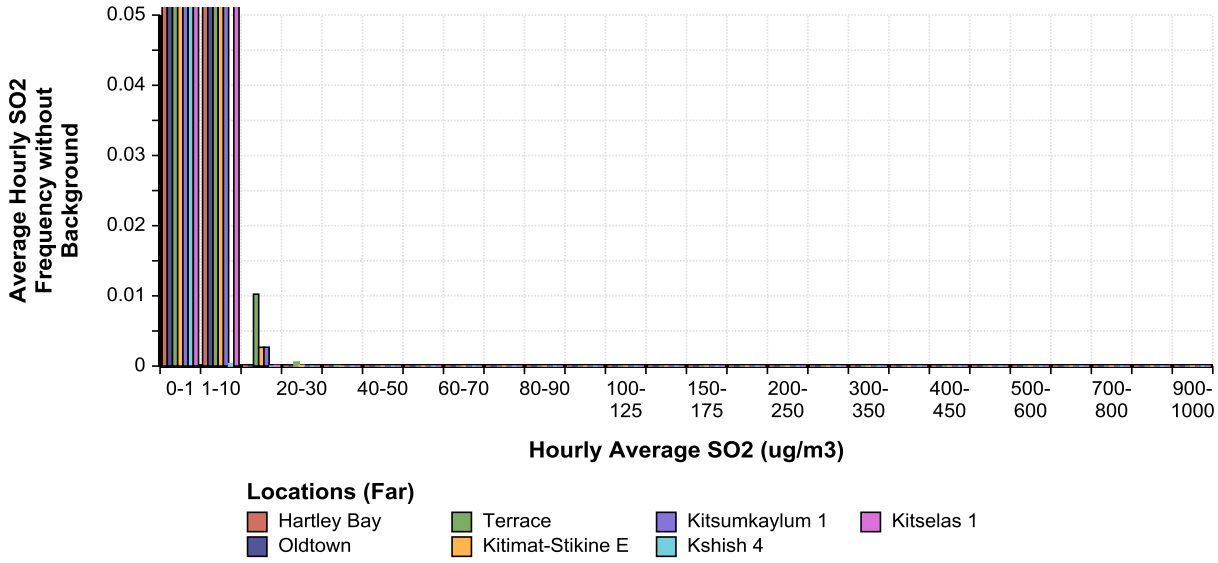


Figure 3-9. Histogram of Hourly SO_2 concentrations for the Far locations for Scenario A_28.2 "zoomed in" to show only frequencies in the range of 0 to 5%. (Same data as shown in Figure 3-7, with modified scale on vertical axis.)

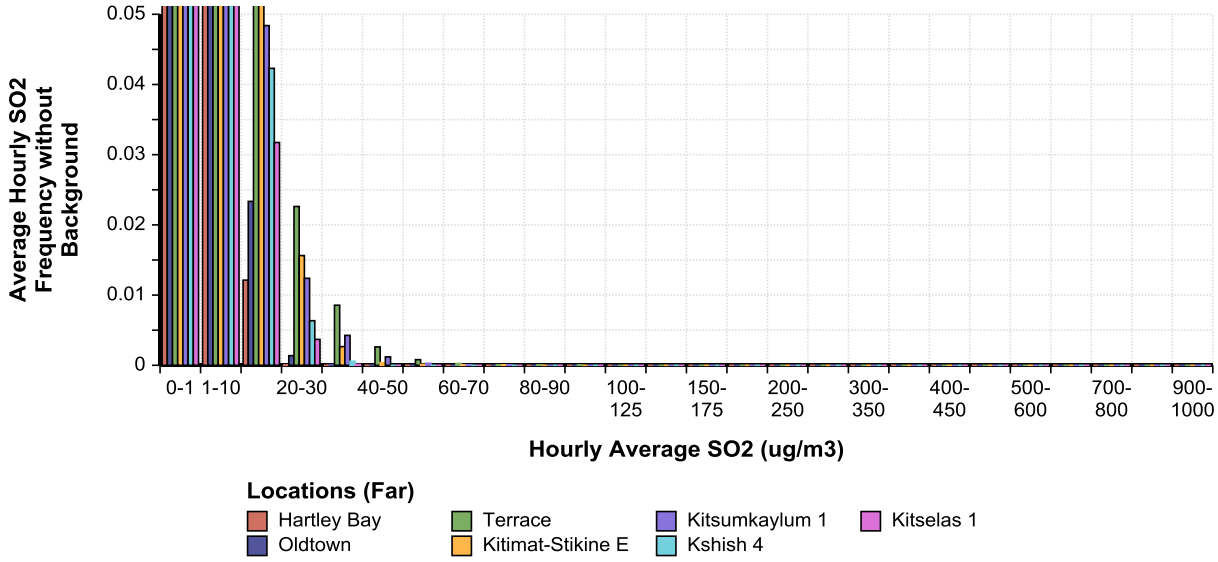


Figure 3-10. Histogram of Hourly SO_2 concentrations for the Far locations for Scenario H_82.6 "zoomed in" to show only frequencies in the range of 0 to 5%. (Same data as shown in Figure 3-8, with modified scale on vertical axis.)

3.4.3 Annual Average Concentrations of SO_2

The annual average concentration of SO_2 is shown in Figure 3-11. These results are provided to illustrate the relative long-term contribution to SO_2 concentrations in the ten locations. This graph includes a background annual average concentration of approximately 1 µg/m^3.

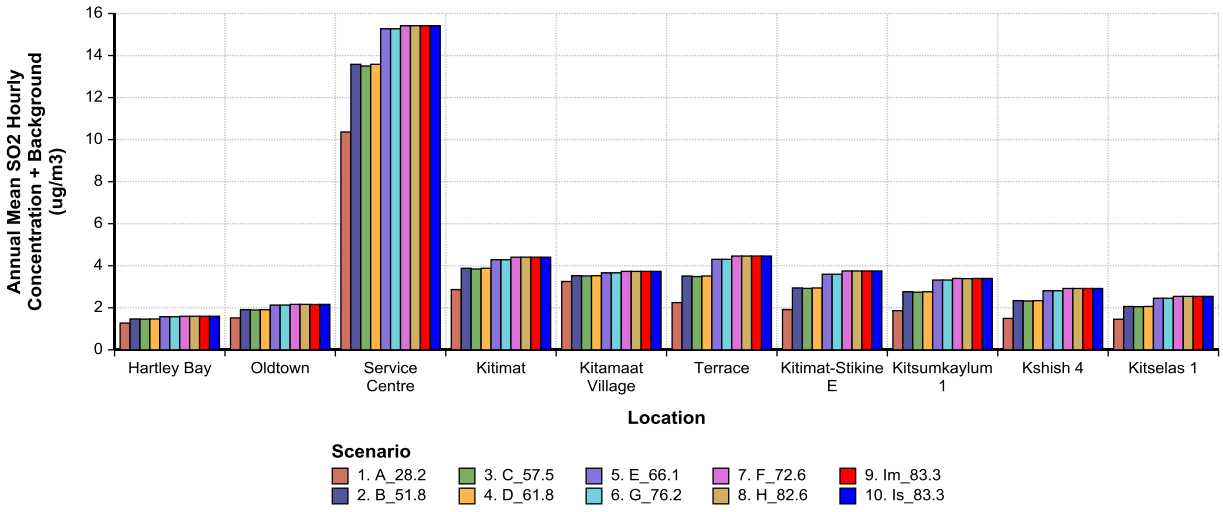


Figure 3-11. Annual average SO_2 concentration, including background for all locations, for Scenario A_28.2 through Scenario Is_83.3.

3.4.4 Overview of Modelled Concentrations of NO_2 (Hourly)

The relative frequency of hourly average concentrations of NO_2 is illustrated below in a series of histograms. The histograms show only the concentrations contributed by the modelled sources of NO_2 and do not include background levels of NO_2, which are included later when the modelled concentrations are compared to thresholds.

Figure 3-12 shows a histogram depicting the relative frequency of hourly averaged concentrations of NO_2 for the three Near locations (Kitimat, Kitamaat Village, and the Service Centre) for the lowest emission scenario (A_28.2). Figure 3-13 provides the same illustration for Scenario H_82.6. These histograms look quite similar, but some difference can be seen in the frequency of the lowest concentrations, and differences across the three locations can also be seen.

Due to the relatively high frequency of very low concentrations (more than 80% of the hours in Scenario H_82.6 for the most impacted area, the Service Centre, are below 10 µg/m^3), it is difficult to illustrate the frequency of higher concentrations on a single histogram view. Therefore, the histograms in Figure 3-14 and Figure 3-15 have been given a modified vertical scale to better illustrate the relative frequency of higher concentration values (the vertical axis is "zoomed in" to show the range from 0 to 5%).

The same sets of histograms are shown for the seven Far locations in Figure 3-16 through Figure 3-19, with the latter two figures "zoomed in" to show frequencies less than 1% due to low frequency of occurrence of concentration values above 10 µg/m^3 in these locations.

Ambient modelled concentrations (without background) for NO_2 demonstrate a similar pattern as seen for SO_2, with a high frequency of relatively low hourly average concentrations and a long "tail" of higher concentrations with correspondingly decreasing frequency.

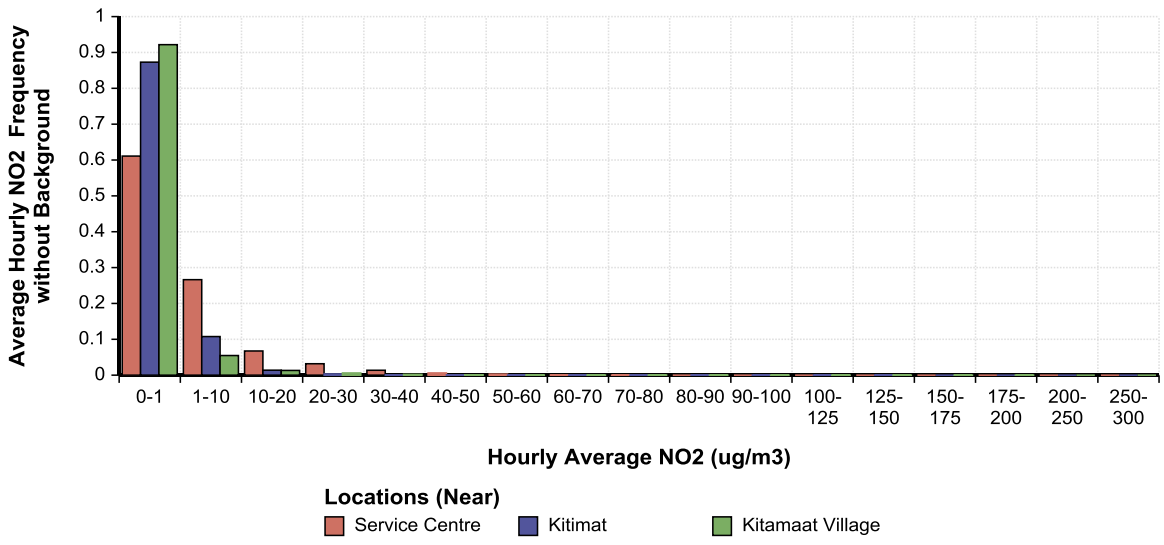


Figure 3-12. Histogram of NO_2 hourly averaged concentrations derived from modelled emissions for the three Near locations, for Scenario A_28.2.

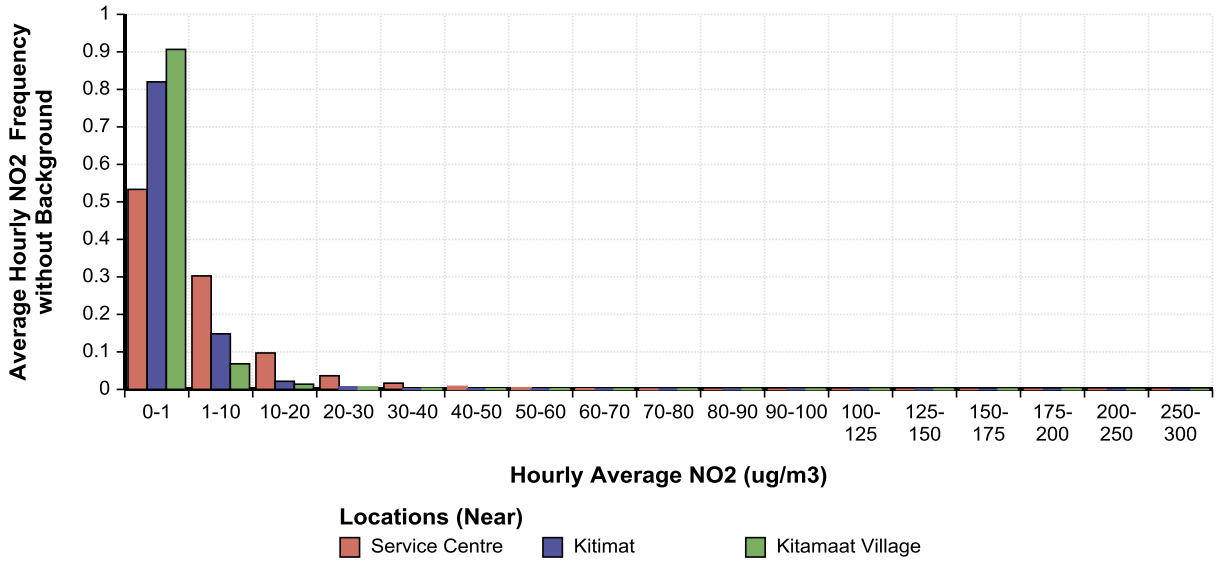


Figure 3-13. Histogram of NO_2 hourly averaged concentrations derived from modelled emissions for the three Near locations, for Scenario H_82.6.

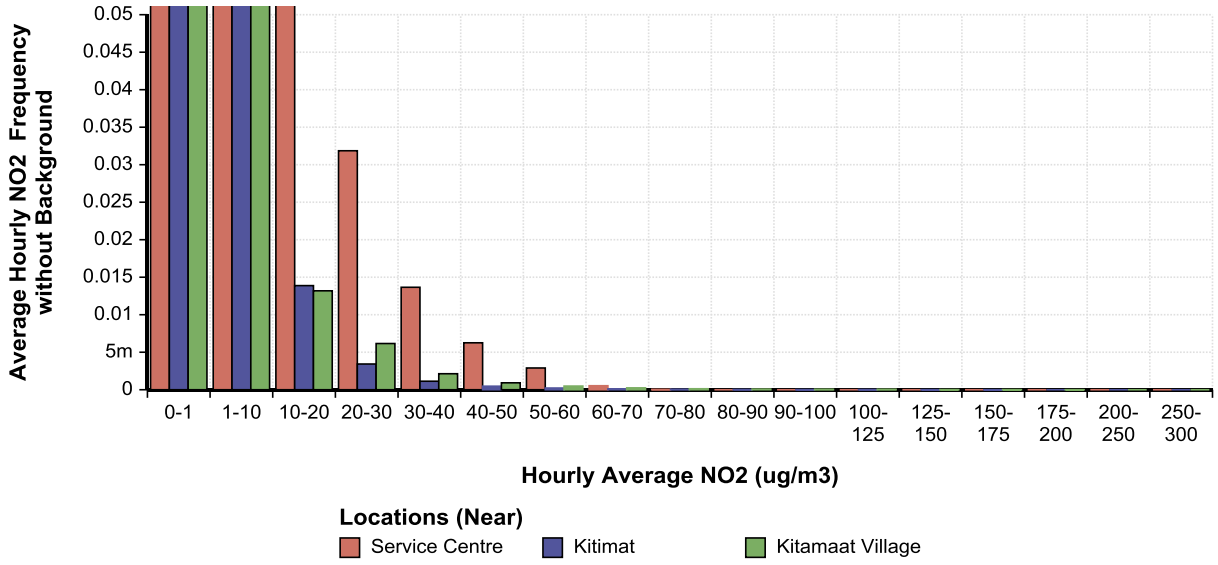


Figure 3-14. Histogram of hourly NO_2 concentrations for the Near locations for Scenario A_28.2 "zoomed in" to show only frequencies in the range of 0 to 5%. (Same data as shown in Figure 3-12, with modified scale on vertical axis.)

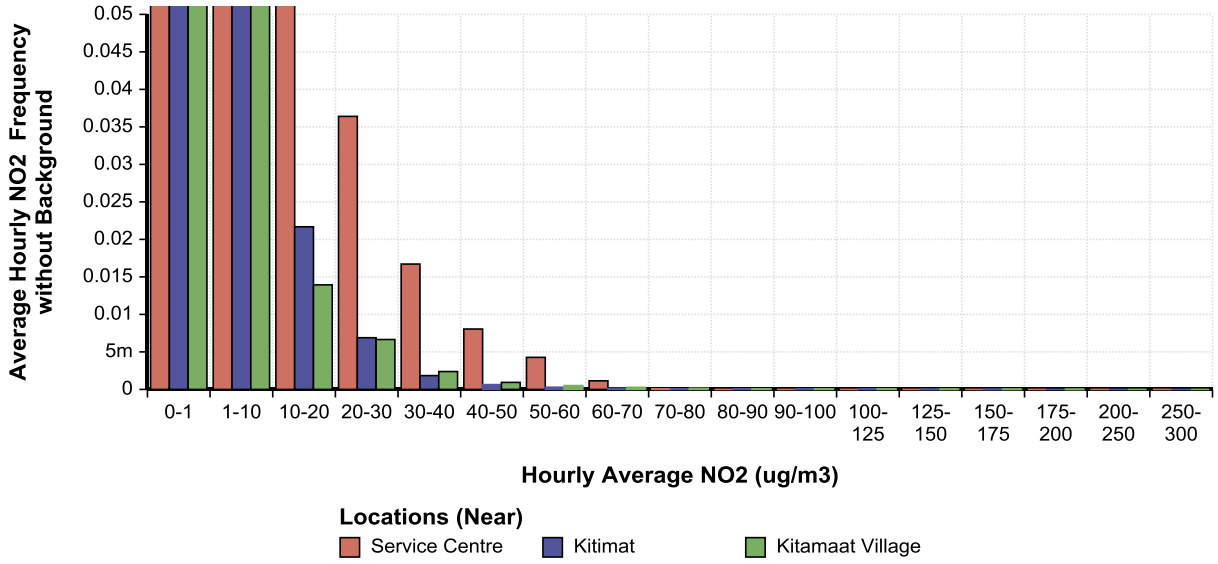


Figure 3-15. Histogram of hourly NO_2 concentrations for the Near locations for Scenario H_82.6 "zoomed in" to show only frequencies in the range of 0 to 5%. (Same data as shown in Figure 3-13, with modified scale on vertical axis.)

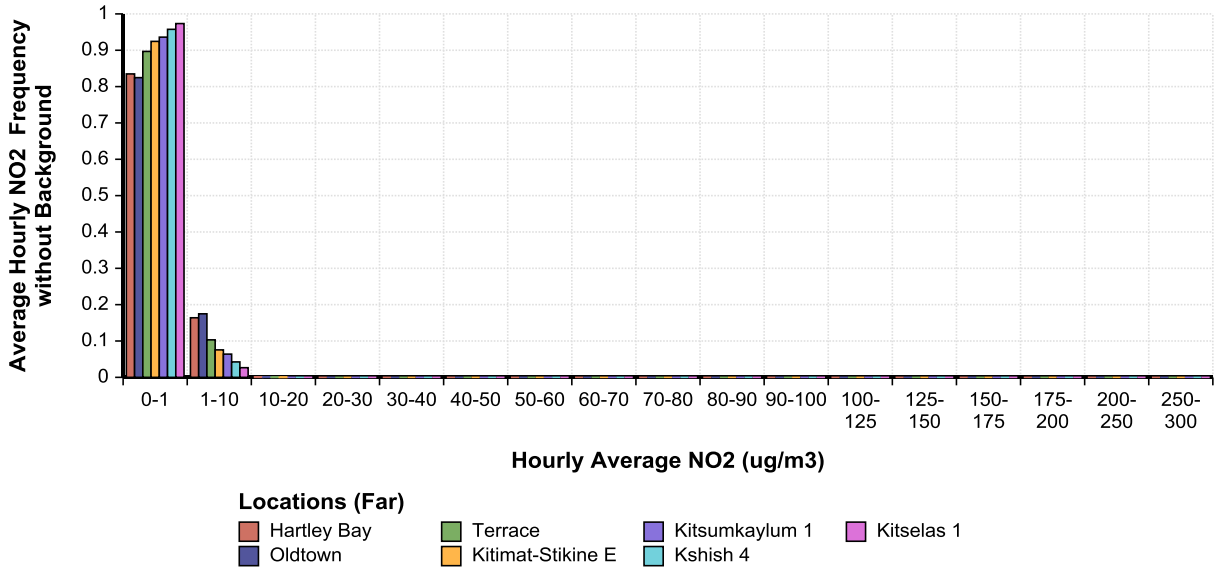


Figure 3-16. Histogram of NO_2 hourly averaged concentrations derived from modelled emissions for the seven Far locations, for Scenario A_28.2.

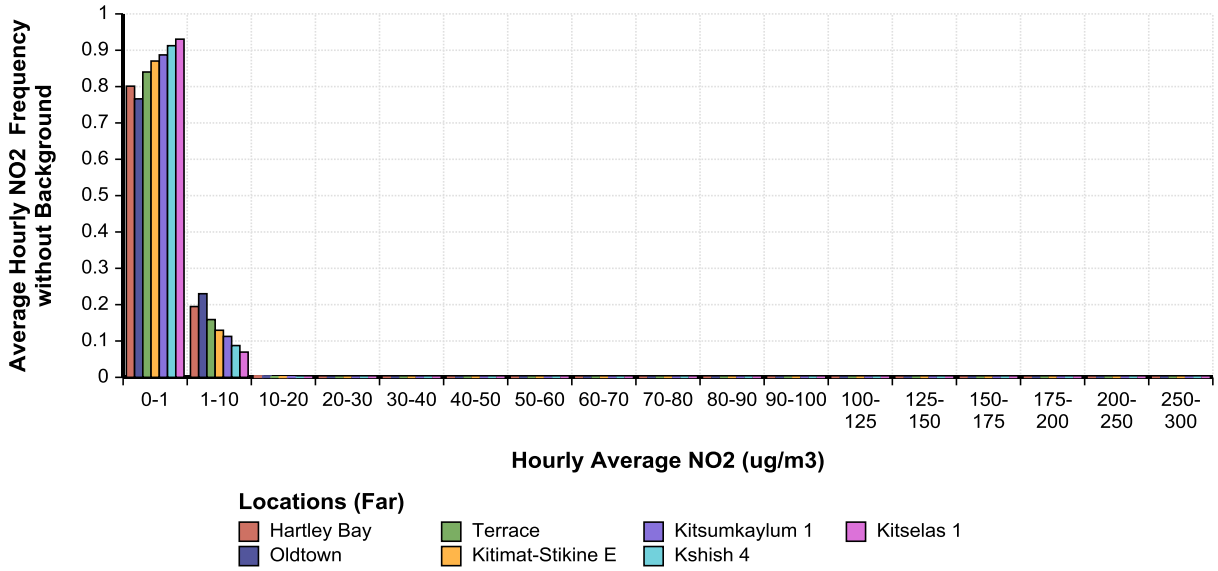


Figure 3-17. Histogram of NO_2 hourly averaged concentrations derived from modelled emissions for the seven Far locations, for Scenario H_82.6.

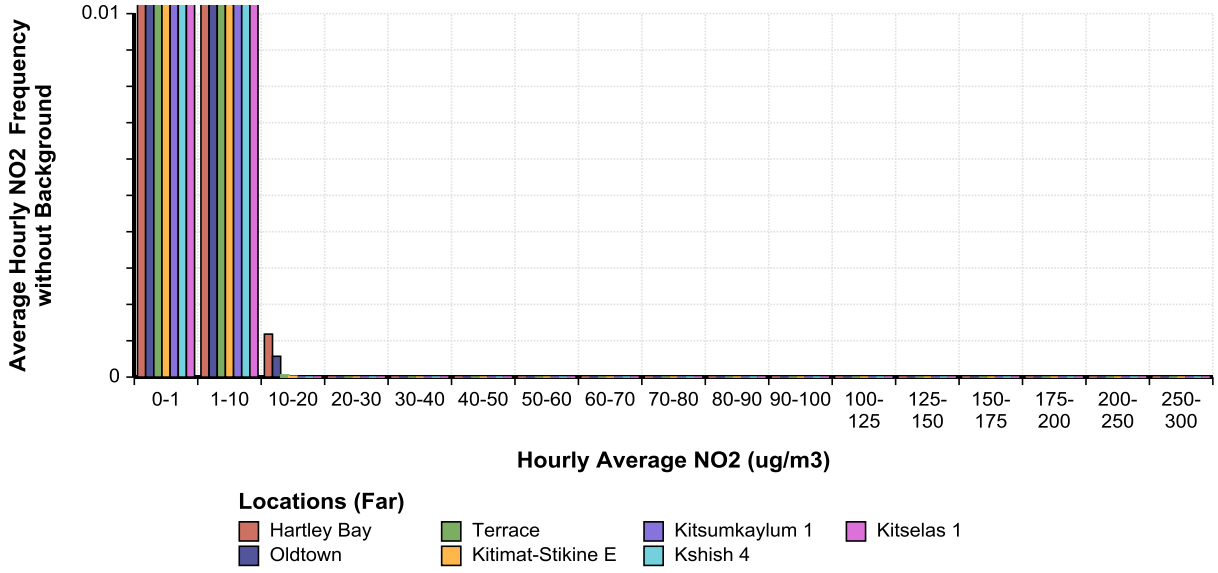


Figure 3-18. Histogram of hourly NO_2 concentrations for the Far locations for Scenario A_28.2 "zoomed in" to show only frequencies in the range of 0 to 1%. (Same data as shown in Figure 3-16, with modified scale on vertical axis.)

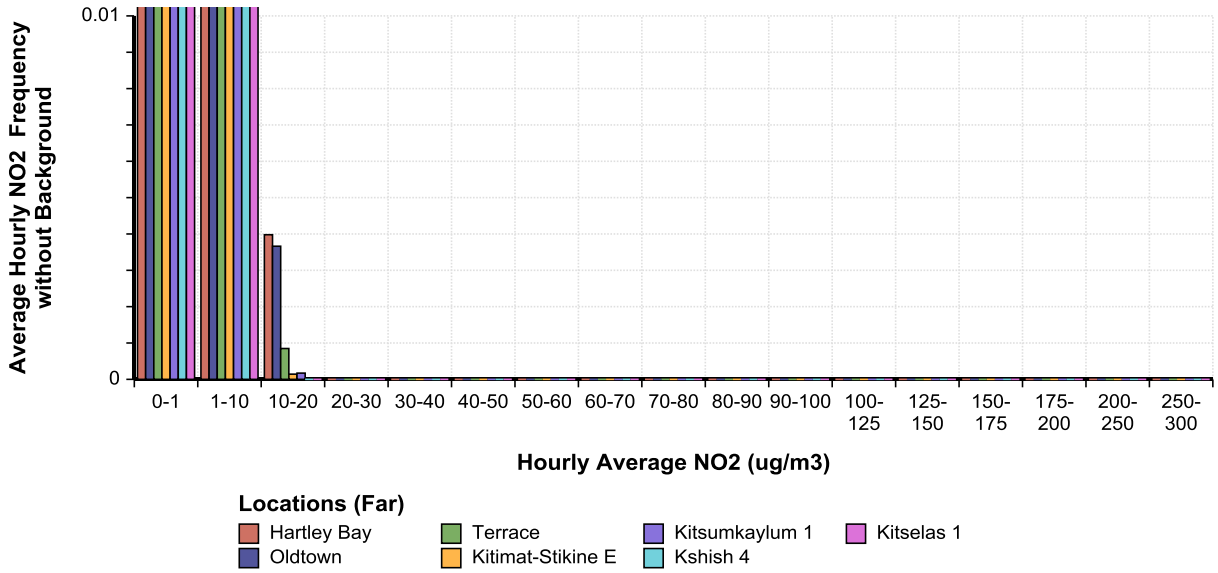


Figure 3-19. Histogram of Hourly NO_2 concentrations for the Far locations for Scenario H_82.6 "zoomed in" to show only frequencies in the range of 0 to 1%. (Same data as shown in Figure 3-17, with modified scale on vertical axis.)

3.4.5 Annual Average Concentrations of NO_2

Figure 3-20 provides the annual average NO_2 concentration at each location where all of the hours for all of the grid points in each location are pooled, for each of the 10 scenarios considered. This figure does not include an estimate of the regional background for NO_2.

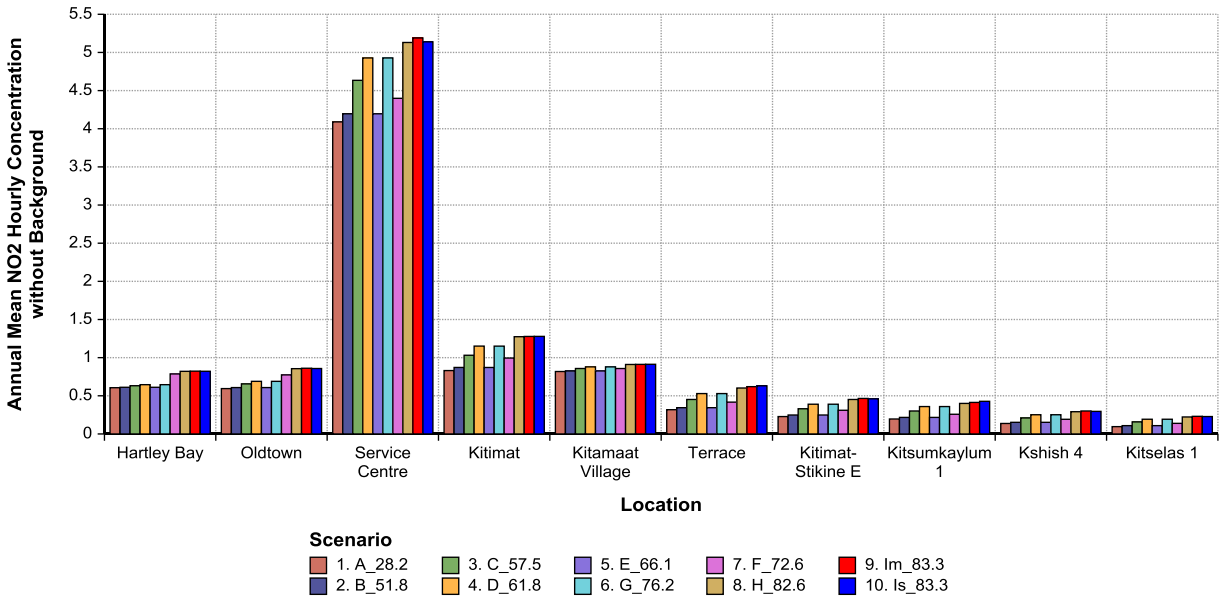


Figure 3-20. Annual average NO_2 concentration for all locations for Scenario A_28.2 through Scenario Is_83.3, not including an estimate of the annual average of regional background concentration levels. Note that this includes temporal as well as spatial averaging among the gridpoints in each location.

3.4.6 Threshold-based Categorization calculated using the EPA NAAQS Protocol

In consultation with MOE, it was determined that the preferred approach to employing the CCME-compatible air quality categorization scheme was to use the US EPA Primary NAAQS for both SO_2 and NO_2, and to use the US EPA's specific methods of calculating the appropriate statistic of the modelled concentrations including treatment of background. This was conducted with the exception of the requirement to average over three years which was not possible given only one year of modelled results.

A key distinction in employing the EPA method is to characterize an area by considering the point within the area that has the largest value (or maximum) of each statistic (i.e., for both averages and percentile values). Additionally, the US EPA approach calls for a specific method to calculate the 99th percentile and the 98th percentile values. The method of calculation involves the following:

- The calculation is done at every grid point, so that there is no spatial pooling of concentration values.
- A constant background value, consisting of the 99th (for SO_2) or 98th (for NO_2) percentile of estimated regional background concentration, is added to the concentration at each grid point.
- For the 99th percentile values (for SO_2), the daily maximum of hourly averages is calculated. The fourth highest daily maximum (including the added background value) is taken as the 99th percentile value for purposes of comparison with the NAAQS value. (The fourth highest is chosen since 1% of 365 days is 3.65 days.)
- The calculation of the 98th percentile (for NO_2) is identical to the calculation of the 99th percentile (for SO_2) except for the exclusion of seven days rather than three. (The seventh highest is chosen since 2% of 365 days is 7.3 days.)

- For each location (which consists of multiple grid points), the largest such percentile value among the grid points is compared to the threshold.

When calculating annual average values, several of the same points apply:

- The calculation is done at every grid point, so that there is no spatial pooling of concentration values.
- A constant background value, the annual average of estimated regional background concentrations, is added to the concentration at each grid point.
- For each location (which consists of multiple grid points), the largest such annual average value among the grid points is compared to the threshold.

The background values used for each calculation are listed in the table below. For the purposes of comparison to the associated thresholds, the background values for SO_2 are largely unimportant when compared to the modelled values. However, for NO_2, these values contribute substantially to the overall calculation of the statistic that is compared to the threshold.

SO_2 Annual Average	1.07 µg/m^3
SO_2 Hourly 99th Percentile	3.92 µg/m^3
NO_2 Annual Average (Quesnel-based)	17.74 µg/m^3
NO_2 Annual Average (Kitimat mobile monitor)	4.3 µg/m^3
NO_2 Hourly 98th Percentile (Quesnel-based)	57.53 µg/m^3
NO_2 Hourly 98th Percentile (Kitimat mobile monitor)	18.00 ug/m^3

3.4.7 Categorization of Annual Average Concentrations of SO_2

When including the estimated background annual mean concentration, the resulting values (the maximum annual average among gridpoints in each location) range from very small (1.27 µg/m^3) to 15.41 µg/m^3 for Scenarios F_72.6, H_82.6, Im_83.3, and Is_83.3 (Figure 3-21). The threshold separating the Yellow and Orange categories is 15 µg/m^3, set at approximately half of the Canadian National Ambient Air Quality Objective (CNAAQO) (Desirable Category) of 30 µg/m^3. Note that the CNAAQO labelled "Acceptable" for annual average SO_2 is 60 µg/m^3, such that this categorization scheme (equating the exceedance of the "Desirable" threshold with the Red category) represents a conservative interpretation of the intent of those objectives.

As a result, the annual average concentration of SO_2 is categorized as Yellow for Scenarios A_28.2 through I_83.3 in all locations except the Service Centre. For the Service Centre, the values span the range from 10.48 to 15.41 and therefore are Orange for some higher emissions scenarios (E_66.1 through Is_83.3).

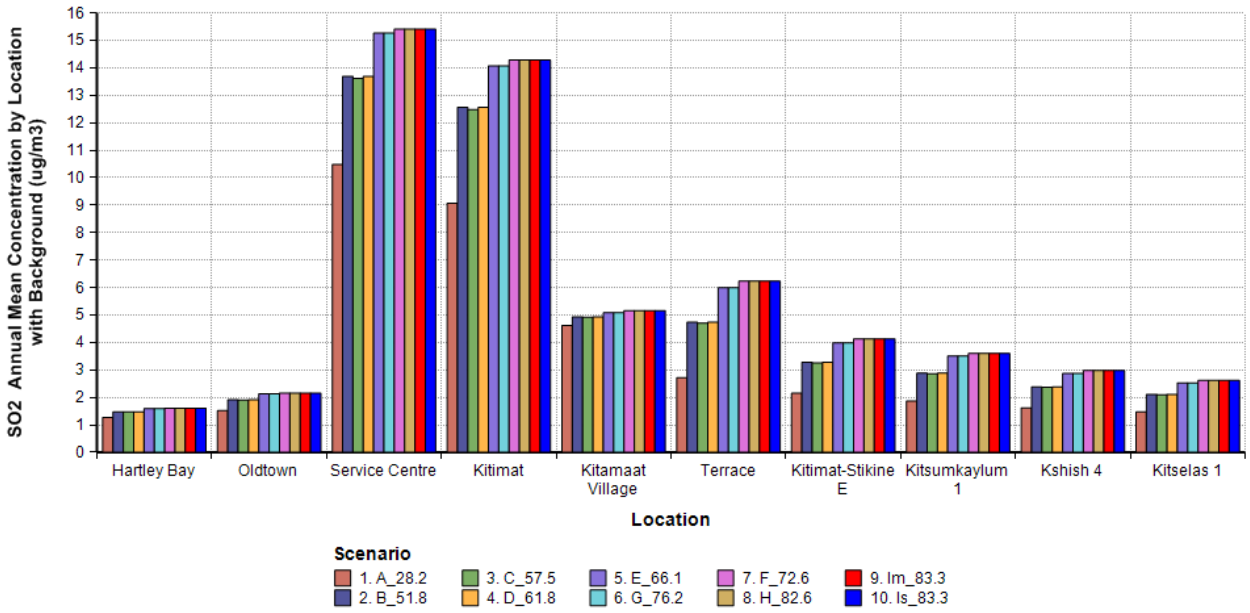


Figure 3-21. Annual Mean SO_2 concentration, including background of 1.07 µg/m^3, by location and scenarios.

3.4.8 Categorization of Annual Average Concentrations of NO_2

When including the estimated background annual mean concentration, the resulting values are on the order of 20 µg/m^3, as seen in Figure 3-22. This value is less than half of the threshold between Yellow and Orange (49 µg/m^3). Note that the values shown are dominated by a comparably larger background value of 17.74 µg/m^3, which may be a very conservative (i.e., high) estimate of annual average background NO_2 concentrations, and is almost certainly so for the residential locations outside of the larger communities of Kitimat and Terrace.

Given that the threshold separating the Yellow and Orange categories is 49 µg/m^3, the annual average concentration clearly falls in the Yellow category for Scenarios A_28/2 though Is_83.3, and in all locations.

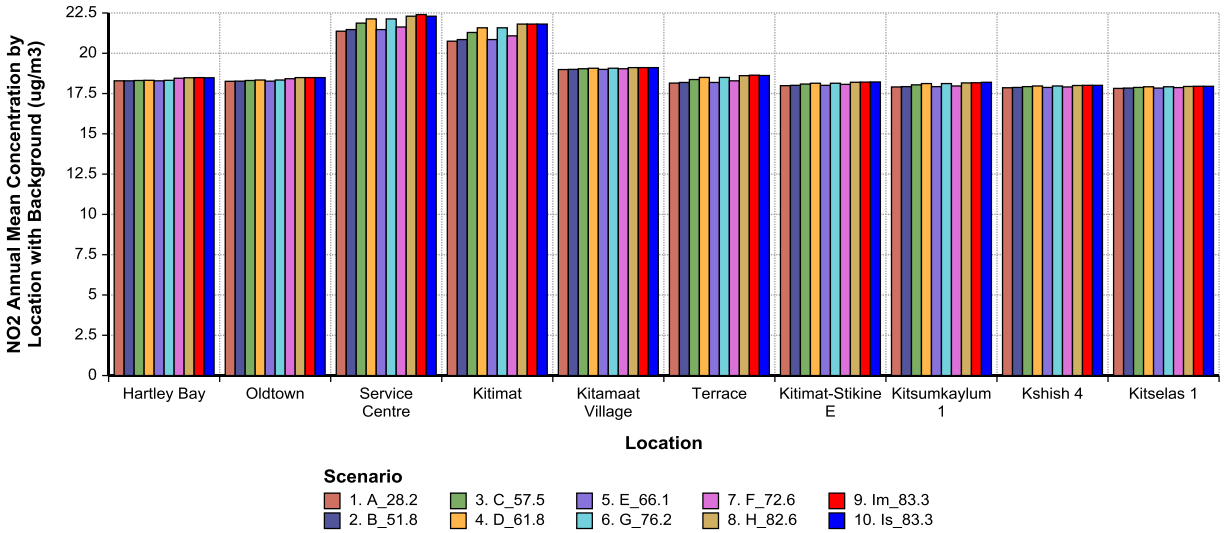


Figure 3-22. Annual Mean NO_2 concentration, including background of 17.74 µg/m^3, by location and scenario. The maximum value among gridpoints in each location is shown.

3.4.9 Categorization of Hourly Average Concentrations of SO_2

The categorization of hourly average concentrations for SO_2 is based on the 99th percentile of the modelled concentrations, including the addition of an estimate of the 99th percentile of background SO_2. In this case, the impact of the estimated background concentration is relatively small (less than 4 µg/m^3) and will not contribute substantially to making the overall 99th percentile value more conservative (as compared to the situation for NO_2).

As seen in Figure 3-23, the three Near areas have maximum 99th percentile values over 196 µg/m^3 for all scenarios (with one exception, Scenario A_28.2 for the Service Centre location). These locations, for essentially all scenarios, fall into the Red category for this metric. The Far locations all have maximum 99th percentile values below 100 µg/m^3 for all scenarios, and are therefore categorized as Yellow.

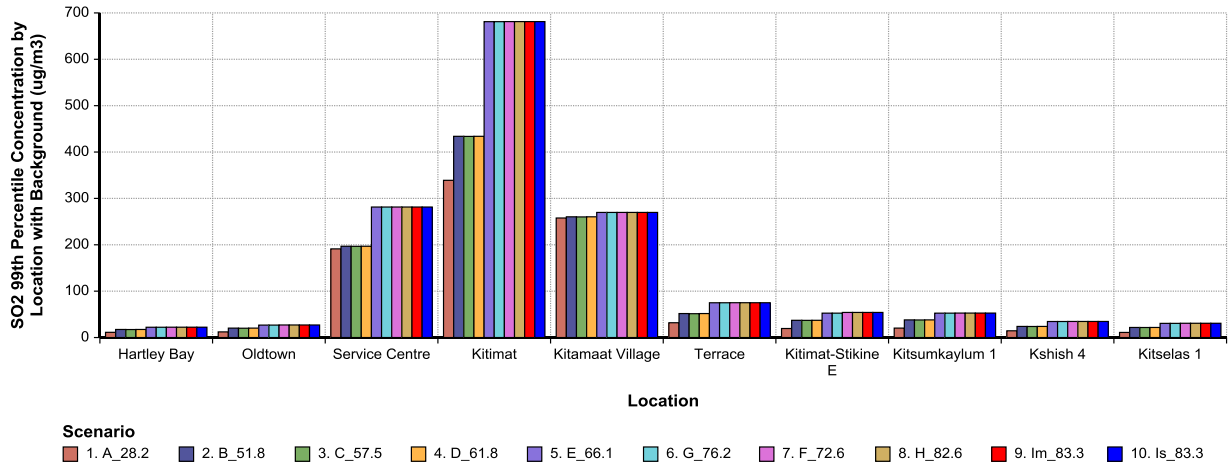


Figure 3-23. Maximum values, by location and scenario, of the 99th percentile hourly average concentrations of SO_2.

3.4.10 Categorization of Hourly Average Concentrations of NO_2

The categorization of hourly average concentrations for NO_2 is based on the 98th percentile of the modelled concentrations, including the addition of an estimate of the 98th percentile of background NO_2. In this case, the impact of the estimated background concentration is quite large (approximately 57 µg/m^3) and contributes substantially to making the overall estimate of the 98th percentile values more conservative. As discussed above, the background estimates are derived from another location (Quesnel). Another estimate of background was provided by MOE based on a mobile monitoring station which measured NO_2 levels in Kitimat from 13 Sept 2010 – 21 Nov 2011. The 98th percentile value for this period was approximately 18 µg/m^3. Due to the magnitude of the difference (approximately 40 µg/m^3), both backgrounds are used below.

When employing the Quesnel background, as seen in Figure 3-24, the three Near areas have maximum 98th percentile values above 105 µg/m^3 and below 188 µg/m^3 for all scenarios and are categorized as Orange. The Far locations all have maximum 98th percentile values below 105 µg/m^3 for all scenarios, and are therefore categorized as Yellow.

When employing the Kitimat mobile monitoring background, as seen in Figure 3-25, all areas except Kitimat have maximum 98th percentile values below 105 µg/m^3 for all scenarios and would therefore be categorized as Yellow. For the Kitimat location, the values essentially "straddle" the threshold of 105 µg/m^3 (ranging from 103 to 109 µg/m^3). The Kitimat location is therefore categorized as Yellow for Scenarios A_28.2, B_51.8 and E_66.1, and Orange for all other scenarios.

Given that the Kitimat location is the most affected with respect to this metric, it is appropriate to use the Kitimat monitoring data rather than the Quesnel data for the purposes of this categorization.

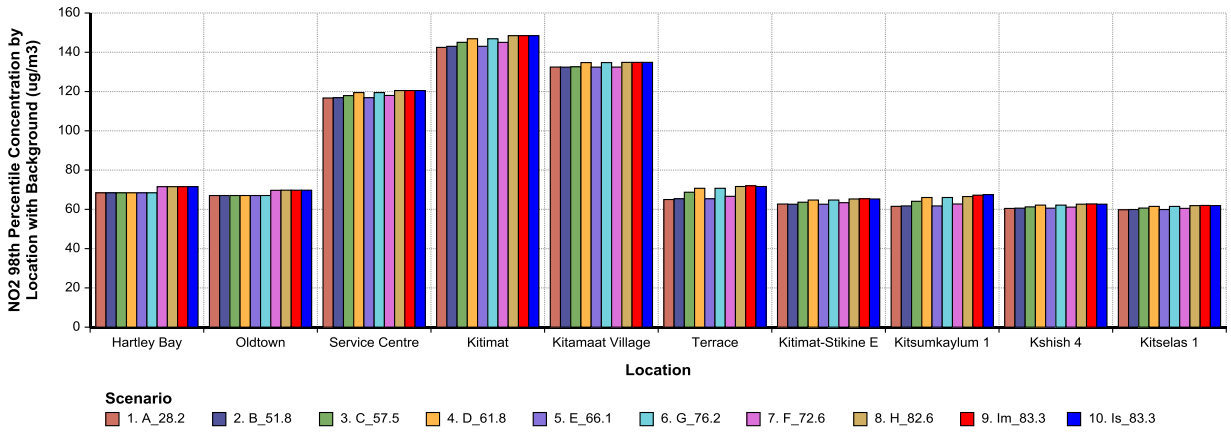


Figure 3-24. Maximum values, by location and scenario, of the 98th percentile hourly average concentrations of NO_2. This graphs shows the value when the Quesnel-based background is applied.

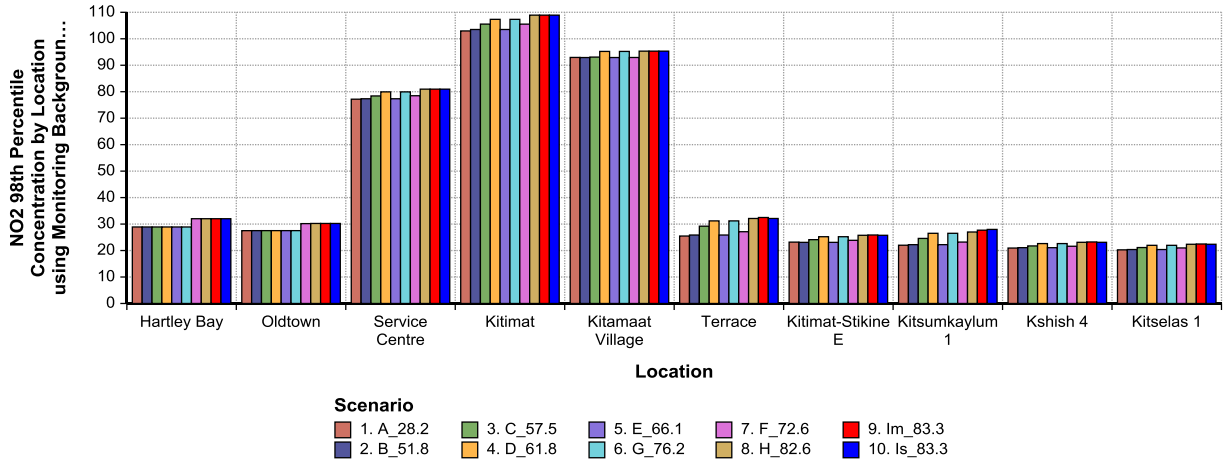


Figure 3-25. Maximum values, by location and scenario, of the 98th percentile hourly average concentrations of NO_2. This graphs shows the value when the Kitimat mobile monitoring background is applied.

3.4.11 Summary of Categorization of Results

The human health categorization has been conducted using a modified version of the CCME air quality categorization scheme, adding thresholds for SO_2 (hourly and annual) and NO_2 (hourly and annual). This includes thresholds which categorize modelled concentrations into four categories, depicted by the colours Green, Yellow, Orange and Red, implying the need for increased efforts to manage air quality as described by the CCME (CCME 2012).

The results of the risk categorization are provided in Table 3-5.

Table 3-5. Human health effect categorization.

Criterion	Scenarios	Locations	Categorization
SO_2 Annual Average	All	All, except Service Centre	Yellow
SO_2 Annual Average	A_28.2, B_51.8, C_57.5, D_61.8	Service Centre	Yellow
SO_2 Annual Average	E_66.1, F_72.6, G_76.2, H_82.6, I_83.3	Service Centre	Orange
NO_2 Annual Average	All	All	Yellow
SO_2 Hourly 99th Percentile	All[a]	Service Centre[a], Kitimat, Kitamaat Village	Red
	All	All "Far" locations	Yellow
NO_2 Hourly 98th Percentile (Quesnel background)	All	All "Far" locations	Yellow
	All	Service Centre, Kitimat, Kitamaat Village	Orange
NO_2 Hourly 98th Percentile (Kitimat mobile monitor background)	All	All "Far" locations, Service Centre, Kitamaat Village	Yellow
	A_28.2, B_51.8, E_66.1	Kitimat	Yellow
	C_57.5, D_61.8, F_72.6, G_76.2, H_82.6, I_83.3	Kitimat	Orange

[a] Note: for Scenario A_28.2, the Service Centre location (192 µg/m^3) is slightly below 196 µg/m^3 and would strictly be classified as Orange.

3.4.12 Relative Health Risk Estimates for SO_2

In order to describe the amount of change in health risk related to asthma symptoms that may be associated with increasing concentrations of SO_2, a relative risk estimation process was conducted for the three most affected locations with respect to SO_2 (the Near locations: Service Centre, Kitimat, Kitamaat Village). This calculation employed the dose-response relationship previously developed by US EPA (2008) and other calculation methods and assumptions described in the KMP SO_2 Technical Assessment Report (ESSA et al. 2013). As a relative risk estimate exercise, certain variables common to all scenarios can be assumed to be equal (e.g., exercise frequency, indoor-outdoor ratio of activity, percentage of persons with chronic respiratory diseases) and are therefore not described here. The only thing that is assumed to change from one scenario to the next is the modelled frequency of hourly-average concentrations. In these calculations, the relative frequency of concentrations in any location is derived from pooling all of the hourly concentrations from all grid points within each location area, representing exercise events occurring randomly in both space and time within each location area. There is an additional layer of conservatism relative to the KMP SO_2 technical assessment calculations in that the entire 24-hour period is included, rather than being limited to the hours between 6 am and 10 pm. This will tend to include periods of higher concentrations which may occur overnight.

The calculations consider the entire spectrum of hourly concentrations, rather than simply the average, or the very conservatively-estimated high percentile value of the hourly concentrations. The results are shown in two different contexts, both of which are informative. In Figure 3-26, the percentage increase in the number of SO_2-related asthma symptom exacerbation events (respiratory responses) is estimated relative to Scenario A_28.2. This helps to understand the change to be expected from one scenario to the next. Scenarios B_51.8, C_57.5, and D_61.8 generate an increase of approximately 40% as compared to Scenario A_28.2, while Scenarios E_66.1 through Is_83.3 generate an increase of approximately 70% as compared to Scenario A_28.2.

However, these increases need to be understood in the broader context of all causes of respiratory responses among the affected populations. In Figure 3-27, the percent increase is shown relative to all causes of respiratory responses, assuming that affected individuals will experience respiratory symptoms at least once per week, on average. As illustrated, the percent increase is up to 2% in the Service Centre location, but is less than 0.5% in the Kitimat and Kitamaat Village locations.

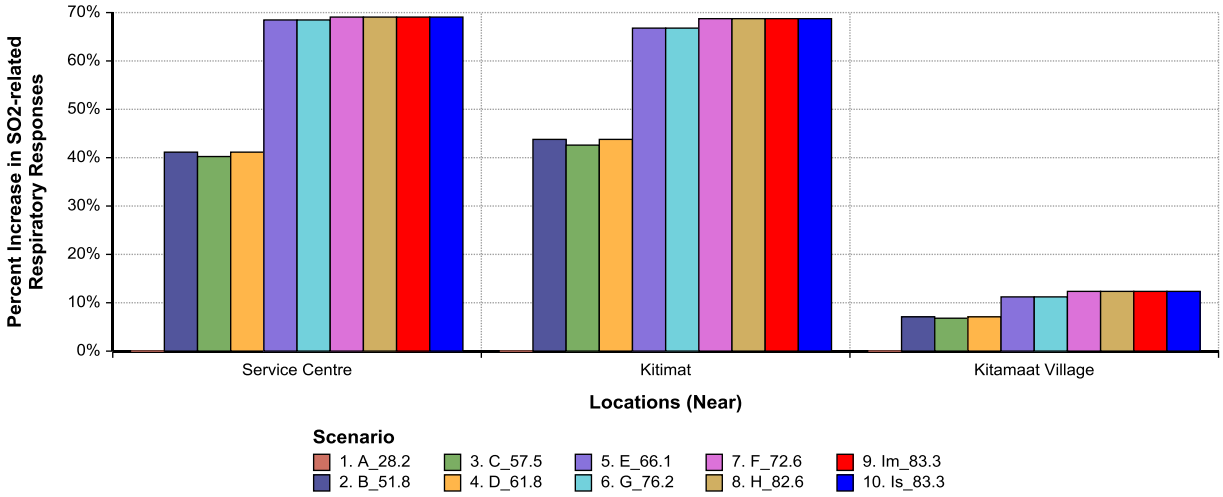


Figure 3-26. Percent increase in SO_2-related respiratory responses relative to Scenario A_28.2. Scenario A_28.2 is considered the baseline (with a separate baseline value in each location) and is therefore set to zero.

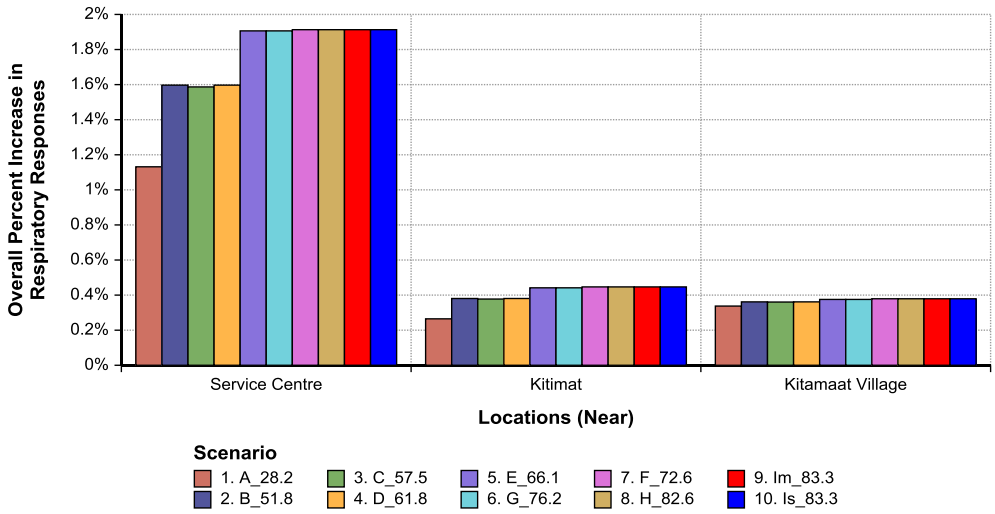


Figure 3-27. Overall percent increase in respiratory responses among affected individuals. This assumes a background rate of one respiratory symptom response per week per affected individual from all causes. These values are not relative to Scenario A_28.2.

3.4.13 Relative Health Risk Estimation for NO_2

For the present assessment, we have used a surrogate estimate of health risk to express the relative risk associated with the various scenarios as compared to each other, and to background exposures of NO_2. We use the annual average NO_2 concentration as a surrogate for health risk. This is based on the literature-review findings that, where dose-response relationships have been estimated, they tend to be linear and a threshold below which no health effects are seen has not been identified. As a result of the linear dose-response curve, the annual average may be a reasonable surrogate for the estimated level of health risk, particularly on a relative basis.

As seen in Figure 3-28, when considering Quesnel as the basis for background exposure (annual average of 17.74 µg/m^3), the increase in annual average concentration is relatively small, except in the Service Centre location. In Figure 3-29, using the annual average from the Kitimat mobile monitor as an estimate of annual average background (approximately 4.3 µg/m^3), the percentage increase is comparably higher, but based on a much smaller background level.

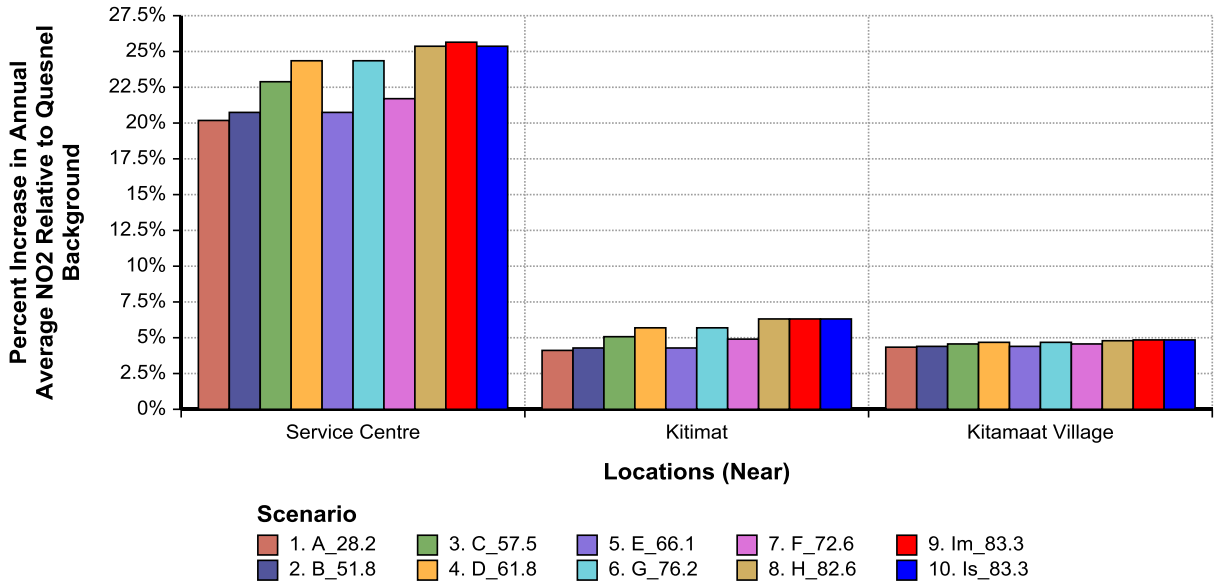


Figure 3-28. Percent increase in annual average NO_2 relative to Quesnel background.

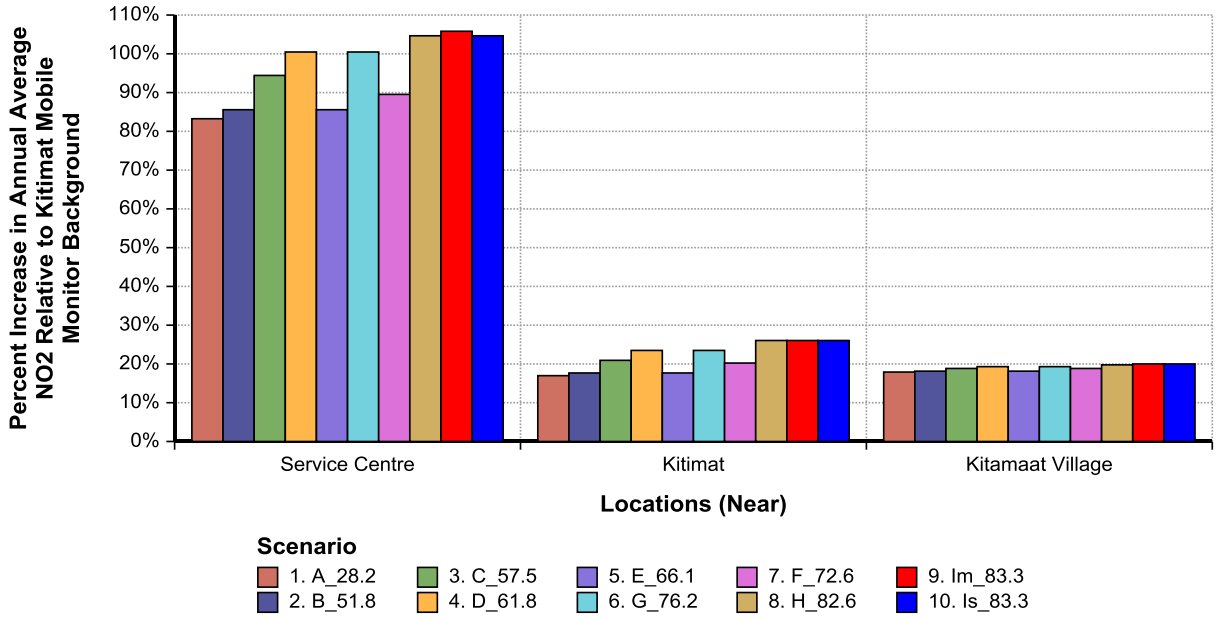


Figure 3-29. Percent increase in annual average NO_2 relative to Kitimat mobile monitor background.

3.4.14 Applicability of Threshold-based Risk Characterization

The characterization of the scenarios above demonstrates the need to be very cautious in interpreting the threshold-based categorization of health effects. The CCME approach using multiple thresholds, combined with using the US EPA's very conservative protocol for generating concentration estimates to compare against thresholds, leads to potentially distorted characterizations of the "state of the air."

It is important to understand that neither SO_2 nor NO_2 is known to have a threshold below which no health effects occur. Accordingly, there is no specific health consequence or change in health state of the population associated with an increase that causes a threshold to be exceeded in one of the metrics (an average or a percentile) of pollutant concentration. All increases in pollutant concentrations are associated with the expectation of some increased risk, such that increases that lead to the crossing of thresholds are not distinct from a human health perspective. As a result, the segregation of the modelled concentration results into colour-coded "bins" represents an arbitrary conversion of a continuous phenomenon into discrete categories. Nonetheless, such schemes are commonplace in health risk assessment and risk management generally and can be a useful management tool provided they are not misunderstood to represent a "step-wise" change in the level of public health risk.

3.4.15 Context-Specific Interpretation of the 98th and 99th Percentile Calculations

Although the 98th and 99th percentile values for NO_2 and SO_2, respectively, were chosen based on the US EPA precedent and the potential compatibility with the CCME threshold approach, they may not be ideal indicators for scoping the combined impact of multiple point sources within an airshed. The 98th and 99th percentile values are likely to be dominated by particular occurrences involving a single source and a single wind direction or meteorological condition. These values may not be changed at all, even given the addition of significant amounts of pollutants from other sources, if they remain driven by a

dominant combination of a single source, which may be different for each location, and a meteorological condition relating to that specific source and location.

The calculation method of percentile values for comparison to thresholds further distorts the values and deviates from a risk-based perspective on the pattern of concentrations:

- As seen from the various histograms, these values represent extreme tail values that do not contribute significantly to health risk when compared to the much lower and more frequent values, as described in the KMP SO_2 Technical Assessment Report (ESSA it al. 2013).
- The addition of 98th percentile background to the 98th percentile modelled results can generate a very conservative estimate of the 98th percentile (less important for SO_2 due to the very low background).
- As opposed to demonstrating industrial process or traffic-related variability, they represent only meteorological variability.
- The protocol does not differentiate between daytime and nighttime hours, which is important to predict exercise-related exposure events.
- The location is characterized by infrequent meteorological events and based on its worst gridpoint.

The range of 99th and 98th percentile values within a location can be quite large, as seen in Table 3-6 for Kitimat (Scenario H_82.6, Quesnel background). The 99th percentile values range from 58 to 681 for SO_2, spanning the Yellow through Red categories. The 98th percentile values for NO_2 range from 67 to 148, spanning Yellow (75% of gridpoints) and Orange. Only the last row (maximum) is used to define the category (Red and Orange) respectively. The maximum values are shown in Figure 3-23 and Figure 3-24.

Table 3-6. Range of values within the Kitimat location for the 99th and 98th percentile calculations. Only the maximum values are used in categorization.

Percentile among gridpoints	99th Percentile (SO_2)	98th Percentile (NO_2)
0 (minimum)	57.7	67
25	111	79.2
50 (median)	150	87.8
75	239.25	103
100 (maximum)	681	148

The high values of the maximum 99th percentile values of SO_2 (which yields the Red categorization) seen in the Near locations do not translate to a significantly increased public health risk. This conclusion is supported by the relative risk assessment results which predict an increase of less than 2% in overall asthma symptom events for the worst affected location, and less than a 0.5% increase in all other areas.

As discussed above with respect to increases in NO_2 emissions, when causality is assumed, a linear dose response is often commonly assumed, which makes the annual average a potentially appropriate risk indicator for both short-term and long-term health effects. The incremental impact of the combined NO_2 emissions may be best represented by variations on Figure 3-29, showing the change in the annual average NO_2 for each scenario, relative to estimates of background levels of NO_2 measured in Kitimat. This indicator may serve as a surrogate estimate of the relative increase in risk due to NO_2 for both short-term exposures and the potential effects of any long-term exposures.

3.4.16 Characterization of the Impact of Uncertainties

Most of the uncertainty or ambiguity associated with interpretation of the risk characterization comes from the following sources:

- Uncertainties which are related to air dispersion modelling generally since they are relied upon for these conclusions.
- Several categories of health effects that are arguably more serious than the health effects currently causally linked to SO_2 and NO_2 (see Table 3-1) may ultimately be linked, but are not yet thought to be linked with sufficient certainty, to exposure to SO_2 and NO_2. The changing epistemic status of these links to more serious health outcomes may significantly change the perceived tolerability of the thresholds associated with these categories (as may be re-assessed by US EPA, CCME, MOE or other organizations).

4 VEGETATION

4.1 Methods

Oxides of sulphur and nitrogen are both known to be directly injurious (either visible injury to leaves or reductions in growth or yields) to vegetation when they occur in ambient exposures that surpass thresholds in concentration, time, or some critical combination. Minimum exposure times or concentrations bound potential effects on the low end (e.g., very low concentrations or very short exposure durations), and the start and end of the growing season generally bound the potential long-term low-level chronic effects. Multiple-year, chronic effects causing decline in perennial plants can occur. Based on these considerations, critical exposure durations and concentrations have been established in the scientific literature through research and observations over many decades, and these form the basis for risk assessments in North America and Europe. That substantial body of scientific literature has allowed the development of air quality objectives (Canada), standards (United States), and recommendations (Europe). The literature relating to effects of SO_2 and NO_2 has been recently reviewed and synthesized (WHO 2000; Laurence 2012; US EPA 2011; European Environment Agency 2013). Based on recent scientific reviews and assessments, air quality objectives and guidelines have been left unchanged for a number of years; there is little new research on the direct effects of the pollutants under controlled exposures (most was conducted in the 1970s – 1980s) and there is little or no evidence that the existing objectives and standards are not effective (US EPA 2008, 2011).

Both SO_2 and NO_2 are taken up during the process of gas exchange by plants, so the flux of pollutant into leaves is determined by the concentration in the air and the rate of exchange between the leaf and the atmosphere. Because of that, exposures that take place in different seasons of the year, different times of the day, or under variable weather conditions can have different effects on the physiology of the plant. (The detailed analysis of the time series of predicted exposures is outside the scope of this analysis.) Repeated exposures below a threshold may cause unexpected effects if the exposures occur close in time or several times through the growing season. Similarly, exposures to high concentrations at times of the day when plants are not physiologically active may not cause injury. Effects of pollutant exposure may also accumulate through the growing season, or over multiple growing seasons, resulting in symptoms of chronic exposure. Therefore, we used vegetation thresholds and summary statistics in this analysis to account for variability and uncertainty, and to assess the margin of safety we might expect.

Air pollutants may also interact with other stressors, such as insects or pathogens. If plants are placed under substantial stress, they may become more susceptible to attack, particularly by pests and pathogens related to decline diseases (rather than primary pests and pathogens). There is evidence of a relationship between an insect outbreak and emissions from RTA in the 1960s and 1970s, although an exact cause of the saddleback looper infestation was never determined. There have been no noticeable occurrences in the past 30 or more years (L.H. Weinstein, pers. comm., and author's 10 seasons of experience conducting vegetation surveys in the valley since 1997).

Based on syntheses of the most recent North American and European literature (US EPA 2008, 2011; WHO 2000; European Environment Agency 2013), current air quality objectives for BC, and standards for the US, a set of metrics was selected to assess the likelihood of direct effects of SO_2 and NO_2 exposure on vegetation in the Kitimat airshed. Table 4-1 lists the metrics selected for evaluation. We examined an

annual averaging period as well as averaging periods of 1, 3 and 24 hours. Since plants respond to a variety of exposure types (e.g., short-term, high concentration, long-term, low concentration), using a variety of averaging periods allows us to assess the likelihood of direct effects on vegetation due to a range of exposures. Vegetation may also respond to peak, rather than mean, concentrations. By evaluating the exceedance of thresholds at different averaging periods, we can assess whether exposures are likely to be acute (short term peak) or chronic (long term mean). Many European thresholds for vegetation exposure are set based on annual means. The European Directive is currently set at annual averages of 30 µg/m^3 for NO_2 and 20 µg/m^3 for SO_2 to protect vegetation (EU 2008). WHO (2000) suggests a level of SO_2 of 10µg/m^3 to protect lichen taxa. While we do not tabulate exceedance of European directives, we do illustrate the spatial extent of relevant exposures.

Table 4-1. BC and Canadian Air Quality Objectives, and US EPA Standards for SO_2 and NO_2 for a range of averaging times. N/A indicates no objective or standard for that averaging time.

Averaging Period	SO_2 Threshold (µg/m^3)	NO_2 Threshold (µg/m^3)
	BC Air Quality Objectives	Canada Air Quality Objectives
1-hour	Lower: 450	Acceptable: 400
1-hour	Upper: 900	Tolerable: 1000
3-hour	Lower: 375	N/A
3-hour	Upper: 665	N/A
24-hour	Lower: 160	Acceptable: 200
24-hour	Upper: 260	Tolerable: 300
Annual	Lower: 25	Desirable: 60
Annual	Upper: 75	Acceptable: 100
	US EPA Secondary Standard	
3-hour	Half-standard: 650	
3-hour	Standard: 1300	
Annual	N/A	Standard: 100

In addition to the metrics shown in Table 4-1, we also computed the same metrics using exposures during the growing season (April 15 – September 15). The growing season was determined by when the mean daily temperature was greater than 5°C. Examining exposures during this period allows evaluation of likely effects of direct exposure since plants do not generally respond to exposures outside the growing season and uptake of gaseous pollutants is not significant during periods of reduced light. On warm, sunny days outside the growing season, conifers may take up small amounts of pollutants, but given the climate conditions of Kitimat, gas exchange during those periods is unlikely to be significant. Lichens and bryophytes are exceptions, so a combination of metrics may be used to assess the likely effects on those life forms. We report exceedances of these thresholds during the entire year and display exceedances within the growing season as well.

The metrics provide a range of thresholds and include, in the case of BC and Canadian objectives, lower and upper (or desirable, acceptable, and tolerable) levels. For SO_2, using the lower objectives and the half-standard[20] will provide a conservative comparison: direct effects of SO_2 would not be expected on vegetation at exposures less than those concentrations and times. In the case of NO_2, since plants are quite tolerant of the gas in terms of direct effects (exposures that are reported to cause direct effects

[20] The half-standard is literally half of the standard objective.

take, in general, many hours, days, or weeks at the specified concentrations), the objectives and standards are protective and injury to vegetation would not be expected to occur in response to those exposure levels. Short-term exposures reported to injure vegetation are often in the parts per million range (where 1 ppm = 1,880 µg/m^3) (US EPA 2011).

This discussion and the methods described relate to direct effects of SO_2 and NO_2 on vegetation, including bryophytes and lichens. It is established that both pollutants may cause indirect effects on vegetation through acidification processes discussed in Section 5, Soils.

Exposure statistics were calculated from the results of air quality dispersion modelling for each of the 12 scenarios. Total concentrations of NO_X are reported as NO_2, because thresholds for direct effects on vegetation are based on NO_2 exposure (and NO_2 is the most phytotoxic form of NO_X). Exposure statistics are based on thresholds identified in the literature, but also tailored for vegetation response and to reduce uncertainty associated with predicted air concentrations as described above.

For the purposes of estimating effects on vegetation in the airshed, we excluded concentrations at receptors located within the industrial zone because this area has been heavily impacted for decades. We also excluded the area over Douglas Channel because terrestrial vegetation does not occur there. Consequently, some of the highest concentrations modelled will not occur at a location of concern with respect to vegetation. The locations of the excluded receptors are shown in Figure 4-1.

In order to assess the likelihood and consequence of direct effects of SO_2 and NO_2 on vegetation, a combination of scientific literature review and best professional judgement was used to estimate potential effects. The likelihood and consequence dimensions of the risk assessment framework are defined below. Lichens are not included in this risk framework since the current distribution of lichens in the area is unknown (but under evaluation by the BC Ministry of Environment (MOE)). However, metrics of interest to assess the effects of deposition on lichens (annual mean concentration) are discussed.

For SO_2, the likelihood and consequence matrix was adopted from the KMP SO_2 Technical Assessment (ESSA et al. 2013) (Table 4-2, Table 4-3, Table 4-4). In the case of NO_2, the matrix was developed based on a recent synthesis of literature (Table 4-5, Table 4-6, Table 4-7) (US EPA 2008). The authors of that literature synthesis found that, in the hundreds of studies conducted to assess the effects of NO_2 on vegetation, clear dose-response relationships were not found. Visible injury was found to be unlikely at exposures of less than 360 µg/m^3 for at least 100 hours. In the short term, concentrations of 1,800 µg/m^3 for less than one day caused visible injury on some plants. WHO (2000) suggests that in Europe, exposures of 20 µg/m^3 for 1 year, 200 µg/m^3 for 1 day, or 1,000 µg/m^3 for 1 hour establish a critical level. The European Directive of 2008 (EU 2008) suggests that annual means of 20 µg/m^3 for SO_2 and 30µg/m^3 for NO_2 are appropriate as critical levels. There are limited studies of the effects of SO_2 and NO_2 in combination on plants, however, interactive effects were minor and at prolonged exposure (US EPA 2008), so they are not considered in the risk matrix. It should also be noted that characteristics of exposure are likely to be different in Europe given the configuration of sources. Additionally, levels of ozone (another phytotoxic pollutant) are likely to be greater in Europe than in the Kitimat area and could figure into the reported response of vegetation to other pollutants.

Table 4-2. Likelihood levels used in the risk assessment framework for vegetation and SO_2.

A – Almost Certain	B – Likely	C – Possible	D – Unlikely	E – Very Unlikely
Exposure of sensitive vegetation to >2,600 µg/m^3 for ≥1 hour during daylight hours of the growing season; Exposure of sensitive vegetation to 1,300 µg/m^3 for >3 hours on more than one occasion during daylight hours of the growing season	Exposure of the most sensitive vegetation to 1,300 µg/m^3 for 3 hours during daylight hours of the growing season	Exposure of the most sensitive vegetation to 650 µg/m^3 for >8 hours during daylight hours of the growing season	Exposure of the most sensitive vegetation to 650 µg/m^3 repeated daily during daylight hours of the growing season	Exposure of vegetation to less than 1,300 µg/m^3 for 3 hours or 650 µg/m^3 for 8 hours during daylight hours of the growing season

Table 4-3. Consequence levels used in the risk assessment framework for vegetation for SO_2.

1 - Minor	2 - Medium	3 - Serious	4 - Major	5 - Catastrophic
Occasional symptoms of injury due to SO_2 on leaves of the most sensitive species in the immediate vicinity of the industrial area	Symptoms of SO_2 injury extending beyond immediate vicinity of the industrial areas; Chronic symptoms (chlorosis/necrosis) resulting in unsightly appearance or indicating potential minor effects on growth	Severe and repeated symptoms of SO_2 injury on more than the most sensitive species, including species of economic or social importance; Symptoms of acute or chronic SO_2 injury at remote monitoring locations	Defoliation of trees and shrubs of high public importance at multiple locations due to SO_2	Death of trees, shrubs, and forbs of high public importance at multiple locations due to SO_2 exposures

Table 4-4. Impact categories from the combined likelihood and consequence dimensions of the risk assessment framework for vegetation for SO_2.

Likelihood (definitions in Table 4-2)	**Consequence** (definitions in Table 4-3)				
	1 – Minor	2 – Medium	3 – Serious	4 – Major	5 – Catastrophic
A – Almost certain	**Moderate**	**High**	**Critical**	**Critical**	**Critical**
B – Likely	**Moderate**	**High**	**High**	**Critical**	**Critical**
C – Possible	**Low**	**Moderate**	**High**	**Critical**	**Critical**
D – Unlikely	**Low**	**Low**	**Moderate**	**High**	**Critical**
E – Very Unlikely	**Low**	**Low**	**Moderate**	**High**	**High**

Table 4-5. Likelihood levels used in the risk assessment framework for vegetation and NO_2.

A – Almost Certain	B – Likely	C – Possible	D – Unlikely	E – Very Unlikely
Exposure of sensitive vegetation to >1,800 µg/m^3 for 24 hours or more during the growing season; Exposure of sensitive vegetation to 400 µg/m^3 for >100 hours continuously on one or more occasions during the growing season	Exposure of the most sensitive vegetation to 1000 µg/m^3 for 24 hours during the growing season	Exposure of the most sensitive vegetation to 300 µg/m^3 for >24 hours during the growing season	Exposure of the most sensitive vegetation to 400 µg/m^3 for 8 hours repeatedly during daylight hours of the growing season	Exposure of vegetation to less than 30 µg/m^3 continuously during daylight hours of the growing season

Table 4-6. Consequence levels used in the risk assessment framework for vegetation for NO_2.

1 - Minor	2 - Medium	3 - Serious	4 - Major	5 - Catastrophic
Occasional symptoms of injury due to NO_2 on leaves of the most sensitive species in the immediate vicinity of the industrial area	Symptoms of NO_2 injury extending beyond immediate vicinity of the industrial areas; Chronic symptoms (chlorosis/necrosis) indicating potential growth effects	Severe and repeated symptoms of NO_2 injury on more than the most sensitive species, including species of economic or social importance; Symptoms of NO_2 injury at remote monitoring locations	Defoliation of trees and shrubs of high public importance at multiple locations due to NO_2	Death of trees, shrubs, and forbs of high public importance at multiple locations due to NO_2 exposures

Table 4-7. Impact categories from the combined likelihood and consequence dimensions of the risk assessment framework for vegetation for NO_2.

Likelihood (definitions in Table 4-5)	**Consequence** (see definitions in Table 4-6)				
	1 – Minor	2 – Medium	3 – Serious	4 – Major	5 – Catastrophic
A – Almost certain	**Moderate**	**High**	**Critical**	**Critical**	**Critical**
B – Likely	**Moderate**	**High**	**High**	**Critical**	**Critical**
C – Possible	**Low**	**Moderate**	**High**	**Critical**	**Critical**
D – Unlikely	**Low**	**Low**	**Moderate**	**High**	**Critical**
E – Very Unlikely	**Low**	**Low**	**Moderate**	**High**	**High**

4.2 Results

Modelled concentrations for metrics of interest for SO_2 for all of the scenarios are shown in Section 4.2.1, and for NO_2 they are shown in Section 4.2.2. The numbers of exceedances of metrics of interest for SO_2 are shown in Section 4.2.3. Threshold metrics of interest for NO_2 were only exceeded in Scenario Jm_86.1 (Table 4-23) and only for the Maximum Acceptable 1-hour level.

Maximum concentrations of SO_2 occurred in Scenarios E_66.1, F_72.6, G_76.2, H_82.6, Is_83.3 and Im_83.3. The maximum and second maximum for 1-hour, 3-hour, and 24-hour averaging times occurred outside the growing season or at night, or both (Table 4-12, for instance). While there were many exceedances of the minimum 1-hour objective at receptors during the year, the percentage of receptor hours that were exceeded remains quite low. During the growing season (the period of concern), concentrations of SO_2 rarely exceeded the upper BC objective (e.g., Table 4-26 shows that the 1-hour objective was exceeded 4 times out of over 3,672 possible hours at each of 9,727 receptors).

Concentration isopleths for SO_2 maximum 3-hour averages during the growing seasons for Scenarios A_28.2 and H_82.6 are shown in Figure 4-2 and Figure 4-3. Concentration isopleths for the maximum 1-hour NO_2 concentrations are shown in Figure 4-4 and Figure 4-5 for Scenarios A_28.2 and H_82.6, respectively. Maximum 1-hour and annual average NO_2 isopleths for Scenario Jm_86.1 and Js_86.1 are shown in Figure 4-14 and Figure 4-15. In general, the occurrence of elevated concentrations is limited to the lower Kitimat Valley. Exposures do not pose a great concern for vegetation.

There are few exceedances of threshold metrics for SO_2 during the year, including during the growing season. The BC objective upper level of 665 µg/m^3 for 3 hours (approximately the same as 50 percent of the US EPA standard) was only exceeded once at 42 receptors in the worst case SO_2 scenarios (E_66.1, F_72.6, G_76.2, H_82.6, Is_83.3, and Im_83.3) and the 3-hour minimum level was exceeded at 131 receptors with a maximum of three times at any one receptor over the course of the growing season (Table 4-26 and Table 4-27). In Scenario A_28.2, there were only a few scattered exceedances of the metrics near the industrial area. These exceedances are well below the concentrations thought to cause direct effects on sensitive plant species. The location of exceedances is displayed in Figure 4-6 and Figure 4-7 for Scenarios A_28.2 and H_82.6 respectively. Under Scenario H_82.6, the exceedances are primarily confined to a residential area of Kitimat, with scattered exceedances occurring elsewhere in the valley, primarily against the valley wall to the west. Details of exceedances were not available for Scenario Jm_86.1.

Table 4-8 compares the numbers of threshold exceedances for SO_2 for the eight scenarios. Scenarios E_66.1, F_72.6, G_76.2, H_82.6, Is_83.3, Im_83.3, Js_86.2 and Jm_86.2 generate the greatest SO_2 exposures, while the base case, Scenario A_28.2, results in the fewest exceedances of the threshold metrics. Scenarios B_51.8, C_57.5, and D_61.8 are intermediate, but much more similar to the base case. The number of exceedances represents projections for over 35 million receptor-hours modelled.

The location of the BC Hydro electric generating facility did not change the conclusions from the results of the analysis with respect to potential direct effects of SO_2 or NO_2 on vegetation.

None of the scenarios are likely to result in widespread or severe effects on vegetation, based on the response of plants reported in the literature. Depending on the temporal distribution of exposures, visible injury on the most sensitive plants might be observed in some residential areas of Kitimat,

although effects on growth, yield, or the quality of produce would not be expected (US EPA 2008; Laurence 2012; ESSA et al. 2013). Direct injury would primarily result in unsightly appearance, similar to the sort of visual effect caused by insects or disease.

Threshold metrics for NO_2 were only exceeded for 1-hour concentration under Scenario Jm_86.1. However, exposures are well below those reported in the literature to cause visible injury to sensitive plant species (WHO 2000; US EPA 2008). Annual average concentrations that exceed European guidelines extend to approximately the same locations as under Scenarios Is_83.3 and Im_83.3.

Although interactions of pollutants are known to occur, the concentrations and durations of exposures expected under the scenarios modelled here are below those that have been reported to cause synergistic effects. Exposures are also below those that have been reported to impact the development of insects or diseases that affect plants.

The worst-case SO_2 annual mean of 42 $\mu g/m^3$ (and a growing season mean of 58 $\mu g/m^3$) exceeds the level of 10 $\mu g/m^3$ recommended by WHO (2000) to protect lichens, but high annual means are restricted to a small area. Figure 4-8 and Figure 4-9 show the extent of the annual mean SO_2 exposure for Scenarios A_28.2 and H_82.6, respectively. Figure 4-10 through Figure 4-12 illustrate the spatial extent of annual mean NO_2 exposures. Annual mean exposures that exceed the WHO recommendation are restricted to the valley west of the channel and east of the first major ridge, north about 10-20 km (depending on scenario), and as far south as the proposed site of Kitimat LNG.

Preliminary surveys indicate that the lichen flora east of Minette Bay are healthy and of the diversity expected for areas that have not been impacted by industrial pollution. The area to the west of Minette Bay shows the effects of industrial activities and forest harvest practices through reduced abundance and diversity, as would be expected (Patrick Williston, MOE, pers. comm.). The spatial distributions of pollutant exposure in the scenarios under study are similar, or more restricted than those that have occurred historically, in particular prior to reductions of emissions at the aluminum smelter.

There are sources of uncertainty in the analysis of the modelled scenarios with respect to plant response. The greatest source of uncertainty is that only one meteorological year was modelled, thus it is possible that conditions in other years could cause exposures to higher concentrations for greater periods of time, thereby increasing the probability of direct effects on vegetation. There is also uncertainty associated with the modelling of pollutant dispersion in complex terrain. In both cases, using threshold metrics that are conservative (e.g., the BC objectives and 50 percent of the US Standard) with respect to exposures that have been reported to injure vegetation provides a margin of error to accommodate the uncertainty in estimation of exposures.

A second source of uncertainty is the lack of knowledge about the sensitivity of plants in the Kitimat Valley to SO_2 and NO_2. In the case of NO_2, it is unlikely that the sensitivity of plants is so much greater than that reported in the literature so as to cause a problem. In the case of SO_2, there have been significant sources of SO_2 in the valley for some time and a vegetation monitoring program has been in effect. The results of decades of visual inspections indicate that direct effects of SO_2 on vegetation in the valley have not been a problem to date, and the likelihood of future problems has been addressed (ESSA et al. 2013). There is also a potential for chronic effects on plants, particularly perennial plants, from repeated years of exposure. There is little evidence, based on over 40 years of observations, that chronic effects (e.g., reduced needle retention in some Sitka spruce trees) occur outside of the primary industrial area on the west side of Minette Bay.

A third source of uncertainty relates to the interaction of pollutant emissions with other stresses. The literature indicates that SO_2 may alter the susceptibility of plants to attack by certain insects or pathogens. In general, studies under controlled conditions would indicate that exposures in excess of what are predicted here would be required to cause such interactions. There have been severe insect outbreaks in the Kitimat Valley in the past that may have been related to industrial emissions, but none have been reported for about the last 30 years. The scientific literature also documents indirect effects on vegetation due to deposition of acidifying pollutants (addressed in Sections 5 and 6 of this report). There is little known about the response of plants that are stressed from soil conditions to additional direct pollutant exposure, other than from those related to nutrient deficiencies in agricultural crops. So, for instance, the potential direct effects of SO_2 or NO_2 on plants in an ecosystem where S or N critical loads have been exceeded are unknown. To mitigate the effects of these uncertainties, we believe the use of a conservative threshold metric for exposures of concern should provide a margin of safety in estimation of effects.

Based on the results of the modelling from the scenarios and the exposures that are projected to occur, all scenarios result in a low risk in the risk characterization matrix. The probability of any scenario resulting in other than an unlikely occurrence at any distance from the industrial area of a minor effect of NO_2 is low based on the modelling results, thus most of the matrix is in the realm of exceedingly unlikely to occur. In the case of SO_2, it is unlikely that more than a minor consequence will be observed at a distance from the industrial area, resulting in a moderate risk rating at the maximum. It is likely that under the worst case, lichen diversity and abundance will continue to be of concern in the area west of Minette Bay, about 15 km north and south of Kitimat. Until more information is available on the current status, it is not possible to estimate the likelihood of future changes in the status of lichens.

The estimated likelihood and consequence, and the associated estimated risk for each scenario are shown in Table 4-29.

4.2.1 Tabular SO_2 Averaging Periods and Modelled Concentrations for all Scenarios

Table 4-8. Averaging periods and modelled concentrations for SO_2 under Scenario A_28.2. Exceedances are shown in bold.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] (µg/m^3)	BC Pollution Control Objectives [b] (µg/m^3)		US EPA STANDARD (µg/m^3)	Maximum Date and Time - All Receptors	
			Lower	Upper		Day of the year	Time
1-hour	1st	**536**	450	900	N/A	216	0000
1-hour	2nd	517	450	900	N/A	229	0000
3-hour	1st	**401**	375	665		091	2100
3-hour	2nd	376	375	665	1300	275	0000
24-hour	1st	138	160	260	N/A	201	0000
24-hour	2nd	110	160	260	N/A	189	0000
Annual	Mean	**36**	25	75	N/A		
Annual Growing Season [c]	Mean	36	N/A	N/A	N/A		
Annual Growing Season [c]	Mean	52	N/A	N/A	N/A		

Table 4-9. Averaging periods and modelled concentrations for SO_2 under Scenarios B_51.8 and D_61.8. Exceedances are shown in bold.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] (µg/m^3)	BC Pollution Control Objectives [b] (µg/m^3)		US EPA STANDARD (µg/m^3)	Maximum Date and Time - All Receptors	
			Lower	Upper		Day of the year	Time
1-hour	1st	**1,099**	450	900	N/A	339	1200
1-hour	2nd	781	450	900	N/A	351	1200
3-hour	1st	**569**	375	665		35	1200
3-hour	2nd	408	375	665	1300	91	2100
24-hour	1st	149	160	260	N/A	275	0000
24-hour	2nd	136	160	260	N/A	267	0000
Annual	Mean	**41**	25	75	N/A		
Annual Growing Season [c]	Mean	57	N/A	N/A	N/A		

[a] Modelled concentrations represent the maximum of the 2008 meteorological year modelled, and include background concentrations corresponding to the appropriate averaging period. Background concentrations are based on monitoring data at the nearby Kitamaat Village monitoring station, as follows:
1.5 ppb 3.92 µg/m^3 for 1-hour and 3-hour averaging period
1.2 ppb 3.13 µg/m^3 for 24-hour averaging period
0.4 ppb 1.07 µg/m^3 for Annual averaging period
[b] Comparisons to the PCOs do not provide conclusions related to impacts on the environment or human health.
[c] Growing Season is from April 15 through September 15. The annual background concentration is applied to these concentrations.

Table 4-10. Averaging periods and modelled concentrations for SO_2 under Scenario C_57.5. Exceedances are shown in bold.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	BC Pollution Control Objectives [b] ($\mu g/m^3$)		US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			Lower	Upper		Day of the year	Time
1-hour	1st	**1,098**	450	900	N/A	339	1200
1-hour	2nd	781	450	900	N/A	351	1200
3-hour	1st	**568**	375	665		035	1200
3-hour	2nd	407	375	665	1300	091	2100
24-hour	1st	149	160	260	N/A	275	0000
24-hour	2nd	136	160	260	N/A	267	0000
Annual	Mean	**41**	25	75	N/A		
Annual Growing Season [c]	Mean	56	N/A	N/A	N/A		

Table 4-11. Averaging periods and modelled concentrations for SO_2 under Scenarios E_66.1 and G_76.2. Exceedances are shown in bold.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	BC Pollution Control Objectives [b] ($\mu g/m^3$)		US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			Lower	Upper		Day of the year	Time
1-hour	1st	**1,749**	450	900	N/A	339	1200
1-hour	2nd	**1,259**	450	900	N/A	023	1300
3-hour	1st	**853**	375	665		035	1200
3-hour	2nd	611	375	665	1300	035	1200
24-hour	1st	**214**	160	260	N/A	267	0000
24-hour	2nd	200	160	260	N/A	301	0000
Annual	Mean	**42**	25	75	N/A		
Annual Growing Season [c]	Mean	58	N/A	N/A	N/A		

[a] Modelled concentrations represent the maximum of the 2008 meteorological year modelled, and include background concentrations corresponding to the appropriate averaging period. Background concentrations are based on monitoring data at the nearby Kitamaat Village monitoring station, as follows:
1.5 ppb 3.92 $\mu g/m^3$ for 1-hour and 3-hour averaging period
1.2 ppb 3.13 $\mu g/m^3$ for 24-hour averaging period
0.4 ppb 1.07 $\mu g/m^3$ for Annual averaging period
[b] Comparisons to the PCOs do not provide conclusions related to impacts on the environment or human health.
[c] Growing Season is from April 15 through September 15. The annual background concentration is applied to these concentrations.

Table 4-12. Averaging periods and modelled concentrations for SO_2 under Scenarios F_72.6 and H_82.6. Exceedances are shown in bold.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	BC Pollution Control Objectives [b] ($\mu g/m^3$)		US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			Lower	Upper		Day of the year	Time
1-hour	1st	**1,749**	450	900	N/A	339	1200
1-hour	2nd	**1,260**	450	900	N/A	023	1300
3-hour	1st	**853**	375	665		035	1200
3-hour	2nd	611	375	665	1300	035	1200
24-hour	1st	**214**	160	260	N/A	267	0000
24-hour	2nd	200	160	260	N/A	301	0000
Annual	Mean	**42**	25	75	N/A		
Annual Growing Season [c]	Mean	58	N/A	N/A	N/A		

Table 4-13. Averaging periods and modelled concentrations for SO_2 under Scenario Is_83.3, Im_83.3, Js_86.1 and Jm_86.1. Exceedances are shown in bold.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	BC Pollution Control Objectives [b] ($\mu g/m^3$)		US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			Lower	Upper		Day of the year	Time
1-hour	1st	**1,749**	450	900	N/A	339	1200
1-hour	2nd	**1,260**	450	900	N/A	023	1300
3-hour	1st	**853**	375	665		035	1200
3-hour	2nd	611	375	665	1300	035	1200
24-hour	1st	**214**	160	260	N/A	267	0000
24-hour	2nd	200	160	260	N/A	301	0000
Annual	Mean	**42**	25	75	N/A		
Annual Growing Season [c]	Mean	58	N/A	N/A	N/A		

[a] Modelled concentrations represent the maximum of the 2008 meteorological year modelled, and include background concentrations corresponding to the appropriate averaging period. Background concentrations are based on monitoring data at the nearby Kitamaat Village monitoring station, as follows:
1.5 ppb 3.92 $\mu g/m^3$ for 1-hour and 3-hour averaging period
1.2 ppb 3.13 $\mu g/m^3$ for 24-hour averaging period
0.4 ppb 1.07 $\mu g/m^3$ for Annual averaging period
[b] Comparisons to the PCOs do not provide conclusions related to impacts on the environment or human health.
[c] Growing Season is from April 15 through September 15. The annual background concentration is applied to these concentrations.

4.2.2 Tabular NO_2 Averaging Periods and Modelled Concentrations for all Scenarios

Table 4-14. Averaging periods and modelled concentrations for NO_2 under Scenario A_28.2.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	245	N/A	400	1000	N/A	362	2100
1-hour	2nd	239	N/A	400	1000	N/A	163	200
3-hour	1st	207	N/A	N/A	N/A	N/A	365	0600
3-hour	2nd	185	N/A	N/A	N/A	N/A	275	0000
24-hour	1st	93	N/A	200	300	N/A	201	0000
24-hour	2nd	87	N/A	200	300	N/A	178	0000
Annual	Mean	30	60	100	N/A	100		
Annual Growing Season [c]	Mean	35	N/A	N/A	N/A	N/A		

Table 4-15. Averaging periods and modelled concentrations for NO_2 under Scenario B_51.8 and E_66.1.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	246	N/A	400	1000	N/A	362	2100
1-hour	2nd	240	N/A	400	1000	N/A	163	0200
3-hour	1st	208	N/A	N/A	N/A	N/A	365	0600
3-hour	2nd	185	N/A	N/A	N/A	N/A	275	0000
24-hour	1st	94	N/A	200	300	N/A	201	0000
24-hour	2nd	87	N/A	200	300	N/A	178	0000
Annual	Mean	30	60	100	N/A	100		
Annual Growing Season [c]	Mean	36	N/A	N/A	N/A	N/A		

[a] Modelled concentrations represent the maximum of the 2008 meteorological year modelled. For short term averaging periods, the maximum NO_X concentration is scaled to assume 80% of NO_X is NO_2, then a background concentrations is added as determined by the 98th percentile of NO_2 data from three years in Quesnel. For the annual averaging period, the maximum NO_X concentration is scaled to assume 75% of NO_X is NO_2, then a background concentration is added as determined by Quesnel annual average data. Therefore the model output (MO) is updated as follows MO * NO_X/NO_2 Ratio + Background = Reported Result.

30.6 ppb 57.53 $\mu g/m^3$ 80% NO_x is NO_2 for 1-hour and 3-hour averaging period
23.9 ppb 44.93 $\mu g/m^3$ 80% NO_x is NO_2 for 24 hour averaging period
9.4 ppb 17.74 $\mu g/m^3$ 75% NO_x is NO_2 for Annual averaging period

[b] Comparisons to the PCO thresholds do not provide conclusions related to impacts on the environment or human health. MDL=Maximum Desirable Level, MAL=Maximum Acceptable level, MTL=Maximum Tolerable level.

[c] Growing Season is from April 15 through September 15. The annual background concentration is applied to these concentrations.

Table 4-16. Averaging periods and modelled concentrations for NO_2 under Scenario C_57.5.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	286	N/A	400	1000	N/A	205	0300
1-hour	2nd	242	N/A	400	1000	N/A	163	0200
3-hour	1st	210	N/A	N/A	N/A	N/A	365	0600
3-hour	2nd	187	N/A	N/A	N/A	N/A	275	0000
24-hour	1st	94	N/A	200	300	N/A	201	0000
24-hour	2nd	87	N/A	200	300	N/A	255	0000
Annual	Mean	31	60	100	N/A	100		
Annual Growing Season [c]	Mean	36	N/A	N/A	N/A	N/A		

Table 4-17. Averaging periods and modelled concentrations for NO_2 under Scenario D_61.8.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	308	N/A	400	1000	N/A	205	0300
1-hour	2nd	244	N/A	400	1000	N/A	163	0200
3-hour	1st	211	N/A	N/A	N/A	N/A	365	0600
3-hour	2nd	192	N/A	N/A	N/A	N/A	194	2100
24-hour	1st	94	N/A	200	300	N/A	201	0000
24-hour	2nd	88	N/A	200	300	N/A	255	0000
Annual	Mean	31	60	100	N/A	100		
Annual Growing Season [c]	Mean	37	N/A	N/A	N/A	N/A		

[a] Modelled concentrations represent the maximum of the 2008 meteorological year modelled. For short term averaging periods, the maximum NO_X concentration is scaled to assume 80% of NO_X is NO_2, then a background concentrations is added as determined by the 98th percentile of NO_2 data from three years in Quesnel. For the annual averaging period, the maximum NO_X concentration is scaled to assume 75% of NO_X is NO_2, then a background concentration is added as determined by Quesnel annual average data. Therefore the model output (MO) is updated as follows MO * NO_X/NO_2 Ratio + Background = Reported Result.

30.6 ppb 57.53 $\mu g/m^3$ 80% NO_x is NO_2 for 1-hour and 3-hour averaging period
23.9 ppb 44.93 $\mu g/m^3$ 80% NO_x is NO_2 for 24 hour averaging period
9.4 ppb 17.74 $\mu g/m^3$ 75% NO_x is NO_2 for Annual averaging period

[b] Comparisons to the PCO thresholds do not provide conclusions related to impacts on the environment or human health. MDL=Maximum Desirable Level, MAL=Maximum Acceptable level, MTL=Maximum Tolerable level.

[c] Growing Season is from April 15 through September 15. The annual background concentration is applied to these concentrations.

Table 4-18. Averaging periods and modelled concentrations for NO_2 under Scenario F_72.6.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	250	N/A	400	1000	N/A	362	2100
1-hour	2nd	241	N/A	400	1000	N/A	163	0200
3-hour	1st	209	N/A	N/A	N/A	N/A	365	0600
3-hour	2nd	186	N/A	N/A	N/A	N/A	275	0000
24-hour	1st	94	N/A	200	300	N/A	201	0000
24-hour	2nd	87	N/A	200	300	N/A	178	0000
Annual	Mean	30	60	100	N/A	100		
Annual Growing Season [c]	Mean	36	N/A	N/A	N/A	N/A		

Table 4-19. Averaging periods and modelled concentrations for NO_2 under Scenario G_76.2.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	308	N/A	400	1000	N/A	205	0300
1-hour	2nd	244	N/A	400	1000	N/A	163	0200
3-hour	1st	211	N/A	N/A	N/A	N/A	365	0600
3-hour	2nd	192	N/A	N/A	N/A	N/A	197	2100
24-hour	1st	94	N/A	200	300	N/A	201	0000
24-hour	2nd	88	N/A	200	300	N/A	255	0000
Annual	Mean	31	60	100	N/A	100		
Annual Growing Season [c]	Mean	37	N/A	N/A	N/A	N/A		

[a] Modelled concentrations represent the maximum of the 2008 meteorological year modelled. For short term averaging periods, the maximum NO_X concentration is scaled to assume 80% of NO_X is NO_2, then a background concentrations is added as determined by the 98th percentile of NO_2 data from three years in Quesnel. For the annual averaging period, the maximum NO_X concentration is scaled to assume 75% of NO_X is NO_2, then a background concentration is added as determined by Quesnel annual average data. Therefore the model output (MO) is updated as follows MO * NO_X/NO_2 Ratio + Background = Reported Result.

30.6 ppb 57.53 $\mu g/m^3$ 80% NO_x is NO_2 for 1-hour and 3-hour averaging period

23.9 ppb 44.93 $\mu g/m^3$ 80% NO_x is NO_2 for 24 hour averaging period

9.4 ppb 17.74 $\mu g/m^3$ 75% NO_x is NO_2 for Annual averaging period

[b] Comparisons to the PCO thresholds do not provide conclusions related to impacts on the environment or human health. MDL=Maximum Desirable Level, MAL=Maximum Acceptable level, MTL=Maximum Tolerable level.

[c] Growing Season is from April 15 through September 15. The annual background concentration is applied to these concentrations.

Table 4-20. Averaging periods and modelled concentrations for NO_2 under Scenario H_82.6.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	308	N/A	400	1000	N/A	205	0300
1-hour	2nd	246	N/A	400	1000	N/A	163	0200
3-hour	1st	212	N/A	N/A	N/A	N/A	365	0600
3-hour	2nd	195	N/A	N/A	N/A	N/A	197	2100
24-hour	1st	94	N/A	200	300	N/A	201	0000
24-hour	2nd	88	N/A	200	300	N/A	255	0000
Annual	Mean	31	60	100	N/A	100		
Annual Growing Season [c]	Mean	37	N/A	N/A	N/A	N/A		

Table 4-21. Averaging periods and modelled concentrations for NO_2 under Scenario Is_83.3.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	309	N/A	400	1000	N/A	205	0300
1-hour	2nd	246	N/A	400	1000	N/A	163	0200
3-hour	1st	212	N/A	N/A	N/A	N/A	365	0600
3-hour	2nd	195	N/A	N/A	N/A	N/A	197	2100
24-hour	1st	94	N/A	200	300	N/A	201	0000
24-hour	2nd	88	N/A	200	300	N/A	255	0000
Annual	Mean	31	60	100	N/A	100		
Annual Growing Season [c]	Mean	37	N/A	N/A	N/A	N/A		

[a] Modelled concentrations represent the maximum of the 2008 meteorological year modelled. For short term averaging periods, the maximum NO_X concentration is scaled to assume 80% of NO_X is NO_2, then a background concentrations is added as determined by the 98th percentile of NO_2 data from three years in Quesnel. For the annual averaging period, the maximum NO_X concentration is scaled to assume 75% of NO_X is NO_2, then a background concentration is added as determined by Quesnel annual average data. Therefore the model output (MO) is updated as follows MO * NO_X/NO_2 Ratio + Background = Reported Result.

30.6 ppb 57.53 $\mu g/m^3$ 80% NO_x is NO_2 for 1-hour and 3-hour averaging period
23.9 ppb 44.93 $\mu g/m^3$ 80% NO_x is NO_2 for 24 hour averaging period
9.4 ppb 17.74 $\mu g/m^3$ 75% NO_x is NO_2 for Annual averaging period

[b] Comparisons to the PCO thresholds do not provide conclusions related to impacts on the environment or human health. MDL=Maximum Desirable Level, MAL=Maximum Acceptable level, MTL=Maximum Tolerable level.

[c] Growing Season is from April 15 through September 15. The annual background concentration is applied to these concentrations.

Table 4-22. Averaging periods and modelled concentrations for NO_2 under Scenario Im_83.3.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	330	N/A	400	1000	N/A	205	0300
1-hour	2nd	254	N/A	400	1000	N/A	215	0400
3-hour	1st	212	N/A	N/A	N/A	N/A	365	0600
3-hour	2nd	195	N/A	N/A	N/A	N/A	197	2100
24-hour	1st	94	N/A	200	300	N/A	201	0000
24-hour	2nd	88	N/A	200	300	N/A	255	0000
Annual	Mean	31	60	100	N/A	100		
Annual Growing Season [c]	Mean	37	N/A	N/A	N/A	N/A		

[a] Modelled concentrations represent the maximum of the 2008 meteorological year modelled. For short term averaging periods, the maximum NO_X concentration is scaled to assume 80% of NO_X is NO_2, then a background concentrations is added as determined by the 98th percentile of NO_2 data from three years in Quesnel. For the annual averaging period, the maximum NO_X concentration is scaled to assume 75% of NO_X is NO_2, then a background concentration is added as determined by Quesnel annual average data. Therefore the model output (MO) is updated as follows MO * NO_X/NO_2 Ratio + Background = Reported Result.

30.6 ppb 57.53 $\mu g/m^3$ 80% NO_x is NO_2 for 1-hour and 3-hour averaging period

23.9 ppb 44.93 $\mu g/m^3$ 80% NO_x is NO_2 for 24 hour averaging period

9.4 ppb 17.74 $\mu g/m^3$ 75% NO_x is NO_2 for Annual averaging period

[b] Comparisons to the PCO thresholds do not provide conclusions related to impacts on the environment or human health. MDL=Maximum Desirable Level, MAL=Maximum Acceptable level, MTL=Maximum Tolerable level.

[c] Growing Season is from April 15 through September 15. The annual background concentration is applied to these concentrations.

Table 4-23. Averaging periods and modelled concentrations for NO_2 under Scenario Js_86.1.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	309	N/A	400	1000	N/A	205	0300
1-hour	2nd	246	N/A	400	1000	N/A	163	0200
3-hour	1st	212	N/A	N/A	N/A	N/A	365	0600
3-hour	2nd	195	N/A	N/A	N/A	N/A	197	2100
24-hour	1st	94	N/A	200	300	N/A	201	0000
24-hour	2nd	88	N/A	200	300	N/A	255	0000
Annual	Mean	31	60	100	N/A	100		
Annual Growing Season [c]	Mean	37	N/A	N/A	N/A	N/A		

[a] Modelled concentrations represent the maximum of the 2008 meteorological year modelled. For short term averaging periods, the maximum NO_X concentration is scaled to assume 80% of NO_X is NO_2, then a background concentrations is added as determined by the 98th percentile of NO_2 data from three years in Quesnel. For the annual averaging period, the maximum NO_X concentration is scaled to assume 75% of NO_X is NO_2, then a background concentration is added as determined by Quesnel annual average data. Therefore the model output (MO) is updated as follows MO * NO_X/NO_2 Ratio + Background = Reported Result.

30.6 ppb 57.53 $\mu g/m^3$ 80% NO_x is NO_2 for 1-hour and 3-hour averaging period
23.9 ppb 44.93 $\mu g/m^3$ 80% NO_x is NO_2 for 24 hour averaging period
9.4 ppb 17.74 $\mu g/m^3$ 75% NO_x is NO_2 for Annual averaging period

Table 4-24. Averaging periods and modelled concentrations for NO_2 under Scenario Jm_86.1. Exceedances are in bold.

Averaging Period	Rank	Maximum Concentration - All Receptors [a] ($\mu g/m^3$)	Canadian Air Quality Objectives [b] ($\mu g/m^3$)			US EPA STANDARD ($\mu g/m^3$)	Maximum Date and Time - All Receptors	
			MDL	MAL	MTL		Day of the year	Time
1-hour	1st	**414**	N/A	400	1000	N/A	205	0300
1-hour	2nd	355	N/A	400	1000	N/A	121	0400
3-hour	1st	276	N/A	N/A	N/A	N/A	121	0300
3-hour	2nd	201	N/A	N/A	N/A	N/A	142	0000
24-hour	1st	110	N/A	200	300	N/A	048	0000
24-hour	2nd	96	N/A	200	300	N/A	267	0000
Annual	Mean	31	60	100	N/A	100		
Annual Growing Season [c]	Mean	37	N/A	N/A	N/A	N/A		

[a] Modelled concentrations represent the maximum of the 2008 meteorological year modelled. For short term averaging periods, the maximum NO_X concentration is scaled to assume 80% of NO_X is NO_2, then a background concentrations is added as determined by the 98th percentile of NO_2 data from three years in Quesnel. For the annual averaging period, the maximum NO_X concentration is scaled to assume 75% of NO_X is NO_2, then a background concentration is added as determined by Quesnel annual average data. Therefore the model output (MO) is updated as follows MO * NO_X/NO_2 Ratio + Background = Reported Result.

30.6 ppb 57.53 $\mu g/m^3$ 80% NO_x is NO_2 for 1-hour and 3-hour averaging period
23.9 ppb 44.93 $\mu g/m^3$ 80% NO_x is NO_2 for 24 hour averaging period
9.4 ppb 17.74 $\mu g/m^3$ 75% NO_x is NO_2 for Annual averaging period

[b] Comparisons to the PCO thresholds do not provide conclusions related to impacts on the environment or human health. MDL=Maximum Desirable Level, MAL=Maximum Acceptable level, MTL=Maximum Tolerable level.

[c] Growing Season is from April 15 through September 15. The annual background concentration is applied to these concentrations.

4.2.3 Tabular SO_2 Exceedances

Table 4-25. Exceedances of SO_2 metrics during 2008 under Scenario A_28.2.

Averaging Period	Threshold ($\mu g/m^3$)	Full Year[a]			Growing Season[a] (April 15-September 15)		
		Maximum # Exceedances	Total # Exceedances	# Receptors with ≥ 1 exceedance	Maximum # Exceedances	Total # Exceedances	# Receptors with ≥1 exceedance
BC Air Quality Objectives							
1-hour	Minimum:450	4[b]	34	22	3[b]	21	14
1-hour	Maximum:900	0	0	0	0	0	0
3-hour	Minimum:375	2[b]	7	6	1[b]	5	5
3-hour	Maximum:665	0	0	0	0	0	0
24-hour	Minimum:160	0	0	0	0	0	0
24-hour	Maximum:260	0	0	0	0	0	0
Annual[b]	Minimum:25	1[b]	2	2	1[b]	7	7
Annual	Maximum:75	0	0	0	0	0	0
EPA Standards[c]							
3-hour[c]	Half-standard:650	0	0	0	0	0	0
3-hour[c]	Standard:1300	0	0	0	0	0	0

[a] The maximum number of exceedances is the greatest number of exceedances at a single receptor for the given year. The total number of exceedances is the sum of exceedances at all receptors for the given year. Receptors located on RTA's property and those on the channel located in the local domain are excluded from this analysis. Receptors located on the channel located in the regional domain are included in this analysis.

[b] There are multiple receptors that show the maximum number of exceedances of the threshold level.

[c] The secondary standard for the 3-hour averaging period is not to be exceeded more than once per calendar year. The number of exceedances shown here are the number of 3-hour periods that the threshold level is exceeded.

Table 4-26. Exceedances of SO_2 metrics during 2008 under Scenarios E_66.1, F_72.6, G_76.2 and H_82.6.

Averaging Period	Threshold ($\mu g/m^3$)	Full Year			Growing Season (April 15-September 15)		
		Maximum # Exceedances	Total # Exceedances	# Receptors with ≥ 1 exceedance	Maximum # Exceedances	Total # Exceedances	# Receptors with ≥1 exceedance
BC Air Quality Objectives							
1-hour	Minimum:450	26	1929	528	10[b]	376	193
1-hour	Maximum:900	6	52	38	1[b]	4	4
3-hour	Minimum:375	10	484	313	3[b]	138	131
3-hour	Maximum:665	1[b]	42	42	0	0	0
24-hour	Minimum:160	4	7	4	0	0	0
24-hour	Maximum:260	0	0	0	0	0	0
Annual	Minimum:25	1[b]	16	16	1[b]	39	39
Annual	Maximum:75	0	0	0	0	0	0
EPA Standards [c]							
3-hour	Half-standard:650	1[b,c]	48	48	0[c]	0	0
3-hour	Standard:1300	0[c]	0	0	0[c]	0	0

[a] The maximum number of exceedances is the greatest number of exceedances at a single receptor for the given year. The total number of exceedances is the sum of exceedances at all receptors for the given year. Receptors located on RTA's property and those on the channel located in the local domain are excluded from this analysis. Receptors located on the channel located in the regional domain are included in this analysis.

[b] There are multiple receptors that show the maximum number of exceedances of the threshold level.

[c] The secondary standard for the 3-hour averaging period is not to be exceeded more than once per calendar year. The number of exceedances shown here are the number of 3-hour periods that the threshold level is exceeded.

Table 4-27. Exceedances of SO_2 metrics under Scenario ls_83.3 and lm_83.3.

Averaging Period	Threshold ($\mu g/m^3$)	Full Year			Growing Season (April 15-September 15)		
		Maximum # Exceedances	Total # Exceedances	# Receptors with ≥ 1 exceedance	Maximum # Exceedances	Total # Exceedances	# Receptors with ≥1 exceedance
BC Air Quality Objectives							
1-hour	Minimum:450	26	1929	528	10[b]	376	193
1-hour	Maximum:900	6	52	38	1[b]	4	4
3-hour	Minimum:375	10	484	313	3[b]	138	131
3-hour	Maximum:665	1[b]	42	42	0	0	0
24-hour	Minimum:160	4	7	4	0	0	0
24-hour	Maximum:260	0	0	0	0	0	0
Annual	Minimum:25	1[b]	16	16	1[b]	39	39
Annual	Maximum:75	0	0	0	0	0	0
EPA Standards [c]							
3-hour	Half-standard:650	1[b,c]	48	48	0[c]	0	0
3-hour	Standard:1300	0[c]	0	0	0[c]	0	0

[a] The maximum number of exceedances is the greatest number of exceedances at a single receptor for the given year. The total number of exceedances is the sum of exceedances at all receptors for the given year. Receptors located on RTA's property and those on the channel located in the local domain are excluded from this analysis. Receptors located on the channel located in the regional domain are included in this analysis.

[b] There are multiple receptors that show the maximum number of exceedances of the threshold level.

[c] The secondary standard for the 3-hour averaging period is not to be exceeded more than once per calendar year. The number of exceedances shown here are the number of 3-hour periods that the threshold level is exceeded.

4.2.4 Tabular Summary Results Across Scenarios

Table 4-28. Comparison of maximum number of exceedances at a single receptor across scenarios.

Scenario	A_ 28.2	B_ 51.8	C_ 57.5	D_ 61.8	E_ 66.1	F_ 72.6	G_ 76.2	H_ 82.6	Is_ 83.3	Im_ 83.3	Js_ 86.1	Jm_ 86.1
Total # exceedances of vegetation metrics for SO_2 during growing season	5	8	8	8	15	15	15	15	15	15	15	15
Total # exceedances of vegetation metrics for NO_2 during growing season	0	0	0	0	0	0	0	0	0	0	0	[a]

[a] Due to time constraints, NO_2 exceedance details were not available for Scenario Jm_86.1.

Table 4-29. Estimated likelihood, consequence, and resulting risk of direct effects of SO_2 and NO_2 on vegetation in the Kitimat airshed.[a]

Scenario	SO_2				NO_2		
	Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
A_28.2	E	1	**Low**		E	1	**Low**
B_51.8	E	1	**Low**		E	1	**Low**
C_57.5	E	1	**Low**		E	1	**Low**
D_61.8	E	1	**Low**		E	1	**Low**
E_66.1	E	2	**Low**		E	1	**Low**
F_72.6	E	2	**Low**		E	1	**Low**
G_76.2	E	2	**Low**		E	1	**Low**
H_82.6	E	2	**Low**		E	1	**Low**
Is_83.3	E	2	**Low**		E	1	**Low**
Im_83.3	E	2	**Low**		E	1	**Low**
Js_86.1	E	2	**Low**		E	1	**Low**
Jm_86.1	E	2	**Low**		E	1	**Low**

[a] Values for likelihood, consequence, and risk are defined in tables at the end of Section 4.1.

4.2.5 Maps of Spatial Distribution of SO_2 and NO_2 Concentrations and Exceedances

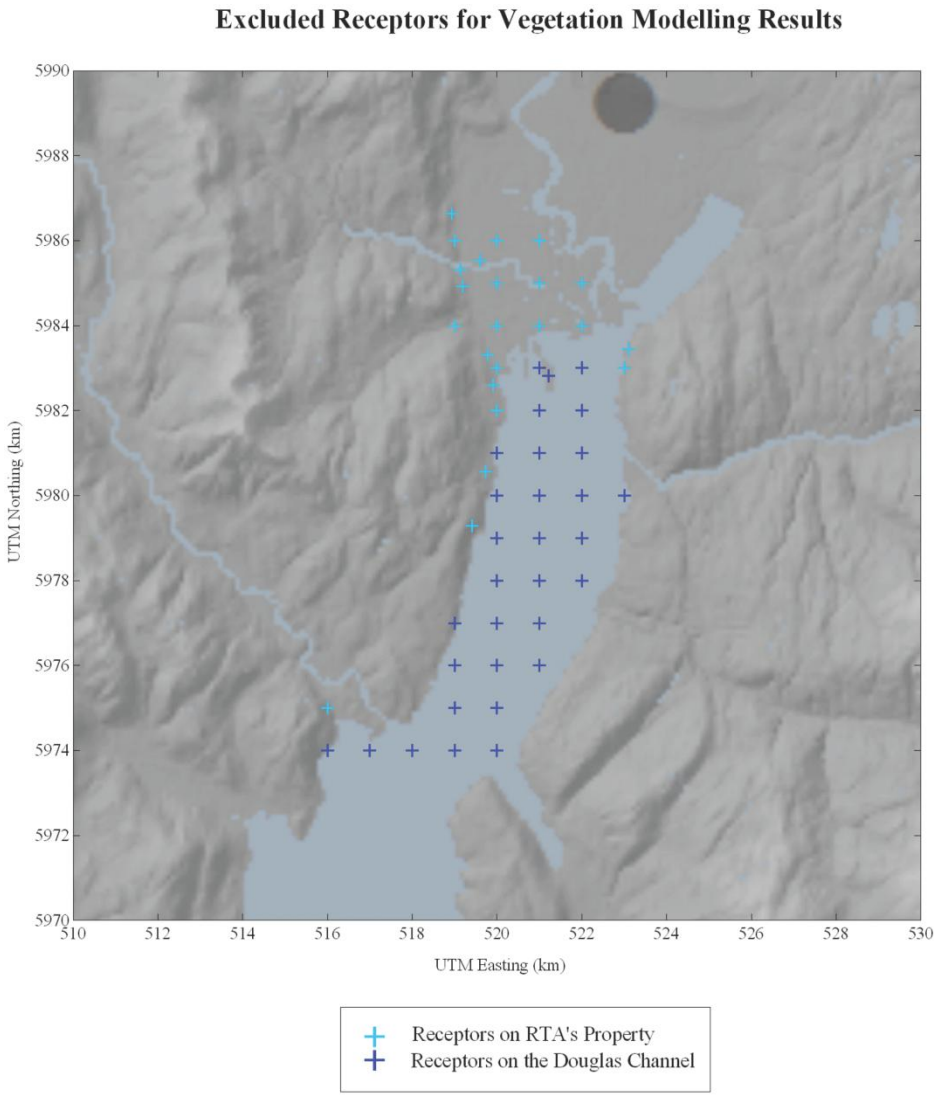


Figure 4-1. Location of receptors excluded from the vegetation analysis due to location in the industrial zone or over water.

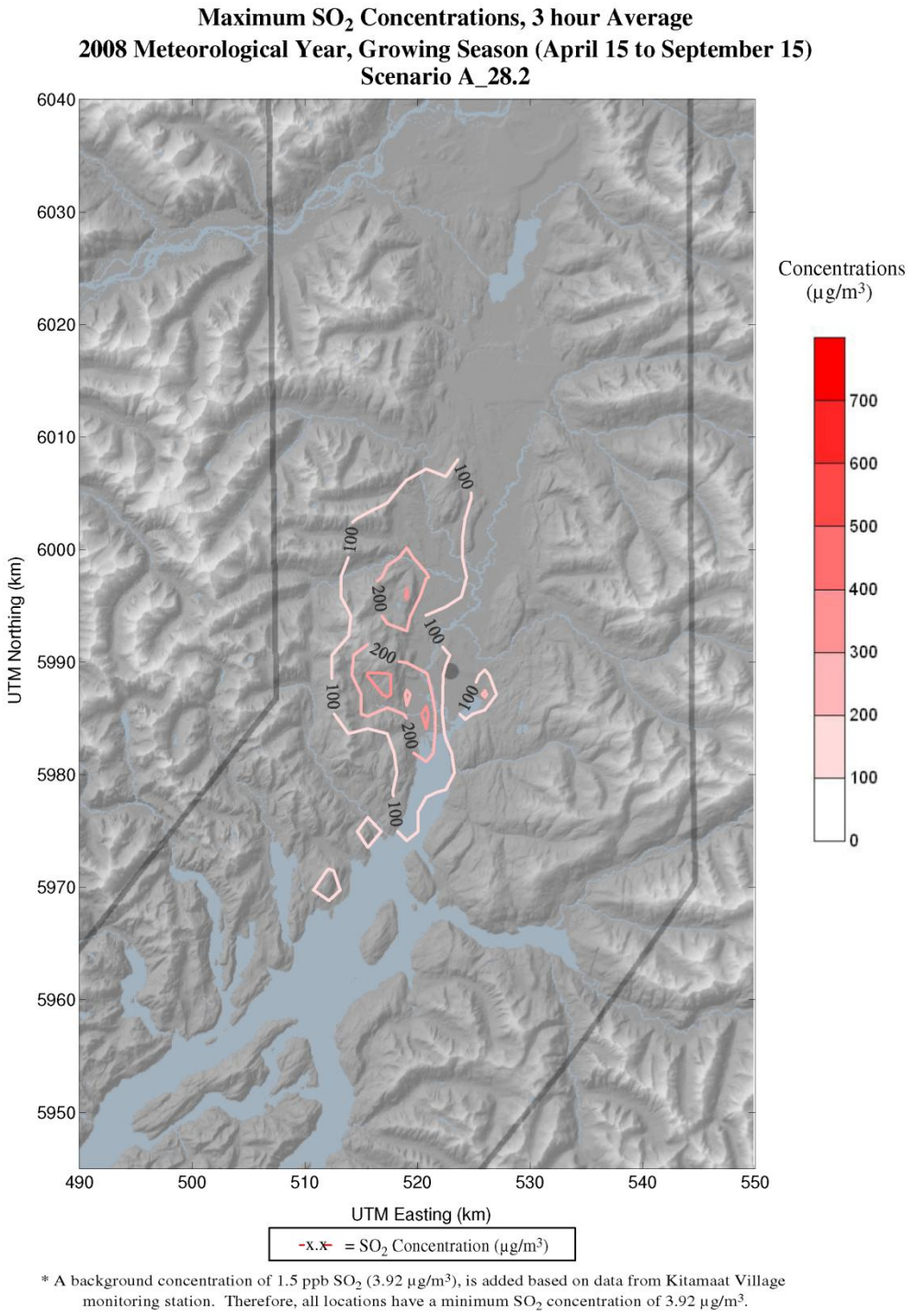


Figure 4-2. Distribution of modelled maximum 3-hour average SO_2 concentrations during the growing season of 2008 for Scenario A_28.2.

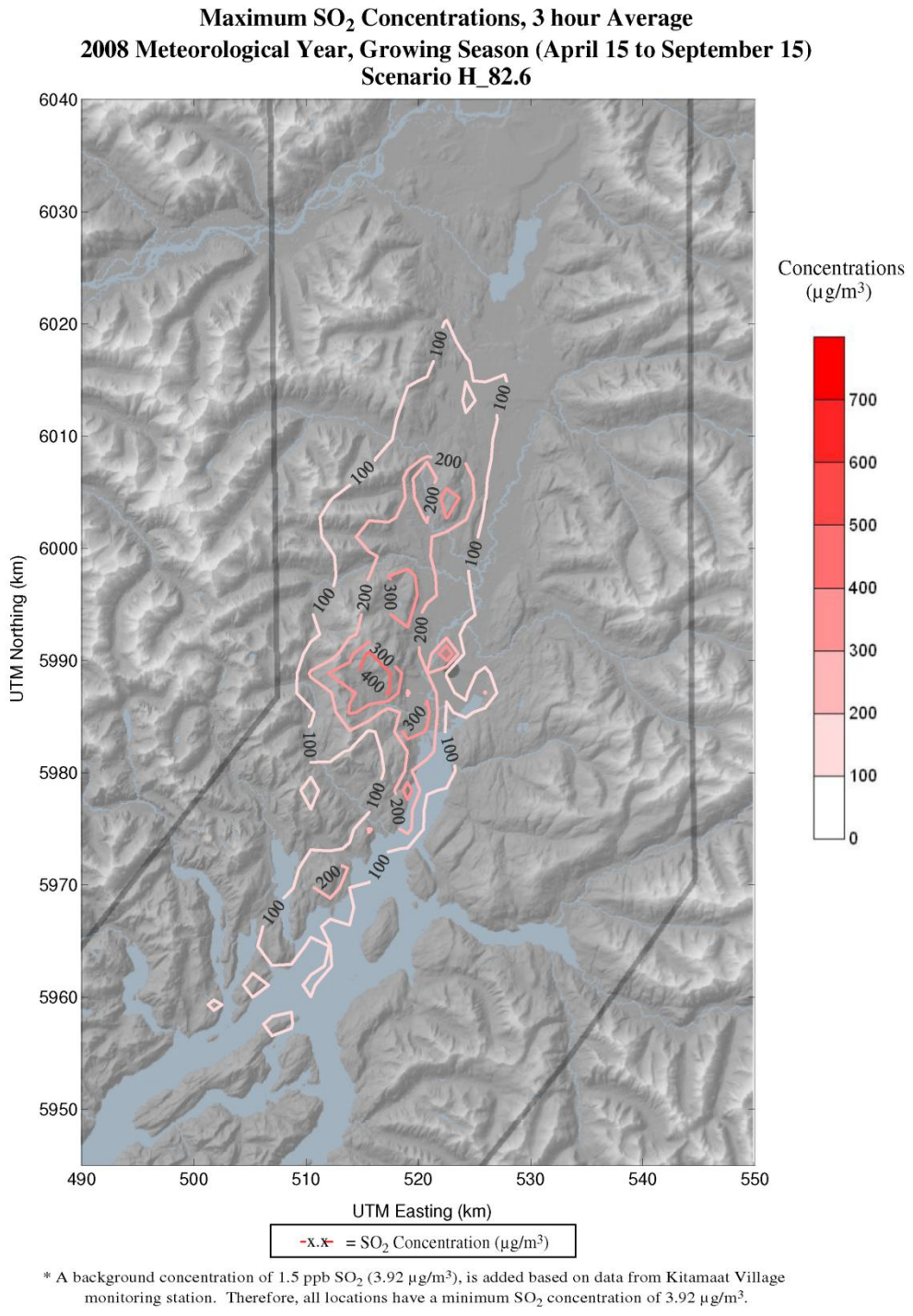
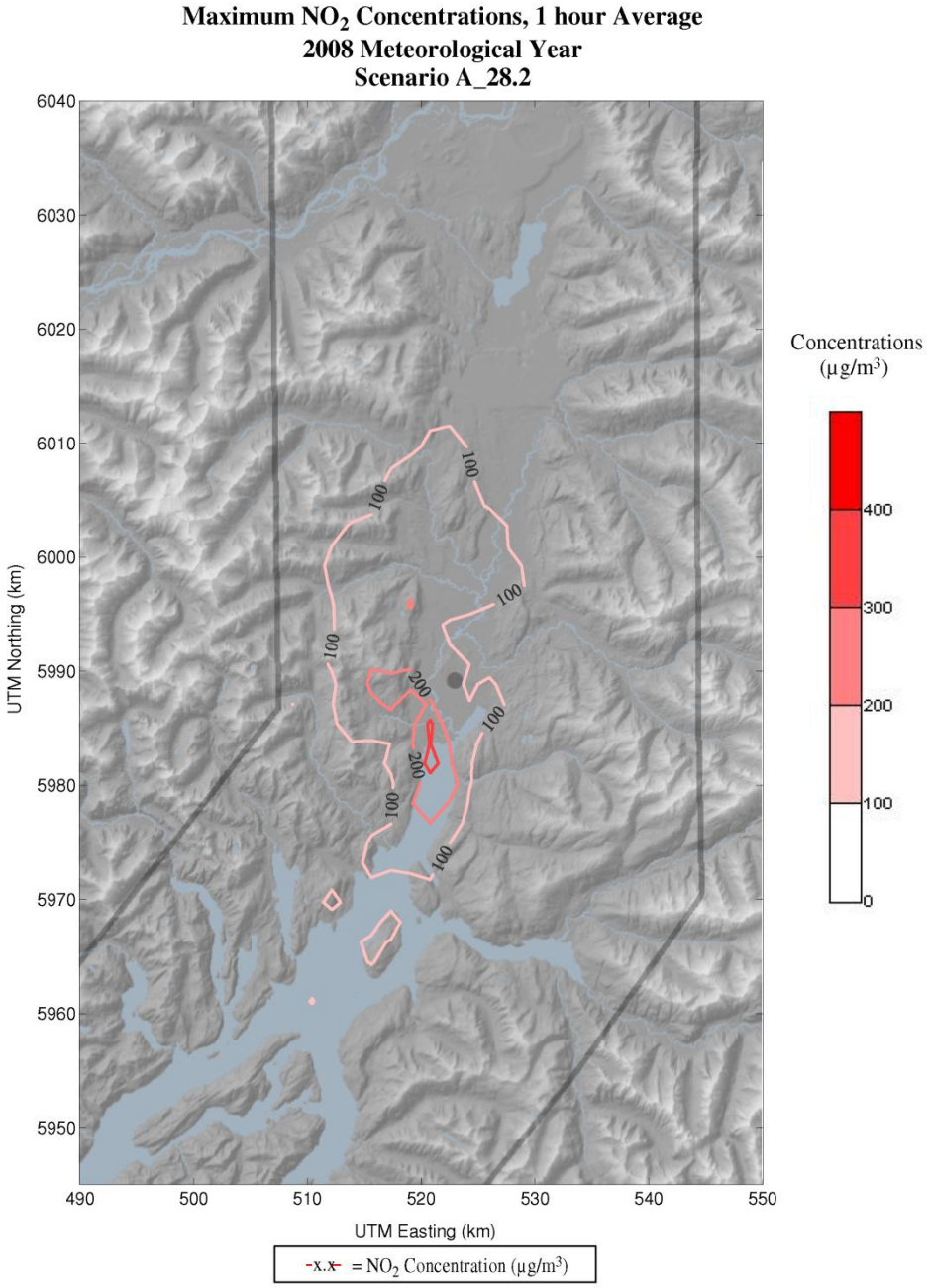
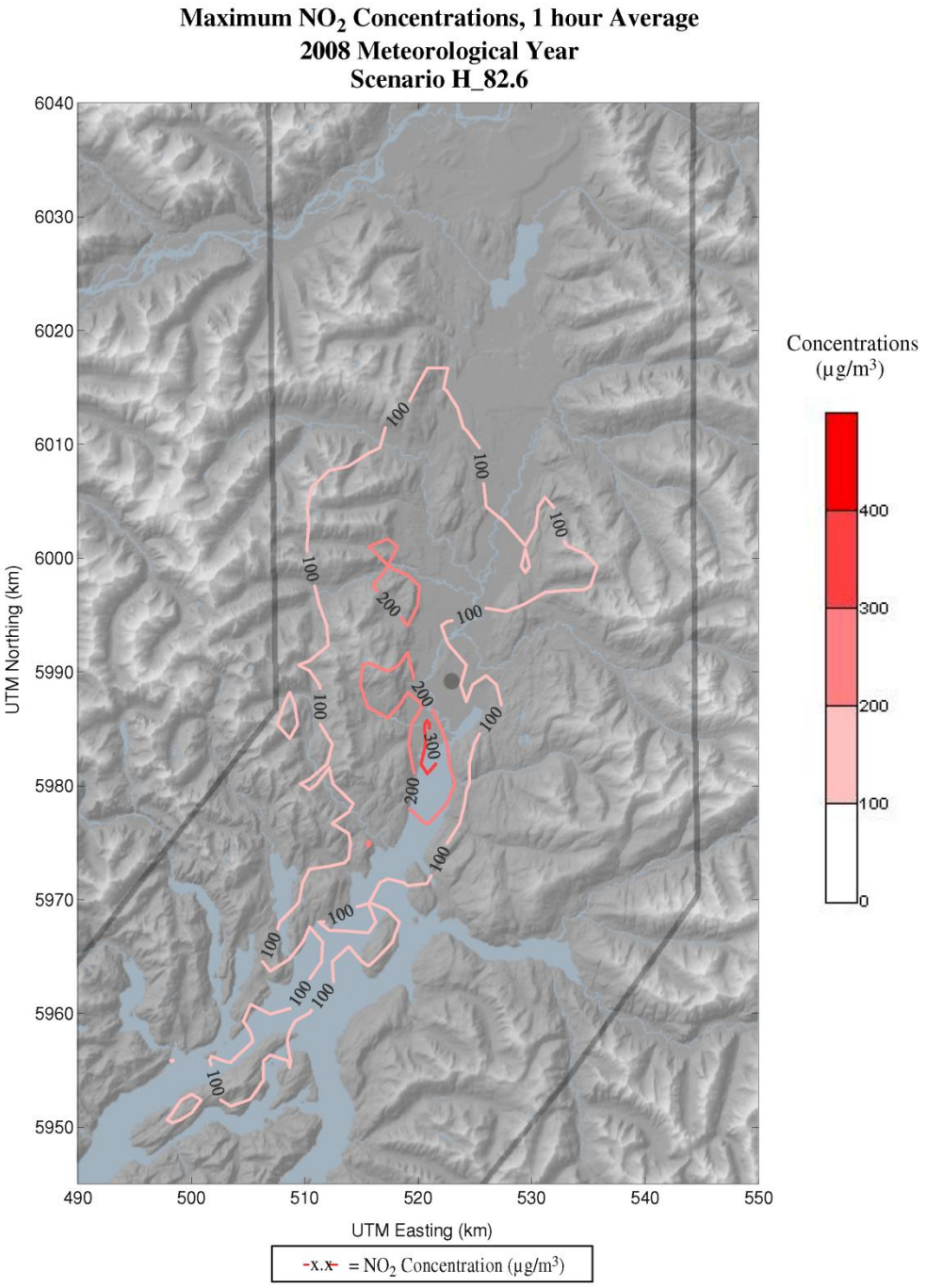


Figure 4-3. Distribution of modelled maximum 3-hour average SO_2 concentrations during the growing season of 2008 for Scenario H_82.6.



* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m^3), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m^3.

Figure 4-4. Distribution of modelled maximum 1-hour average NO_2 concentrations during the meteorological year of 2008 for Scenario A_28.2.



* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m³.

Figure 4-5. Distribution of modelled maximum 1-hour average NO_2 concentrations during the meteorological year of 2008 for Scenario H_82.6.

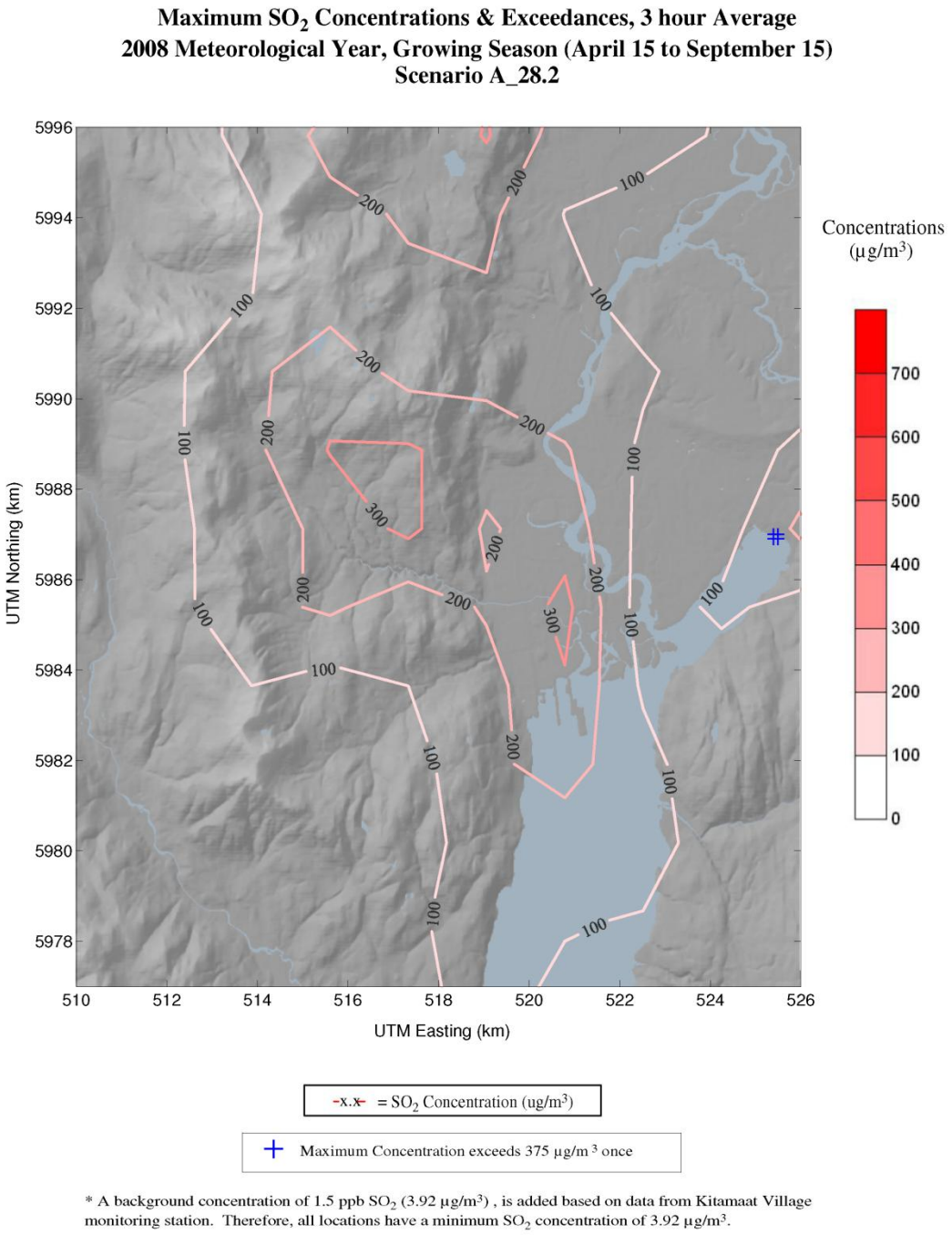


Figure 4-6. Exceedance of threshold metrics for SO_2 during the growing season in 2008 for Scenario A_28.2.

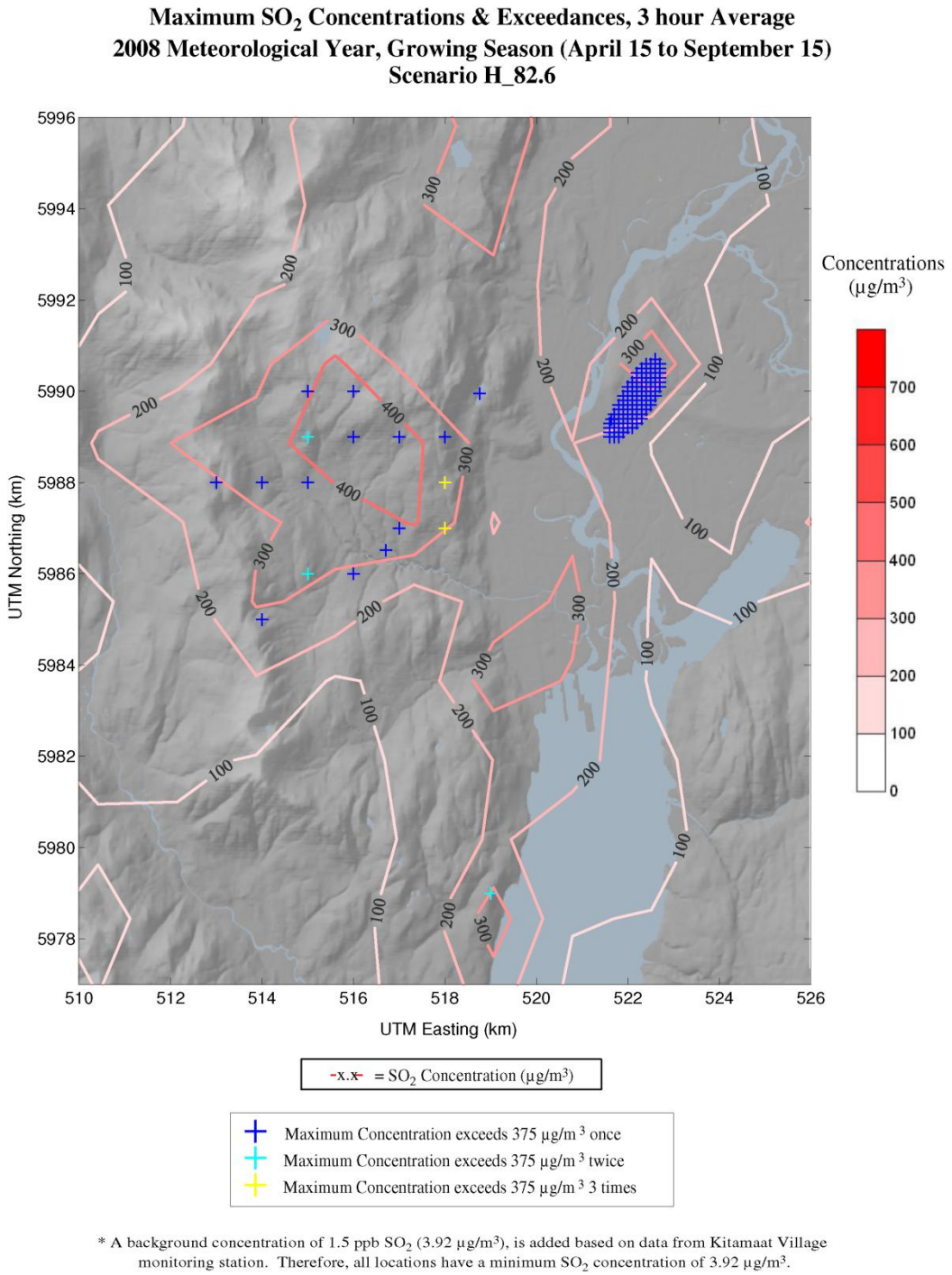


Figure 4-7. Exceedance of threshold metrics for SO_2 during the growing season in 2008 for Scenario H_82.6.

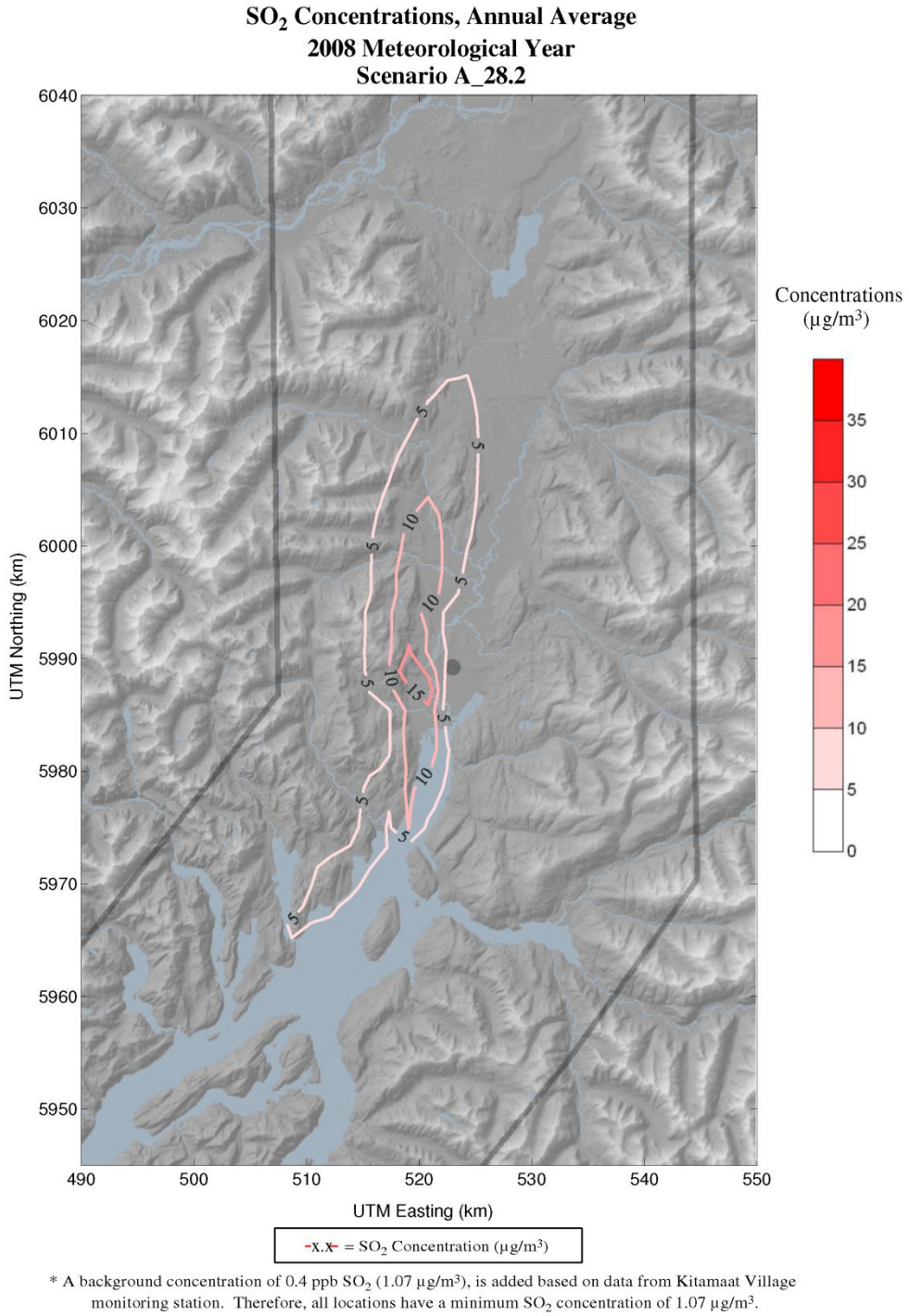


Figure 4-8. Distribution of modelled annual mean SO_2 concentrations during the meteorological year 2008 for Scenario A_28.2.

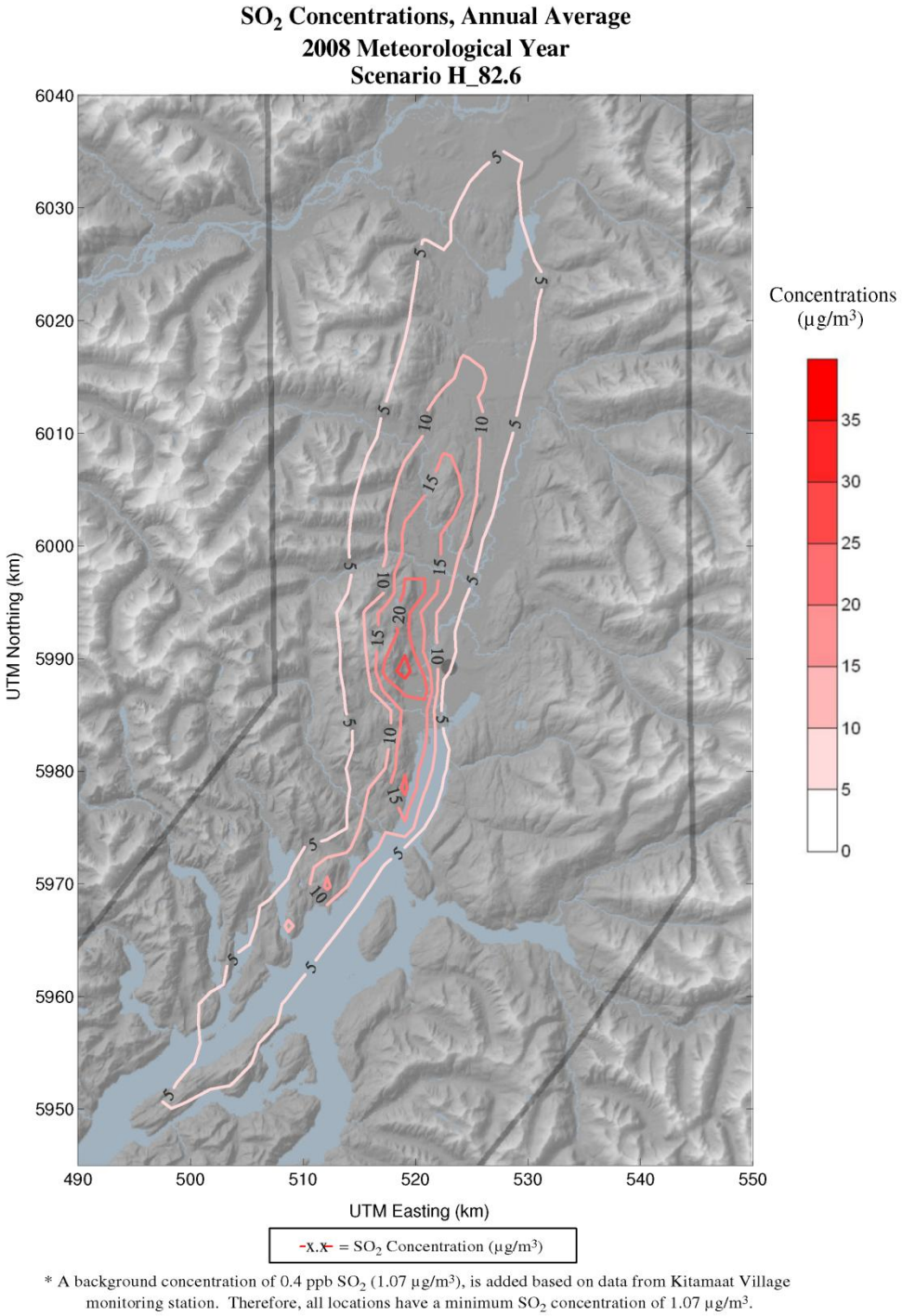
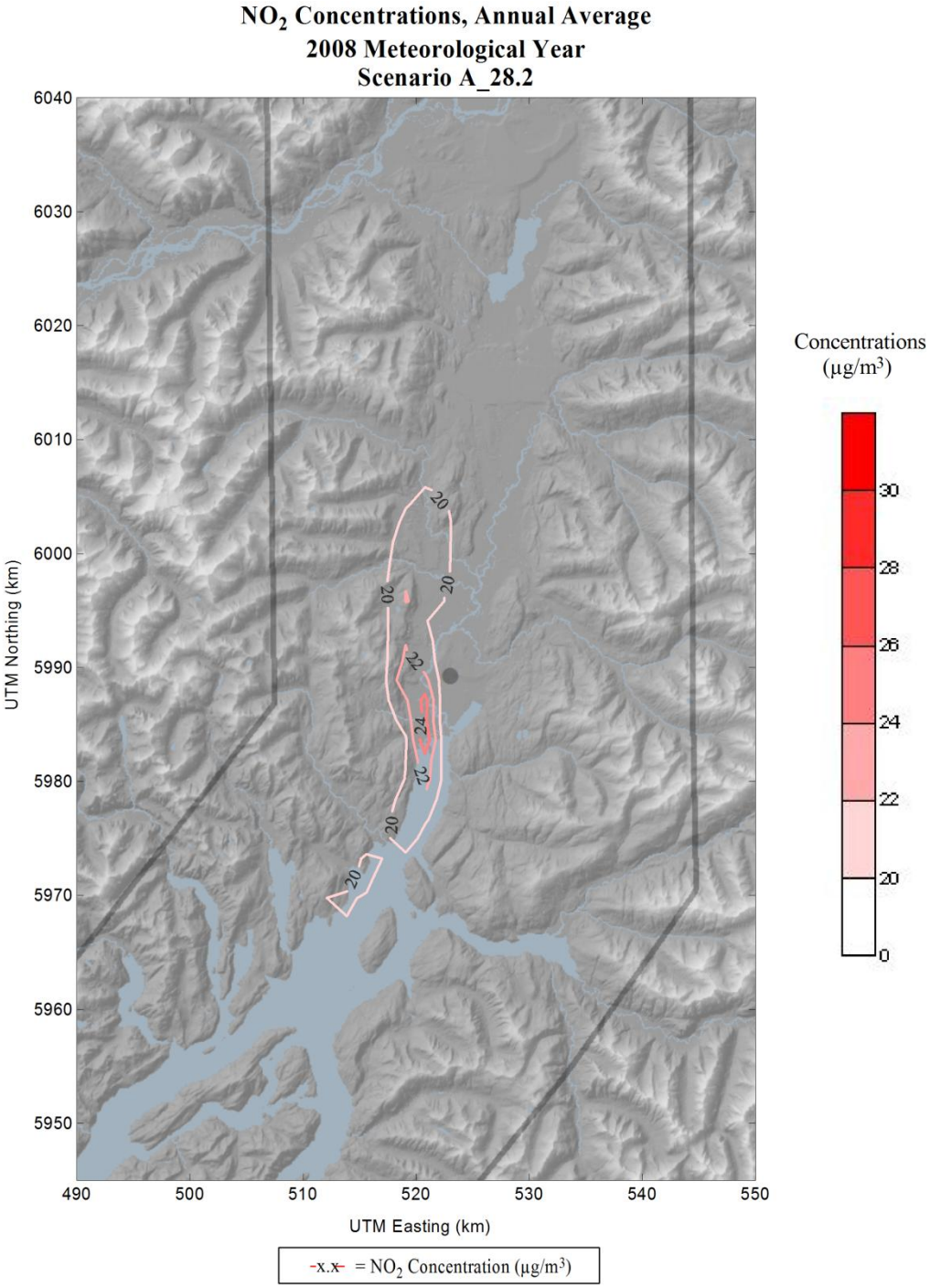
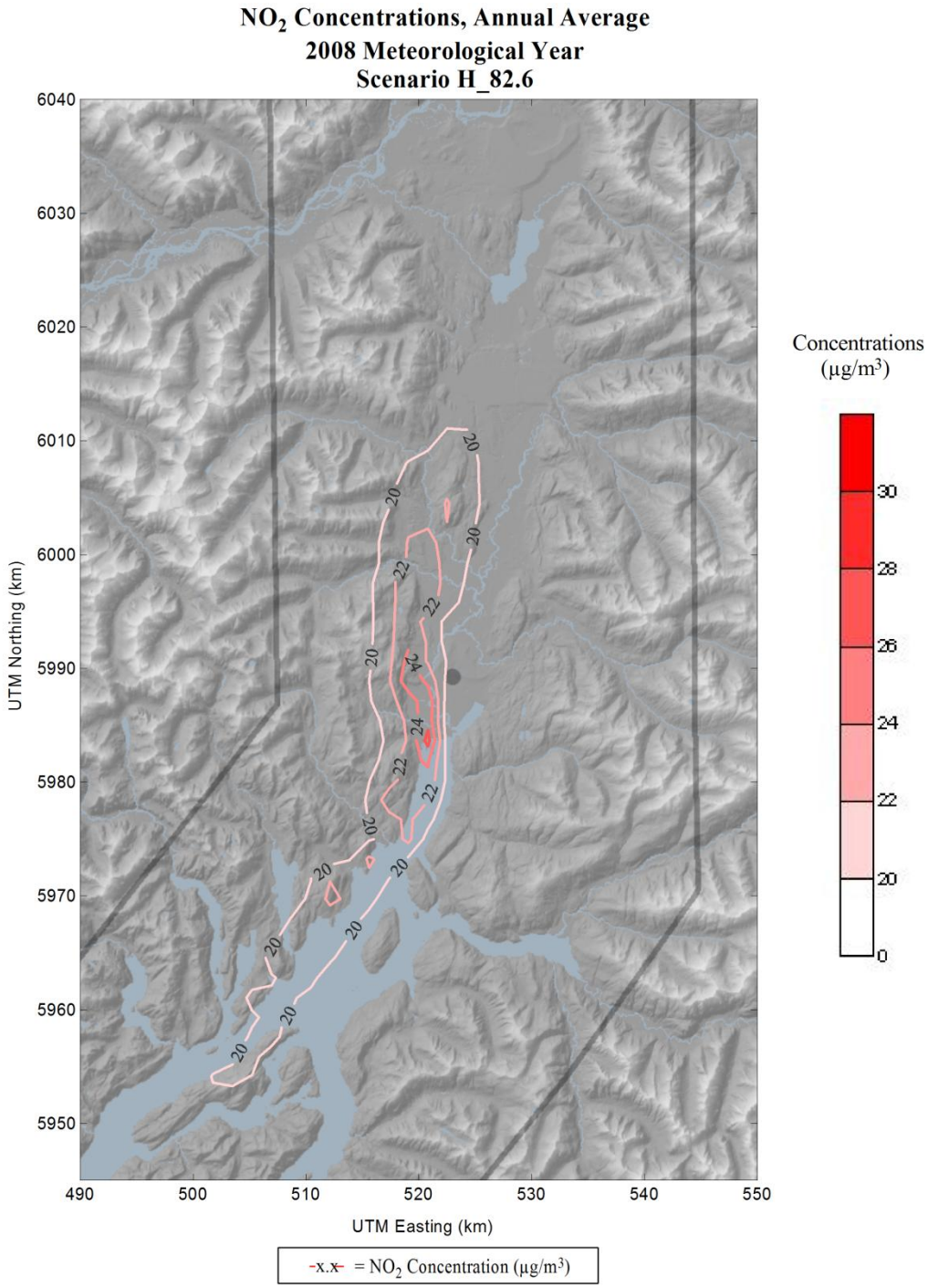


Figure 4-9. Distribution of modelled annual mean SO_2 concentrations during the meteorological year 2008 for Scenario H_82.6.



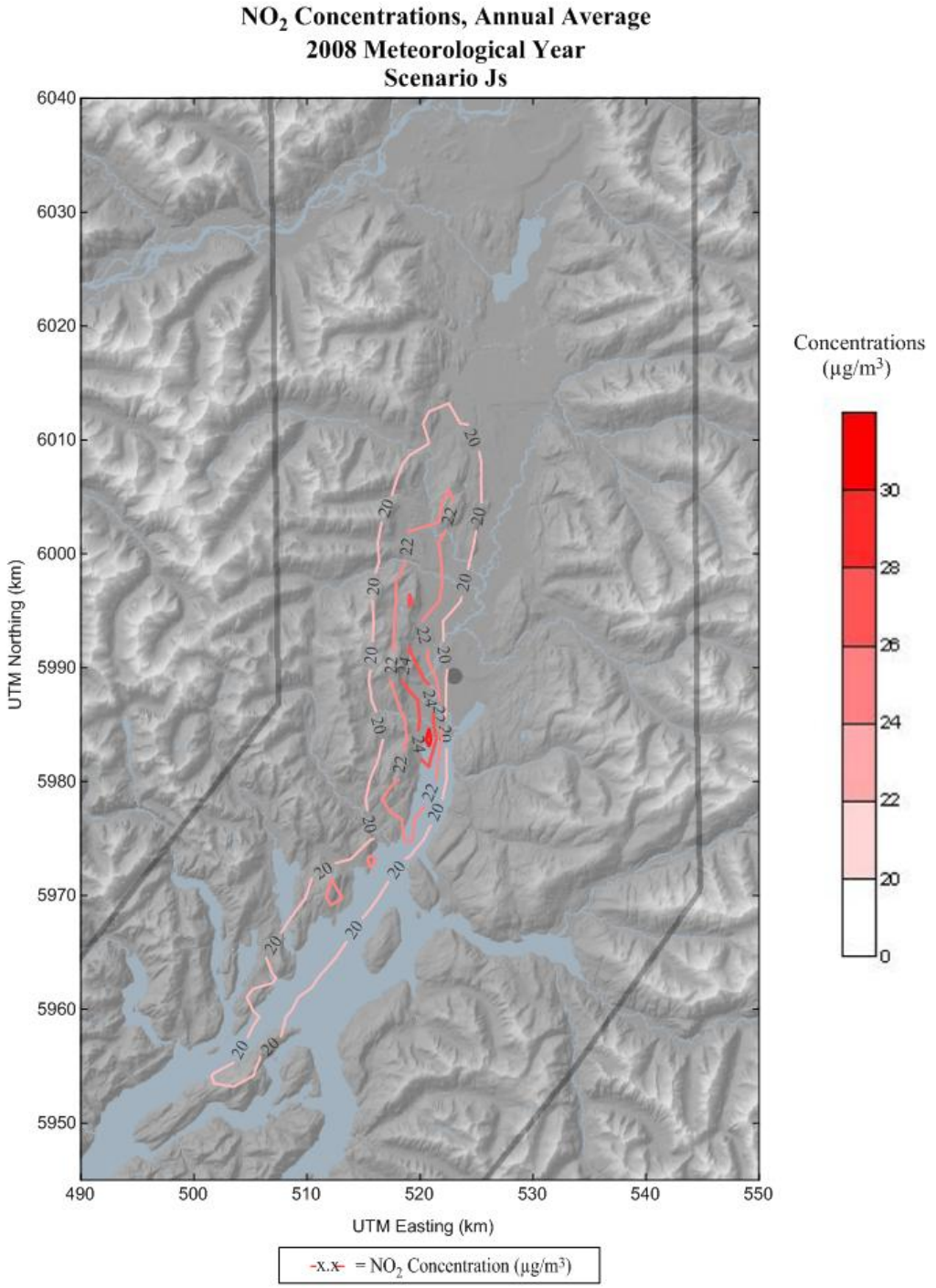
* The modelled NOx concentrations are scaled to assume 75% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 9.4 ppb NO_2 (17.74 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 17.74 µg/m³.

Figure 4-10. Distribution of modeled annual mean NO_2 concentrations during the meteorological year 2008 for Scenario A_28.2.



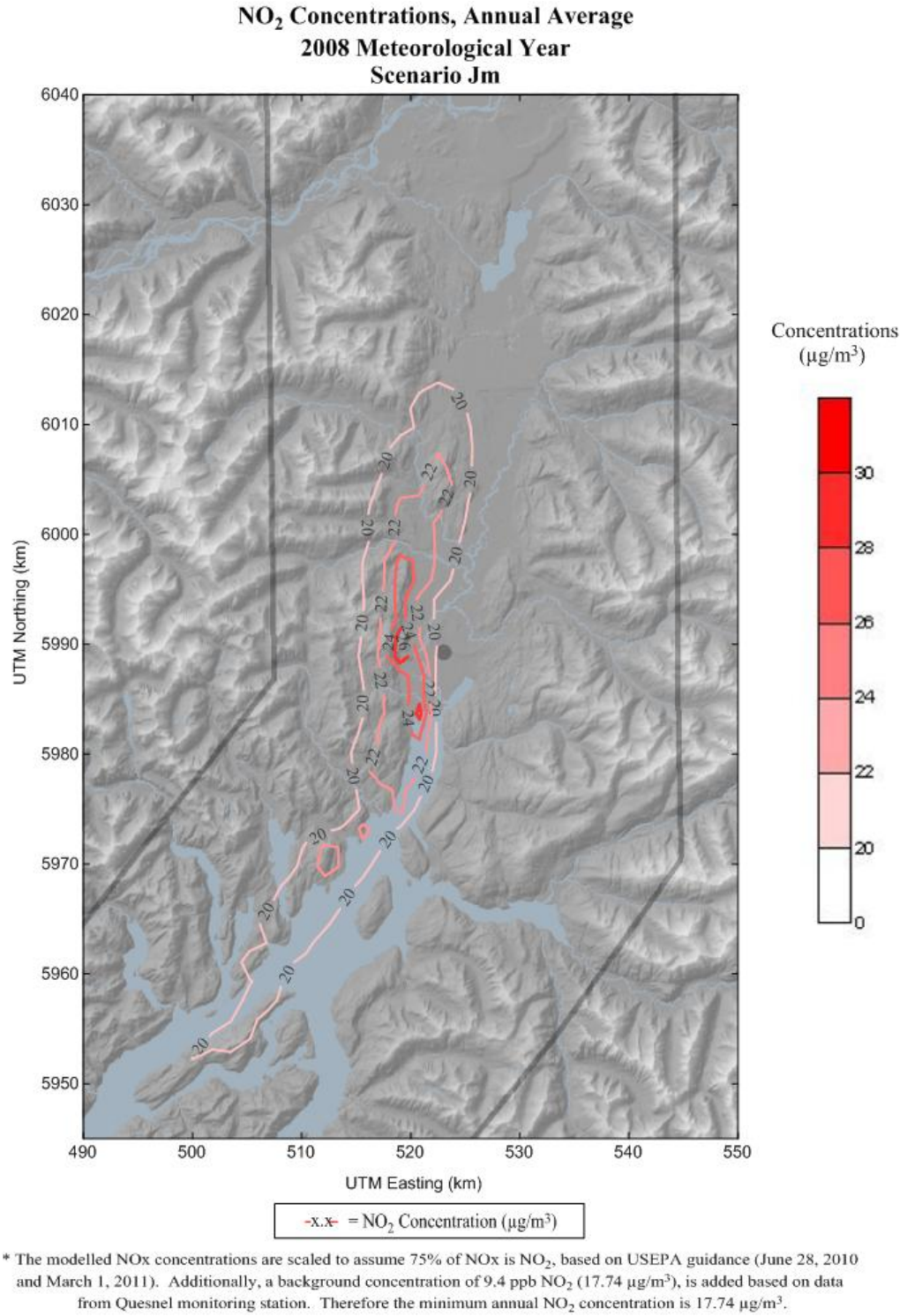
* The modelled NOx concentrations are scaled to assume 75% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 9.4 ppb NO_2 (17.74 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 17.74 µg/m³.

Figure 4-11. Distribution of modelled annual mean NO_2 concentrations during the meteorological year 2008 for Scenario H_82.6.



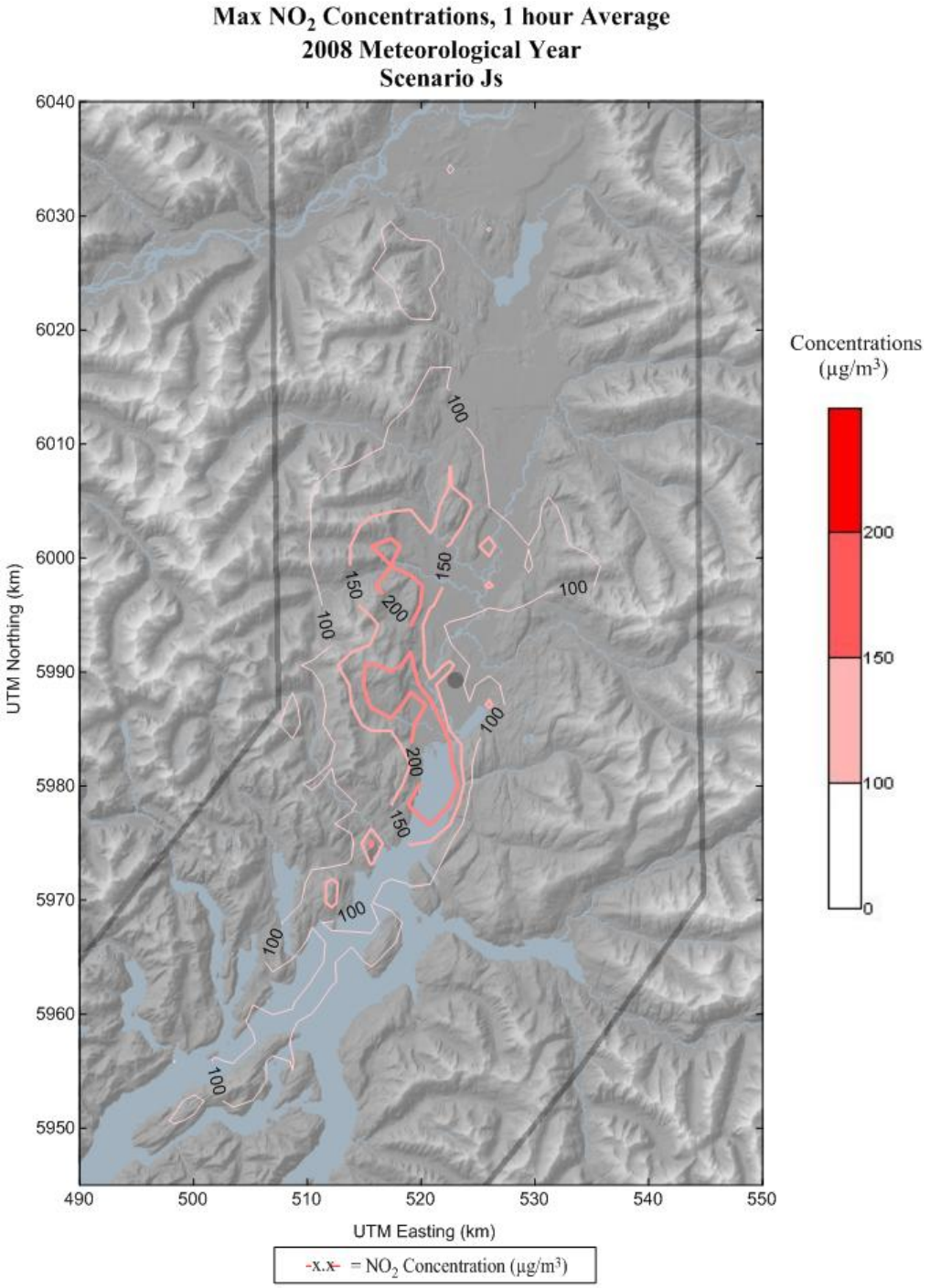
* The modelled NOx concentrations are scaled to assume 75% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 9.4 ppb NO_2 (17.74 µg/m^3), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 17.74 µg/m^3.

Figure 4-12. Distribution of modelled annual mean NO_2 concentrations during the meteorological year 2008 for Scenario Js_86.1.



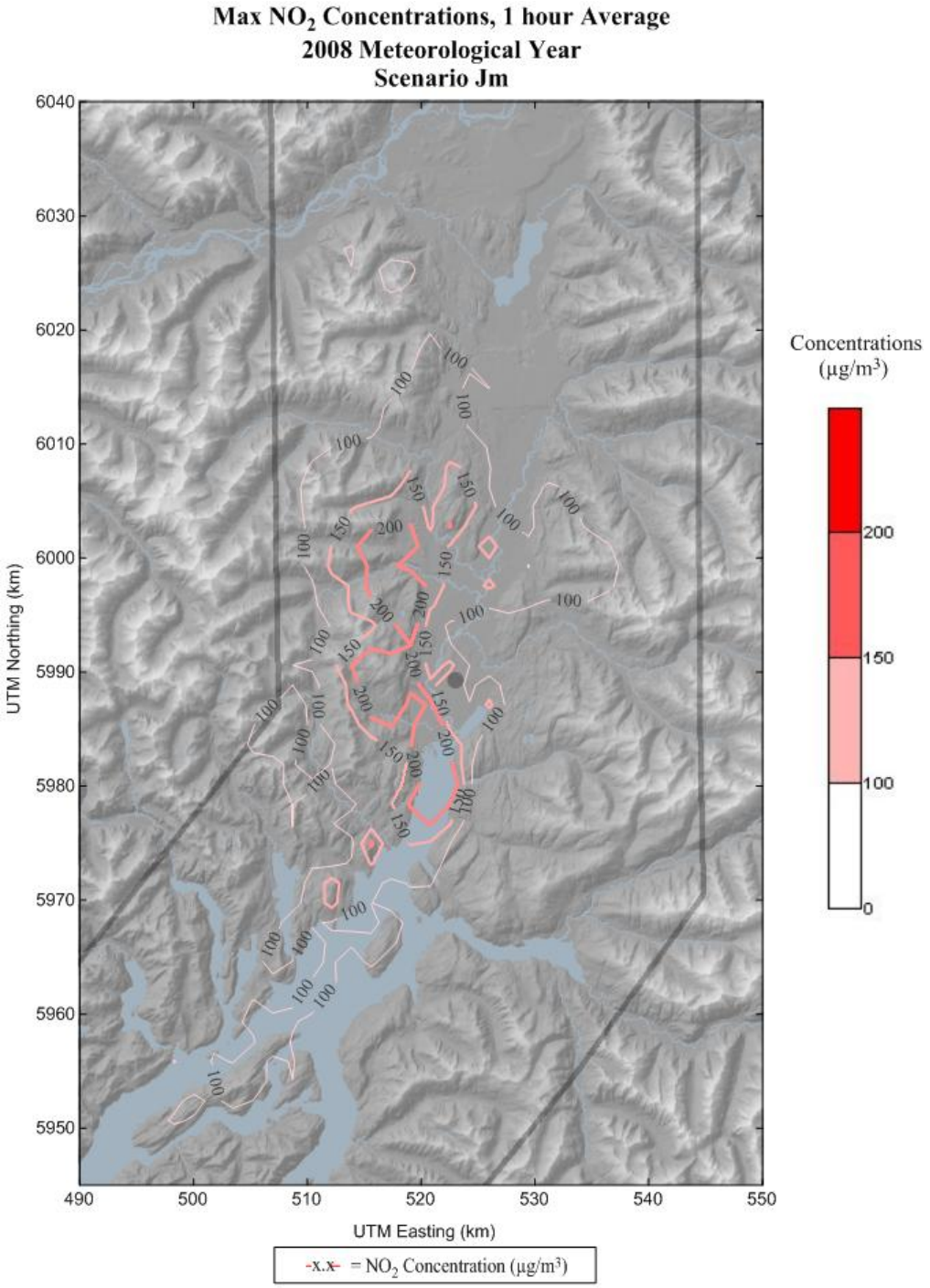
* The modelled NOx concentrations are scaled to assume 75% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 9.4 ppb NO_2 (17.74 µg/m^3), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 17.74 µg/m^3.

Figure 4-13. Distribution of modelled annual mean NO_2 concentrations during the meteorological year 2008 for Scenario Jm_86.1.



* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum 1-hour NO_2 concentration is 57.53 µg/m³.

Figure 4-14. Distribution of modelled maximum 1-hour average NO_2 concentrations during the meteorological year of 2008 for Scenario Js_86.1.



* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum 1-hour NO_2 concentration is 57.53 µg/m³.

Figure 4-15. Distribution of modelled maximum 1-hour average NO_2 concentrations during the meteorological year of 2008 for Scenario Jm_86.1.

5 TERRESTRIAL ECOSYSTEMS

The terrestrial ecosystems assessment comprised a determination of the risk of acidification and eutrophication, based on exceedance of critical loads.

- Critical loads of acidity (sulphur and nitrogen) were determined for forest ecosystems on mineral soil (acidification receptor), covering 65% of the study area.
- Critical loads of nutrient nitrogen were determined for semi-natural terrestrial habitats (eutrophication receptor) covering 85% of the study area.
- Exceedance of critical loads was estimated for eight anthropogenic sulphur and nitrogen emissions scenarios and four Electrical Generating Facility siting scenarios (plus background sulphur and nitrogen deposition) for receptor ecosystems in every 1 km × 1 km grid across the study domain.

5.1 Methods

5.1.1 Environmental Data

The determination and mapping of critical loads[21] (acidity and eutrophication) for terrestrial ecosystems (Figure 5-1) in the study region incorporated point observations and continuous digital (mapped) coverages for a range of environmental data (Table 5-1). Digital soil maps were not available for the study area, therefore forest soil point observations were used to generate coverages (e.g., organic matter, sand, coarse fragment and base cation weathering) required to estimate critical loads. Soil data (at 80 locations; Figure 5-1) were obtained from two field surveys conducted during June 2012 (n = 51) and October 2013 (n = 29); both surveys were carried out by Cambria Gordon Consultants using consistent field protocols (described in ESSA et al. 2013). The soil sampling was stratified by bedrock geology to ensure sample replication within the principal bedrock types (scale 1:250 000; Massey et al. 2005) and surficial geologies (scale 1:5000 000; Fulton 1996) for forest soils in the study region. In general, soil sampling locations were randomly selected from mapped geology units; however, sites were weighted towards road accessible areas (ESSA et al. 2013). At each sampling location, soil samples were collected from the four corners and centre point of a 10 m by 10 m quadrate using a soil auger, and composited to obtain a representative sample for chemical analysis (ESSA et al. 2013). Mineral soils were sampled at three fixed depths (0–10 cm; 15–25 cm and 40–50 cm) approximately representing the A, and upper and lower B soil horizons. At one location (the centre point), a small quadrate (400 cm^2) was used to collect the LFH (litter-fibric-humic) layer; the average depth of the LFH layer was also recorded at all five sampling points per site. In addition to the composite soil samples, a fixed-volume bulk density core sample was taken at each mineral soil depth from the centre point.

All composite mineral soils (three depths per site) were analysed for pH, loss-on-ignition (LOI: estimate of soil organic matter) and particle size (sand, silt and clay). Field soil moisture content (during sampling) and bulk density were determined on the fixed-volume core samples from the centre pit for each site. A weighted-average mineral soil sample for each site (i.e., composite of all depths weighted by bulk density) was analysed for total oxide content (n = 80), and a weighted-average composite sample of 4 to

[21] A critical load is defined as 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge' (Nilsson and Grennfelt 1988).

6 sites per bedrock type was analysed for qualitative mineralogy (n = 27). Prior to analysis all mineral soil samples were air-dried and sieved to 2 mm, the weight and volume of the >2 mm coarse fragments were recorded for the fixed-volume core samples, and samples for oxide and qualitative mineralogy were further pulverized to ~ 100 µm. Total oxide analysis was carried out by the Analytical Sciences Laboratory, Western University, Ontario on a PANalytical PW-2400 X-ray Flourescence Spectrometer. Qualitative mineralogy analysis was carried out by the Department of Earth, Oceans and Atmospheric Sciences, University of British Columbia by X-ray Diffraction on a Siemens (Bruker) D5000 Bragg-Brentano diffractometer.

The average profile bulk density was 0.733 g/cm^3 and soil organic matter content (LOI) was 15.2% for mineral soil across the 80 study sites (see Table A12-1 in Appendix 12). The soils were predominantly medium texture dominated by sand (average profile: sand 53.3%, silt 41.9%, and clay 4.4%); similarly major oxide analysis was dominated by quartz (average: 54.5%, range: 22.5–70.8%), with average calcium oxide comprising less than 2% (range: 0.5–5.0%; see Table A12-2 in Appendix 12). The average mineral soil depth was >100 cm at ~55% of the sampling plots and ≥50 cm at 90% of the plots. Average coarse fragment content by volume (i.e., stones and pebbles >2 mm) in the top 50 cm of mineral soil was 10% (range: 0.1–45.4%). These data represent the principal quantitative soil information used in the critical loads assessment. Additional soil information within the study region provided supplemental qualitative information (Table 5-1).

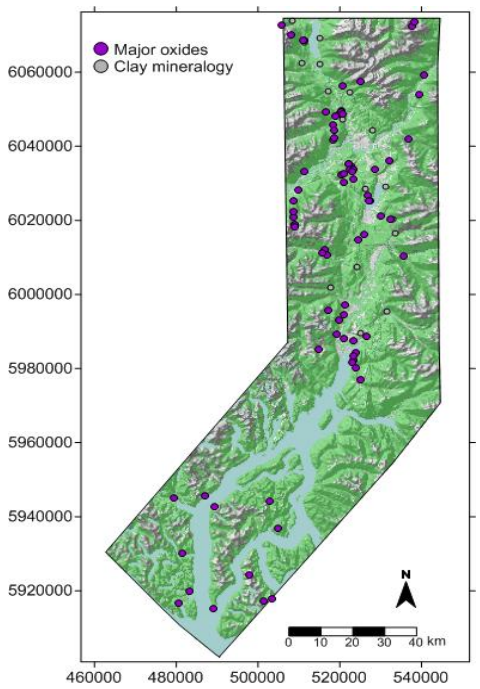


Figure 5-1. Map of the Kitimat study area depicting the coverage of the terrestrial ecosystem assessment. Acidification was assessed for forested ecosystems (shown in green) on mineral soils (65% of the study area). Eutrophication was assessed for all semi-natural terrestrial areas (green and grey, 83% of the study area). The location of soil sampling sites with geochemical (major oxide) analysis (purple filled circles; n = 80) and locations with supplemental soil clay mineralogical data (grey filed circles). Map projection: Universal Transverse Mercator (UTM) Zone 9 (North American Datum 1983).

Table 5-1. Environmental data (site-specific observations and digital [mapped] coverages) for terrestrial ecosystems in the study area.

Data	Description and Source
Soil geochemistry	Site-specific data in the study area (80 locations; see Figure 5-1), with observations of location (co-ordinates), organic matter content, major oxide content, qualitative mineralogy and site descriptions (Appendix 12). Source: BC Ministry of Environment.
Soil chemistry	Site-specific observations of soil chemistry and soil mineralogy from existing studies, e.g., Talisman (1999), Turchenek and Tashe (2010), Clague (1984).
Soils and geology	– British Columbia Digital Geology (scale: varies from 1:50 000 to 1:250 000). Source: OpenFile 2013-4 (version: 2.1, August 2013). – Dominant surficial geology (scale 1:20 000 and 1: 50 000). Source: TEI (BC Ministry of Environment). Surficial geology (scale 1:5 000 000). Source: Fulton (1996) and Clague (1977). – EcoGeo (scale 1:250 000; provincial map derived from bedrock geology and quaternary sediments layer). Source: BC Ministry of Environment.
Elevation	– Digital Elevation Model (scale: 1:20 000). Source: BC Ministry of Environment.
Meteorology	Climate normals (1961–1990) for annual rainfall and annual average temperature estimated by PRISM at a 4 km by 4 km grid resolution (Daly et al. 1994, downscaled to 400 m by 400 m using ClimateWNA (Wang et al. 2006)). Source: www.climatewna.com.
Hydrology	Long-term modelled average annual runoff for the 1961–1999 period for the entire study area on a 0.4 km x 0.4 km. Source: Distributed Climate Water Balance Model (Moore et al. 2012).
Land cover	– The British Columbia Watershed Atlas of aquatic-related features, e.g., streams, lakes, wetlands, obstructions, dams, etc (scale: 1:50 000). Source: BC Ministry of Environment. – Ministry of Forestry VRI (*covers TSAs but not TFLs)* – Landsat 1999–2004 (grids 103H and 103I) – Consolidated cutblock data 2013
Forest harvesting	Extend approach used in the KMP SO_2 Technical Assessment (ESSA et al. 2013) using, where available, additional data on Timber Supply Areas (TSAs), Tree Farm Licences (TFLs), or community forests in the study area.

5.1.2 Critical Loads

Critical loads of acidification and eutrophication (nutrient nitrogen) for terrestrial ecosystems in the Kitimat study area were estimated following methods described in UNECE (2004). The assessment focused on forested ecosystems (on mineral soils, covering 65% of the study area; Figure 5-1) for acidification and eutrophication effects using mass balance models, but also included a wider empirical assessment for nutrient nitrogen for terrestrial ecosystems (covering 83% of the study area). Critical loads of acidification and eutrophication were determined using the steady-state mass balance (SSMB) and nutrient mass balance models, respectively, for forested ecosystems (UNECE 2004). Additionally, an empirical assessment for nutrient nitrogen was applied to all semi-natural terrestrial habitats in the study area following Bobbink and Hettelingh (2010).

The acidifying impact of sulphur and nitrogen define a critical load function (CLF) incorporating the most important biogeochemical processes that affect long-term soil acidification (UNECE 2004). The function is defined by three quantities (see Table 5-2: Equations 1–4): the maximum critical load of sulphur ($CL_{max}(S)$), minimum critical load of nitrogen ($CL_{min}(N)$) and the maximum critical load of nitrogen ($CL_{max}(N)$). Similarly, the critical load of nutrient nitrogen for forested ecosystems is derived from the balance of long-term nitrogen sources and sinks (see Table 5-2: Equation 5). The level of protection for

the chosen receptor ecosystem (e.g., forests) is specified via a critical ANC[22] leaching (acidification [Equations 1 and 4]) and acceptable nitrate leaching (nutrient nitrogen [Equation 5]). Habitat-specific empirical critical loads of nutrient nitrogen ($CL_{emp}(N)$) for the study area were based upon the current state-of-knowledge following Bobbink et al. (2010), Bobbink and Hettelingh (2010), Pardo et al. (2011) and Blett et al. (2014).

Five critical loads variables were determined and mapped across the Kitimat study area: $CL_{max}(S)$, $CL_{min}(N)$, $CL_{max}(N)$, $CL_{nut}(N)$ and $CL_{emp}(N)$. The required model inputs for the mass balance models (Table 5-3) were obtained from existing environmental data sets (Table 5-1) and literature values (e.g., UNECE 2004, Bobbink and Hettelingh 2010). Spatial prediction or regionalisation of soil input parameters, e.g., base cation weathering rates and soil organic matter, was carried out using established geostatistical mapping techniques (McBratney et al. 2003), i.e., regression-kriging following Hengl et al. (2004). The final mapped resolution was consistent with the modelled deposition scenarios (See Section 2: Air Dispersion and Deposition Modelling): 1 km × 1 km.

Table 5-2. Critical load mass balance models for the assessment of acidification and eutrophication of forested ecosystems; see Table 5-3 for a described of model parameters and data sources.

Critical load	Equation	Number
$CL_{max}(S)$	$CL_{max}(S) = BC_{dep} - Cl_{dep} + BC_{w} - Bc_{u} - ANC_{le(crit)}$	Eqn (1)
	[23]Where $ANC_{le(crit)} = -Q^{\frac{2}{3}} \cdot \left(1.5 \cdot \left(\frac{Bc_w + Bc_{dep} - Bc_u}{(Bc:Al)_{crit} \cdot K_{gibb}} \right) \right)^{\frac{1}{3}} - 1.5 \cdot \left(\frac{Bc_w + Bc_{dep} - Bc_u}{(Bc:Al)_{crit}} \right)$	Eqn (2)
$CL_{min}(N)$	$CL_{min}(N) = N_i + N_u$	Eqn (3)
$CL_{max}(N)$	$CL_{max}(N) = CL_{min}(N) + CL_{max}(S) / (1 - f_{de})$	Eqn (4)
$CL_{nut}(N)$	$CL_{nut}(N) = CL_{min}(N) + N_{le(acc)} / (1 - f_{de})$	Eqn (5)

Table 5-3. Description of input parameters required to determine critical loads of acidity and eutrophication for terrestrial ecosystems (see Table 5-2) and their data sources for this assessment.

Critical load	Parameter	Description	Data source
$CL_{max}(S)$	BC_{dep}	Non-marine base cations (BC = Bc + Na^+ (sodium), Bc = Ca^{2+} (calcium) + Mg^{2+} (magnesium) + K^+ (potassium)) deposition	Derived from observations of wet deposition and long-term rainfall volume (Table 5-1: Meteorology). Wet deposition observations were obtained from the NADP[24] (two stations: Haul Road and Lakeelse Lake in the Kitimat Valley) and Emili and

[22] Acid Neutralising Capacity (ANC); the most common approach is based on a critical molar Bc:Al ratio as an indicator of damage to plant fine roots, in general most chemical criteria incorporate aluminium concentration as the indicator of damage.
[23] Equation 2 depends on the chosen chemical criteria, a molar Bc:Al was selected under the Kitimat Airshed Emissions Effects Assessment scoping study.
[24] National Atmospheric Deposition Program [URL: http://nadp.sws.uiuc.edu/]

Critical load	Parameter	Description	Data source
			Price (2013; Diana Lake Provincial Park).
	Cl_{dep}	Non-marine chloride deposition	Assumed to be negligible.
	BC_w	Base cation weathering rate	Estimated using the A2M-PROFILE model chain (Warfvinge and Sverdrup 1992 (PROFILE); Posch and Kurz 2007 (A2M)) from site-specific soil and soil geochemical observations at 80 locations (Figure 5-1, and Appendix 12); regionalised using a regression-kriging approach (Hengl et al. 2004); see Figure 5-2.
	Bc_u	Base cation removal in harvested biomass	Based on the Annual Allowable Cut (AAC) and literature values for base cation (Ca^{2+}, Mg^{2+} and K^{+})[25] concentrations in tree species (Western Hemlock). Source: ESSA Technologies (updated from ESSA et al. 2013).
	$Bc:Al_{(crit)}$	Critical molar base cation to aluminum ratio	Chemical criterion associated with ecosystem damage. Set to Bc:Al = 1.0 for coniferous forests and Bc:Al = 6.0 for deciduous and mixed forests (Sverdrup and Warfinge 1993).
	Q	Long-term annual soil percolation or runoff	Obtained from the Distributed Climate Water Balance Model (Moore et al. 2012; see Table 5-1: Hydrology).
	K_{gibb}	Gibbsite equilibrium	Based on soil organic matter content following UNECE (2004) $-pK_{gibb}$ = 9.0 (LOI <5%), 8.5 (LOI >5% and <15%),and 7.6 (LOI >15%). Site observations of LOI (Appendix 12) were regionalised using a regression-kriging approach.
$CL_{min}(N)$	N_i	Long-term nitrogen immobilization	Linearly interpolated between 0.5 kg N/ha/yr (3.57 meq/m^2/yr) and 1.0 kg N/ha/yr (7.14 meq/m^2/yr) scaled on the minimum and maximum (respectively) soil organic matter content (LOI). Site observations of LOI (Appendix 12) were regionalised using a regression-kriging approach.
	N_u	Nitrogen removal in harvested biomass	Based on Annual Allowable Cut (AAC) and literature values for nitrogen concentration in for tree species (Western Hemlock). Source: ESSA Technologies (updated from ESSA et al. 2013).
$CL_{max}(N)$	f_{de}	The fraction of atmospherically deposited nitrogen that is denitrified	Based on soil drainage classes (UNECE 2004); in the study area it was assumed soil organic matter content (LOI) was related to drainage. Linearly interpolated between 0.1 (well drained) and 0.7 (poorly drained) soils scaled on the minimum and maximum (respectively) soil organic matter content. Site observations of LOI (Appendix 12) were regionalised using a regression-kriging approach.
$CL_{nut}(N)$	$N_{le(acc)}$	Acceptable nitrogen leaching	Chemical criterion associated with ecosystem damage; set to 0.2 mg N/L for forest ecosystems to protect against nutrient imbalances (UNECE 2004).

[25] Sodium (Na+) is a minor minor component of forest biomass.

Critical loads of acidity and nutrient nitrogen were determined for forested ecosystems on mineral soils, covering approximately 65% of the Kitimat study area (Figure 5-1: derived from landcover classified as forest or previously forested (Figure 5-3), excluding areas with surficial geology classified as organic material (Table 5-1)). Mapped forest area was delineated into 1 km × 1 km grids aligned with the modelled deposition grid, and the proportion of coniferous and deciduous (including mixed) forest recorded for each grid. Not all grids had 100% forest coverage: average forest cover within each 1 km × 1 km grid was 69% (range: 1–100%). The total number of receptor grids was 6,218; critical loads of acidity (sulphur and nitrogen) and eutrophication (Table 5-2) were estimated for forest ecosystems in each 1 km × 1 km grid across the study area (see Figure 5-1) by combining existing mapped input parameters (Table 5-3) with derived parameters, e.g., soil base cation weathering rate, based on point observations regionalised using a geostatistical regression-kriging approach (Figure 5-2).

In brief, site-specific estimates of normalised[26] base cation weathering rates were estimated at each location with soil major oxide content (Figure 5-1, and Appendix 12) using the Analysis to Mineralogy (A2M) solver (Posch and Kurz 2007) and the PROFILE model (Sverdrup and Warfvinge 1988; Warfvinge and Sverdrup 1992). Base cation weathering was determined for the top 50 cm of the mineral soil (using bulked soil observation data; see Appendix 12), which was assumed to represent the dominant tree rooting depth[27]. The normalised weathering rates, sand fraction, coarse fragment, and organic matter content (estimated as loss-on-ignition) at each point location was regionalised using geostatistical regression-kriging (Hengl et al. 2004). Geostatistical methods are optimal when data are normally distributed and stationary. Predictor variables with continuous coverage (n = 70) assumed to represent soil forming processes (i.e., scorpan factors: McBratney et al. 2003) were assembled for each point location. All predictor (explanatory) variables were transformed to ensure normality[28] and their predictive capacity evaluated against the dependent variables using linear regression. The explanatory variable with the greatest predictive capacity was selected for each dependent variable; at most explanatory values predicted 30% to 40% of the variation in the dependent variables. A semi-variogram model was fitted to the residuals of each dependent variable to characterise their spatial correlation and interpolated (on a 2.5 km × 2.5 km grid) across the study domain using kriging, which is an optimal interpolation technique that employs semi-variogram models. Continuous coverage maps for each dependent variable (normalised weathering rates, sand fraction, coarse fragment, and organic matter content) were produced by combining the linear regression model and interpolated residuals. Normalised weathering rates were modified by bulk density, surface area[29] and temperature (BST-model) to generate site-specific weathering rates for each 1 km × 1 km grid square. The soil rooting depth of 50 cm was modified by coarse fragment (%) to reflected the amount of fine earth (soil <2 mm) in the top 50 cm of soil. Bulk density and soil surface area for each 1 km × 1 km grid square were estimated from mapped soil organic matter and sand fraction based on linear relationships derived from the 80 point observations (Figure 5-3). Continuous coverage maps were used to derive input parameters (Table 5-3) and estimate critical loads (Table 5-2) for forested mineral soils in each 1 km × 1 km grid square (Figure 5-2).

[26] Normalised indicates that average bulk density, surface area and temperature were used to estimate weathering rates in the PROFILE model.

[27] Field observations at the 80 soil sampling locations recorded visible roots in 96% of the sites at 0–10 cm depth, 65% of the sites at 15–25 cm depth and 21% of the sites at the 40–50 cm depth.

[28] Predictor variables that could not be transformed were further excluded from the analysis.

[29] Soil mineral surface area was estimated from particle size analysis (sand, silt and clay fractions) according to (Sverdrup and Warfvinge 1988): $8.0 \times X_{clay} + 2.2 \times X_{silt} + 0.3 \times X_{sand}$ (units: m^2/g).

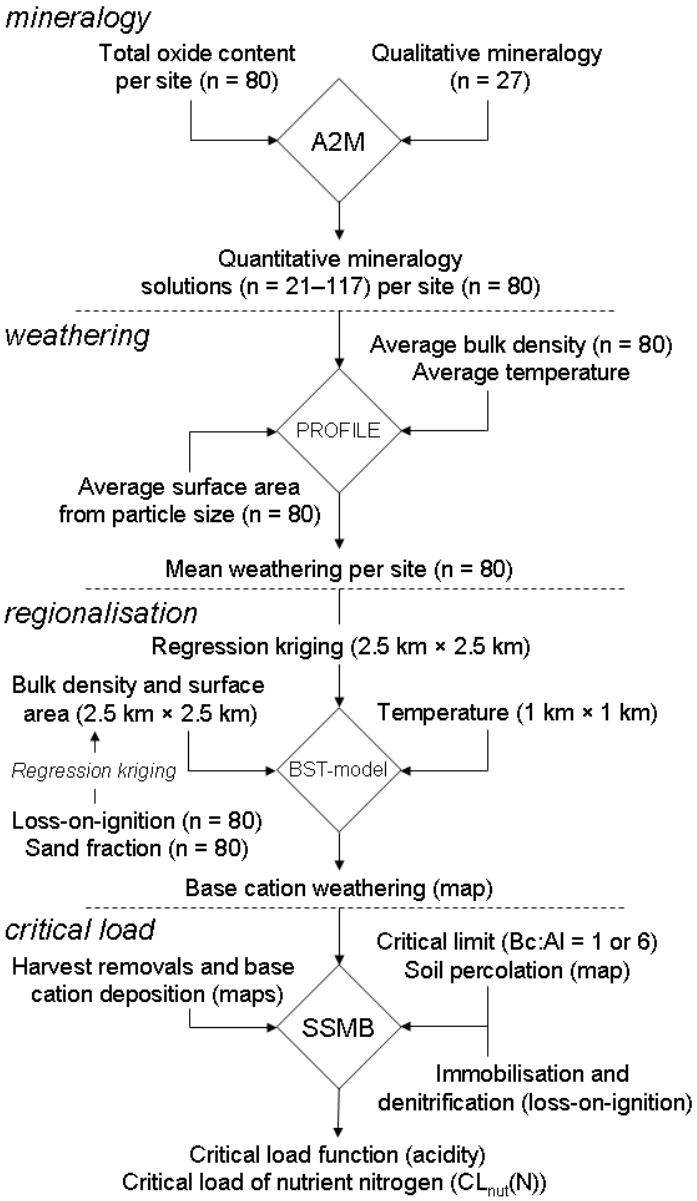


Figure 5-2. Schematic representation of the model chain used to estimate and regionalize base cation weathering rates and critical loads of acidity for forested mineral soils in the study area. Quantitative mineralogy was estimated using A2M; these data were used in combination with site-specific observations to estimate average weathering rates using PROFILE. Weathering was regionalized using regression-kriging and modified by site-specific bulk density, surface area and temperature (BST-model); finally critical loads were estimated using the SSMB model for forested mineral soils in each 1 km × 1 km receptor grid cell (n = 6,218) across the study area.

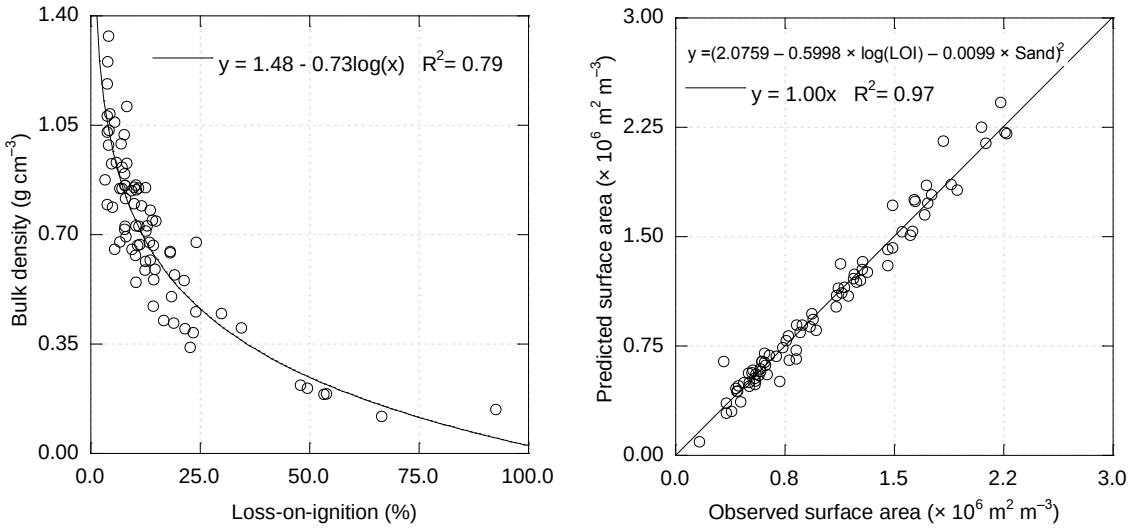


Figure 5-3. Relationship between log of loss-on-ignition (organic matter content; %) and soil bulk density (g/cm^3), and observed and predicted square root of surface area at the 80 soil sampling locations (Figure 5-1).

Empirical Critical Loads for Nutrient Nitrogen: Empirical critical loads ($CL_{emp}(N)$) are determined from observations of detrimental responses to an ecosystem or ecosystem component under nitrogen deposition; this level of deposition is set as the critical load. Empirical critical loads for N published in the peer-reviewed literature are based on measurements from numerous gradient studies, field experiments, or long-term monitoring sites, and are typically synthesised as ranges for broader ecosystem or habitat classifications (Bobbink et al. 2010; Pardo et al. 2011; Blett et al. 2014). Landcover classes (Figure 5-4) within the study a were assigned the lower end of the range from published empirical critical loads for N associated with the most relevant ecosystem types reported by Bobbink et al. (2010), Pardo et al. (2011), and Blett et al. (2014) (Table 5-4). When more than one potential ecosystem type was reported for a landcover classification, the lowest $CL_{emp}(N)$ was chosen (Table 5-4).

A study by Geiser et al. (2010) suggested that $CL_{emp}(N)$ could be as low as 19.2 meq/m^2/yr (2.7 kg N/ha/yr) based on community changes in epiphytic macro-lichen communities in western Oregon and Washington forests. However this $CL_{emp}(N)$ was considered applicable to low (440 mm) precipitation areas (Geiser et al. 2010). In areas with median (1,860 mm) precipitation, a $CL_{emp}(N)$ of 35.7 meq/m^2/yr (5 kg N/ha/yr) was reported and in high (4,510 mm) precipitation areas, a $CL_{emp}(N)$ of 65.7 meq/m^2/yr (9.2 kg N/ha/yr) was suggested (Geiser et al. 2010). Consequently, to protect lichen communities in coniferous forests in the study area, a conservative $CL_{emp}(N)$ of 28.6 meq/m^2/yr (4 kg N/ha/yr) was chosen based on a synthesis of multiple studies (Bobbink et al. 2010; Pardo et al. 2011; Blett et al. 2014). Empirical critical loads for nitrogen were estimated for semi-natural terrestrial habitats covering 85% of the study domain; agricultural land, developed land, snow and ice and water landcover classes were not included in the assessment.

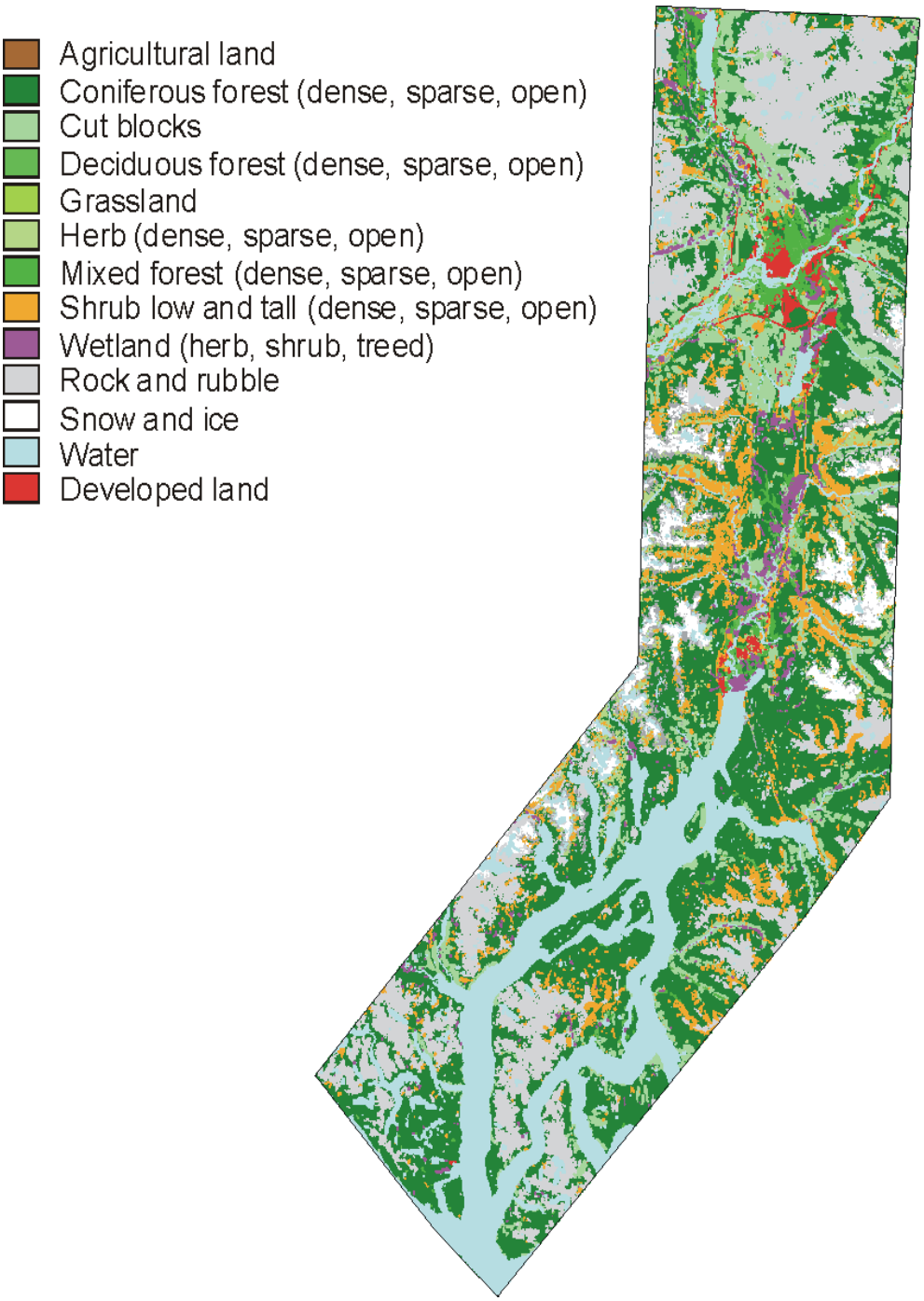


Figure 5-4. Landcover classes for the Kitimat study area (see Table 5-1 for data sources). Empirical critical loads of nutrient nitrogen for each landcover class are given in Table 5-4. Map projection: Albers equal-area conic projection.

Table 5-4. Landcover classes (see Figure 5-4), reported values (ranges) of empirical critical loads for nutrient nitrogen ($CL_{emp}(N)$) for related habitat or ecosystem types[a], and selected $CL_{emp}(N)$ for the Kitimat study area (given in kg N/ha/y and meq/m^2/yr).

Landcover	Habitat or ecosystem type and reported $CL_{emp}(N)$ ranges (kg N/ha/yr)[b]	Area (km^2)	Area (%)	$CL_{emp}(N)$ (kg N/ha/yr [meq/m^2/yr])
Coniferous forest (dense, open and sparse); Cut blocks	Coniferous Forests Northwest: 10–15 Mountain Forests: 4–10 Marine West Coast Forests: 5 Spruce Forests: 5–7	4002.4	59.1	4 [28.6]
Deciduous forest (dense, open and sparse)	Deciduous Forests: 10–15	58.6	0.9	10 [71.4]
Mixed forest (dense, open and sparse)	Temperate Forests Northwest: 10–15 Mountain Forests: 4–10 Marine West Coast Forests: 5	109.3	1.6	4 [28.6]
Grassland; Herb (dense, open and sparse)	Alpine / Subalpine Grassland: 5–10	102.8	1.5	5 [35.7]
Shrub low (dense, open and sparse); Shrub tall (dense, open and sparse)	Arctic, Alpine and Subalpine Scrub Habitats: 5–15	219.0	3.2	5 [35.7]
Rock/Rubble; Exposed land; Unclassified	Moss and Lichen Dominated Mountain Summits: 5–10	830.1	15.4	5 [35.7]
Wetland (herb, shrub and treed)	Raised and Blanket Bogs: 5–10 Poor Fens: 10–20	56.0	0.8	5 [35.7]

[a] Source: Bobbink et al. (2010), Pardo et al. (2011), and Blett et al. (2014).
[b] Empirical critical loads for nutrient nitrogen ($CL_{emp}(N)$) are reported in the literature in units of kg N/ha/yr, which is converted to meq/m^2/yr as 1 kg N/ha/yr = 7.1 meq/m^2/yr.

5.1.3 Critical Limits and Exceedance

Critical Chemical Criteria. The most widely used acidification threshold linking soil chemical status and plant response is a critical[30] molar base cation (Bc) to aluminium ratio; sodium is excluded as it does not protect plant roots against aluminium. A soil solution critical molar Bc:Al ratio = 1.0[31] within the top 50 cm (the principal rooting zone) was chosen to be conservatively protective of the dominant tree species (Western Hemlock) in the region (Sverdrup and Warfvinge 1993). In areas dominated by deciduous (or mixed) forests a critical Bc:Al ratio = 6.0 within the top 50 cm was chosen to ensure protection of the more sensitive deciduous tree species, such as *Populus tremula* (Sverdrup and Warfvinge 1993). The average critical load for each 1 km × 1 km grid was determined by weighting coniferous and deciduous critical load estimates by their areal coverage. Notably a range of chemical indicators of acidification have been proposed for forest ecosystems (see Table 5-5); while the molar Bc:Al ratio is the most widely used criterion (see Cronan and Grigal 1995 for support) it has also been highly criticized (Løkke et al. 1996), as such several studies have used alternative or multiple criteria (Aherne et al. 2001; Hall et al. 2001; Reinds et al. 2008). The uncertainty in predicted exceedance associated with the choice of critical chemical criteria was evaluated under Scenario H_82.6 for multiple

[30] Refers to the critical limit which is the most unfavourable value for the chemical criterion, i.e., the critical chemical criterion for protection of structure and function of the chosen receptor ecosystem.
[31] A range of critical values has been proposed which depends on plant species (see Sverdrup and Warfvinge 1993). The most widely used critical chemical criterion is Bc:Al = 1.0, as such it was used under the Kitimat Airshed Emissions Effects Assessment scoping study.

criteria (see Table 5-5). Acceptable nitrogen leaching is the chemical criterion associated with ecosystem damage under (mass balance) nutrient nitrogen deposition in forested ecosystems; acceptable nitrogen leaching was set to 0.2 mg N/L in all forest types to protect against nutrient imbalances (UNECE 2004).

Table 5-5. Link between air pollution impacts, chemical indicators and critical limits (ecological thresholds) for terrestrial ecosystems. Ecological thresholds given are typical values that vary depending on ecological and environmental conditions, and desired level of protection.

Impact	Ecological Response	Chemical Indicator	Critical Limit (Ecological Threshold)	
Acidification	▪ Decreased forest growth ▪ Increased susceptibility to disease ▪ Decreased soil nutrient status ▪ Loss of soil structural integrity ▪ Increased export of toxic metals	Molar Bc:Al or molar Ca:Al ratio	< 1[a]	Indicator of damage to plant fine roots
		Soil solution Al^{3+} (Al)	< 0.2 eq/m^3	Indicator of damage to plant fine roots
		Soil solution pH	< 4.0–4.2	Mobilisation of toxic metals and damage to plant roots
		Al mobilisation (p)	<2 eq/eq	Indicator of depletion of secondary Al phases and soil structural changes
		Soil base saturation	< 10%	Indicator of the soil acid status and nutrient deficiencies
Nutrient enrichment	▪ Nutrient imbalances ▪ Elevated nitrogen leaching ▪ Loss of sensitive plant species ▪ Increase in invasive plants ▪ Increased tree mortality	Nitrogen leaching	< 0.2 mg N/L	Indicator of elevated nitrate leaching, nutrient imbalances and vegetation changes
		Nitrogen deposition	> 5–10 kg N/ha/yr[b]	Indicator of shift in plant species composition (see Table 5-4)

[a] Bc:Al = 1.0 is the most commonly used critical limit but values depend on species (see Sverdrup and Warfvinge 1993).
[b] 35.7–71.4 meq/m^2/yr.

Exceedance of Critical Load. Exceedance of critical loads of acidity and nutrient nitrogen was estimated under eight sulphur and nitrogen emissions Scenarios (A_28.2–H_82.6), presenting a range in potential emissions. An additional four scenarios (building on Scenario H_82.6) were evaluated to assess the impacts of emissions and siting location from a proposed Electrical Generating Facility (see Section 2). All critical load exceedance calculations further included background sulphur deposition of 10 meq/m^2/yr and nitrogen deposition of 5 meq/m^2/yr owing to transboundary emission sources (see Appendix 12.1). Exceedance for a given pair of sulphur and nitrogen depositions is the sum of the sulphur and nitrogen deposition reductions required to reach the critical load function (CLF) by the 'shortest' path (Figure 5-5). The computation of the exceedance function followed the methodology described by UNECE (2004). The proportional area of exceedance was defined as the mapped receptor area under exceedance relative to an '*effects domain*' which was defined as the area receiving ≥15 meq/m^2/yr modelled sulphur and nitrogen deposition owing to anthropogenic emissions under Scenario H_82.6 (1,388 km^2).

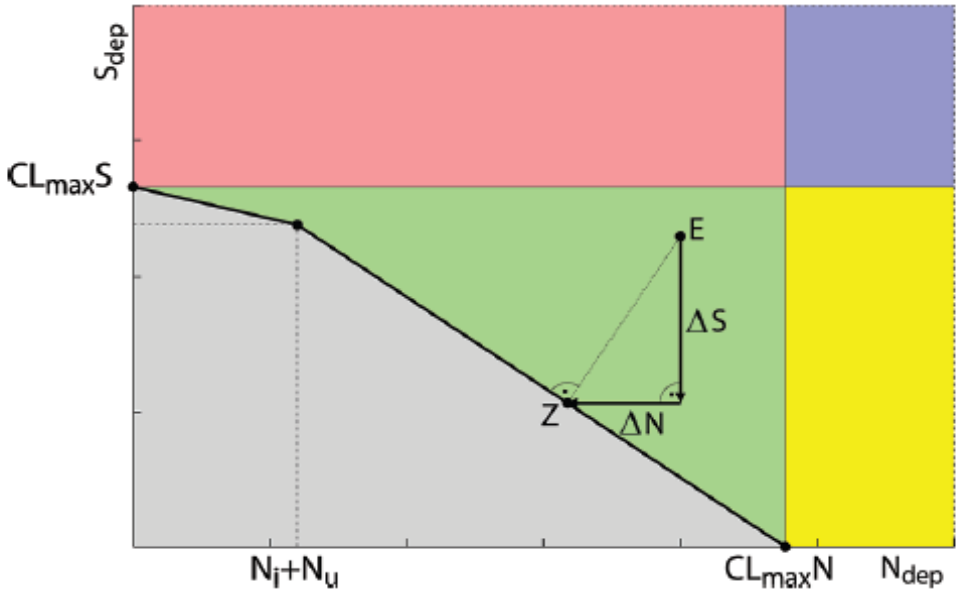


Figure 5-5. Piece-wise critical load function (CLF) for sulphur (S) and acidifying nitrogen (N) as defined by soil properties (thick black line), and the terrestrial system ANC is kept above the critical level. For a given deposition pair (N_{dep}, S_{dep}) the critical load exceedance is calculated by adding the N and S deposition reductions needed to reach the CLF via the shortest path (E→Z): Ex = ΔS + ΔN. The grey area below the CLF denotes deposition pairs resulting in non-exceedance of critical loads. If a deposition pair is located in the green area (such as E), non-exceedance can be achieved by reducing N or S deposition (or both); in the pink (or yellow) area S_{dep} (or N_{dep}) must be reduced to achieve non-exceedance; and in the blue area both N_{dep} and S_{dep} must be reduced.

Risk Assessment Framework. A rating of risk was assigned to each emission scenario based on the area and magnitude of exceedance under acidification and eutrophication assessments. The BC Ministry of Environment determined the exceedance thresholds between the risk categories, primarily based on the areal extent of exceedance (with respect to the 'effects domain'); see Table 5-6. The magnitude of exceedance was also considered, and if areal extent was dominated by uniform low levels of exceedance, i.e., <10 meq/m^2/yr, then the risk rating was modified (lower); however this situation did not occur.

Table 5-6. Risk categories and definitions for the terrestrial ecosystem receptors.

Low	No exceedance, or an areal exceedance of critical loads of acidity and (or) critical loads of nutrient nitrogen[a] ≤0.05%: emissions scenarios expected to have no, or negligible, areal impact.[b]
Moderate	Areal exceedance of critical loads of acidity and (or) critical loads of nutrient nitrogen ≤2.5%: emissions scenarios expected to have an impact, but of a magnitude or spatial extent considered to be acceptable.[c]
High	Areal exceedance of critical loads of acidity and (or) critical loads of nutrient nitrogen >2.5% and ≤5%: emissions scenarios expected to have an impact of a magnitude or spatial extent considered to be unacceptable;[c] further investigation is needed into the implications of the assumptions in this scoping-level assessment to determine if reducing uncertainties and refining assessment inputs lowers the risk category.
Critical	Areal exceedance of critical loads of acidity and (or) critical loads of nutrient nitrogen >5%: scenarios expected to have an impact of a magnitude or spatial extent, considered to be extremely unacceptable;[c] further investigation could be made into the implications of the assumptions in this scoping-level assessment to determine if reducing uncertainties and refining assessment inputs lowers the risk category, but would be unlikely to reduce the impact sufficiently to be considered acceptable.

[a] Critical loads of nutrient nitrogen were assessed using mass balance ($CL_{nut}(N)$ and empirical ($CL_{emp}(N)$) approaches; assignment of risk was based on the approach with the highest exceedance.
[b] Areal exceedance was estimated as a proportion of the '*effect domain*', i.e., area receiving ≥15 meq/m^2/yr modelled sulphur and nitrogen deposition owing to anthropogenic emissions under Scenario H_82.6.
[c] "Acceptability" of impacts depends on one's values, and is ultimately a policy decision.

5.2 Results

5.2.1 Soil Organic Matter Content and Base Cation Weathering

Soil organic matter content in mineral forest soils was estimated to range from 3.9% to 21.5% (average: 11.3%) across the study area (Figure 5-6). The lowest values (<5% LOI) were observed north of Lakelse Lake associated with fluvial, glaciofluvial and marine surficial deposits (covering <2% of the mapped receptor ecosystems). In contrast, the highest values (>15% LOI) were predicted to occur in mountainous regions east and west of the Kitimat Valley (covering 19% of the receptor area). Soil organic matter was used to predict and spatially define several soil parameters including bulk density (Figure 5-3), nitrogen immobilisation, denitrification fraction and the gibbsite equilibrium constant (see Table 5-3 for further details).

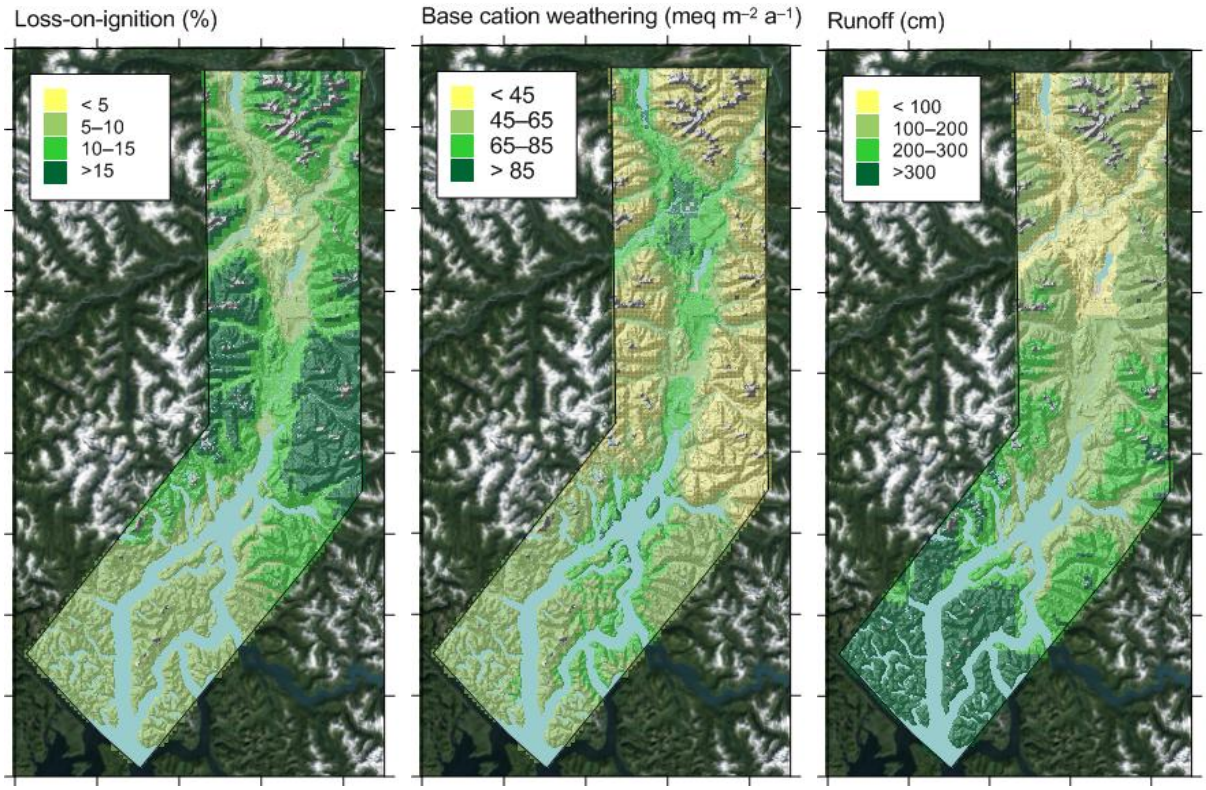


Figure 5-6. Mapped soil organic matter content estimated from loss-on-ignition (LOI [%]), soil base cation weathering (meq/m^2/yr), and modelled soil water percolation or runoff (Q [mm]; see Table 5-3) for the Kitimat study area. Soil LOI and base cation weathering are presented as weighted averages for the entire profile (0–50 cm adjusted by volume of coarse fragment); their mapped values only refer to the forested mineral soil fraction of each 1 km × 1 km grid (see Figure 5-1 for coverage of the forest receptor [green shading]).

Base cation weathering rate (sum of calcium, magnesium, potassium and sodium weathering) for mineral forest soils was estimated to range from 18.7 meq/m^2/yr to 113.5 meq/m^2/yr (average: 56.6 meq/m^2/yr) in the top 50 cm[32]. In general, estimated weathering rates were similar to other acid sensitive regions in Canada: 3–13 meq/m^2/yr Nova Scotia (Whitfield et al. 2006); 58–446 meq/m^2/yr Quebec (Houle et al. 2012); 21–79 meq/m^2/yr Ontario (Koseva et al. 2010); 0.1–8000 meq/m^2/yr Saskatchewan (Whitfield and Watmough 2012); and 19–351 meq/m^2/yr British Columbia (Mongeon et al. 2010). The highest base cation weathering rates were predicted north and south of Lakelse Lake (comprising 16% of the receptor ecosystems), associated with glaciofluvial surficial deposits owing to higher soil bulk density, annual average air temperature and greater estimated soil surface area. In contrast, the lowest weathering rates (comprising 21% of the receptor ecosystems) were generally observed north, east and west of the Kitimat Valley corresponding with course texture mountain soils with low bulk density. On average, sodium weathering (17.1 meq/m^2/yr) comprised approximately 29% of estimated base cation weathering rate, ranging from 15–46%; in contrast, calcium weathering (22.5

[32] Soil depth was adjusted by the volume of coarse fragments to reflect the amount of fine earth (<2 mm) in the top 50 cm, as such, soil depth ranged from 35.6 cm to 49.5 cm (average: 43.6 cm).

meq/m^2/yr)[33] comprised approximately 40%, ranging from 23–50%. Base cation weathering minus sodium (i.e., Bc) and calcium weathering are important parameters used to derive chemical criteria or indicators of damage under the critical loads function (see Table 5-3 and Table 5-5).

Modelled soil water percolation or runoff (Q; Table 5-3) derived from the Distributed Climate Water Balance Model (Moore et al. 2012) was highly variable across the study area. Long-term runoff ranged from 421 mm to 5,340 mm, with an average of 2,046 mm. The high runoffs reflect the high precipitation volume in the more coastal and mountainous regions (i.e., the southern portion) of the study area. Runoff was used to estimate the critical ANC leaching and acceptable nitrogen leaching which incorporate the chemical criteria or indicators of damage (see Table 5-3 and Table 5-5). As such, previous studies have noted that high runoff will lead to high critical loads suggesting regional insensitivity to the chosen chemical indicator of damage (Reinds et al. 2008). To evaluate the influence of runoff on critical load exceedance, a sensitivity analysis was carried out by randomly varying modelled runoff by ±20% under Scenario H_82.6 (see Section 5.2.5).

5.2.2 Critical Loads of Acidity and Nutrient Nitrogen

The spatial pattern of $CL_{max}(S)$ was similar to base cation weathering (Figure 5-6), although significantly greater in magnitude across the region (× ~2.5) owing to the dominance of the $ANC_{le(crit)}$ term, which was twice the average weathering rate (see Table 5-2: Equation 1). The estimated $ANC_{le(crit)}$ was strongly influenced by runoff, which is most notable in the southern portion of the study area (compare Figure 5-6 and Figure 5-7). In regions with high runoff, a critical chemical criterion based on a Bc:Al ratio = 1.0 incorporated into the leaching term will result in high critical loads (compared with weathering rates); all chemical criteria incorporated into leaching terms will show the same pattern (Table 5-2 and Table 5-5). Similarly, estimated $CL_{max}(N)$ was high; 66.3% of the mapped receptors had $CL_{max}(S)$ >150 meq/m^2/yr and 47.1% had $CL_{max}(N)$ >300 meq/m^2/yr (Figure 5-7). As such, much of the study region is considered to have moderate to high critical loads of acidity, and consequently have moderate to low sensitivity to acidic deposition.

In contrast, critical loads for nutrient nitrogen were much lower, with $CL_{nut}(N)$ estimated to be <100 meq/m^2/yr across 96.6% of the mapped receptor ecosystems, and $CL_{emp}(N)$ ranging between 28.6 meq/m^2/yr (4 kg N/ha/yr) and 35.7 meq/m^2/yr (5 kg N/ha/yr) across most of the study area (Figure 5-7). The estimated $CL_{emp}(N)$ was smaller than $CL_{nut}(N)$, with similar values for $CL_{nut}(N)$ covering only 25% of the mapped ecosystems. The average $CL_{nut}(N)$ was approximately 57 meq/m^2/yr (8 kg N/ha/yr) compared with 28.6–35.7 meq/m^2/yr (4–5 kg N/ha/yr) for $CL_{emp}(N)$. Mapped habitats were assigned the lowest $CL_{emp}(N)$ values from the range reported for each ecosystem type in the study area, the mid-point of the range would result in greater correspondence with estimated $CL_{nut}(N)$ and may be more appropriate for the region. However, the lowest value was selected as a conservative approach to mapping $CL_{emp}(N)$ in this study.

[33] Weathering rates were estimated for each individual cation, i.e., calcium, magnesium, potassium and sodium, at the soil sampling sites (n = 80); however, the regional map of calcium weathering was estimated through linear regression with base cations owing to the high correspondence between the two parameters (adjusted R^2 = 89.7).

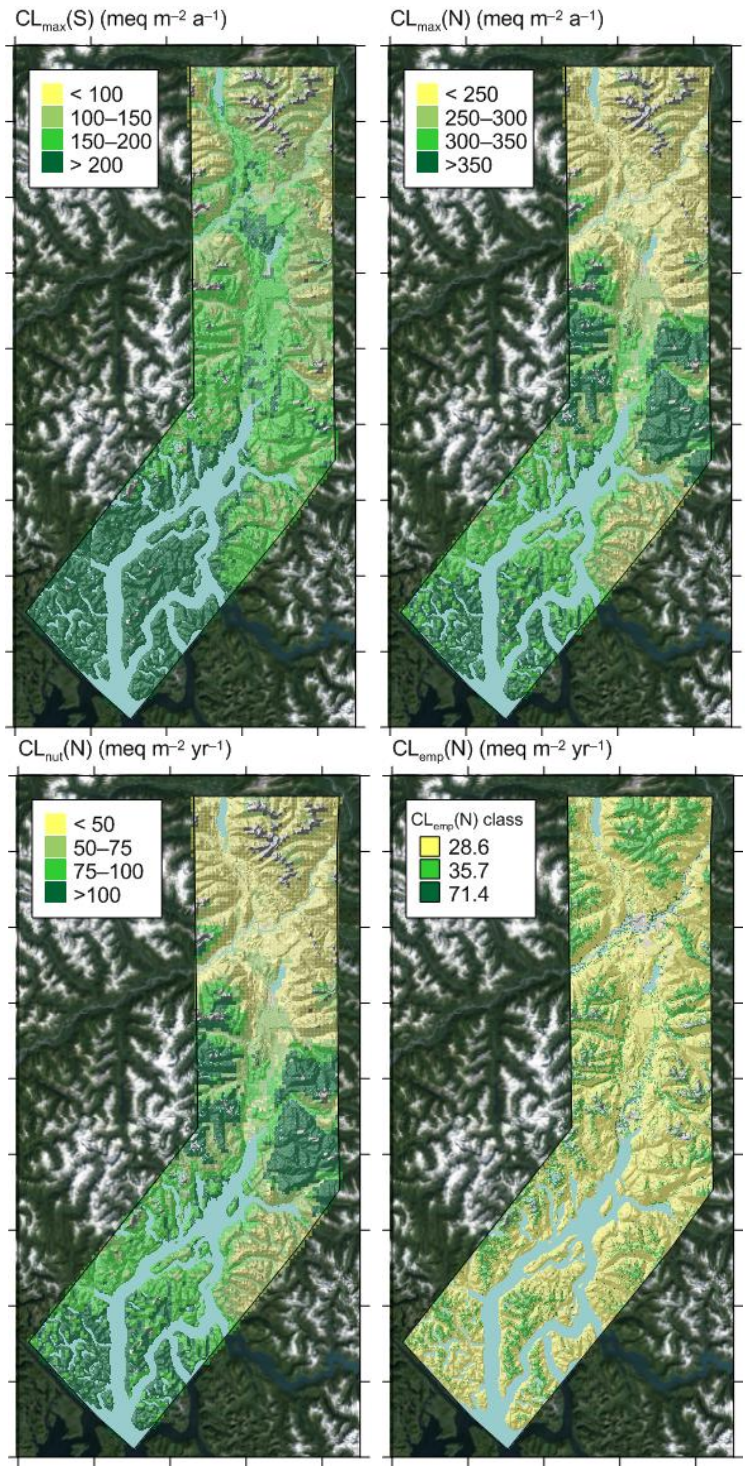


Figure 5-7. Maximum critical load of sulphur [$CL_{max}(S)$], maximum critical load of nitrogen [$CL_{max}(N)$], critical load of nutrient nitrogen [$CL_{nut}(N)$] and empirical critical loads of nutrient nitrogen [$CL_{emp}(N)$]. Note: the $CL_{emp}(N)$ mapped data refer to discrete classes and not ranges. The mapped values for $CL_{max}(S)$, $CL_{max}(N)$ and $CL_{nut}(N)$ only refer to the forested mineral soil fraction of each 1 km × 1 km grid (see Figure 5-1 for coverage of the forest receptor [green shading]).

5.2.3 Exceedance of Critical Loads for Scenarios A_28.2 through H_82.6

Exceedance of critical loads of acidity and nutrient nitrogen was estimated under eight sulphur and nitrogen emissions scenarios (A_28.2–H_82.6), presenting a range in potential emissions. An additional four scenarios (building on Scenario H_82.6) were evaluated to assess the impacts of emissions and siting location from a proposed Electrical Generating Facility (see Section 2). Despite the significance of nitrogen emissions under many of the scenarios, i.e., NO_x emissions are 50% of the SO_2 emissions under Scenario H_82.6 (see Section 2), very little nitrogen deposition was predicted across the study area (e.g., maximum nitrogen deposition is <10% of maximum sulphur deposition [units: meq/m^2/yr] under Scenario H_82.6), as such estimates of exceedance are dominated and driven by sulphur deposition. This is clearly demonstrated by plotting sulphur and nitrogen deposition (under emission Scenario H_82.6) onto the percentile critical load function for the entire study area (Figure 5-8). This suggests that observations of exceedance primarily require sulphur reductions to achieve non-exceedance.

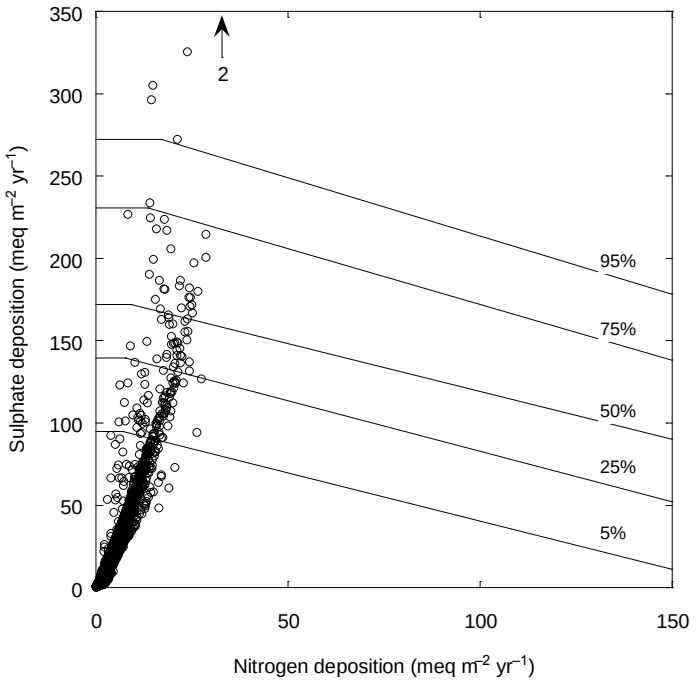


Figure 5-8. Percentile Critical Load Function (CLF: see Figure 5-5) representing percentiles for the 6,218 (1 km × 1 km) grid squares with occurrence of forest ecosystems across the Kitimat study area (Figure 5-1). The open circles represent sulphur and nitrogen deposition to each (1 km × 1km) receptor grid square under emissions Scenario H_82.6.

Critical Loads of Acidity: The area of the receptor ecosystem (forests) exceeded under the eight emissions scenarios was low, ranging from 0.56 km^2 (Scenario A_28.2) to 26.91 km^2 (Scenario H_82.6). Under Scenarios A_28.2 through D_61.8, < 1.0 km^2 was predicted to be exceeded (under Scenario A_28.2 exceedance was negligible), whereas under Scenarios E_66.1 through H_82.6 between 25.22 km^2 and 26.91 km^2 were predicted to be exceeded (Table 5-7). The greatest areal exceedance (occurring under Scenario H_82.6) represented <2% of the mapped receptor ecosystem within the effects domain. Even though a relatively small area was predicted to be exceeded, the average exceedance was high; ~50 meq/m^2/yr under all emissions scenarios (the highest magnitude was estimated under Scenario A_28.2 owing to the negligible area [0.04%] of exceedance), indicating that a small area of forested

ecosystems on mineral soil will receive acidic deposition greatly in excess of their critical load (Table 5-7; e.g., 14.88 km^2 with exceedance >20 $meq/m^2/yr$ under Scenario H_82.6). The exceeded area was located north of the principal sulphur emissions sources in the Kitimat Valley, i.e., north of the Rio Tinto Alcan smelter (Figure 5-9). Under all emissions scenarios, sulphur exceedance (see Figure 5-5 and Figure 5-8) was greater than nitrogen exceedance (Table 5-7). As such, the majority of the exceeded receptor grids (1 km × 1 km) require sulphur reductions to achieve non-exceedance, compared with nitrogen or sulphur (or both) reductions, e.g., under Scenario H_82.6, 31 grids require sulphur reductions (see red region in Figure 5-5 and see 'red grids' in Figure 5-9) compared with 5 grids that require nitrogen or sulphur reductions (or both).

Critical Loads of Nutrient Nitrogen: Under all scenarios the exceeded area was greater using empirical critical loads ($CL_{emp}(N)$) compared with the nutrient mass balance ($CL_{nut}(N)$; Table 5-8). Small $CL_{emp}(N)$ exceedances (<1 km^2) were predicted under emissions Scenarios A_28.2, B_51.8, E_66.1 and F_72.6 (Table 5-8). Under the four remaining scenarios, the exceeded area was between 2.07 km^2 (Scenario C_57.5) and 15.97 km^2 (Scenario H_82.6). Although several ecosystem types were included in the empirical assessment (see Table 5-4), the majority of the exceeded area was forested (Table 5-8). The greatest areal exceedance represented <1.2% (Scenario H_82.6) of the mapped receptor ecosystem within the effects domain. Areal exceedance under $CL_{nut}(N)$ was negligible (< 0.05%).

Overall Risk: Based on these exceedance values the impact of Scenario A_28.2 was considered to be Low, i.e., scenarios expected to have no, or negligible, impact; whereas the impact of emissions Scenarios B_51.8 through H_82.6 weres considered to be Moderate, i.e., scenarios expected to have an impact, but of a magnitude, or spatial extent, that is considered acceptable. The risk ranking is primarily based on acidification impacts and does not accommodate uncertainties (see Section 5.2.5).

Table 5-7. Exceedance of the Critical Load Function (CLF: see Figure 5-5) for acidification (defined by $CL_{max}(S)$, $CL_{min}(N)$ and $CL_{max}(N)$) of forest ecosystems on mineral soil (see Figure 5-1).

Scenario_(SO_2 + NO_x) (t/d)	A_ 28.2	B_ 51.8	C_ 57.5	D_ 61.8	E_ 66.1	F_ 72.6	G_ 76.2	H_ 82.6
Risk category [a]								
Average exceedance ($meq/m^{/2}/yr$)	100.7	48.0	50.9	51.2	50.4	52.4	52.3	53.0
Average exceedance S ($meq/m^2/yr$)	69.0	39.4	40.9	40.5	42.8	43.9	42.3	42.4
Average exceedance N ($meq/m^2/yr$)	31.7	8.6	10.0	10.7	7.7	8.6	10.0	10.7
Exceeded area (%) [b]	0.04	0.64	0.61	0.64	1.82	1.82	1.89	1.94
Exceeded area (km^2)	0.56	8.91	8.52	8.91	25.22	25.22	26.21	26.91
Exceeded area >10 $meqm^2/yr$ (km^2)	0.56	6.09	6.09	7.67	17.44	21.55	23.45	23.45
Exceeded area >20 $meq/m^2/yr$ (km^2)	0.56	3.78	3.78	4.76	13.49	14.43	14.88	14.88

[a] Risk category based on exceedance area (%).
[b] Exceeded area presented as a proportion (%) of the effects domain, which is defined as the area enclosed by a 15 $meq/m^2/yr$ modelled S and N deposition isopleth under Scenario H_82.6 (1,388 km^2).

Table 5-8. Exceedance of critical load of nutrient nitrogen ($CL_{nut}(N)$) and empirical nutrient nitrogen ($CL_{emp}(N)$) for forest ecosystems on mineral soil (see Figure 5-1) and terrestrial habitats (see Figure 5-4), respectively in the study area.

Scenario	A_ 28.2	B_ 51.8	C_ 57.5	D_ 61.8	E_ 66.1	F_ 72.6	G_ 76.2	H_ 82.6
Emissions (NO_x) (t/d)	11.9	13.2	19.4	23.2	13.2	16.8	23.2	26.8
Risk category [a]								
$CL_{nut}(N)$ exceedance (meq/m^2/yr)	3.15	4.87	7.39	8.98	5.56	6.45	9.67	10.56
$CL_{nut}(N)$ exceeded area (%) [b]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
$CL_{nut}(N)$ exceeded area (km^2)	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
$CL_{emp}(N)$ exceedance (meqm^2/yr)	1.94	2.88	1.89	2.40	3.20	3.86	1.96	1.83
$CL_{emp}(N)$ exceeded area (%) [b]	0.05	0.05	0.15	0.32	0.05	0.05	0.49	1.15
$CL_{emp}(N)$ exceeded area (km^2)	0.76	0.76	2.07	4.38	0.76	0.76	6.85	15.97
$CL_{emp}(N)$ exceeded forest area (km^2) [c]	0.58	0.58	1.90	4.13	0.58	0.58	6.60	15.72

[a] Risk category based on $CL_{nut}(N)$ and $CL_{emp}(N)$ exceeded area (%).
[b] Exceeded area presented as a proportion (%) of the effects domain, which is defined as the area enclosed by a 15 meq/m^2/yr^1 modelled S and N deposition isopleth under Scenario H_82.6 (1,388 km^2).
[c] Exceedance for coniferous and mixed forest ecosystems (see Table 5-4).

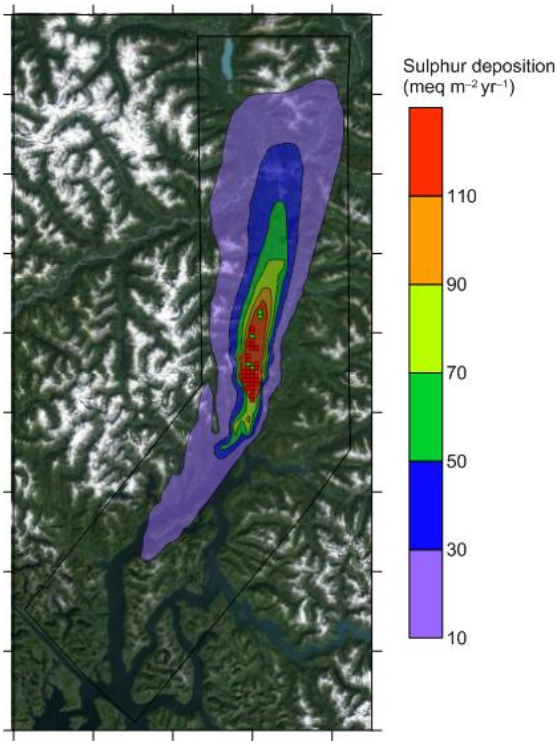


Figure 5-9. Predicted areal exceedance of critical loads of acidity for forested ecosystems on mineral soils under emissions scenario H_82.6. The plot depicts the location of mapped (1 km × 1 km) receptor ecosystem grids that receive sulphur and nitrogen deposition above their critical load, and the exceedance region (see Figure 5-5): green = non-exceedance can be achieved by reducing nitrogen or sulphur deposition (or both) and red = sulphur deposition must be reduced to achieve non-exceedance. Modelled anthropogenic sulphur deposition under emissions scenario H_82.6 (excluding background deposition) is also shown. Note: exceedance refers only to the area of forest ecosystem on mineral soil within each 1 km × 1 km grid; colours do not represent risk categories.

5.2.4 Exceedance of Critical Loads under the Electrical Generating Facility Siting Scenarios

Critical Loads of Acidity: The area of exceedance under the four electrical generating facility siting scenarios ranged from 26.91 km^2 (Scenarios Im_83.3, Is_83.3 and Js_86.1) to 27.91 km^2 (Scenario Jm_86.1). Areal exceedance was <2% of the mapped receptor ecosystem within the effects domain under Scenarios Im_83.3, Is_83.3 and Js_86.1; exceedance under Scenario Jm_86.1 was 2.01% (Table 5-9). The magnitude and extend of exceedance under all four scenarios was similar to Scenario H_82.6, only Scenario Jm_86.1 showed slightly higher magnitude and extent (Table 5-9). Similarly the exceeded area was located north of the principal sulphur emissions sources in the Kitimat Valley, i.e., north of the Rio Tinto Alcan smelter (Table 5-10).

Critical Load of Nutrient Nitrogen: Under the four scenarios the exceeded area was greater using empirical critical loads ($CL_{emp}(N)$) compared with the nutrient mass balance ($CL_{nut}(N)$; Table 5-10). The exceeded area under $CL_{emp}(N)$ was between 15.97 km^2 (Is_83.3) and 31.14 km^2 (Jm_86.1). The greatest areal exceedance represented approximately 2.25% (Scenario Jm_86.1) of the mapped receptor ecosystem within the effects domain.

Overall Risk: The impact of the four electrical generating facility siting scenarios was considered to be Moderate, i.e., scenarios expected to have an impact, but of a magnitude, or spatial extent, that is considered acceptable. Scenario Jm_86.1 was the only scenario showing greater than 2% areal exceedance under acidification and nutrient nitrogen (but <2.5%). The risk rating does not accommodate uncertainties (see Section 5.2.5).

Table 5-9. Exceedance of the Critical Load Function (CLF: see Figure 5-5) for acidification (defined by $CL_{max}(S)$, $CL_{min}(N)$ and $CL_{max}(N)$) of forest ecosystems on mineral soil (see Figure 5-1) under the electrical generating facility siting scenarios.

Scenario_(SO_2 + NO_x) (t/d)	A_ 28.2	H_ 82.6	Im_ 83.3	Is_ 83.3	Jm_ 86.1	Js_ 86.1
Risk category [a]						
Average exceedance (meq/m^2/yr)	100.7	53.0	53.6	53.1	54.1	53.3
Average exceedance S (meq/m^2/yr)	69.0	42.4	42.6	42.4	42.2	42.4
Average exceedance N (meqm^2/yr)	31.7	10.7	11.0	10.7	11.9	10.8
Exceeded area (%) [b]	0.04	1.94	1.94	1.94	2.01	1.94
Exceeded area (km^2)	0.56	26.91	26.91	26.91	27.91	26.91
Exceeded area >10 meq/m^2/yr (km^2)	0.56	23.45	24.21	23.45	24.21	24.21
Exceeded area >20 meq/m^2/yr (km^2)	0.00	14.88	15.66	14.88	17.44	14.88

[a] Risk category based on exceedance area (%).
[b] Exceeded area presented as a proportion (%) of the effects domain, which is defined as the area enclosed by a 15 meq/m^2/yr modelled S and N deposition isopleth under Scenario H_82.6 (1,388 km^2).

Table 5-10. Exceedance of critical load of nutrient nitrogen ($CL_{nut}(N)$) and empirical nutrient nitrogen ($CL_{emp}(N)$) for forest ecosystems on mineral soil (see Figure 5-1) and terrestrial habitats (see Figure 5-4), respectively, under the electrical generating facility siting scenarios.

Scenario	A	H	Im	Is	Jm	Js
Emissions (NO_X) (t/d)	11.9	26.8	27.5	27.5	30.3	30.3
Risk category [a]						
$CL_{nut}(N)$ exceedance (meq/m^2/yr)	3.15	10.56	10.59	10.60	2.98	10.79
$CL_{nut}(N)$ exceeded area (%) [b]	0.04	0.04	0.04	0.04	0.16	0.04
$CL_{nut}(N)$ exceeded area (km^2)	0.56	0.56	0.56	0.56	2.17	0.56
$CL_{emp}(N)$ exceedance (meq/m^2/yr)	1.94	1.83	2.23	1.89	3.99	2.04
$CL_{emp}(N)$ exceeded area (%) [b]	0.05	1.15	1.41	1.15	2.24	1.22
$CL_{emp}(N)$ exceeded area (km^2)	0.76	15.97	19.62	15.97	31.14	16.96
$CL_{emp}(N)$ exceeded forest area (km^2) [c]	0.58	15.72	19.37	15.72	30.03	16.72

[a] Risk category based on $CL_{nut}(N)$ and $CL_{emp}(N)$ exceeded area (%).
[b] Exceeded area presented as a proportion (%) of the effects domain, which is defined as the area enclosed by a 15 meq/m^2/yr modelled S and N deposition isopleth under Scenario H_82.6 (1,388 km^2).
[c] Exceedance for coniferous and mixed forest ecosystems (see Table 5-4).

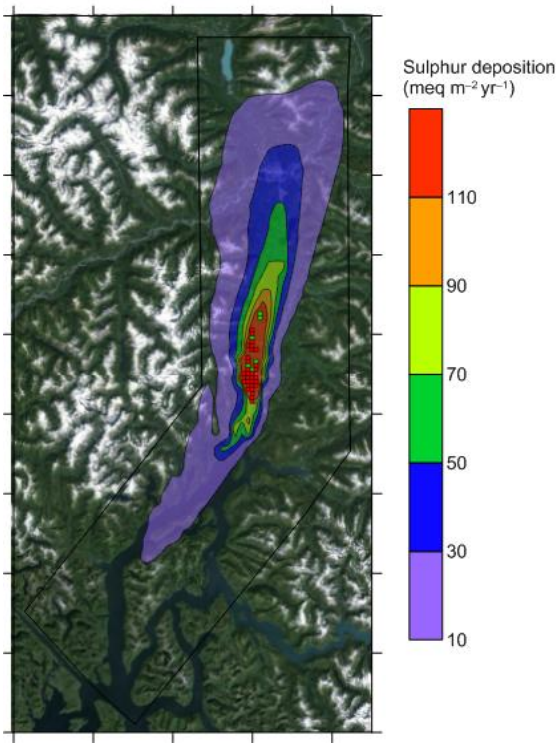


Figure 5-10. Predicted areal exceedance of critical loads of acidity for forested ecosystems on mineral soils under emissions Scenario Jm_86.1. The plot depicts the location of mapped (1 km × 1 km) receptor ecosystem grids that receive sulphur and nitrogen deposition above their critical load, and the exceedance region (see Figure 5-5): green = non-exceedance can be achieved by reducing nitrogen or sulphur deposition (or both) and red = sulphur deposition must be reduced to achieve non-exceedance. Modelled anthropogenic sulphur deposition under emissions scenario H (excluding background deposition) is also shown. Note: exceedance refers only to the area of forest ecosystem on mineral soil within each 1 km × 1 km grid; colours do not represent risk categories.

5.2.5 Uncertainty in Exceedance and Risk Rating

The predicted level of exceedance is subject to uncertainty associated with model input parameters (Table 5-3), i.e., parametric uncertainty. Several studies have evaluated parametric uncertainty in PROFILE and mass balance critical load models (Jönsson et al. 1995; Skeffington 2006; Li and McNulty 2007). In general, parametric uncertainty does not bias the predicted level of exceedance in either direction. The principle sources of uncertainty in this study were as follows:

1. **Soil Sampling Sites**. Soil observations (n = 80) were used to generate regional maps of base cation weathering, organic matter, etcetera (see Section 5.1) for the determination of critical loads. The soil sites were predominantly weighted towards (lower elevation) road-accessible locations. As such, the sites were not uniformly distributed across the study area (Figure 5-1). The clustered location of the soil sampling sites led to higher uncertainty in the spatial prediction of soil properties in under-sampled regions. Further studies should evaluate the influence of sampling location and, where possible, include additional sites to reduce uncertainty in spatial prediction.

2. **Atmospheric Deposition**. Modelled atmospheric sulphur and nitrogen deposition was subject to several uncertainties, e.g., the magnitude of background deposition, the representation of dry deposition processes and the use of one meteorological year. This study used uniform background sulphur and nitrogen deposition across the study area (Appendix 12.1); however, actual deposition will vary. Background deposition may therefore be underestimated or overestimated in some regions. Estimated background deposition was based on the best available data for the region (Appendix 12.1).We recommend that the values be reviewed as further data become available. The CALPUFF model includes a comprehensive description of dry deposition processes accounting for land cover (see Section 2). Average dry SO_2 deposition velocity modelled by CALPUFF was similar to observation-based estimates (Zhang et al. 2003), however the range in modelled deposition velocities was greater than observation-based ranges. Future studies should evaluate the difference between CALPUFF-modelled and observation-based total sulphur and nitrogen deposition. Modelled deposition estimates for this rapid scoping study were based on one meteorological year. The 2008 meteorological year was precautionary from a deposition standpoint because 2008 had the highest average deposition levels of the three years used in the KMP SO_2 Technical Assessment (i.e., the study area used in ESSA et al 2013). A sensitivity analyses showed that using 2008 deposition for the KMP study area (in ESSA et al. 2013) led to greater exceedance compared with using the three-year average (Appendix 12.3). While the use of one meteorological year (2008) resulted in higher deposition compared with the average of three meteorological years, it is unclear if this biased the assessment of exceedance in this scoping study given the differences in data, regionalisation approaches, and critical load models between the two studies.

3. **Critical Chemical Criteria**. The estimated exceedance of critical loads for acidity and subsequent risk rating was based on one chemical criterion under two critical values, i.e., Bc:Al = 1.0 for coniferous forest, and Bc:Al = 6.0 for deciduous (and mixed) forest. Further, the associated critical ANC leaching ($ANC_{le(crit)}$) parameter (Table 5-2) dominated the critical load estimates owing to the high levels of runoff. A multi-criteria approach was carried out under emission scenario H_82.6 to evaluate the influence of the chosen criterion on predicted exceedance. Additionally, runoff was randomly varied by ±20% of the modelled value for each grid (1 km by 1 km) to assess its influence on predicted exceedance. Four critical chemical criteria were selected

(Table 5-5) following UNECE (2004), and evaluated under scenario H_82.6. The soil pH criterion was set at pH= 4.5 based on an approximate 0.5 pH unit shift from the average pH observed at the soil sampling profiles (n = 80). The molar calcium to aluminium (Ca:Al) ratio was set to 1.0 (Cronan and Grigal 1995), and other critical limits were taken from UNECE (2004). The proportion of exceeded area increased from 1.94% to 4.14% under the H_82.6 emission scenario using Ca:Al = 1.0 (Figure 5-11); the pH criterion showed a similar level of areal exceedance (3.77%). In contrast, aluminium mobilisation and soil solution aluminium showed low levels of areal exceedance (<0.5%) under scenario H_82.6 (Table 5-11). Variable runoff had limited impact; predicted areal exceedance increased from 1.94% to 2.08% under ±20% variation in runoff. The high runoff equally influenced critical load and exceedance under all chemical criteria owing to the dominance of the $ANC_{le(crit)}$ term.

Overall Risk. What to protect, and at what level of protection, are ethical questions, and will ultimately be policy decisions. It is clear that the chosen chemical criterion (Bc:Al) linking atmospheric deposition to ecosystem impacts and the level of protection (critical limit) have a considerable influence on the predicted level of exceedance. Emissions scenarios E_66.1 to H_82.6 were given a Moderate risk rating (Table 5-7); however, under Ca:Al ratio = 10.0, the risk rating would become High for these scenarios. However, it is unlikely that areal exceedance would be >5% of the effects domain for any scenario, i.e., a risk rating of Critical (Table 5-6) is unlikely.

Table 5-11. Exceedance of the Critical Load Function (CLF: see Figure 5-5) for acidification (defined by $CL_{max}(S)$, $CL_{min}(N)$ and $CL_{max}(N)$) of forest ecosystems on mineral soil (see Figure 5-1) under Scenario H_82.6 using multiple chemical criteria and variable hydrology.

Scenario	H_82.6	H_82.6	H_82.6	H_82.6	H_82.6	H_82.6
Chemical criterion (Table 5-5)	Bc:Al	Ca:Al	pH	p	Al	Bc:Al
Critical limit (Table 5-5)	1	1	4.5	2	0.2	Q [a]
Risk category [b]						
Average exceedance (meq/m^2/yr)	53.0	47.01	51.93	77.19	156.47	50.81
Average exceedance S (meq/m^2/yr)	42.4	35.88	40.63	60.89	124.25	40.39
Average exceedance N (meq/m^2/yr)	10.7	11.13	11.30	16.30	32.22	10.42
Exceeded area (%) [c]	1.94	4.14	3.77	0.24	0.07	2.08
Exceeded area (km^2)	26.91	57.44	52.33	3.37	1.01	28.82
Exceeded area >10 meq/m^2/yr (km^2)	23.45	47.87	45.86	3.35	1.01	23.95
Exceeded area >20 meq/m^2/yr (km^2)	14.88	38.56	36.73	3.08	1.01	17.89

[a] Sensitivity analysis of modelled runoff (Q); Q was randomly varied by ±20% under Scenario H_82.6 using Bc:Al = 1.0 as the critical chemical criteria.
[b] Risk category based on exceeded area (%).
[c] Exceeded area presented as a proportion (%) of the effects domain, which is defined as the area enclosed by a 15 meq/m^2/yr modelled S and N deposition isopleth under Scenario H_82.6 (1,388 km^2).

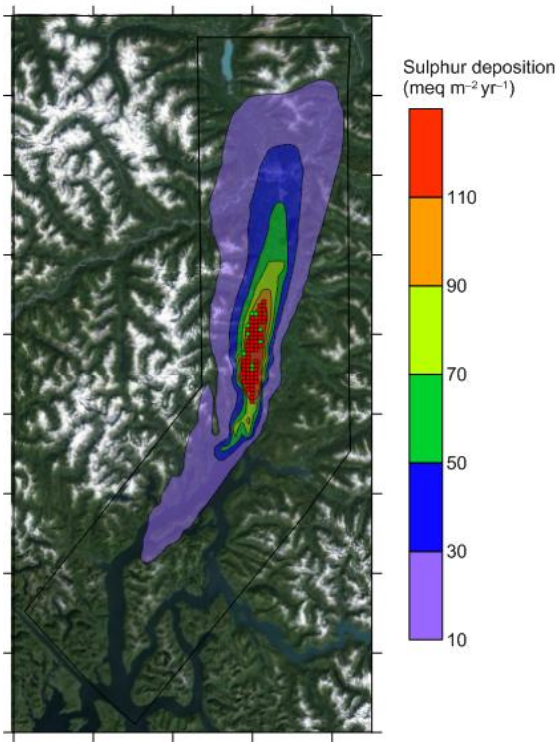


Figure 5-11. Predicted areal exceedance of critical loads of acidity for forested ecosystems on mineral soils under emissions Scenario H_82.6 using molar Ca:Al = 1.0 as the critical chemical indicator. The plot depicts the location of mapped (1 km × 1 km) receptor ecosystem grids that receive sulphur and nitrogen deposition above their critical load, and the exceedance region (see Figure 5-5): green = non-exceedance can be achieved by reducing nitrogen or sulphur deposition (or both) and red = sulphur deposition must be reduced to achieve non-exceedance. Modelled anthropogenic sulphur deposition under emissions scenario H_82.6 (excluding background deposition) is also shown. Note: exceedance refers only to the area of forest ecosystem on mineral soil within each 1 km × 1 km grid; colours do not represent risk categories.

6 AQUATIC ECOSYSTEMS

6.1 Methods

6.1.1 Environmental Data

6.1.1.1 Water Chemistry Data – Kitimat Study Area Lakes

Three lake data sets were used for this study, as explained in detail in Appendix 13, illustrated in Figure 6-1, and summarized below:

1. **Data set 1 (DS1)** includes 41 lakes sampled in August 2012 by Limnotek and analyzed by ESSA for the KMP SO_2 Technical Assessment (ESSA et al. 2013).
2. **Data set 2 (DS2)** includes 28 lakes sampled by Limnotek in October 2013 under a separate part of the Kitimat Airshed Emissions Effects Assessment Project (Perrin et al. 2014).
3. **Data set 3 (DS3)** includes 13 lakes in the study region sampled by Environment Canada in October 2013.

In summary, a total of 82 lakes were sampled and analyzed in this study – 38 selected from areas with bedrock geology sensitive to acidification, 33 chosen based on their proximity to moderate-to-high sulphate deposition from KMP, and 11 selected based on five BC Ministry of Environment (MOE) criteria described in Appendix 13. The higher elevation lakes on the east and west boundaries of the study area, and some of the lakes along steep-sided areas along Douglas Channel, have outlet streams with gradients greater than 25%, and are therefore not accessible to fish (Figure 6-2).

The sampled lakes are generally representative of the study area in terms of their average size and the percent of lakes that are accessible to fish (Table 6-1). However, given the mix of criteria used to choose these 82 lakes, the data set cannot be considered to be a statistically representative sample of all lakes within the Kitimat Airshed Emissions Effects Assessment study area. Rather, the data set is deliberately biased towards more acid-sensitive lakes and regions with higher levels of acidic deposition so as to maximize the potential for detecting impacts. While most acidification studies in the United States have been based on a statistically representative sample of lakes from a specific target population (e.g., Sullivan et al. 1988; Baker et al. 1991), many acidification studies in Canada have included all lakes within the area of interest for which data are available. That is, the lakes in the Canadian studies were not necessarily selected through a statistically rigorous approach and the process involved a mix of selection criteria (e.g., Jones et al. 1990; Jeffries 1997; Jeffries et al. 2000; Henriksen et al. 2002; Dupont et al. 2005). As described above, the data sets used in this study also comprise a mix of lake selection criteria. It is not known how these criteria compare to the criteria used in other regional acidification studies completed in Canada. While it is straightforward in this study to compute the percent of sampled lakes and percent of sampled lake area with characteristics of interest (e.g., CL exceedance), there is much more uncertainty in estimating these metrics for the entire population of lakes in the study area. We considered these sampling issues in assessing the risk to surface waters from the modelled scenarios by developing a range of performance measures, as described in Section 6.1.2.

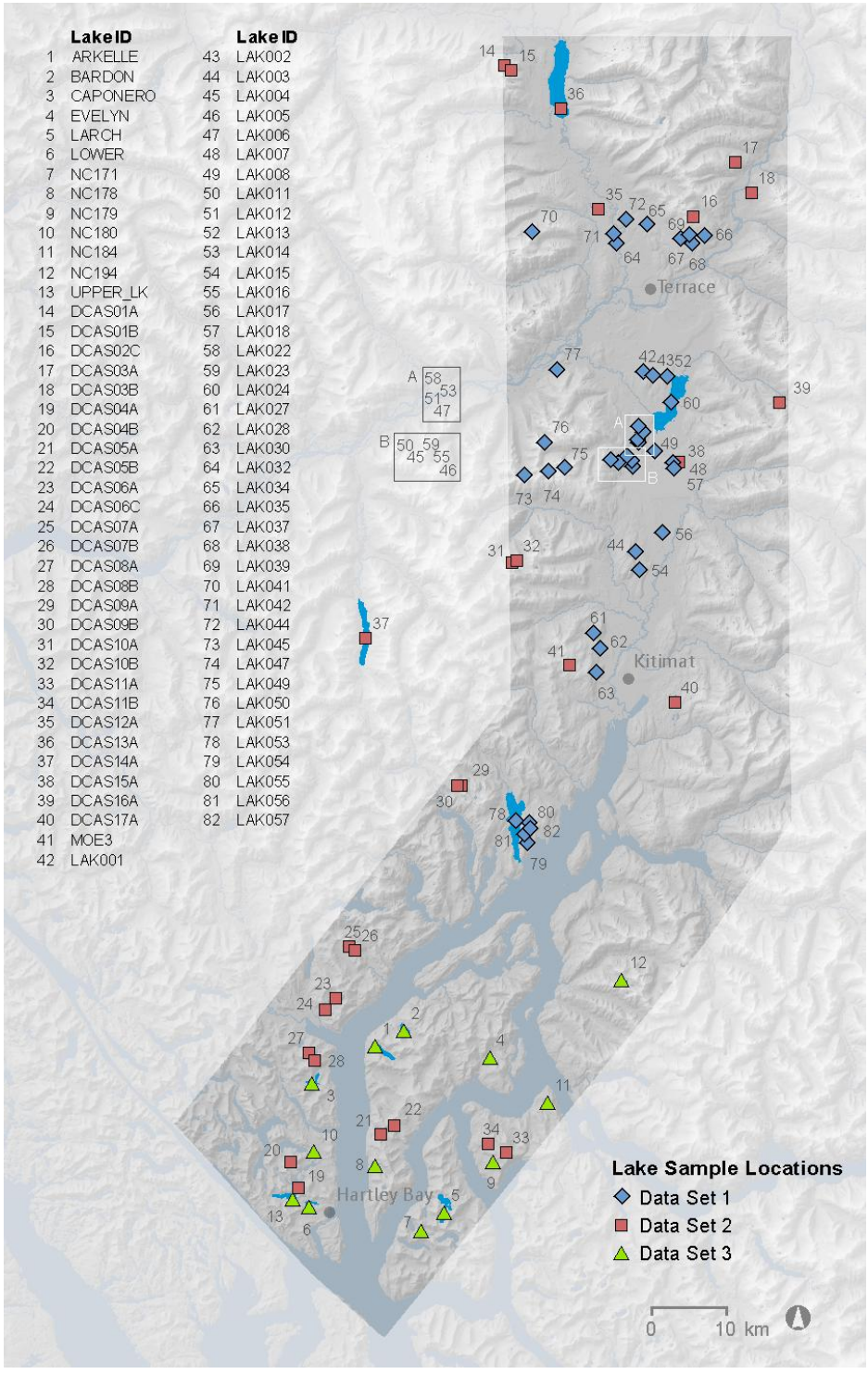


Figure 6-1. Map of study area showing the lakes sampled in October 2013. Lake DCAS14A (not shown) was chosen as a reference lake outside of the study area.

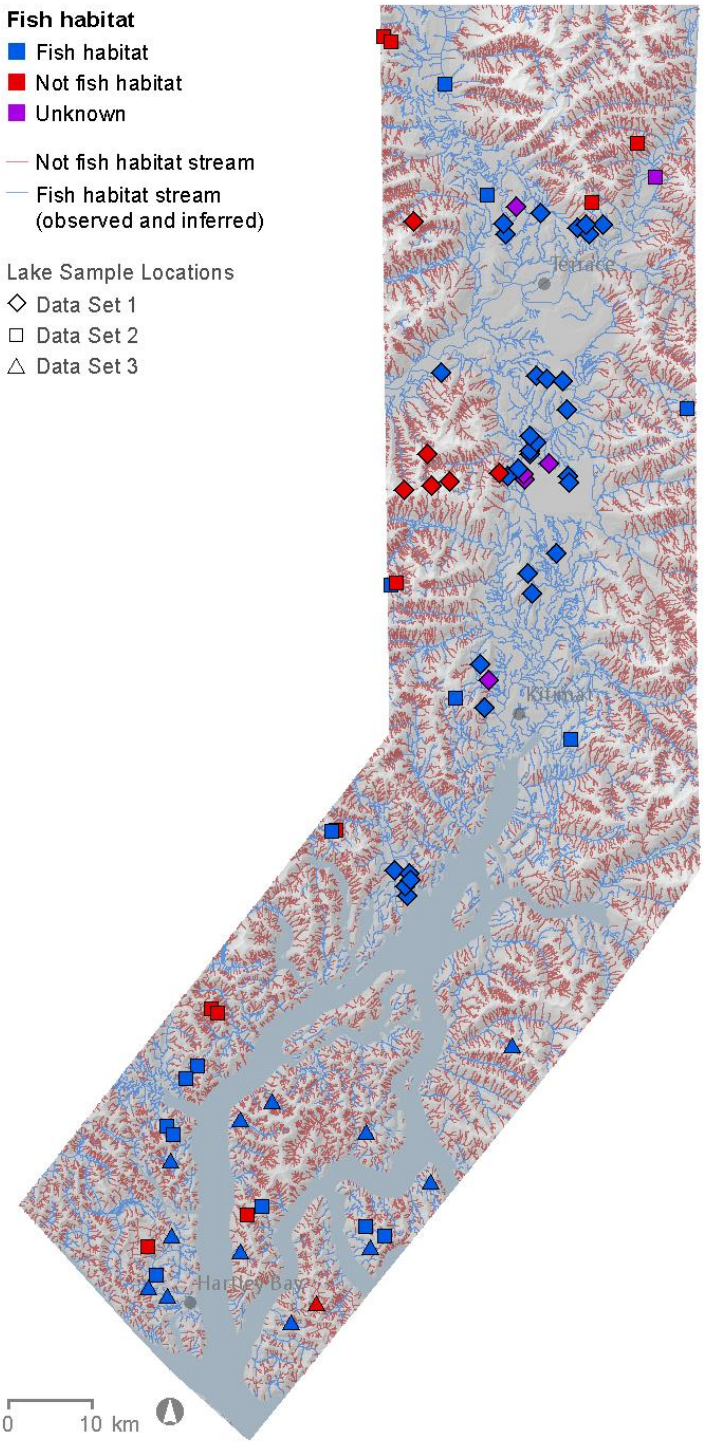


Figure 6-2. Accessibility of study area streams and lakes to fish. Blue symbols and streams are accessible to fish, while red symbols and streams are not. Source: BC MOE 2011. Fish Passage GIS analysis, FishHabitat [data set]. Craig Mount, MOE [distributor].

Table 6-1. General characteristics of lakes in the study area and the subset that were sampled. The three largest lakes in the area are Kitsumkalum (1,907 ha), Lakelse (1,374 ha) and Jesse (1,167 ha), whose aggregate area of 4,448 ha makes up 36% of the total area of lakes in the study area.

	Average lake area[a]	On streams accessible to fish	Inaccessible or unknown	Total #	Total Area
Study area lakes	21.3 ha	273 (73%)	100 (27%)	373	12,333 ha
Sampled & analyzed lakes	21.2 ha	57 (71%)	23 (29%)	80	6,079 ha
Sampled lakes as % of study area lakes				21%	49%

[a] Statistics on average lake area exclude Kitsumkalum, Lakelse and Jesse lakes.

Data Quality

As described in Appendix 14, we applied four methods to confirm quality of the data inputs prior to their use for data analyses and modelling:

- Evaluation of the accuracy and precision of field and laboratory methods (see Limnotek 2012, and Perrin et al. 2013, 2014)
- Assessment of the charge balance for all of the sampled lakes (see ESSA et al. 2013, Section 8.6.3.2 for details of rationale and procedure)
- Comparison of the measured conductivity for each sample to a calculated estimate of conductivity based on the ion concentrations (see ESSA et al. 2013, Section 8.6.3.2 for details of rationale and procedure)
- Analysis of lake chloride levels to detect possible road salt effects (Appendix 14)

Data set 1 was used for the KMP SO_2 Technical Assessment (ESSA et al. 2013). Data set 2 was received in December 2013 from Limnotek (Perrin et al. 2014) following chemical analyses by Trent University and ALS Environmental. Data set 3 was received from Environment Canada in January 2014. The samples for the Environment Canada lakes followed standard methods for sample collection and handling (P. Shaw, pers. comm.) and the samples were analyzed at Environment Canada's Pacific Environmental Science Centre, following data quality procedures similar to those described in Strang et al. (2010).

Data Inputs for Critical Load Modelling

All the sources of input data for water chemistry modelling are described in Appendix 15. The three lake chemistry data sets were organized in spreadsheets for critical load (CL) and quality assurance/quality control (QA/QC) analyses, based on the structure of the work completed for KMP in ESSA et al. (2013) using the Steady State Water Chemistry model (SSWC) (Henriksen et al. 2002; UNECE 2004) and extended to include the First-order Acidity Balance (FAB) model (Henriksen and Posch 2001; UNECE 2004; Posch et al. 2012).

6.1.2 Analyses of Aquatic Ecosystems: Critical Loads and Exceedance Maps, and Risk Classification

We used the following approach to determine the relevant characteristics of the sampled lakes, and the potential impacts of the emission scenarios on these lakes:

1. We examined the statistical and spatial distributions of total alkalinity, Gran ANC and pH to determine the sensitivity of the sampled lakes to acidification (Section 6.2.2).
2. We evaluated the dominant and influential anion composition of the lakes in data sets 2 and 3, as described in Sections 8.6.3.3 and 9.4.1.2.3 of Volume 2 of the KMP SO_2 Technical Assessment Report (ESSA et al. 2013), to determine the likely causes of current pH_t values less than 6.0 (Section 6.2.2, Appendix 20).
3. We calculated the original, pre-industrial pH (pH_o) in the absence of any anthropogenic deposition (from either existing, proposed, or long distance emission sources) using a modified ESSA/DFO model for predicting changes in pH (see Section 8.6.3.4 in ESSA et al. 2013), adjusted to include nitrogen deposition as well as sulphate deposition, as explained in Appendix 16 (see also Section 8.6.3.4 in ESSA et al. 2013).
4. We applied the Steady State Water Chemistry (SSWC) model (Henriksen et al. 2002; UNECE 2004) to all lakes included in the analysis because it is required as an input to FAB (Henriksen and Posch 2001; UNECE 2004; Posch et al. 2012); see Figure 6-3 for a graphical representation of the flow of analyses and required inputs for using the SSWC and FAB models to calculate critical loads and exceedances.
5. We estimated surface water CLs using the FAB as described in UNECE (2004), Aherne et al. (2002, 2004), and Henriksen and Posch (2001), ensuring that these inputs were consistent with those used for the soil CL model (Steady State Mass Balance) – see Appendix 15 for a description of data inputs to CL models.
6. We derived a critical load function (CLF) for each modelled lake showing combinations of S and N CLs (e.g., Figure 6-4 shows the CLF for a single, hypothetical lake)[34].
7. We created a map plotting CLmax(S) for all sampled lakes in the study area (the Y-intercept in Figure 6-4), and a similar map showing CLmax(N), the X-intercept in Figure 6-4.
8. We used lake-specific CLFs to estimate *N exceedance, S exceedance,* and *total exceedance* of CLs for each lake (lines ΔN, ΔS and ΔN + ΔS, respectively in Figure 6-4).
9. We displayed the total exceedance in map form for each emission scenario using the same base map as the CL map in step 5.
10. We described the characteristics of lakes with exceedance under any of the scenarios, including lake area, current pH and anion dominance, estimated pre-industrial pH, documented fish presence, and accessibility to fish populations[35].

[34] As in the KMP SO_2 Technical Assessment Report (ESSA et al. 2013, pg. 242), we constrained CLs to be a minimum of zero (i.e., cannot be negative). We implemented this constraint by adjusting the critical ANC limit for such lakes to equal the non-marine contribution of base cations from weathering (i.e., $ANC_{limit} = BC^*_0$). The rationale for this constraint is that our assessment focuses on estimating exceedances due to various new pollution sources. The KMP SO_2 assessment demonstrated that several lakes in the Kitimat Valley have high concentrations of dissolved organic carbon and low ANC values, and some are naturally acidic (ANC <0). If a naturally low ANC or acidic lake or stream is estimated to have a negative critical load (i.e., original base cations less than the ANC limit), it would have exceedance even with zero acidic deposition.

[35] There are 373 lakes within the study area with area greater than 1 ha, 273 of which are on fish accessible streams. Of these 373 lakes, 42 (15 fish accessible) are classed as 'indefinite' lakes (*shoreline is obscured on the source data*), and two (one fish accessible) are classed as 'intermittent' (*a fresh water body that is normally dry at some time during the year*).

11. We compared the cumulative frequency distributions of total exceedance across all lakes and emission scenarios.
12. We compared the relative performance of different emission scenarios in tabular form, using a consistent set of performance measures.
13. We described the distribution of estimated critical loads by Acid Sensitivity Class for all sampled lakes (Appendix 22).
14. We summarized the level of risk to surface waters associated with each scenario, based on a risk assessment framework described below in Section 6.1.2.1.

6.1.2.1 Risk Assessment Framework

The Canada-wide Acid Rain Strategy for Post-2000 (CCME 1998; pg. 5) contained the following primary goal: "ensure that critical loads for acid deposition are achieved across Canada thereby ensuring the health of our forests and aquatic ecosystems". Critical loads were defined by CCME (1998; pg. 4) as "the amount of sulphate that can be deposited on the area and still maintain 95% of the lakes in the region at or above a pH of 6". The CCME strategy recognized that critical loads for sulphur deposition were being exceeded in southeastern Canada, and that very substantial reductions in emissions (ranging from 30% to 75% below existing caps) would be required to meet the primary goal. For other areas of Canada outside of the southeastern management region, the goal of the strategy was to "keep clean areas clean", or more specifically, that "emissions of SO_2 and NO_X need to be managed to ensure deposition levels do not approach the critical load" (CCME 1998; pg. 7). Studies of acidification impacts on biota in Sweden (Fölster et al. 2007) provided an operational rule for the protection of surface waters, namely that lakes should be maintained within 0.4 pH units of their original, pre-industrial pH_o.

While acknowledging past and present sulphur emissions in the Kitimat airshed, MOE interprets the CCME (1998) strategy as a direction to avoid critical load exceedance in the Kitimat airshed. Based on CCME (1998), and adapting the work by Fölster et al. (2007), MOE developed the following 2-stage risk assessment process for use in this study:

1. **Stage 1.** Assess the risk of CL exceedance.
2. **Stage 2.** For lakes which do have CL exceedance, assess the risk of future pH change >0.3 units from *current* pH levels:
    a. The Low risk category is indicated by 0 lakes with a ΔpH ≥0.3
    b. The Moderate risk category is indicated by 1-2 lakes with ΔpH ≥0.3
    c. The High risk category is indicated by 3-5 lakes with ΔpH ≥0.3
    d. The Critical risk category is indicated by 6 or more lakes with ΔpH ≥0.3
3. Lakes which do not have CL exceedance, but which are predicted to have a ΔpH ≥0.3, should be included in Stage 2. Though this might imply that CL exceedance does not affect the risk rating (and that Stage 1 is unnecessary), lakes with **both** CL exceedance **and** a predicted ΔpH ≥0.3 are at greater risk than lakes which do not have CL exceedance but do have a predicted ΔpH ≥0.3. This point is clarified below in the discussion entitled "Application of the Risk Framework".

MOE provided the following clarifications on the above guidance:

- The High-Critical threshold is sufficient to protect 93.75% of the *sampled* lakes (i.e., 75 of 80). Given that the lake sampling was intentionally biased toward sensitive lakes, this represents significantly more than 95% protection of *all* lakes in the study area. The situation in BC is

considerably different than eastern Canada and Europe where the policy is directed at restoring acidified landscapes to 95% protection. A precautionary approach is appropriate to avoid the necessity of restoration efforts.

- The Moderate-High threshold (three lakes) is half of the High-Critical threshold (six lakes), consistent with the approach to determine human health and soils thresholds.
- Lake valuation or rating should be used to inform the interpretation of the risk ranking, but does not comprise a formal stage in the assessment.
- Lakes with low natural pH should not be excluded from the assessment, though the unique sensitivities of dilute coastal lakes should be considered.

Application of the Risk Framework

In applying the above policy guidance from MOE, we needed to recognize that we have used a combination of models to assess CL exceedance (SSWC and FAB models) and potential pH change (modified ESSA/DFO model). This creates four possible categories of biological concern for each lake (Table 6-2), ranging from no concern (CL not exceeded, pH change not biologically significant) to high concern (CL exceeded and biologically significant pH change). Category 3 is somewhat counter-intuitive (i.e., CL not exceeded but ΔpH ≥0.3). This reflects the fact that though the SSWC/FAB and ESSA/DFO models use some common inputs (e.g., runoff, lake sulphate concentrations, deposition), the SSWC/FAB models are primarily driven by current base cation concentrations, and the modified ESSA/DFO model is primarily driven by current Acid Neutralizing Capacity (ANC). Using two complimentary models is a precautionary approach.

Table 6-2. Categories of biological concern based on all aquatic assessment models.

SSWC/FAB	**Modified ESSA/DFO Model**	
	pH change <0.3	**pH change >0.3**
CL exceeded	**2. Low concern** (CL exceeded but pH change not biologically significant)	**4. Highest concern** (CL exceeded **and** biologically significant pH change)
CL not exceeded	**1. No concern** (CL not exceeded and pH change not biologically significant)	**3. Intermediate concern** (CL not exceeded but biologically significant pH change)

Combining Table 6-2 with the policy guidance from MOE yields the following approach, which we apply in Section 6.2.3.2:

- The Low risk category is indicated by 0 lakes with a ΔpH ≥0.3 (all lakes are in category 1 in Table 6-2, none exceed CL or have ΔpH ≥0.3).
- The Moderate risk category is indicated by 1 or 2 lakes with ΔpH ≥0.3 (in categories 3 or 4 in Table 6-2).
- The High risk category is indicated by 3 to 5 lakes with ΔpH ≥0.3 (in categories 3 or 4 in Table 6-2).
- The Critical risk category is indicated by 6 or more lakes with ΔpH ≥0.3 (in categories 3 or 4 in Table 6-2).

Notwithstanding the uncertainty associated with this metric, it is of interest to estimate the percent of lakes in the study area which exceed their CL under different emission scenarios. We recognized that the sampled lakes were deliberately selected from acid-sensitive bedrock geologies, and therefore estimated a range of metrics under different assumptions:

1. The minimum estimate of the percent of lakes with critical load (CL) exceedance is 100* [# of sampled lakes with CL exceedance] / [total # lakes in the study area], (an underestimate, since it assumes that only sampled lakes exceed their CL, and no unsampled lakes exceed their CL).
2. The maximum estimate of the percent of lakes with critical load (CL) exceedance is the percent of sampled lakes with CL exceedance (an overestimate, since it assumes that the sampled lakes are representative of all study area lakes, while the sampled lakes were deliberately selected from acid-sensitive bedrock geologies).
3. The above percentages are estimated both for all sampled lakes, and for the subset of lakes which are estimated to have had a pre-industrial pH_o >6.0.

Some large scale regional analyses have excluded lakes with an original, pre-industrial pH_o < 6 or CL < 0 as naturally acidified lakes (e.g., Jeffries et al. 2000, Dupont et al. 2005). However, naturally acidified lakes made up a small percentage of the number of sampled lakes in these studies (e.g., 0.4 to 3.5% of the lakes in five of six regions studied by Jeffries et al. 2000; 2.6% of the lakes studied by Dupont et al. 2005). By contrast, naturally acidified lakes with an original, pre-industrial pH_o <6 make up 29% of the 80 analyzed lakes in this study. Since natural and industrial sources of acidity are additive, and industrial acidification of a naturally acidified lake can still cause biological impacts (Jones et al. 1986), we included all sampled lakes in the analysis and risk assessment. To be consistent with the previous studies mentioned above, we do however present summary metrics both with and without naturally acidified lakes.

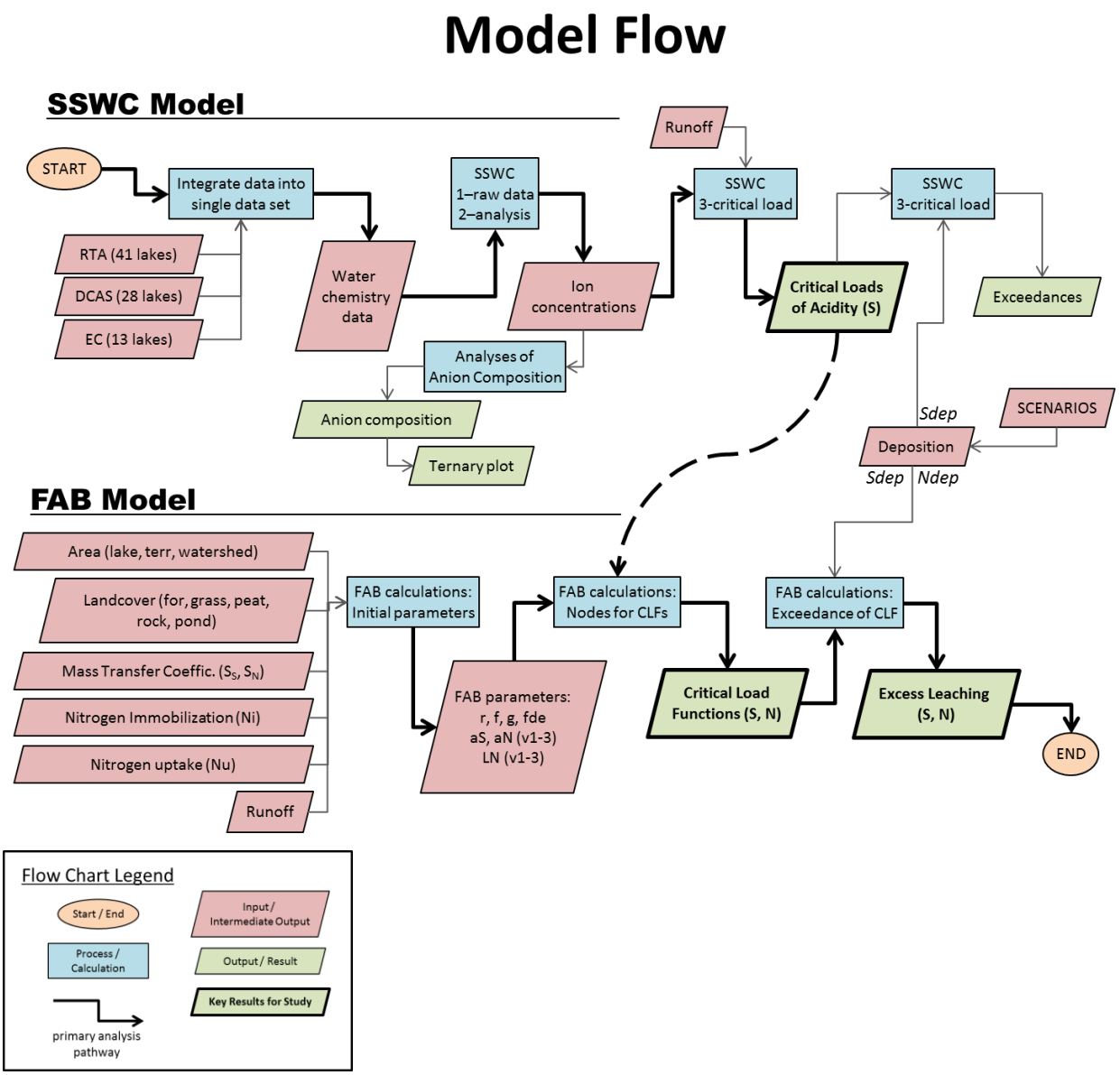


Figure 6-3. Schematic of the flow of analyses required to calculate the critical loads and exceedances for study area lakes using the SSWC and FAB models.

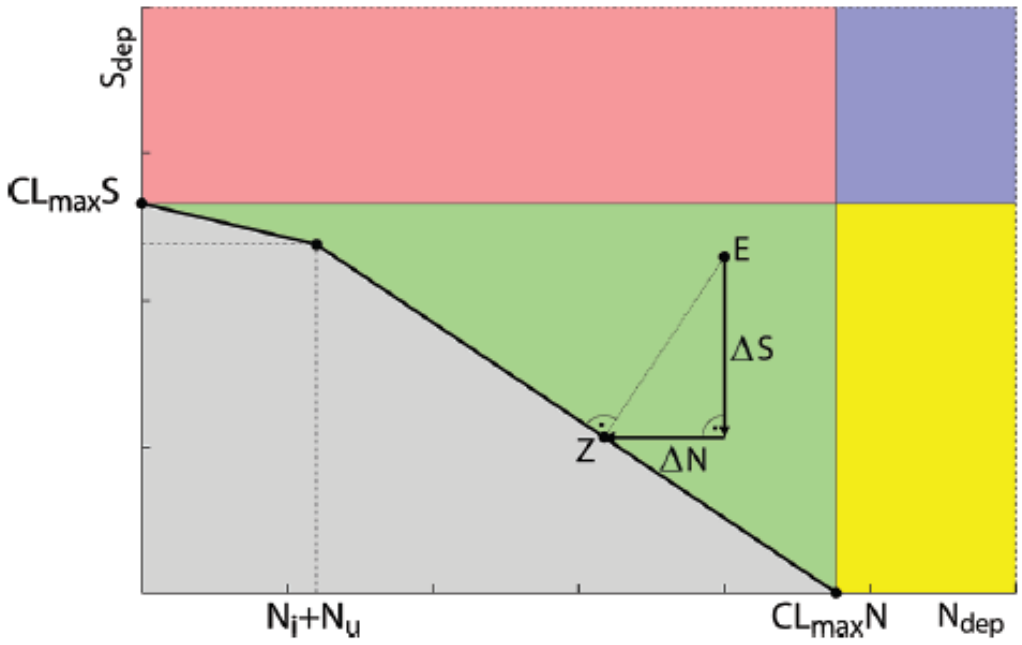


Figure 6-4. Piece-wise critical load function (CLF) for sulphur (S) and acidifying nitrogen (N) as defined by catchment properties (thick black line), for one lake and its catchment. Every combination of S and N deposition values that lies on the critical load function (CLF) of a particular lake represents a critical load for that lake. The grey-shaded area below the critical load function defines deposition pairs (N_{dep},S_{dep}) for which there is no exceedance, and the lake's ANC is kept above the critical level. For a given deposition pair (N_{dep}, S_{dep}) the critical load total exceedance is calculated by adding the N and S deposition reductions needed to reach the CLF via the shortest path (E→Z): Ex = ΔS + ΔN. The grey area below the CLF denotes deposition pairs resulting in non-exceedance of critical loads. If a deposition pair is located in the green area (such as E), non-exceedance can be achieved by reducing N or S deposition (or both); in the red (yellow) area S_{dep} (N_{dep}) has to be reduced to achieve non-exceedance; and in the blue area both N_{dep} and S_{dep} have to be reduced. The two most commonly reported values along the CLF are the maximum critical load for S (CLmax(S), which represents the critical load for S when N deposition is 0) and the maximum critical load for N (CLmax(N), which represents the critical load for N when S deposition is 0). CLmax(S) and CLmax(N) are the Y-intercept and X-intercept, respectively. Source: Posch et al. (2012), Figure 5.7 in UNECE (2004) and associated text.

6.2 Results

6.2.1 Data Quality

6.2.1.1 Final Data Set for Analyses

Two lakes were excluded from further analyses:

- DCAS014A (Alastair Reference Lake) was excluded from the analyses because it is located outside of the study region boundaries used for the runoff and deposition modelling[36]. Therefore it was not possible to model its critical load in the SSWC and FAB models.
- DCAS015A (Onion Lake) was excluded from the analyses because it could not be modelled by the SSWC model due to exceptionally high chloride levels, as explained in Appendix 17.

The subsequent analyses are based on the remaining set of 80 lakes.

6.2.1.2 Analysis of Charge Balance and Predicted vs. Measured Conductivity

These two tests of data quality integrate all of the cumulative analytical errors in all measured parameters. The analysed samples showed an excellent charge balance and very strong relationship between predicted and measured conductivity (see Appendix 14, Figure A14-1 and Figure A14-2). These results provide a very high level of confidence in the field and laboratory procedures, and the quality of the data they generated.

6.2.1.3 Determination of Critical ANC

For a particular set of lakes, the critical ANC is the level corresponding to a critical pH threshold, which we assumed to be 6.0 (as discussed in ESSA et al. 2013, Section 3.5). The critical ANC for the study region was determined to be 26.0 µeq/L, based on the best fit of the Small and Sutton (1986) equation to the laboratory pH and Gran ANC data for the 41 lakes in data set 1 (ESSA et al. 2013, Section 9.4.1.1.3). Lydersen et al. (2004) developed an approach for estimating the critical ANC for Norwegian lakes that varies with the lake's total or dissolved organic carbon (TOC or DOC). While we did explore the approach of Lydersen et al. (2004), we chose to apply the critical ANC developed in ESSA et al. 2013, since it was based on local data, and the charge density of DOC can vary from one region to another.

6.2.2 Characteristics and Composition of Lakes

The following three subsections present results of analyzing the data from 80 sampled lakes (all but the 2 lakes which were excluded). The water sampling focused on the regions with the highest level of sulphate deposition and most acid-sensitive bedrock types. Therefore, statistics estimated from the sampled sites alone overestimate the sensitivity to acidification of the overall study area.

In the KMP SO_2 assessment, analyses based on water quality were considered a "Level 0 method" to assess sensitivity to acidification[37], and are described in further detail in Section 8.6.3.3 of ESSA et al. (2013).

[36] Deposition was modelled for a single point for the lake, but because the lake is outside of the modelled deposition grid, deposition values for the watershed could not be calculated.

[37] Acidification is defined as a decrease of ANC in water, as caused by either natural or anthropogenic processes. An acidic lake or stream is defined by ANC <0. Therefore, it is possible for a lake or stream to acidify or undergo acidification without becoming acidic.

6.2.2.1 Acid Neutralizing Capacity in Sampled Lakes

The distribution of total alkalinity and Gran ANC values for the 80 sampled lakes included in the analysis is shown in Table 6-3, Figure 6-5, and Figure 6-6. The lakes in data set 3 in the southern part of the study area all have values for total alkalinity < 100 µeq/L and show much less variability in total alkalinity than the lakes in data sets 1 and 2 (Figure 6-5).

Total alkalinity was sampled for all lakes, while Gran ANC was only included in data sets 1 and 2, but not data set 3. On average (for data sets 1 and 2) total alkalinity (titration of the solution with an acid to pH 4.5) is about 11.6 µeq/L higher than Gran ANC (titration of the solution until the amount of acid added equals the amount of acid-neutralizing capacity in the solution) (see Appendix 18, Figure A18-2 for graphical comparison). A pH of 6.0 (considered the threshold for biological effects) is found at a Gran ANC of 26 µeq/L, based on analysis of data set 1 in ESSA et al. (2013), which corresponds with a total alkalinity of 37.9 µeq/L, based on a regression of Gran ANC and total alkalinity for data sets 1 and 2 combined. Of the 80 sampled lakes included in the analysis, 31 (39%) have a total alkalinity less than 37.9 µeq/L and would therefore be expected to have a pH <6 (as discussed below, there are actually 30 lakes with a pH <6, supporting this estimated total alkalinity threshold).

Driscoll et al. 2001 notes that lakes with a Gran ANC <50 µeq/L can potentially experience acidic episodes during storm and snowmelt events, whereas those with a Gran ANC >50 µeq/L are less sensitive to acidic deposition. Based on the linear regression described above, a Gran ANC of 50 µeq/L corresponds to a total alkalinity of about 61.6 µeq/L. In total, 38 of the 80 sampled lakes included in the analysis (48%) had a total alkalinity <61.6 µeq/L and therefore could potentially experience acidic episodes, whereas the remaining 52% of the sampled lakes are less sensitive to acidic deposition.

Measurements of **Gran ANC** (data sets 1 and 2 only; Table 6-3) showed generally similar patterns to total alkalinity, with a smaller proportion (28%) of the sampled lakes having a Gran ANC value below the critical level of 26 µeq/L. The differences reflect the fact that the lakes in data set 3 are on average the most sensitive to acidic deposition. Only four of the 67 lakes with Gran ANC measurements have a Gran ANC <0 µeq/L, and would be classified as acidic lakes (Table 6-3).

Data set 1 included both the most sensitive and least sensitive lakes (Figure 6-5 and Figure 6-6). All lakes in data set 3 had total alkalinity values less than 100 µeq/L, and showed the least variability of the three data sets.

Table 6-3. Distribution of lake total alkalinity and Gran ANC values by category.

	Total Alkalinity		Gran ANC	
Category (µeq/L)	Lakes (#)	Lakes (%)	Lakes (#)	Lakes (%)
<0	4	5%	4	6%
0-26	24	30%	15	22%
>26-50	7	9%	7	10%
>50-200	30	38%	30	45%
>200	15	19%	11	16%
TOTAL	80	100%	67	100%

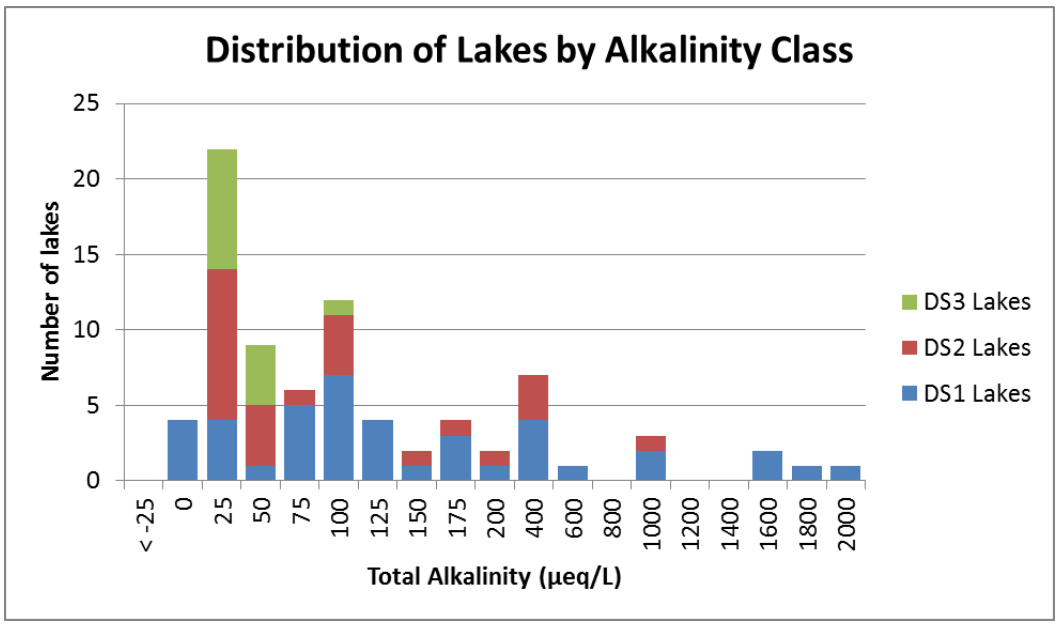


Figure 6-5. Distribution of total alkalinity among sampled lakes, stratified by data set. The number on the X-axis shows the maximum value of the total alkalinity interval (e.g., "25" indicates waters with total alkalinity between 0 and 25 µeq/L). Note that the total alkalinity interval is 25 µeq/L up to 200 µeq/L, and then increases to 200 µeq/L.

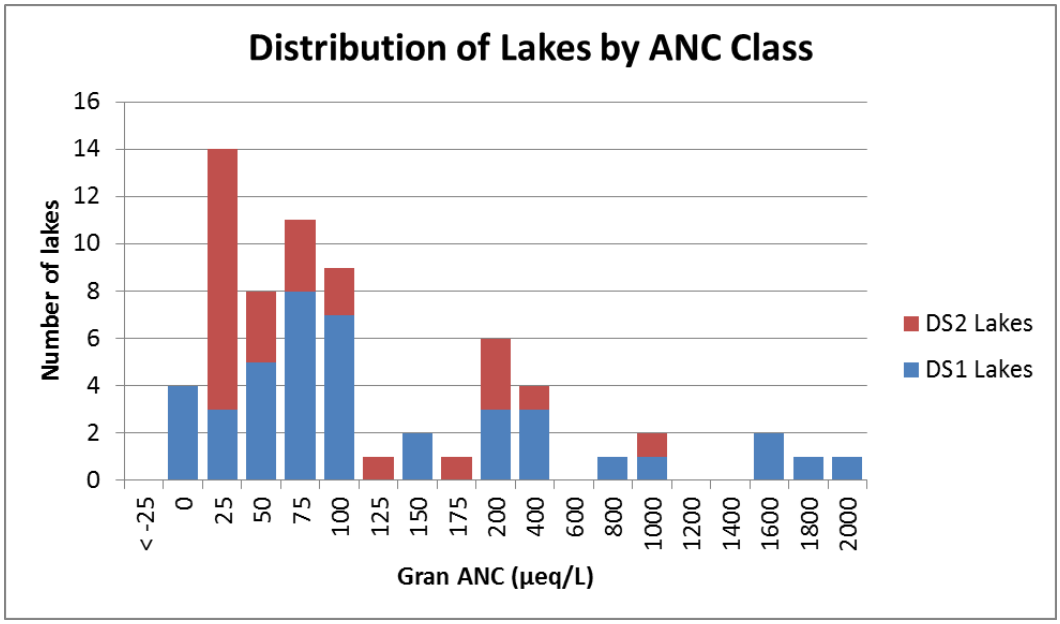


Figure 6-6. Distribution of Gran ANC among sampled lakes, stratified by data set. Gran ANC was not measured for the lakes in data set 3. The number on the X-axis shows the maximum value of the Gran ANC interval (e.g., "25" indicates waters with Gran ANC between 0 and 25 µeq/L). Note that the Gran ANC interval is 25 µeq/L up to 200 µeq/L, and then increases to 200 µeq/L.

6.2.2.2 pH Levels in Sampled Lakes

As shown in Table 6-4 and Figure 6-7, 30 of the 80 sampled lakes (37 %) had a laboratory pH less than 6.0. Data set 3 had the largest proportion of lakes with pH <6.0 (69%). Of the 21 lakes in data sets 1 and 2 with laboratory pH <6.0, 18 had a Gran ANC <26 µeq/L, consistent with the use of 26.0 µeq/L as ANC_{limit} (as discussed above Gran ANC was not available for data set 3).

As shown in Figure 6-8, the majority of the 30 lakes with pH <6 are located in five clusters: two north of Terrace; four southwest of Lakelse Lake; two in the valley north of Kitimat; three near Jessie Lake, southwest of Kitimat along Douglas Channel; and 19 in the southern third of the study area (63% of the sampled lakes with pH <6).

For regional context for these pH data, refer to Appendix 19 which provides data from geochemical surveys of stream pH from the government of British Columbia within and adjacent to the project study area. These geochemical surveys confirm that the southern part of the study area has the highest proportion of lakes with pH values <6.0.

The subsequent section on anion composition discusses the likely causes of pH values <6.0.

Table 6-4. Distribution of sampled lakes by pH category.

pH Category	Lakes (#)	Lakes (%)
<4.5	1	1%
>4.5 to 5	3	4%
>5 to 5.5	4	5%
>5.5 to 6	22	28%
>6 to 6.5	11	14%
>6.5 to 7	24	30%
>7 to 7.5	10	13%
>7.5	5	6%
TOTAL	80	100%

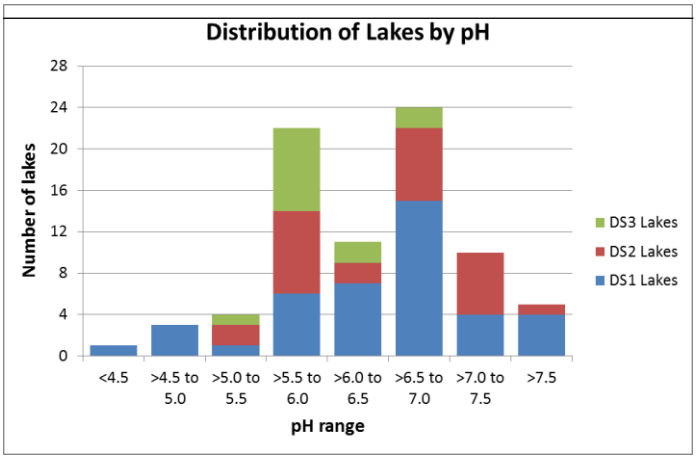


Figure 6-7. Distribution of pH (lab) among sampled lakes, stratified by data set.

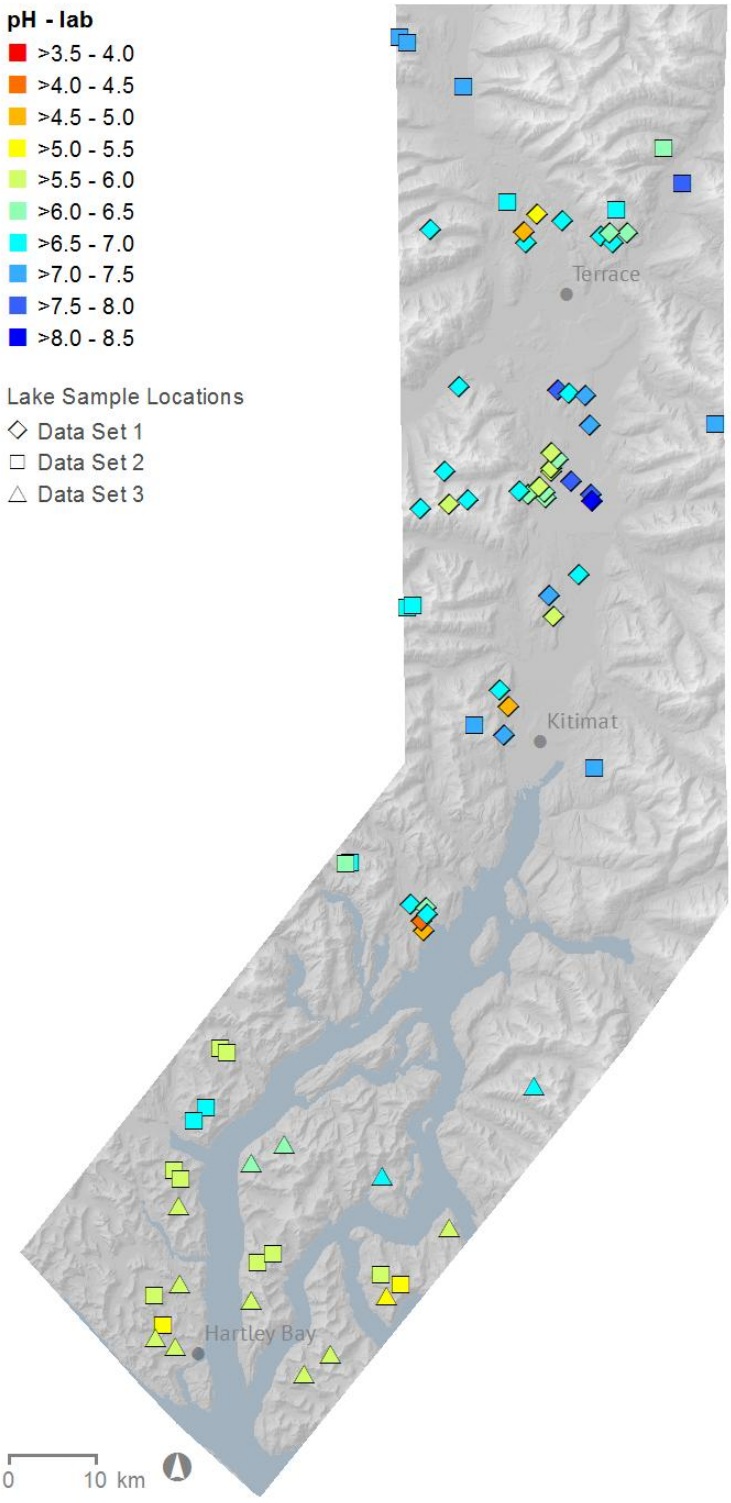


Figure 6-8. Spatial distribution of pH (laboratory) values across the study region.

6.2.2.3 Anion Composition

The anion composition of lakes provides an indication of the causal factors determining their acid-base status (Marmorek et al. 1989; Baker et al. 1991). Appendix 20 provides a detailed assessment of the anion composition of all of the sampled lakes. The remainder of this section focuses exclusively on the anion composition of those lakes with pH <6, to determine why they currently have a relatively low pH.

Across all three data sets, a total of 30 lakes have current pH <6. Table 6-5 shows the anion composition of these 30 lakes, as well as the estimated pre-industrial, original pH (pH_o), based on the modified ESSA/DFO model. The pre-industrial, original pH is calculated to help determine if there are naturally acidified lakes that have always had a pH <6. As shown in Table 6-5, 23 of the 30 lakes with current pH <6 (i.e., 76%) are estimated to have also had a pre-industrial, original pH_o <6, and are thus considered to be naturally acidified lakes. Three lakes are estimated to have experienced more than a 0.4 pH unit change since pre-industrial times (Table 6-5 and Table 6-6), exceeding the criterion proposed by Fölster et al. 2007 for protecting lakes in Sweden. One of these three lakes is about 20 km north of the Kitimat smelter, and experienced very high levels of historical deposition of S (LAK028), while the other two lakes (LAK042 and LAK044) are in the northern part of the study area and experienced much lower levels of historical deposition of S than LAK028 (Table 6-6), but are very dilute waters with low ability to neutralize deposited acids. Testing these model-based estimates of pre-industrial, original pH_o values would require applying paleolimnological approaches such as those used by Dixit et al. (1992) for lakes in the Sudbury area.

Why do these 30 lakes have a current pH <6? Anions associated with organic acids[38] are immensely important in these extremely dilute lakes with very low conductivity and bicarbonate anions. The anion composition data (Table 6-5) indicate that lakes in data set 1 with a pH <6 appear to have been acidified primarily by organic anions or organic anions plus sulphate (see further discussion in ESSA et al. 2013, Section 9.4.1.2.3). LAK028 shows evidence of historic fluoride deposition, presumably from the Kitimat smelter. The lakes in data set 3 with a pH <6 appear to have been acidified primarily by a combination of chloride and organic acids (also see ternary diagrams in Appendix 20, Figure A20-2). Data set 2 has a smaller proportion of organic-influenced or organic-dominated lakes with pH <6 than do data sets 1 and 3 (Table 6-5). Nitrate forms a very small proportion of the total anions, indicating that the effects of historical deposition of N are negligible.

Most of the lakes with pH <6 in data sets 2 and 3 are influenced or dominated by chloride (Table 6-5), reflecting their proximity to Douglas Channel. The movement of salt-enriched precipitation by offshore winds can contribute substantial natural acidity to catchments with naturally acidic soils, even in pristine areas (Wright et al. 1988). When precipitation carrying sea salts lands on acidic soils, the basic elements in the precipitation (e.g., sodium) displace the acidic elements in the soil; the free acidic elements then go into solution and acidify the runoff water (Wright et al. 1988). The spatial pattern of pH values from geochemical data (Appendix 19) suggest that sea salt-driven acidification might be responsible for the greater proportion of lower pH lakes in the southern part of the study area, though testing this hypothesis would require anion data from a subsample of these lakes.

[38] The concentration of organic anions was determined using the method of Oliver et al. (1983) assuming an average charge density of 7.5 µeq per mg of dissolved organic carbon (DOC).

Table 6-5. Analysis of the anion composition of 30 lakes with current pH <6. Highlighted values indicate anion influence or dominance (≥25%), except for F and NO_3, where highlighting indicates notably elevated levels. Bold lettering indicates anion dominance (≥50%). COND=conductivity (µS/cm), DOC = dissolved organic carbon (mg/L), HCO_3 = bicarbonate, Cl = chloride, SO_4 = sulphate, ORG = organic anions, F = fluoride, NO_3 = nitrate. Last column shows estimated pre-industrial pH_o based on modified ESSA/DFO model (ESSA et al. 2013). For this calculation, total alkalinity measured in the data set 3 lakes was converted to Gran ANC using a linear regression. Only seven of the 30 lakes with current pH <6 had an original pH_o >6 (pH_o bolded). The change in pH from pre-industrial to present is shown in the last column (ΔpH, highlighting indicates lakes with a change of >0.4 pH units). Lake names are coloured according to their data set (blue = DS1, red = DS2, green = DS3).

Name	COND (lab)	DOC	pH (lab)	% HCO_3	% Cl	% SO_4	% ORG	% F	% NO_3	pH_o	ΔpH
LAK006	7	3.6	5.79	34%	8%	17%	34%	6%	0%	**6.13**	-0.34
LAK012	13	4.6	5.64	**61%**	4%	6%	26%	4%	0%	5.79	-0.15
LAK015	23	7.6	5.97	38%	2%	34%	23%	3%	0%	5.98	-0.01
LAK022	11	5.3	5.92	24%	7%	29%	35%	6%	0%	**6.21**	-0.28
LAK023	8	4.2	5.70	25%	6%	25%	36%	7%	0%	**6.08**	-0.38
LAK028	12	4.9	4.98	0%	5%	**51%**	25%	18%	0%	5.96	-0.98
LAK042	12	13.2	4.68	0%	7%	8%	**81%**	4%	0%	5.75	-1.07
LAK044	3	1.7	5.40	9%	19%	24%	38%	10%	0%	**6.22**	-0.82
LAK047	3	0.4	5.96	**72%**	7%	8%	10%	1%	3%	**6.09**	-0.13
LAK054	9	6.7	4.59	0%	16%	18%	**61%**	5%	0%	4.95	-0.35
LAK056	13	8.5	4.50	0%	26%	15%	**56%**	4%	0%	4.82	-0.32
DCAS04A	9	4.7	5.48	4%	**50%**	10%	35%	1%	0%	5.60	-0.12
DCAS04B	8	3.7	5.63	13%	41%	10%	35%	1%	0%	5.69	-0.06
DCAS05A	6	3.2	5.68	14%	37%	17%	32%	0%	0%	5.73	-0.05
DCAS05B	4	0.8	5.79	9%	**58%**	18%	13%	1%	0%	5.90	-0.11
DCAS07A	3	0.6	5.91	25%	43%	20%	10%	1%	0%	**6.02**	-0.11
DCAS07B	3	0.5	5.81	28%	43%	18%	10%	1%	1%	5.91	-0.10
DCAS08A	5	1.5	5.74	14%	**52%**	14%	19%	2%	0%	5.86	-0.12
DCAS08B	6	1.7	5.84	24%	44%	12%	17%	2%	2%	5.93	-0.09
DCAS11A	6	3.5	5.28	1%	47%	8%	43%	1%	0%	5.41	-0.13
DCAS11B	8	5.1	5.79	20%	36%	7%	36%	1%	0%	5.81	-0.02
CAPONERO	6	3.3	5.84	19%	33%	15%	30%	1%	2%	5.93	-0.09
LARCH	4	1.1	5.95	24%	45%	18%	13%	1%	0%	**6.05**	-0.10
LOWER	7	0.3	5.69	20%	**61%**	15%	3%	1%	1%	5.81	-0.12
NC171	8	5.6	5.64	15%	29%	14%	41%	0%	0%	5.68	-0.04
NC178	5	3.1	5.86	21%	30%	15%	32%	1%	1%	5.93	-0.07
NC179	9	7.5	5.35	6%	31%	6%	**56%**	1%	1%	5.40	-0.05
NC180	6	3.5	5.59	14%	44%	11%	31%	0%	0%	5.73	-0.14
NC184	10	11.6	5.73	20%	17%	6%	56%	0%	0%	5.76	-0.03
UPPER LK	6	2.6	5.73	15%	48%	12%	22%	1%	1%	5.85	-0.12

Table 6-6. Characteristics of the three lakes with ΔpH (historic to present) >0.4 pH units. ΔSdep and ΔNdep are estimated historical changes in S and N deposition (respectively). F and Fn are fractions of S and N deposition neutralized in the catchment (respectively).

Lake	ΔSdep (meq/ m^2/yr)	ΔNdep (meq/ m^2/yr)	F	Fn	Gran ANC (current)	Δ ANC	ANC_o (estimated original, pre-industrial ANC)	pH_t (current pH)	pH_o (estimated original, pre-industrial pH)	ΔpH (historic to present)
LAK028	-94.6	-6.7	0.44	0.78	-4.0	33.8	29.8	4.98	5.96	-0.98
LAK042	-17.0	-5.6	0.13	0.32	-20.4	31.3	10.8	4.68	5.75	-1.07
LAK044	-17.1	-5.6	0.04	0.04	1.3	34.1	35.4	5.40	6.22	-0.82

6.2.3 Analyses of critical loads and exceedances

6.2.3.1 Critical Loads

The distributions of S critical loads for the sampled lakes, estimated from the SSWC model, are shown in Figure 6-9. There are 15 lakes (18.8% of the analyzed lakes) with a CL ≤0; these lakes show exceedance at any level of acidic deposition. In their study of 2,053 lakes in Quebec, the Maritimes, and the northeastern United States, Dupont et al. (2005) excluded the 53 lakes which had a CL <0 (just 2.6% of their sample), recognizing that these lakes would not recover to a pH >6 even if all anthropogenic acidic deposition were eliminated. We do include these ultra-sensitive lakes in the following discussion, but recognize their special attributes.

The mode of the distribution of CLs is lower for data sets 2 and 3 than for data set 1 (Figure 6-9). However, given their generally lower total alkalinity values compared to data set 1 (Figure 6-5 above), the sulphur CL values for data sets 2 and 3 are actually higher than would be expected (though still generally lower than data set 1). This reflects the fact that the lakes in data sets 2 and 3 are further south and have much higher runoff values than the lakes in data set 1, most of which are in the Kitimat River valley (Table 6-7). Higher runoff essentially provides more dilution of deposited sulphate, thus increasing the CL. Table 6-7 shows that the mean runoff values for catchments in data sets 2 and 3 are (respectively) 2.2 and 3.0 times higher than the mean runoff in the catchments of data set 1. Uncertainty in runoff estimates is discussed in Section 6.2.3.3.

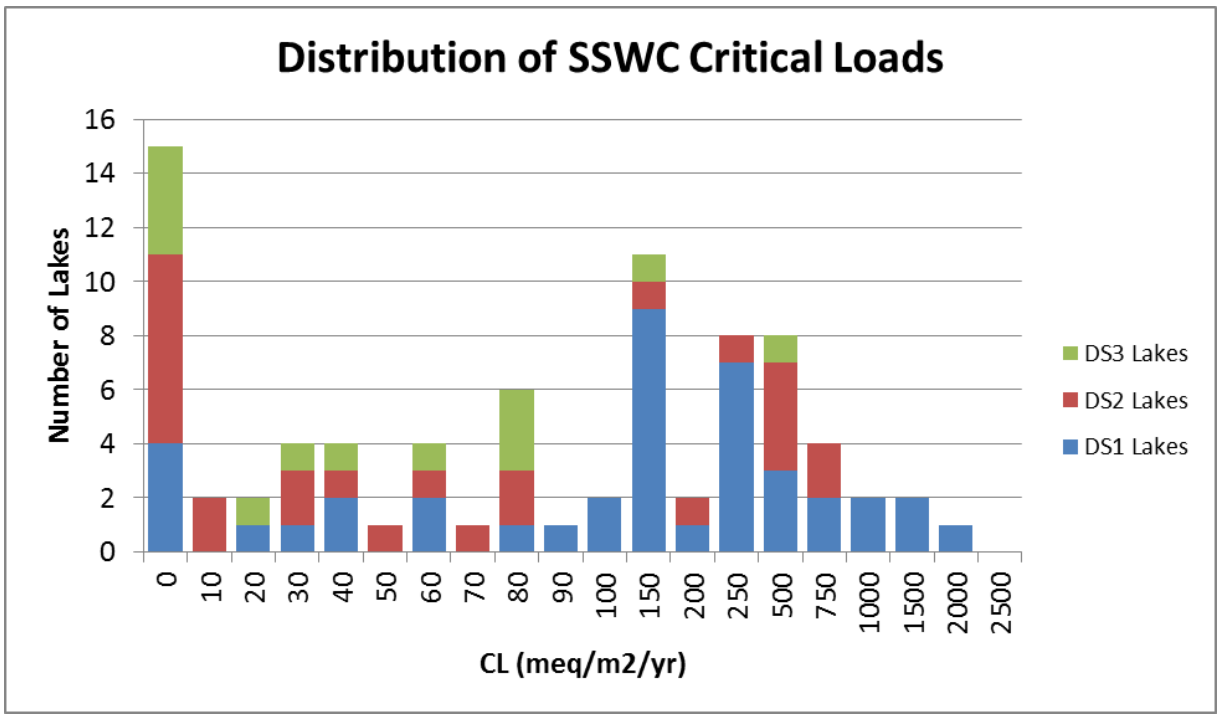


Figure 6-9. Frequency distribution of SSWC critical loads for the sampled lakes. The label below each interval is the maximum value for that critical load category (e.g., 10 is for CL >0 and ≤10). Y-axis indicates number of lakes in each category. The 15 lakes in the lowest category have CL = 0.

Table 6-7. Annual runoff metrics for the three data sets (m/yr).

Runoff metric	Data Set		
	Data set 1 (n=41)	Data set 2 (n=26)	Data set 3 (n=13)
mean	1.25	2.70	3.73
min	0.59	0.63	2.33
max	2.8	4.61	4.45

In the FAB model, the critical load of a sampled lake cannot be defined by a single, definitive combination of S and N deposition values. Instead, critical loads are a function of S and N deposition. The maximum critical loads for S and N estimated from the FAB model (Figure 6-4), are shown in Figure 6-10. The values for CLmax(N) are consistently higher than the values for CLmax(S) (see Appendix 21, Figure A21-1). This is because there are more processes which retain or neutralize acidity derived from deposition of N than for deposition of S (Aherne et al. 2004), and such processes (i.e., N immobilization, denitrification and uptake), are included in the FAB model. The distribution of CLs from the FAB model shows the lowest values for data set 3, intermediate values for data set 2, and the highest values for data set 1 (Figure 6-10). Figure 6-11 shows the percentile distributions of the CLFs for all of the study lakes, and again illustrates that critical loads for N are higher than for S (slope is less than -1). In general, the CLFs in Figure 6-11 indicate that it would take roughly 50% more deposition of N to have the same amount of acidification impact as S deposition. The spatial distributions of CLmax(S) and CLmax(N) are shown in Figure 6-12. As expected, the lowest CLs are in the southern third of the study area.

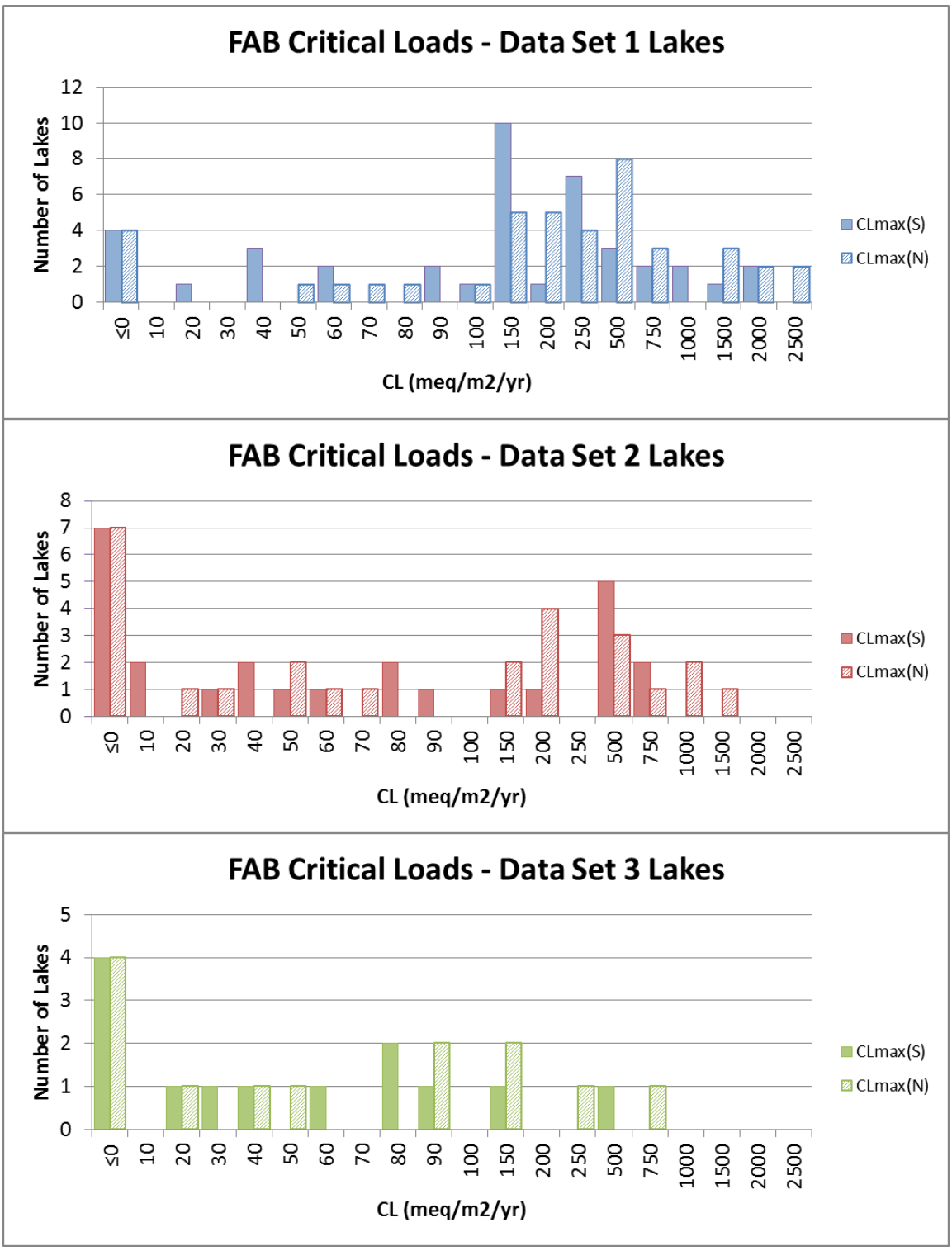


Figure 6-10. Frequency distribution of CLmax(S) and CLmax(N) for the sampled lakes in each of the data sets (upper panel = data set 1, middle panel = data set 2, lower panel = data set 3). The label below each interval is the maximum value for that critical load category (e.g., 10 is for CL >0 and ≤10). Y-axis indicates number of lakes in each category. The lakes in the lowest category (≤0) all have CL = 0.

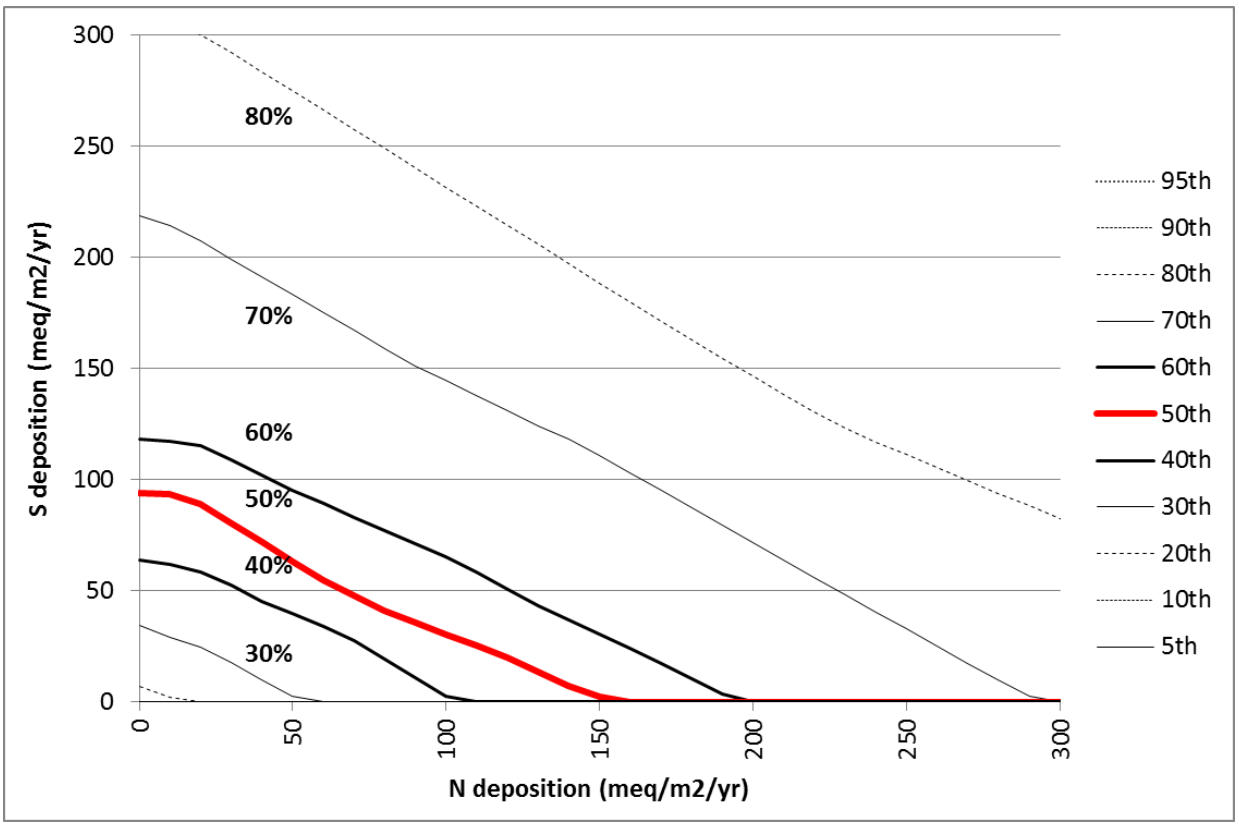


Figure 6-11. Percentile distributions of the Critical Loads Functions for all of the sampled lakes in the study area.

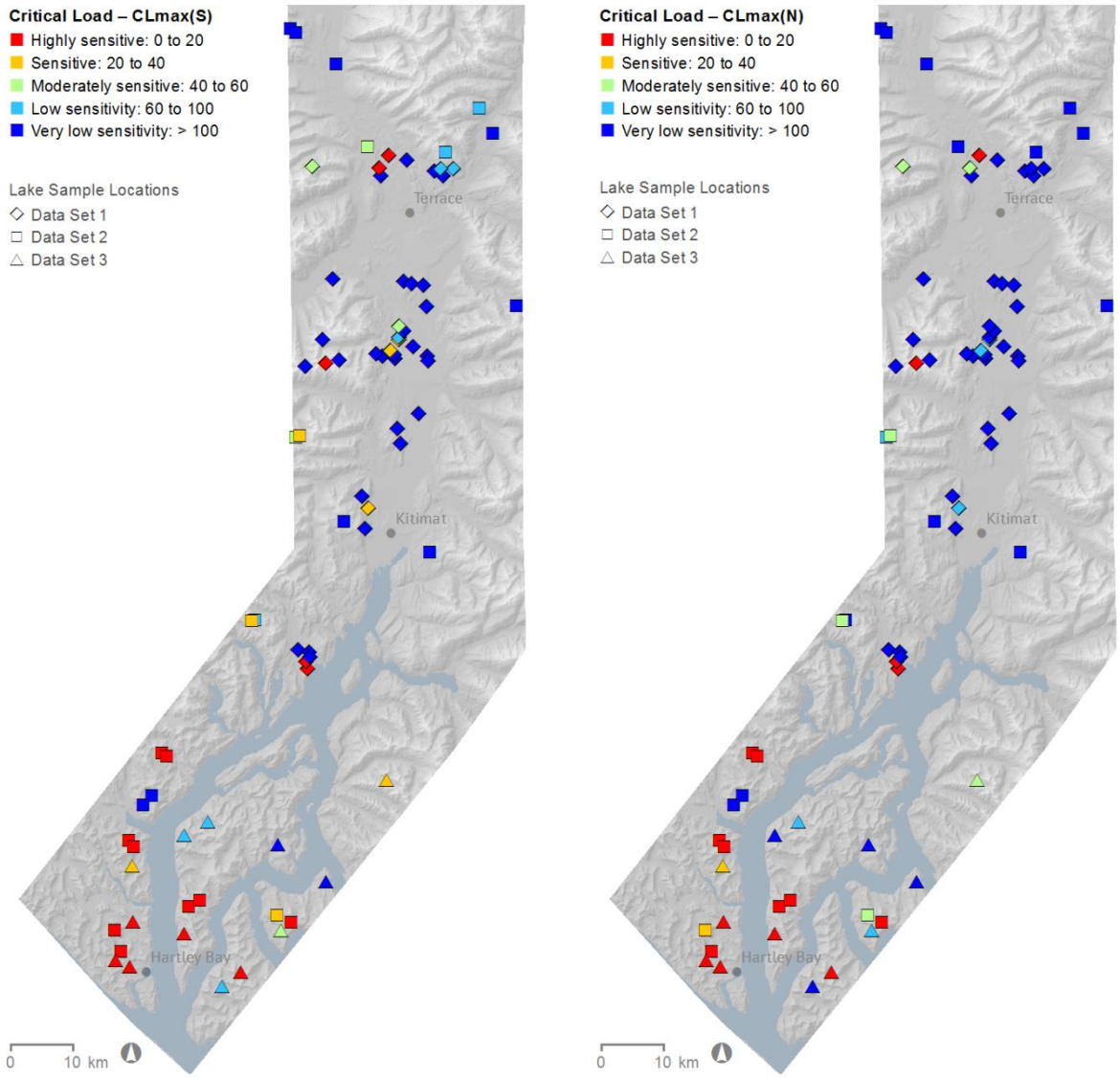


Figure 6-12. Spatial distribution of CLmax(S) (left) and CLmax(N) (right), as calculated by the FAB model, for the sampled lakes in the study region.

Variation in Critical Loads with Bedrock Geology

ESSA et al. (2013) used the relationship between critical loads and Acid Sensitivity Class (ASC) of bedrock geology, to help draw conclusions about unsampled lakes in the study area for the KMP SO_2 Technical Assessment based on the results of the sampled lakes. For the present study, we conducted preliminary analyses to explore the potential relationship between critical loads and ASC for the sampled lakes in the current, larger study area. However, due to much greater variation within classes than between (likely affected by variability in runoff), ASC does not appear to be a good predictor of critical load for this larger set of sampled lakes in the present study. See Appendix 22 for further details.

6.2.3.2 Exceedances and Predicted Changes in Lake pH

Table 6-8 shows the total exceedance, as estimated from the FAB model, for sampled lakes with positive exceedances under at least one of the emission scenarios. The subset of those sampled lakes that are inferred to have not been naturally acidified is shown in Table 6-10. The frequency and spatial distributions of total exceedances under the "bookend" scenarios (i.e., Scenario A_28.2 and Scenario H_82.6) are shown in Figure 6-14 through Figure 6-17 and Table 6-10. Figure 6-14 and Figure 6-15 show the distribution of total exceedance values for each of the scenarios, distinguishing between the entire set of all lakes and the subset of lakes that are inferred to have not been naturally acidified. Maps of total exceedance under each scenario are shown in Figure 6-16 and Figure 6-17. A summary of the number and percentage of sampled lakes with exceedances under each scenario is presented in Table 6-10. Frequency distributions and maps of total exceedance for the sampled lakes under all 10 emission scenarios are included in Appendix 23.

The key findings (and important caveats on these findings) are as follows:

- We can only accurately estimate the magnitude of exceedance and the percent of lakes with exceedance, for the *sampled* lakes, not for all lakes in the study area. The sampled lakes were deliberately selected from the most acid-sensitive regions, and therefore certainly overestimate the percent of all lakes with exceedance. Estimates of the percent of all study area lakes with exceedance (and the percent of lake area with exceedance) can however be made using a range of assumptions, which generate minimum and maximum estimates that bracket the true values.
- A very large fraction of the lakes with exceedance is estimated to have had a pre-industrial pH_o <6.0. Including these lakes in the analysis (which we justified in Section 6.1.2.1), exerts a big effect on the percent of lakes estimated to have CL exceedance.
- The major difference between Scenarios A_28.2 and H_82.6 is the magnitude of exceedance for sampled lakes in data set 1, not the % of lakes with exceedance (Table 6-10, Figure 6-14, and Figure 6-15). These results are consistent with the sensitivity analysis of a halving and doubling of KMP deposition of sulphate (in Section 9.4.1.3.4 of ESSA et al. 2013).
- When we used the modified ESSA/DFO model to predict the future decrease in pH (last two columns of Table 6-8; Table 6-9), we found that none of the 39 lakes in data sets 2 and 3 would experience more than a 0.3 unit change in pH under any of the emission scenarios. In fact, none of the 39 lakes in data sets 2 and 3 experience more than a 0.1 unit change in pH. With respect to Scenario H_82.6 and the categorization scheme in Table 6-2, 25 of 39 lakes are in category 1 (no concern - CL not exceeded and pH change not biologically significant), and 14 are in category 2 (low concern - CL exceeded but pH change not biologically significant).
- The focus of attention for the risk assessment is therefore on the 41 lakes in data set 1. For these 41 lakes under Scenario H_82.6, there are 31 lakes in category 1 (no concern - CL not exceeded and pH change not biologically significant), three lakes in category 2 (low concern - CL exceeded but pH change not biologically significant), one lake in category 3 (intermediate concern - CL not exceeded but biologically significant pH change), and six lakes in category 4 (highest concern - CL exceeded **and** biologically significant pH change). Table 6-11 shows that the magnitude of exceedance under Scenario H_82.6 is much greater for lakes in data set 1 (closer to KMP) than for lakes in data sets 2 and 3 (most of which are further from KMP). Most of the total exceedance in the lakes of data set 1 is due to sulphur deposition (Table 6-13).
- The modified ESSA/DFO model also shows much greater predicted future decreases in pH for the lakes in data set 1 than for the lakes in data sets 2 and 3 (last two columns of Table 6-8).

Under Scenario H_82.6, there are seven lakes in data set 1 with predicted pH declines greater than 0.3 pH units (Table 6-9), and five of these seven lakes have predicted pH declines greater than 0.8 pH units: lakes 006 (End Lake), 022, 023 (West Lake), 028 and 044. Figure 6-13 illustrates that the largest predicted future pH changes are for lakes in data set 1 on the steepest part of the titration curve between pH 5 and pH 6.

- Figure 6-18 and Figure 6-19 show the cumulative frequency distribution of total exceedances across all sampled lakes and all sampled lakes that are not naturally acidified, respectively. Similar to the information represented in Figure 6-14 and Figure 6-15, the cumulative frequency distributions show that the vast majority of the sample lakes are predicted to be below their critical limits under these emissions scenarios.
- The exceedances (Table 6-8), predicted pH changes (Table 6-9), and the cumulative frequency distributions of exceedances (Figure 6-18) show a step increase in effects between Scenarios A_28.2 and B_51.8, and between Scenarios D_61.8 and E_66.1. This is consistent with the step increase in S emissions in Figure 1-5.
- Of the seven lakes with predicted ΔpH ≥0.3 units under Scenario H_82.6 (Table 6-9), three lakes are estimated to have had a pH_o <6 and are therefore considered to have been naturally acidified, while the other four had a pH_o >6. Both types of lakes would be expected to show future decreases in species richness in various taxa with a ΔpH ≥0.3 units. Table 6-10 is similar to Table 6-8, but shows the outcomes just for those lakes which were not naturally acidified and exceeded their CL.
- Emission Scenario D_61.8 has similar total levels of S emissions (38.6 t/d) to the 42 t/d that was assessed in the KMP SO_2 Technical Assessment (ESSA et al. 2013). The exceedances under D_61.8 in this study are however considerably greater than those in KMP SO_2 Technical Assessment (Appendix 24). There are two reasons for these differences:
    1. This study used only the worst case year for deposition (2008), whereas the KMP assessment used the average deposition over three years (2006, 2008, 2009). Sensitivity analyses in Appendix 24 show that using just 2008 deposition for the KMP study area in ESSA et al. 2013 leads to greater magnitudes of exceedance (on average 6.8 meq/m^2/yr more, but up to 51 meq/m^2/yr more) and greater decreases in pH (up to 0.2 pH units more) than using the average deposition for 2006, 2008 and 2009.
    2. Second, the KMP SO_2 Technical Assessment did not include background levels of industrial-origin S and N deposition, whereas this study did (10 and 5 meq/m^2/yr respectively).
- Table 6-11 and Table 6-12, and Figure 6-20 show the range of uncertainty in estimates of the percent of lakes with exceedance (and percent of lake area with exceedance) in the entire study area. These tables and figures illustrate that the biggest influence on these metrics is not the emission scenario, but the set of lakes considered (i.e., all lakes vs. only lakes that were not naturally acidified), and the assumptions made in extrapolating from the sampled lakes to the entire study area. Including naturally acidified lakes, the percent of lakes in the overall study area with critical load exceedance ranges from 5.6% to 26.3% for emission Scenario A_28.2, and from 6.2% to 28.8% for Scenarios E_66.1 to Js_86.1. The lower end of these ranges assumes that there are no unsampled lakes with CL exceedance (clearly an underestimate of the percent of lakes with CL exceedance), and the upper end assumes that unsampled lakes have the same sensitivity to deposition as sampled lakes (clearly an overestimate of the percent of lakes with CL exceedance). The true percent lies somewhere within this range. The percent of total lake area in the study area with CL exceedance shows a somewhat smaller range: 5.6% to 12.7% for

emission Scenario A_28.2, and 6.4% to 12.9% for Scenarios E_66.1 to Js_86.1. Excluding naturally acidified lakes lowers these percentages (Table 6-12 and Figure 6-20); for reasons stated above, we report these metrics but do not recommend excluding these lakes from the analysis.

Table 6-8. Exceedances across scenarios for the 23 lakes with positive exceedances under at least one emission scenario. All lakes with total exceedance >0 in at least one scenario are included. The results are shaded according to exceedance class: red = >20 µeq/L, magenta = 10 to 20 µeq/L, orange = 0 to10 µeq/L, yellow = -10 to 0 µeq/L, and green = -20 to -10 µeq/L. Fish presence is based on the BC Fisheries Information Summary System. Lake IDs in bold indicate lakes for which CL >0. Predicted ΔpH is based on the modified ESSA/DFO model yellow = |ΔpH|>0.1, red = |ΔpH|>0.3).

LakeID	Lake Area (ha)	Fish Presence	Emissions Scenario												Predicted ΔpH	
			A_ 28.2	B_ 51.8	C_ 57.5	D_ 61.8	E_ 66.1	F_ 72.6	G_ 76.2	H_ 82.6	Im_ 83.3	Is_ 83.3	Jm_ 86.1	Js_ 86.1	A_ 28.2	H_ 82.6
LAK006	10.2	Fish Habitat – Observed[a]	1.9	26.8	26.5	27.0	42.8	44.2	42.9	44.4	44.4	44.4	46.2	44.4	-0.03	-1.28
LAK022	5.7	Fish Habitat - Inferred	-27.2	-4.1	-4.4	-3.9	10.7	12.3	10.9	12.5	12.5	12.5	12.6	12.5	-0.02	-1.02
LAK023	6.8	Fish Habitat – Observed[a]	-2.6	22.0	21.6	22.2	37.5	38.4	37.7	38.6	38.7	38.7	38.8	38.7	-0.03	-1.21
LAK028	1.0	Unknown	48.7	109.1	161.4	143.2	146.5	195.9	183.0	179.2	179.2	177.0	183.9	172.5	0.12	-0.71
LAK042	1.5	Fish Habitat - Inferred	0.4	10.0	9.9	10.1	16.3	17.7	16.4	17.7	17.7	17.7	17.8	17.8	-0.02	-0.36
LAK044	2.0	Fish Absent[a]	23.4	33.8	34.4	35.1	40.3	42.2	41.6	43.6	43.7	43.8	44.1	44.7	-0.05	-0.87
LAK047	1.6	Not Fish Habitat	21.0	25.5	25.9	26.3	28.0	28.5	28.8	29.3	29.4	29.4	29.7	29.7	0.00	-0.07
LAK054	1.5	Fish Habitat - Inferred	31.1	41.6	42.4	43.8	47.4	48.7	49.6	50.9	51.0	50.9	51.6	51.0	-0.04	-0.19
LAK056	1.8	Fish Habitat - Inferred	30.2	40.2	41.0	42.3	45.8	47.0	47.8	49.1	49.3	49.1	49.9	49.2	-0.04	-0.18
DCAS04A	39.9	Fish Habitat - Inferred	17.4	18.3	18.4	18.4	18.8	19.4	19.0	19.5	19.5	19.5	19.5	19.5	-0.01	-0.03
DCAS04B	5.7	Not Fish Habitat	5.0	6.2	6.2	6.3	7.0	7.1	7.0	7.1	7.1	7.1	7.1	7.1	0.00	-0.01
DCAS05A	2.4	Not Fish Habitat	9.1	10.7	10.7	10.8	11.5	11.9	11.7	12.1	12.1	12.1	12.1	12.1	0.00	-0.01
DCAS05B	3.0	Fish Habitat - Inferred	17.0	18.3	18.4	18.6	19.0	19.4	19.3	19.7	19.7	19.7	19.8	19.7	-0.01	-0.03
DCAS07A	9.1	Not Fish Habitat	18.1	20.0	20.1	20.3	21.1	21.6	21.4	21.9	22.0	22.0	22.1	22.0	-0.01	-0.04
DCAS07B	21.3	Not Fish Habitat	18.3	20.3	20.4	20.6	21.4	22.0	21.7	22.3	22.3	22.3	22.4	22.4	-0.01	-0.04
DCAS08A	6.5	Fish Habitat - Inferred	19.0	21.3	21.4	21.6	22.6	23.3	22.9	23.6	23.6	23.6	23.7	23.7	-0.02	-0.05
DCAS08B	9.7	Fish Habitat - Inferred	19.4	21.8	21.9	22.1	23.1	23.9	23.4	24.3	24.3	24.3	24.4	24.3	-0.01	-0.04
DCAS11A	5.9	Fish Habitat - Inferred	15.5	15.8	15.8	15.8	16.0	16.1	16.0	16.2	16.2	16.2	16.2	16.2	0.00	-0.01
LARCH	335.7	Not Fish Habitat	15.7	16.1	16.1	16.2	16.4	16.5	16.4	16.6	16.6	16.6	16.6	16.6	0.00	-0.01
LOWER	93.6	Fish Habitat - Inferred	17.0	17.9	17.9	18.0	18.4	18.8	18.5	19.0	19.0	19.0	19.0	19.0	-0.01	-0.03
NC178	26.9	Fish Habitat - Inferred	0.9	2.0	2.0	2.1	2.6	2.9	2.7	3.0	3.0	3.0	3.0	3.0	0.00	-0.01
NC180	8.1	Fish Habitat - Observed	17.6	18.8	18.9	19.0	19.5	20.0	19.7	20.2	20.2	20.2	20.3	20.2	-0.01	-0.03
UPPER_LK	187.0	Fish Habitat - Inferred	16.9	17.8	17.9	17.9	18.3	18.7	18.4	18.9	18.9	18.9	18.9	18.9	-0.01	-0.02

[a] Field sampling in 2013 found coho, dolly varden, cutthroat trout and stickleback in LAK 006 (End Lake), residualized coho (do not migrate out of the lake after rearing) and stickleback in LAK023 (West Lake), and no fish in LAK044.

Table 6-9. Predicted ΔpH under each emission scenario, for lakes which show ΔpH ≥0.3 units under one or more emission scenarios.

LakeID	Emissions Scenario												Tot Ex in
	A_28.2	B_51.8	C_57.5	D_61.8	E_66.1	F_72.6	G_76.2	H_82.6	Im_83.3	Is_83.3	Jm_86.1	Js_86.1	H_82.6
LAK002	0.00	-0.07	-0.07	-0.07	-0.12	-0.13	-0.12	-0.13	-0.13	-0.13	-0.13	-0.13	-58.3
LAK005	0.00	-0.12	-0.12	-0.12	-0.22	-0.23	-0.22	-0.23	-0.23	-0.23	-0.23	-0.23	-30.4
LAK006	-0.03	-0.66	-0.69	-0.73	-1.20	-1.24	-1.24	-1.28	-1.29	-1.28	-1.30	-1.29	44.4
LAK012	-0.01	-0.15	-0.16	-0.16	-0.28	-0.30	-0.29	-0.31	-0.31	-0.31	-0.32	-0.32	-15.7
LAK014	0.00	-0.08	-0.08	-0.08	-0.14	-0.15	-0.14	-0.15	-0.15	-0.15	-0.15	-0.15	-53.0
LAK016	0.00	-0.08	-0.08	-0.08	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-44.7
LAK022	-0.02	-0.43	-0.44	-0.46	-0.92	-0.98	-0.96	-1.02	-1.02	-1.02	-1.04	-1.03	12.5
LAK023	-0.03	-0.72	-0.74	-0.77	-1.16	-1.18	-1.19	-1.21	-1.21	-1.21	-1.22	-1.22	38.6
LAK028	0.12	-0.50	-0.51	-0.52	-0.69	-0.70	-0.70	-0.71	-0.71	-0.71	-0.72	-0.71	179.2
LAK035	0.00	-0.06	-0.06	-0.06	-0.10	-0.12	-0.10	-0.12	-0.12	-0.12	-0.12	-0.13	-65.8
LAK042	-0.02	-0.23	-0.24	-0.25	-0.33	-0.35	-0.34	-0.36	-0.36	-0.36	-0.37	-0.37	17.7
LAK044	-0.05	-0.60	-0.62	-0.65	-0.79	-0.84	-0.83	-0.87	-0.87	-0.87	-0.88	-0.89	43.6
LAK054	-0.04	-0.13	-0.13	-0.14	-0.17	-0.18	-0.18	-0.19	-0.19	-0.19	-0.20	-0.19	50.9
LAK056	-0.04	-0.12	-0.12	-0.13	-0.15	-0.16	-0.17	-0.18	-0.18	-0.18	-0.18	-0.18	49.1
# lakes with ΔpH ≥0.3	**0**	**5**	**5**	**5**	**6**	**6**	**6**	**7**	**7**	**7**	**7**	**7**	

Table 6-10. Exceedances across scenarios for lakes with positive exceedances, **excluding naturally acidified lakes**. All lakes with total exceedance >0 in at least one scenario are included. The results are shaded according to exceedance class: red = >20 µeq/L, magenta = 10 to 20 µeq/L, orange = 0 to10 µeq/L, yellow = -10 to 0 µeq/L, and green = -20 to -10 µeq/L. Fish presence is based on the BC Fisheries Information Summary System. Lake IDs in bold indicate lakes for which CL >0. Predicted ΔpH is based on the modified ESSA/DFO model (yellow = |ΔpH|>0.1, red = |ΔpH|>0.3).

Lake ID	Lake Area (ha)	Fish Presence	Emissions Scenario												Predicted ΔpH	
			A_ 28.2	B_ 51.8	C_ 57.5	D_ 61.8	E_ 66.1	F_ 72.6	G_ 76.2	H_ 82.6	Im_ 83.3	Is_ 83.3	Jm_ 86.1	Js_ 86.1	A_ 28.2	H_ 82.6
LAK006	10.2	Fish Habitat - Observed	1.9	26.8	26.5	27.0	42.8	44.2	42.9	44.4	44.4	44.4	46.2	44.4	-0.03	-1.28
LAK022	5.7	Fish Habitat - Inferred	-27.2	-4.1	-4.4	-3.9	10.7	12.3	10.9	12.5	12.5	12.5	12.6	12.5	-0.02	-1.02
LAK023	6.8	Fish Habitat - Observed	-2.6	22.0	21.6	22.2	37.5	38.4	37.7	38.6	38.7	38.7	38.8	38.7	-0.03	-1.21
LAK044	2.0	Unknown	23.4	33.8	34.4	35.1	40.3	42.2	41.6	43.6	43.7	43.8	44.1	44.7	-0.05	-0.87
LAK047	1.6	Not Fish Habitat	21.0	25.5	25.9	26.3	28.0	28.5	28.8	29.3	29.4	29.4	29.7	29.7	0.00	-0.07
DCAS07A	9.1	Not Fish Habitat	18.1	20.0	20.1	20.3	21.1	21.6	21.4	21.9	22.0	22.0	22.1	22.0	-0.01	-0.04
LARCH	335.7	Not Fish Habitat	15.7	16.1	16.1	16.2	16.4	16.5	16.4	16.6	16.6	16.6	16.6	16.6	0.00	-0.01

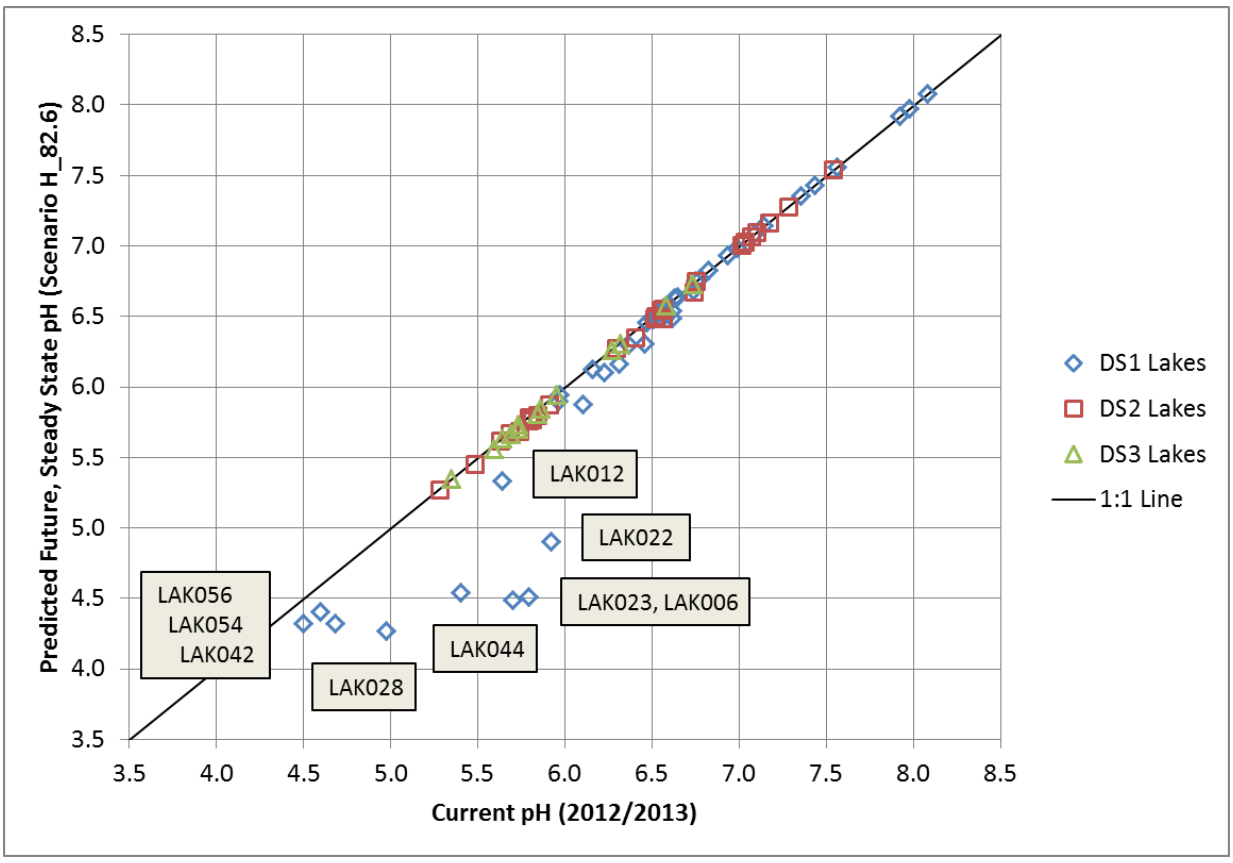


Figure 6-13. Predicted future pH_{∞} vs current pH_t under Scenario H_82.6. Of the 80 analyzed lakes, 66 have a predicted ΔpH <0.1 units, 14 have a predicted ΔpH ≥0.1 units, and 7 show a predicted ΔpH ≥0.3.

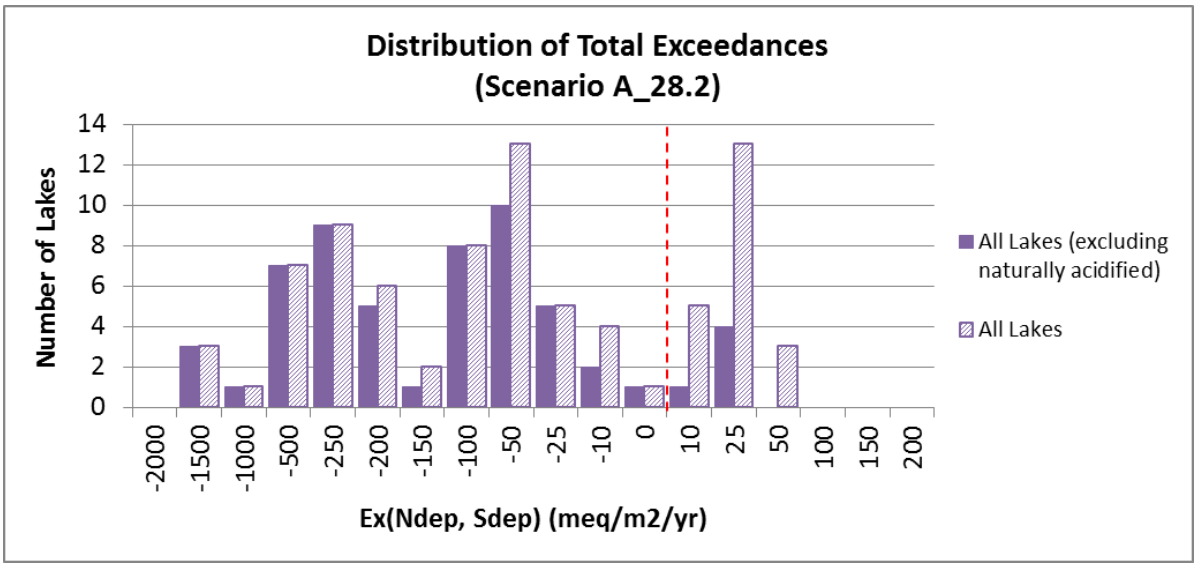


Figure 6-14. Distribution of total exceedances for Scenario A_28.2. The light bars represent all lakes and the dark bars represent the subset of lakes with naturally acidified lakes excluded. Lakes to the right of the vertical red line represent total exceedances >0.

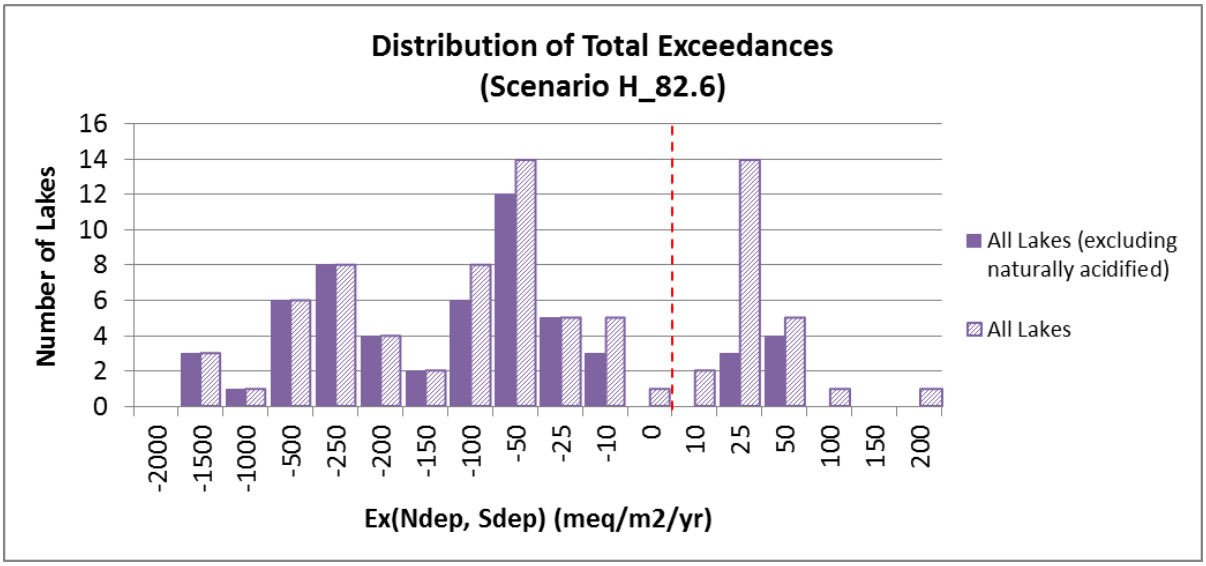


Figure 6-15. Distribution of total exceedances for Scenario H_82.6. The light bars represent all lakes and the dark bars represent the subset of lakes with naturally acidified lakes excluded. Lakes to the right of the vertical red line represent total exceedances >0.

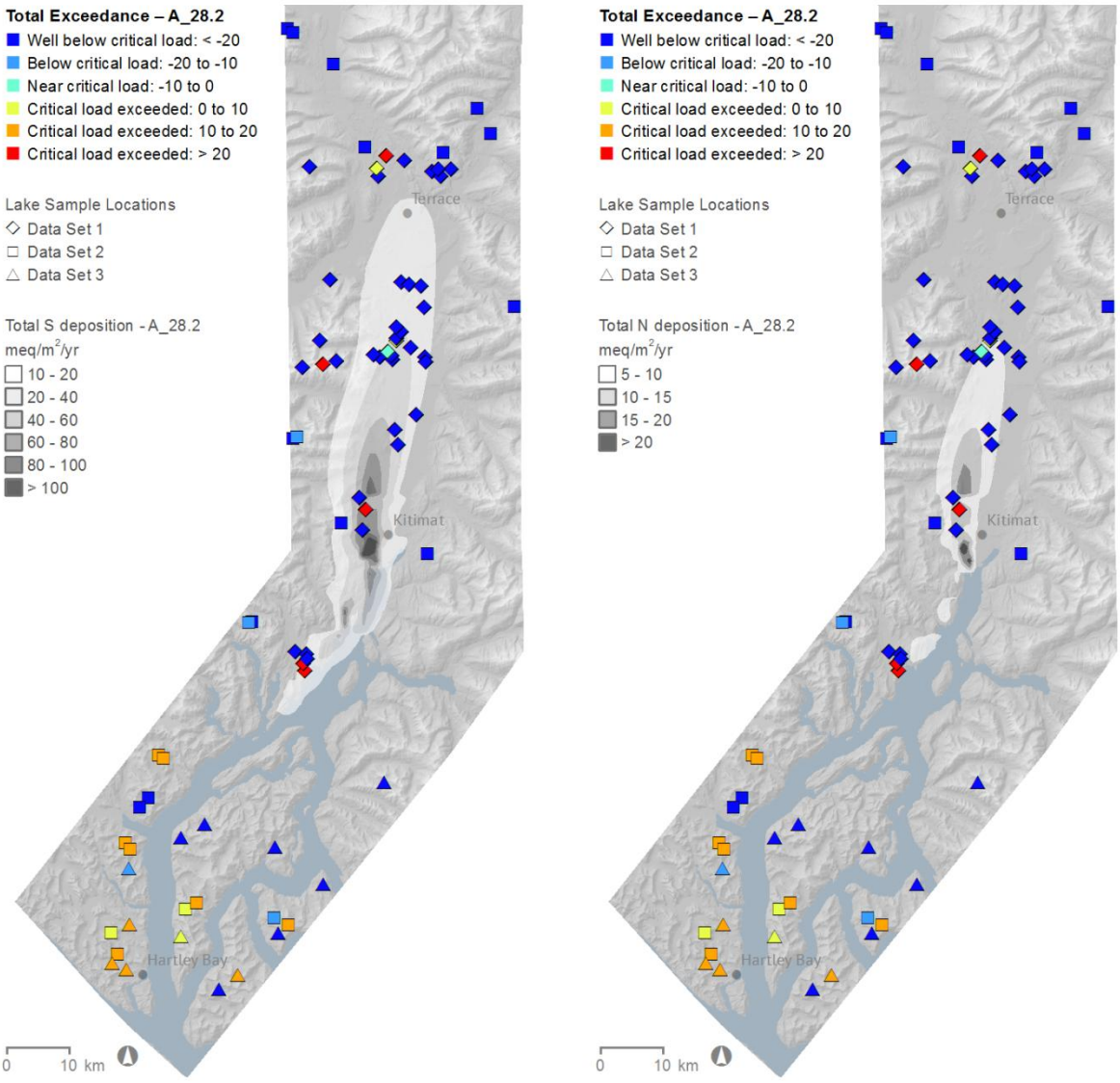


Figure 6-16. Spatial distribution of the total exceedance for sampled lakes under Scenario A_28.2, with deposition shown (S deposition in the left panel; N deposition in the right panel). This map shows incremental deposition associated with this emission scenario *without* background deposition; however background levels of S and N deposition *are* considered in the analyses of exceedance for soils and lakes.

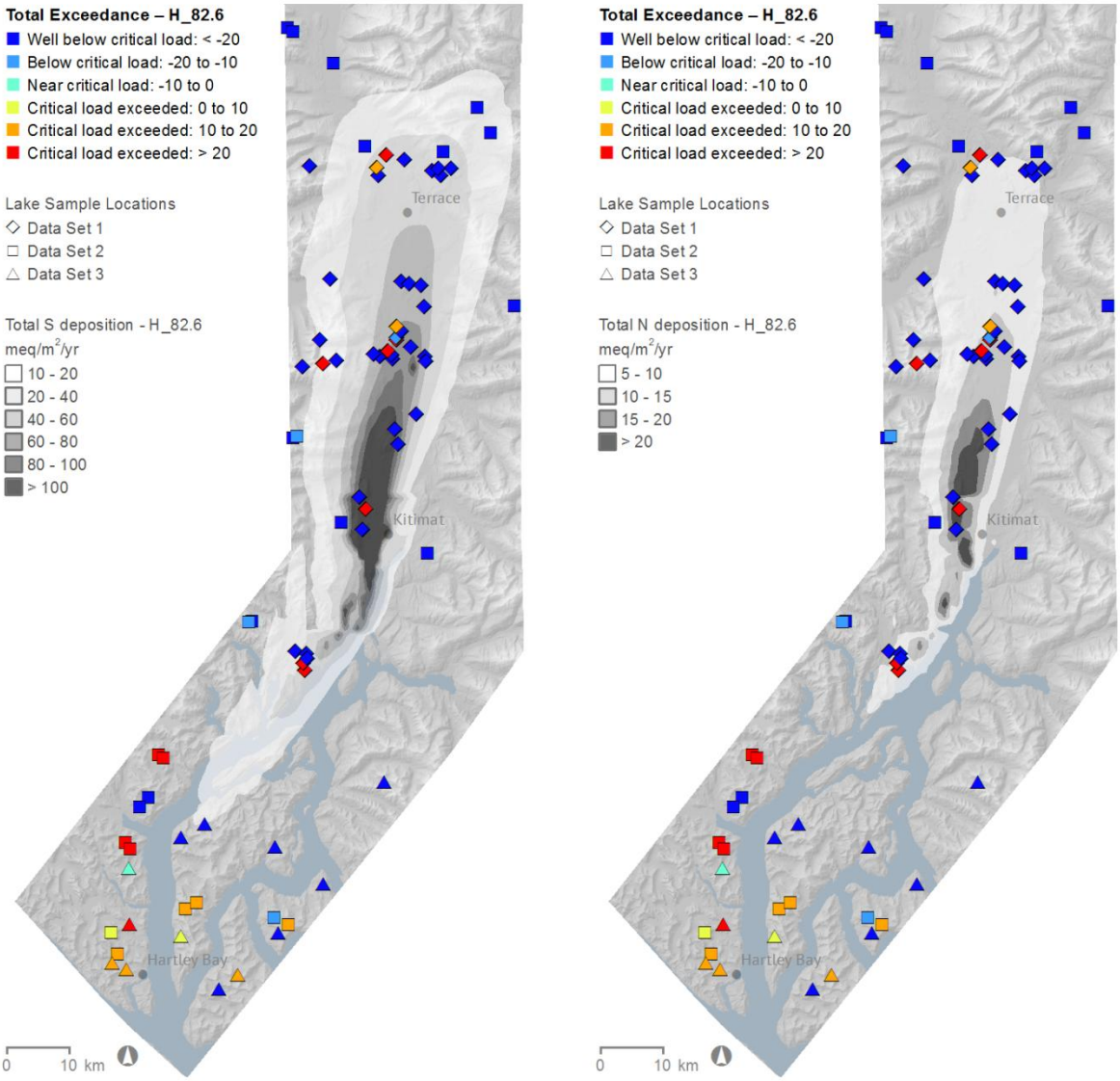


Figure 6-17. Spatial distribution of the total exceedance for sampled lakes under Scenario H_82.6, with deposition shown (S deposition in the left panel; N deposition in the right panel). This map shows incremental deposition associated with this emission scenario *without* background deposition; however background levels of S and N deposition *are* considered in the analyses of exceedance for soils and lakes.

Table 6-11. Lakes with exceedances under each scenario. Count and percentage are shown for all lakes as well as the subset of lakes with naturally acidified lakes excluded. Though there is little change in the number and percent of lakes with exceedance across scenarios, there are changes in the magnitude of exceedance, as shown in Table 6-8.

	Emissions Scenario											
Exceedances	A_ 28.2	B_ 51.8	C_ 57.5	D_ 61.8	E_ 66.1	F_ 72.6	G_ 76.2	H_ 82.6	Im_ 83.3	Is_ 83.3	Jm_ 86.1	Js_ 86.1
All lakes												
Total #	21	22	22	22	23	23	23	23	23	23	23	23
Total %	26%	28%	28%	28%	29%	29%	29%	29%	29%	29%	29%	29%
Excluding naturally acidified lakes												
Total #	5	6	6	6	7	7	7	7	7	7	7	7
Total %	6%	8%	8%	8%	9%	9%	9%	9%	9%	9%	9%	9%

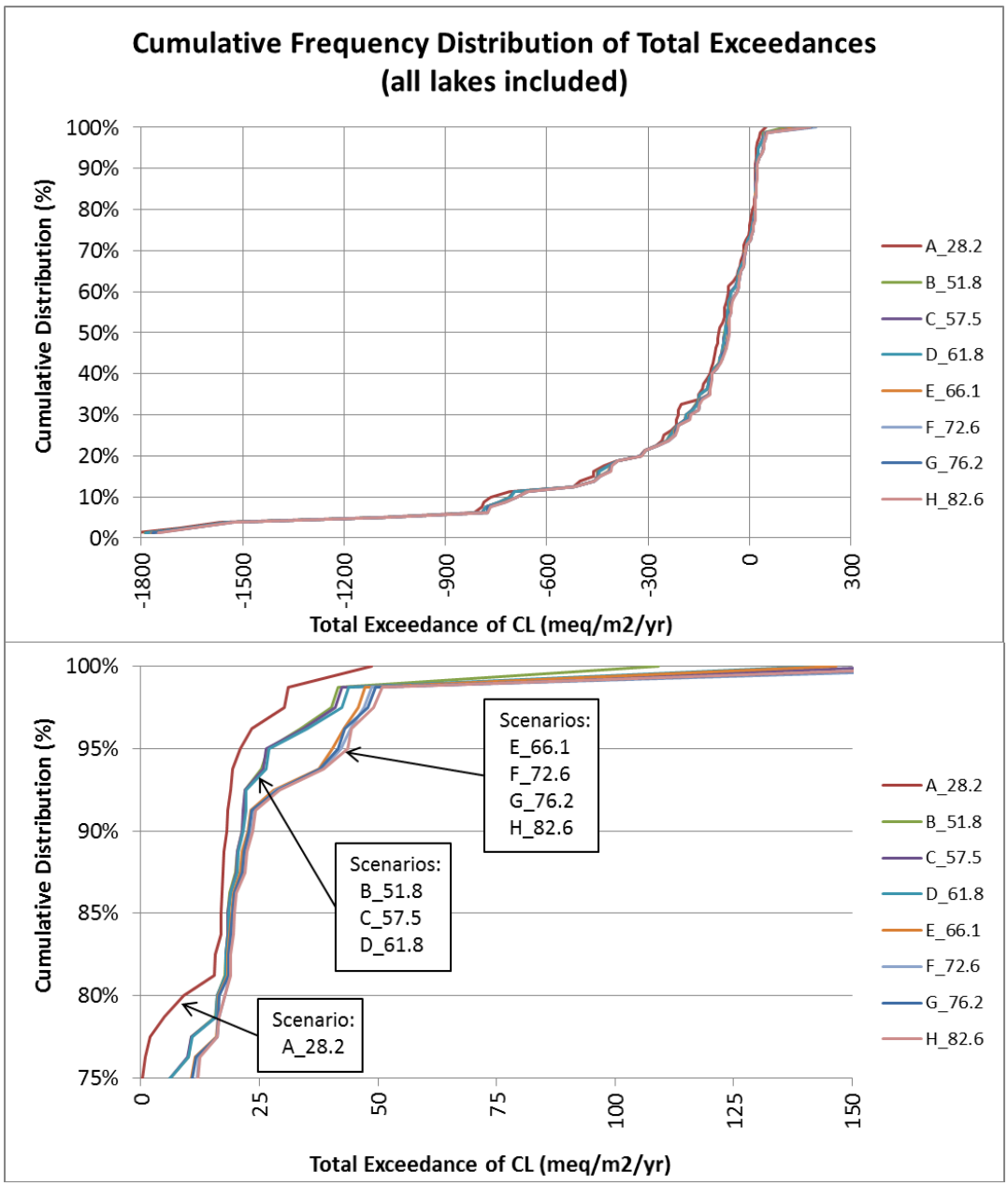


Figure 6-18. Cumulative frequency distributions of total exceedances to compare the effects of the eight emission scenarios on all sampled lakes. The top panel shows the full range of values for total exceedance (i.e., Ex = ΔN + ΔS in Figure 6-4), although it is not possible to distinguish the eight scenarios at this scale. The bottom panel only shows the portion of the top graph where total exceedance >0. For example, Scenario A_28.2 has zero exceedance of CLs in 75% of the sampled lakes with exceedances as high as 49 meq/m^2/yr in the remaining 25% of the lakes. The distributions of exceedances reflect differences in the magnitude and distribution of total acidic deposition under the different scenarios.

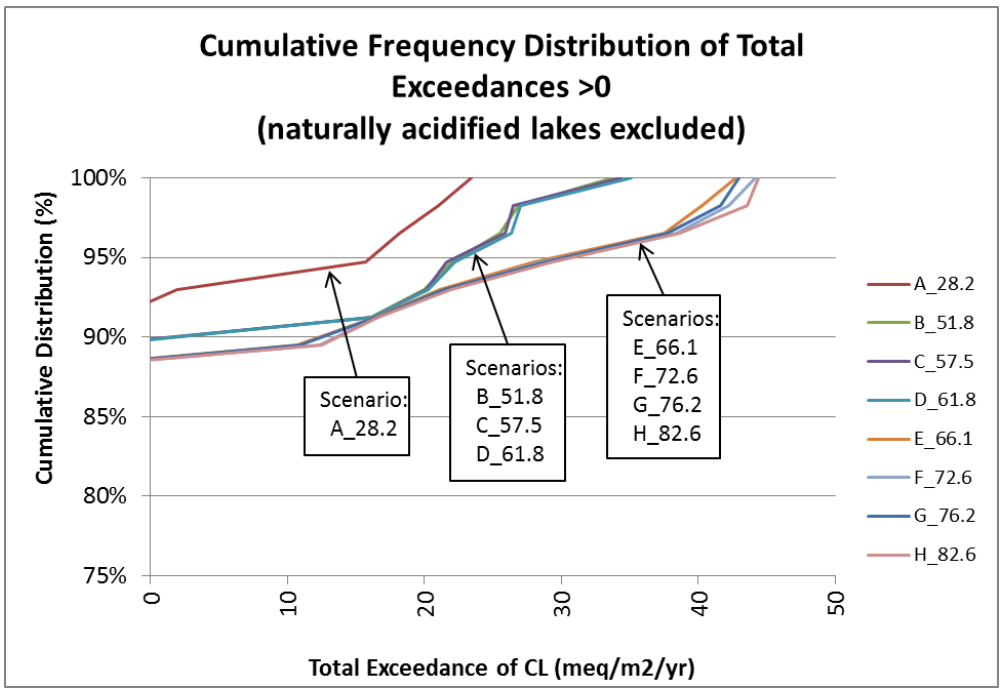


Figure 6-19. Cumulative frequency distributions of total exceedances to compare the effects of the eight emission scenarios on all sampled lakes, **excluding naturally acidified lakes**. The figure only shows the portion of the distribution where total exceedance >0. See Figure 6-18 for further description.

Table 6-12. Relative performance of different emission scenarios across aquatic performance measures.

Performance Measures	Emission Scenarios											
	A_28.2	B_51.8	C_57.5	D_61.8	E_66.1	F_72.6	G_76.2	H_82.6	Im_83.3	Is_83.3	Jm_86.1	Js_86.1
All sampled lakes												
% sampled lakes with CL exceedance	26.3%	27.5%	27.5%	27.5%	28.8%	28.8%	28.8%	28.8%	28.8%	28.8%	28.8%	28.8%
% sampled lake area with CL exceedance	12.7%	12.8%	12.8%	12.8%	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%
Median total exceedance (meq/m2/yr)	-90	-71	-71	-70	-62	-61	-62	-60	-60	-60	-60	-60
Excluding naturally acidified sampled lakes												
% sampled lakes with CL exceedance	6.3%	7.5%	7.5%	7.5%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%
% sampled lake area with CL exceedance	5.9%	6.0%	6.0%	6.0%	6.1%	6.1%	6.1%	6.1%	6.1%	6.1%	6.1%	6.1%
Minimum estimate of percent of lakes / lake area in the study area with CL exceedance												
% study area lakes with CL exceedance	5.6%	5.9%	5.9%	5.9%	6.2%	6.2%	6.2%	6.2%	6.2%	6.2%	6.2%	6.2%
% total area of lakes in the study area with CL exceedance (ha)	6.3%	6.3%	6.3%	6.3%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%
Minimum estimate of percent of lakes / lake area in the study area with CL exceedance excluding naturally acidified lakes												
% study area lakes with CL exceedance	1.3%	1.6%	1.6%	1.6%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%
% total area of lakes in the study area with CL exceedance (ha)	2.9%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%

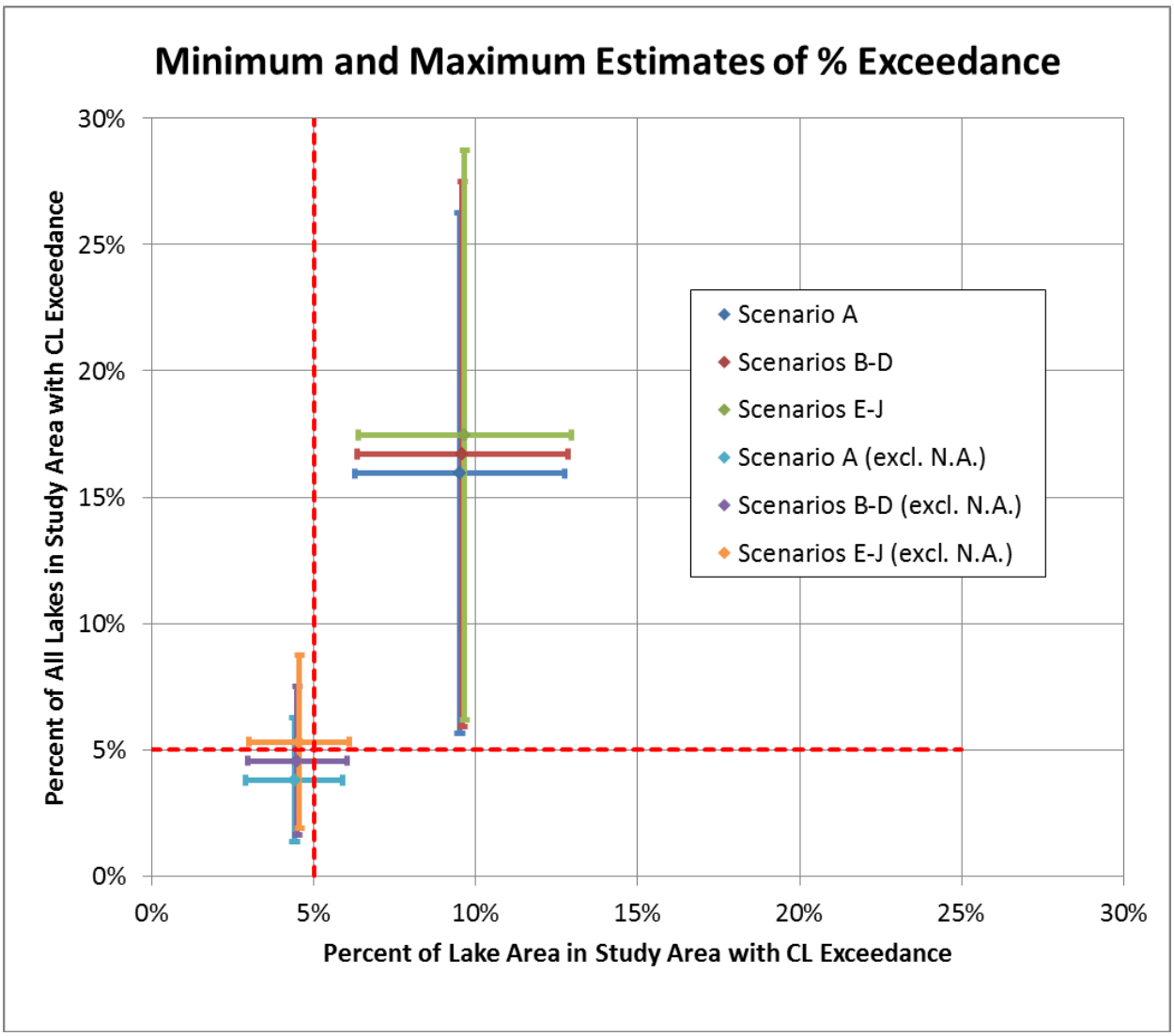


Figure 6-20. Minimum and maximum estimates of the percent of lakes (Y-axis) and lake area (X-axis) with exceedance in the study area. Each scenario or scenario group (where the results are identical) shows the minimum and maximum estimates in both of these dimensions. For example, under Scenario A_28.2 (based on *all* sampled lakes), the minimum estimate of the percent of study area lakes to show exceedance is 5.6% and the maximum estimate is 26.3%. In terms of percent of lake area, the minimum and maximum estimates for Scenario A_28.2 are 6.3% and 12.7%, respectively. Excl. N.A. = excluding naturally acidified lakes. The two red dotted lines indicate 5% thresholds.

6.2.3.3 Relative Contribution of S and N Deposition to Total Exceedance

The relative contributions of S and N deposition to total exceedance are helpful in determining whether it is more important to reduce S or N emissions. As described earlier, for a sampled lake, the total exceedance of the critical load for a given deposition pair (Ndep, Sdep) is calculated by adding the N and S deposition reductions needed to reach the CLF via the shortest path (Ex = ΔS + ΔN). Figure 6-21 and Table 6-13 provide two different ways of looking at exceedances disaggregated into S exceedances and N exceedances. Figure 6-21 shows the exceedances of the sampled lakes under Scenario A_28.2 and Scenario H_82.6 in terms of S exceedance (ΔS) and N exceedance (ΔN) classes. Both scenarios display several common attributes. First, the majority of the sampled lakes are well below their critical loads (i.e., ΔS and ΔN both below -20 µeq/L). Second, the majority of lakes fall along the grey diagonal, indicating that their ΔS and ΔN are within the same class (i.e., 71% for Scenario A_28.2 and 68% for Scenario H_82.6). Third, of those lakes that do not fall along the diagonal, all with positive exceedance show ΔS > ΔN, whereas those with non-exceedance (i.e., <0) show ΔS < ΔN.

The total exceedances for the 23 lakes with positive exceedance under Scenario H_82.6 are broken down into ΔS and ΔN for the two bookend scenarios in Table 6-13. Additionally, Table 6-13 shows ΔS as a proportion of total exceedance. This proportion shows that the contribution of ΔS dominates the contribution of ΔN for the lakes in data set 1, under both scenarios. For lakes in data sets 2 and 3, the contribution of ΔS is either balanced or slightly less than ΔN under Scenario A_28.2, but its proportion of total exceedance increases substantially in Scenario H_82.6. These data confirm the general pattern shown in Figure 6-21, that the lakes with CL exceedances tend to either fall in similar ΔS and ΔN classes or be dominated by ΔS, but there are no cases where total exceedance is dominated by ΔN.

Scenario A_28.2

ΔN Exceedance Class (meq/m2/yr)	ΔS Exceedance Class (meq/m^2/yr): Critical load exceeded: > 20	Critical load exceeded: 10 to 20	Critical load exceeded: 0 to 10	Near critical load: -10 to 0	Below critical load: -20 to -10	Well below critical load: < -20
Critical load exceeded: > 20	-	-	-	-	-	-
Critical load exceeded: 10 to 20	-	-	-	-	-	-
Critical load exceeded: 0 to 10	3	13	5	-	-	-
Near critical load: -10 to 0	-	-	-	2	4	2
Below critical load: -20 to -10	-	-	-	-	1	1
Well below critical load: <-20	-	-	-	-	-	49

Scenario H_82.6

ΔN Exceedance Class (meq/m2/yr)	ΔS Exceedance Class (meq/m^2/yr): Critical load exceeded: > 20	Critical load exceeded: 10 to 20	Critical load exceeded: 0 to 10	Near critical load: -10 to 0	Below critical load: -20 to -10	Well below critical load: < -20
Critical load exceeded: > 20	1	-	-	-	-	-
Critical load exceeded: 10 to 20	2	-	-	-	-	-
Critical load exceeded: 0 to 10	4	13	3	-	-	-
Near critical load: -10 to 0	-	-	-	4	2	1
Below critical load: -20 to -10	-	-	-	-	3	4
Well below critical load: <-20	-	-	-	-	-	43

Figure 6-21. Sampled lakes by ΔS and ΔN exceedance classes, under emission Scenarios A_28.2 (left) and H_82.6 (right). Each cell represents a combination of ΔS and ΔN exceedance classes. The numbers in the cells indicate the count of sampled lakes with that combination of exceedance classes. Shaded grey cells along the diagonal represent situations where ΔS and ΔN exceedances fall in the same class.

Table 6-13. N exceedance (ΔN), S exceedance (ΔS), and total exceedance (Ex(N,S)) under Scenario A_28.2 and Scenario H_82.6. The 23 lakes shown are those that have a positive exceedance under at least one scenario. The last column for each scenario (ΔS / Ex(N,S) indicates the proportional contribution of the S exceedance to the total exceedance.

LakeID	Scenario A_28.2				Scenario H_82.6			
	ΔN	ΔS	Ex(N,S)	ΔS / Ex(N,S)	ΔN	ΔS	Ex(N,S)	ΔS / Ex(N,S)
LAK006	0.1	1.8	1.9	0.9	2.6	41.7	44.4	0.9
LAK022	-1.6	-25.6	-27.2	0.9	0.8	11.7	12.5	0.9
LAK023	-0.2	-2.4	-2.6	0.9	2.9	35.8	38.6	0.9
LAK028	1.4	47.2	48.7	1.0	29.4	149.8	179.2	0.8
LAK042	0.0	0.4	0.4	1.0	0.6	17.1	17.7	1.0
LAK044	6.9	16.6	23.4	0.7	9.8	33.8	43.6	0.8
LAK047	6.4	14.6	21.0	0.7	8.0	21.3	29.3	0.7
LAK054	9.0	22.1	31.1	0.7	12.5	38.3	50.9	0.8
LAK056	8.8	21.4	30.2	0.7	12.2	36.9	49.1	0.8
DCAS04A	6.5	10.8	17.4	0.6	7.1	12.4	19.5	0.6
DCAS04B	0.4	4.7	5.0	0.9	0.5	6.6	7.1	0.9
DCAS05A	3.5	5.6	9.1	0.6	4.6	7.5	12.1	0.6
DCAS05B	5.9	11.1	17.0	0.7	6.5	13.2	19.7	0.7
DCAS07A	6.5	11.7	18.1	0.6	7.3	14.7	21.9	0.7
DCAS07B	6.5	11.8	18.3	0.6	7.4	15.0	22.3	0.7
DCAS08A	7.0	12.0	19.0	0.6	8.0	15.7	23.6	0.7
DCAS08B	7.2	12.2	19.4	0.6	8.2	16.0	24.3	0.7
DCAS11A	5.2	10.2	15.5	0.7	5.4	10.8	16.2	0.7
LARCH	5.4	10.3	15.7	0.7	5.6	11.0	16.6	0.7
LOWER	6.3	10.8	17.0	0.6	6.8	12.2	19.0	0.6
NC178	0.4	0.6	0.9	0.6	1.2	1.8	3.0	0.6
NC180	6.5	11.1	17.6	0.6	7.2	13.0	20.2	0.6
UPPER_LK	6.2	10.8	16.9	0.6	6.7	12.2	18.9	0.6

6.3 Conclusions of the Risk Assessment

Based on the risk assessment criteria identified by the Ministry of Environment described in Section 6.1.2.1, our qualitative rating of risk (bottom row of Table 6-14) is Low for Scenario A_28.2, High for Scenarios B_51.8, C_57.5 and D_61.8; and Critical for all other scenarios.

Acceptability of impacts depends on one's values, and is ultimately a policy decision that will be *informed* by this assessment. The above ratings reflect the policy preferences expressed by the BC Ministry of Environment, and incorporated into the risk assessment criteria.

There is an important qualification to these conclusions (discussed below in Section 6.3.1). Sensitivity analyses in Appendix 24 indicate that if we had used the average deposition over 2006, 2008 and 2009, rather than just deposition year 2008, the risk categories for Scenarios E_66.1 to Js_86.1 would likely have been lowered from Critical to High. This would leave emission Scenario A_28.2 at a Low level of impact, with all other scenarios at a High level of impact. This is a more credible assignment of risk levels, since it is more scientifically defensible to use several years of deposition estimates in steady state acidification models, rather than estimates from just one year.

Table 6-14. Application of risk assessment framework to the 12 emission scenarios using deposition estimates for 2008. As described in the text, the risk categorization for Scenarios E_66.1 to Js_86.1 would likely change from Critical to High if average deposition levels over 2006, 2008 and 2009 were used instead of just 2008.

			Emissions Scenario											
Category	**Exceedance**	**pH Change**	**A_ 28.2**	**B_ 51.8**	**C_ 57.5**	**D_ 61.8**	**E_ 66.1**	**F_ 72.6**	**G_ 76.2**	**H_ 82.6**	**Im_ 83.3**	**Is_ 83.3**	**Jm_ 86.1**	**Js_ 86.1**
1	CL Not Exceeded	Δ pH <0.3	59	57	57	57	57	57	57	56	56	56	56	56
2	CL Exceeded	Δ pH <0.3	21	18	18	18	17	17	17	17	17	17	17	17
3	CL Not Exceeded	Δ pH >0.3	0	1	1	1	0	0	0	1	1	1	1	1
4	CL Exceeded	Δ pH >0.3	0	4	4	4	6	6	6	6	6	6	6	6
Total			80	80	80	80	80	80	80	80	80	80	80	80

Risk Category	**green**	**orange**	**red**

6.3.1 Key Uncertainties in the Risk Assessment for Aquatic Ecosystems

Table 6-15 outlines some of the key assumptions in this assessment and whether they imply overestimating or underestimating the risk of lake acidification. While some assumptions may not bias the assessment in either direction (e.g., runoff, annual allowable cut assumptions), the use of just one deposition year (2008) is likely to cause an overestimate of risk.

Table 6-15. Overview of key assumptions in the assessment and their implications.

Model Assumptions Causing Overestimate of Risk to Lakes	**Model Assumptions Causing Underestimate of Risks to Lakes**
Lake sample from most sensitive bedrock geologies is deliberately biased towards sensitive lakes	
CALPUFF likely to overestimate S and N deposition; S deposition in 2008 was 17% higher than average for 2006, 2008 and 2009 ⇒ overestimates exceedance	
Assumed levels of background S and N deposition from industrial sources outside the study area are applied to all lakes equally; might be higher or lower in some areas	
Assuming entire AAC is logged, overestimates base cations removed in harvest, underestimates CL, overestimates exceedance	Assuming entire AAC is logged, overestimates N removed in harvested trees underestimates N acidification, but assumed N uptake rates are low (minor effect)

Model Assumptions Causing Overestimate of Risk to Lakes	Model Assumptions Causing Underestimate of Risks to Lakes
Runoff may be underestimated for some catchments, leading to an overestimate of acidification risks.	Runoff may be overestimated for some catchments, leading to an underestimate of acidification risks.
Aquatic models use average runoff from 1960-1990. Future runoff is likely to be higher with climate change, diluting acid (Melton et al. 2012).	

Biased Lake Sample. This bias was considered in the development of the risk assessment framework, but nevertheless causes the percent of *sampled* lakes with exceedance to be much greater than the percent of *study area* lakes with exceedance.

Use of 2008 for Deposition. For this scoping study, the meteorological year 2008 was deliberately selected so as to be precautionary (i.e., 2008 had the highest average deposition levels of the 3 years used in the KMP SO_2 Technical Assessment (ESSA et al. 2013)). For steady state models which predict the ultimate consequences of a deposition scenario, it is preferable to use the average estimated deposition over many years. Sensitivity analyses in Appendix 24 show that using just 2008 deposition for the KMP study area in ESSA et al. 2013 leads to greater magnitudes of exceedance and changes in pH than using the average deposition for 2006, 2008 and 2009. Furthermore, Appendix 24 shows that the results from the KMP SO_2 Technical Assessment for lakes in data set 1 are very similar to the results for these lakes from this study under emission Scenario D_61.8. Emission Scenario D_61.8 has similar total levels of S emissions (38.6 t/d) to the 42 t/d that was assessed in the KMP SO_2 Technical Assessment (ESSA et al. 2013). As discussed above, S deposition has a greater influence on total exceedance than N deposition.

We cannot precisely estimate the consequences of using just 2008 for the Kitimat Airshed Emissions Effects Assessment study area without actually running other meteorological years, and there are limitations to the meteorological data for 2006 for the overall study area. However, we can infer from the sensitivity analyses in Appendix 24 that if we had used all three years of deposition data in this study, and then applied MOE risk criteria used in this assessment, the risk categories for Scenarios E_66.1 to Js_86.1 would likely be lowered from Critical to High. This is because two lakes in data set 1 showed a ΔpH >0.3 if we used only deposition year 2008 for the KMP study area, but showed a ΔpH <0.3 when we applied the average deposition over 2006, 2008 and 2009 (as in ESSA et al. 2013). Four of the five lakes with a ΔpH >0.3 under either simulation showed a 0.2 pH unit greater level of pH change when only the 2008 deposition year was used.

Runoff. The primary uncertainties in the model used to predict runoff (Distributed Climate Water Balance Model, or DCWBM) are dominated by errors in the forcing data, monthly temperatures and precipitation values from ClimateWNA. While Moore et al. (2012) did not observe systematic biases in DCWBM runoff prediction outside of forcing data, one limitation in mountainous coastal regions is the monthly timestep used by the DCWBM. This monthly timestep can be too coarse to capture the dynamic changes between rain and snow, particularly in the fall accumulation period, where peak flows due to rain on snow events are possible. These peak flows are not likely to be captured by the DCWBM; however, they are also not likely to be captured in long-term average flow observations from gauging stations.

One other limitation with using the long term mean streamflow in Coastal regions, whether based on stream gauge observations or DCWBM output in Coastal regions, is the significant interannual variability that has been observed. Fleming et al. (2007) observed that it is often an oversimplification to refer to a coastal basin as having a "typical" regime. Coastal watersheds in southern British Columbia were observed to have dramatic changes in the shape of the annual hydrograph dependent on climate modes, such as the Pacific Decadal Oscillation or El Niño Southern Oscillation and on interannual weather variability.

7 SYNTHESIS OF RESULTS

7.1 Overview

Figure 7-1 presents a high-level synthesis of the assessment results according to the four colour-coded risk categories described in Table 7-1. Findings by receptor are summarized on the following pages.

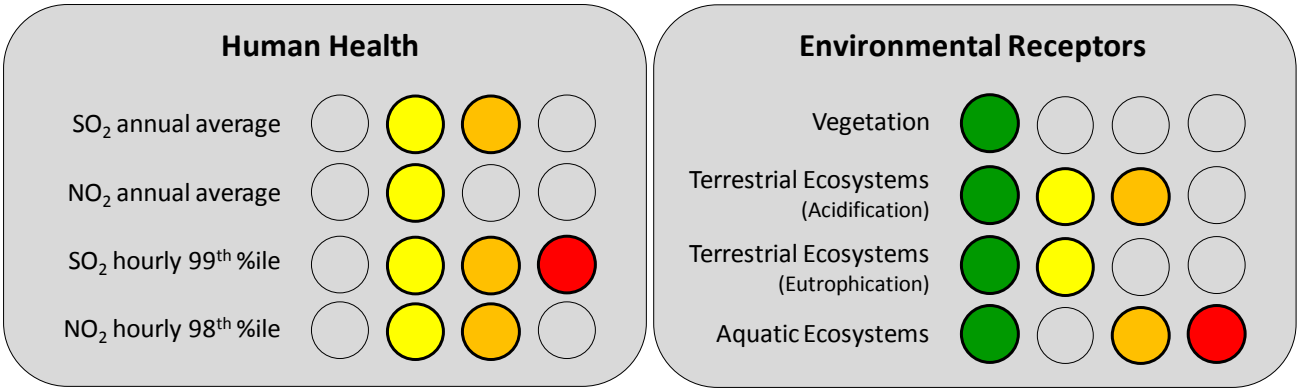


Figure 7-1. Overview of assessment results. Circles are filled in if at least one scenario was in that risk category.

Table 7-1. Description of the meaning of the colour-coded risk categories. Quantitative thresholds between categories are provided in Sections 3, 4, 5 and 6.

For Human Health, which follows a modified version of the CCME air quality categorization scheme:	
	Ambient concentrations associated with "clean" environments
	Modelled concentrations are less than half way between green and red
	Modelled concentrations are more than half way between green and red
	Modelled concentrations are above the US EPA National Ambient Air Quality Standards (or in the case of the annual average for SO_2, from a previous Canadian Air Quality Objective)
For Environmental Receptors (vegetation, terrestrial ecosystems, aquatic ecosystems):	
Low	Scenario expected to have no, or negligible, impact
Moderate	Scenario expected to have an impact, but of a magnitude, frequency, and spatial distribution considered to be acceptable [a]
High	Scenario expected to have an impact of a magnitude, frequency or spatial distribution, considered to be unacceptable [a]; reducing uncertainties and refining assessment inputs may lower the risk category
Critical	Scenario expected to have an impact of a magnitude, frequency or spatial distribution, considered to be extremely unacceptable [a]; reducing uncertainties and refining assessment is unlikely to lower the risk rating sufficiently to be considered acceptable

[a] Acceptability of impacts depends on one's values, and is ultimately a policy decision that will be *informed* by this assessment.

7.2 Human Health

The human health effects assessment was conducted for 10 locations in the study area. For communication purposes, these locations have been grouped and labelled Near and Far. The calculations were conducted in the same way for both groups. These locations are:

- Near: Service Centre, Kitimat, Kitamaat Village
- Far: Gitga'at Old Town, Hartley Bay (Kulkayu), Kitimat-Stikine, Kitselas, Kitsumkaylum, Kshish, Terrace

Table 7-2 presents the human health risk characterization for each scenario. This categorization used a modified version of the CCME air quality categorization scheme, adding hourly and annual thresholds from the US EPA National Ambient Air Quality Standards for SO_2 and NO_2 (and an annual average for SO_2 from a previous Canadian Air Quality Objective) since no Canadian Ambient Air Quality Standards exist yet for these pollutants.

For the human health risk characterization:

- Green = ambient concentrations associated with "clean" environments. (The threshold between Green and Yellow is set at background levels for this study.)
- Yellow = 0–50% of the difference between Green and Red thresholds
- Orange = 50–100% of the difference between the Green and Red thresholds (i.e., the threshold between Yellow and Orange is the half-way point between Green and Red)
- Red = concentrations above the US EPA National Ambient Air Quality Standards (NAAQS)

Annual SO_2 and NO_2 averages: While annual average SO_2 concentration varied greatly among scenarios and locations (from 1.27 µg/m^3 to 15.41 µg/m^3), all locations except the Service Centre were categorized as Yellow for Scenario A_28.2 through to Scenarios Is/Im_83.3. In the Service Centre, the values span the Yellow and Orange category. Annual average NO_2 concentration also fell well within the Yellow category for Scenarios A_28_2 though Is/Im_83.3 and in all 10 locations, with less variation among scenarios and locations than for the annual SO_2 average.

Hourly SO_2 averages: The three Near locations had SO_2 maximum 99th percentile values within the Red category for Scenarios A_28.2 through Is/Im_83.3, with the exception of the Service Centre location in Scenario A_28.2 which was categorized as Orange. All of the seven "Far" locations had maximum 99th percentile values below 100 µg/m^3 for all scenarios, and were therefore categorized as Yellow.

Hourly NO_2 averages: Two different background levels were compared. Using the Quesnel background level, the three Near locations had maximum 98th percentile values categorized as Orange and the Far locations all had maximum 98th percentile values categorized as Yellow for Scenarios A_28.2 through Is/Im_83.3. Using the Kitimat mobile monitoring station background data, all Near and Far areas except Kitimat had maximum 98th percentile values categorized as Yellow. Values for the Kitimat location straddled the threshold from Yellow to Orange, and was consequently categorized as Yellow for Scenarios A_28.2, B_51.8 and E_66.1, and categorized as Orange for all other scenarios. Given that the Kitimat location was the most affected with respect to this metric, the Kitimat background data are the appropriate choice for the purposes of categorization for this study.

The incremental concentrations associated with Scenarios Is_83.3 and Im_83.3 (alternative locations for a gas-fired electrical generating facility with NO_X control) did not provide an appreciable increase in these metrics for either pollutant (or any change in risk category) at any location, relative to Scenario H_82.6.

Caution is needed when interpreting results using a threshold-based categorization of health effects. This is because neither SO_2 nor NO_2 is known to have a threshold below which no health effects occur. Accordingly, there is no specific health consequence or change in state of the health of a population associated with an increase that causes a threshold to be exceeded for any of the listed metrics. All increases in pollutant concentrations are associated with the expectation of some increased risk, and increases that cross a threshold are not distinct from a human health perspective. As a result, the segregation of the modelled concentration results into colour-coded categories represents an arbitrary conversion of a continuous phenomenon into discrete groups. Nonetheless, such schemes are commonplace in health risk assessment, and risk management generally, and can be a useful management tool provided they are not misunderstood to represent a "step-wise" change in the level of public health risk.

Caution is also needed when using the EPA's percentile thresholds to scope comparative impacts of multiple emission sources within an airshed. The 98^{th} (for NO_2) and 99^{th} (for SO_2) percentile values are likely to be dominated by particular occurrences involving a single emission source and a single wind direction or meteorological condition. The extreme percentile values, for example, may not change despite the addition of substantial quantities of pollutants to an airshed from different sources, unless the additional emission sources also generate extreme values.

In order to describe the amount of change in health risk related to asthma symptoms that may be associated with increasing concentrations of SO_2, a relative risk estimation was conducted for the three most affected locations with respect to SO_2 (the Near locations: Service Centre, Kitimat, Kitamaat Village). This helps to understand the change in SO_2-related respiratory responses to be expected from one scenario to the next. Scenarios B_51.8, C_57.5, and D_61.8 generated an increase of approximately 40% compared to Scenario A_28.2, while Scenarios E_66.1 through Is/Im_83.3 generated an increase of approximately 70% as compared to Scenario A_28.2. However, these increases need to be understood in the broader context of all causes of respiratory responses among the affected populations. Assuming that affected individuals (those with chronic respiratory conditions) will experience respiratory symptoms at least once per week, on average, relative to all causes of respiratory responses the increase from modelled scenarios ranged from 0.5% in the Kitimat and Kitamaat Village locations to 2% in the Service Centre location.

For NO_2, under the assumption of a linear dose-response curve, the change in the annual average NO_2 concentration (relative to background) is used as a surrogate for relative health risk estimates. The relative change in annual average is approximately 25% when considering the higher Quesnel-based background, and an increase of approximately 85% when considering the much lower Kitimat mobile monitoring background estimate. The NO_2 annual averages fall into the Yellow category in all locations under the Kitimat monitoring background assumption.

Table 7-2. Summary of risk ratings for human health across emission Scenarios A_28.2 through Is_83.3. Some cells contain smaller rounded squares, which represent the rating for the Service Centre location.

Metric	Scenario								
	A_ 28.2	B_ 51.8	C_ 57.5	D_ 61.8	E_ 66.1	F_ 72.6	G_ 76.2	H_ 82.6	Is/Im_ 83.3[a]
SO_2 Annual Average, all locations [b]									
NO_2 Annual Average, all locations									
SO_2 Hourly 99th %ile (1 year), all 3 Near locations [c]									
SO_2 Hourly 99th %ile (1 year), all 7 Far locations									
NO_2 Hourly 98th %ile (1 yr), Quesnel background, all 3 Near locations									
NO_2 Hourly 98th %ile (1 yr), Quesnel background, all 7 Far locations									
NO_2 Hourly 98th %ile (1 yr), Kitimat background, Kitimat location only									
NO_2 Hourly 98th %ile (1 yr), Kitimat background, all other (9) locations									

[a] Scenarios Is_83.3 and Im_83.3 represent the addition to Scenario H_82.6 of two alternative locations for a gas-fired electrical generating facility, both having NO_X control.
[b] For Scenarios E_66.1 through Is/Im_83.3, the Service Centre location is slightly above the Yellow threshold and that location would be characterized as Orange.
[c] For Scenario A_28.2, the Service Centre location is slightly below the Red threshold and that location would be characterized as Orange.

7.3 Environmental Receptors

Table 7-3 presents the risk characterization results for the environmental receptors for each scenario. The quantitative metrics and thresholds for each of these risk categories are specific to each of the environmental receptors (vegetation, soils and lakes), and are presented in Sections 4, 5 and 6.

Table 7-3. Summary of risk ratings for environmental receptors across all 12 emission scenarios. As explained in Section 6.3, the aquatic ecosystem risk ratings for Scenarios E_66.1 to Js/Jm_86.1 would likely change from Critical to High if average deposition levels over 2006, 2008 and 2009 were used instead of only 2008.

Receptor	Scenario [a]											
	A_ 28.2	B_ 51.8	C_ 57.5	D_ 61.8	E_ 66.1	F_ 72.6	G_ 76.2	H_ 82.6	Is_ 83.3	Im_ 83.3	Js__ 86.1	Jm_ 86.1
VEGETATION												
SO_2												
NO_2												
TERRESTRIAL ECOSYSTEMS												
Acidification, using Bc:Al [b]												
Acidification, using Ca:Al = 1.0												
Eutrophication												
AQUATIC ECOSYSTEMS												
Acidification												

[a] Scenarios Is_83.3, Im_83.3, Js_86.1 and Jm_86.1 represent the addition to Scenario H_82.6 of two alternative locations, and two different treatment levels (with and without NO_X control), for a gas-fired electrical generating facility.
[b] Bc:Al =1 .0 (except 6.0 in deciduous/mixed forest)

7.3.1 Vegetation

SO_2 exposures: There were few exceedances of threshold metrics for SO_2 during the year, including during the growing season. The BC Pollution Control Objective 3-hour upper-level threshold (the US EPA Standard is approximately twice as high) was rarely exceeded in the highest emission scenarios (E_66.1 through Js/Jm_86.1) and the 3-hour lower-level threshold was rarely exceeded during the growing season. In Scenario A_28.2 there were only a few scattered exceedances of the metrics near the industrial area. These exceedances are well below the concentrations thought to cause direct effects on sensitive plant species. Under Scenario H_82.6, exceedances are primarily confined to a residential area of Kitimat, with scattered exceedances occurring elsewhere in the valley, primarily against the valley wall to the west.

NO_2 exposures: Among the threshold metrics for NO_2, only one was exceeded (maximum acceptable 1-hour level) and in only one scenario: Jm_86.1. However, NO_2 exposures even under this scenario are well below those reported in the literature to cause visible injury to sensitive plant species.

None of the 12 scenarios are likely to result in widespread or severe effects on vegetation, based on the response of plants reported in the literature, and are all categorized as Low risk. Depending on the temporal distribution of exposures, visible injury (unsightly appearance, similar to the sort of visual effect caused by insects or disease) on the most sensitive plants might be observed in some residential areas of Kitimat, although effects on growth, yield, or the quality of produce are not expected.

Under the worst case, lichen diversity and abundance will continue to be of concern in the area west of Minette Bay, about 15 km north and south of Kitimat. Until more information is available on the current status of lichens in the area, we cannot estimate the likelihood of future changes in their status.

7.3.2 Terrestrial Ecosystems (Soils)

The risk categorization for soils (for acidification as well as eutrophication) was based on the percentage of area exceeded in the *effects domain*. The effects domain is defined as the locations predicted to receive 15 meq/m^2/yr or more of sulphur and nitrogen deposition from the emissions as modelled in Scenario H_82.6 (1,388 km^2).

Critical Loads of Acidity: The acidification assessment was conducted for forested ecosystems on mineral soils. The area exceeded under all of the emissions scenarios was relatively small, ranging from 0.56 km^2 for Scenario A_28.2 (0.4% of the effects domain) to 27.9 km^2 for Scenario Jm_86.1 (2.1 % of the effects domain). Based on these exceedance values the risk categorization for Scenario A_28.2 was considered to be Low, and the risk under the rest of the scenarios were considered to be Moderate. However the results are sensitive to which chemical criterion is chosen to link atmospheric deposition to acidification impacts. Using a Ca:Al ratio = 1.0 would change the risk rating from Moderate to High for Scenarios E_66.1 through Jm_86.1.

Adding the incremental increase in emissions from a gas-fired electrical generating facility (with, or without, NO_X control) to Scenario A_28.2 does not change the risk rating. In both cases the area exceeded remains in the Low risk category.

Even though a relatively small area was predicted to be exceeded, the average amount exceedance was high: approximately 50 meq/m^2/yr, for all emissions scenarios. This means that a small area of forested ecosystems on mineral soil is predicted to receive acidic deposition greatly in excess of their critical load. The exceeded area is located north of the main sulphur emissions sources in the Kitimat Valley. Under all emissions scenarios, sulphur exceedance was greater than nitrogen exceedance. For this reason, the majority of the exceeded locations will require sulphur reductions to achieve non-exceedance.

Critical Loads of Nutrient Nitrogen: The eutrophication assessment was conducted for all semi-natural terrestrial habitats (i.e., more of the effects domain than assessed for acidification). Several methods were applied, and the risk ratings were based on the method that generated the largest exceedances (and was therefore precautionary). Small exceedances (less than 1 km^2, only 0.04% of the effects domain) were predicted under emissions Scenarios A_28.2, B_51.8, E_66.1 and F_72.6, and were categorized as Low risk. The exceeded area for the remaining scenarios ranged from 2.07 km^2 for Scenario C_57.5, to 15.97 km^2 for Scenario H_82.6, and 31.14 km^2 (2.24% of the effects domain) for Scenario Jm_86.1, and were rated as Moderate. Although several ecosystem types were included in the assessment, the majority of the exceeded area was forested.

Adding the incremental increase in emissions from a gas-fired electrical generating facility (with or without NO_X control) to Scenarios A_28.2, B_51.8, or E_66.1 does not change the Low risk rating – except at the Minette location if there is no NO_X control, in which case the area exceeded would be in the Moderate risk category. However, adding the incremental emissions from a generating facility (with or without NO_X control) to Scenario F_72.6 *does* change the Low risk rating to Moderate – *except* at the Skeena location with NO_X control .

Despite the significance of nitrogen emissions under many of the scenarios, very little nitrogen deposition was predicted across the study area (e.g., while NO_x emissions are 50% of the SO_2 emissions under Scenario H_82.6, maximum nitrogen deposition for that scenario is less than 10% of maximum sulphur deposition). This means that estimates of exceedance are dominated, and driven, by sulphur deposition, and suggests that primarily sulphur reductions would be required to shift predicted exceedance to non-exceedance.

7.3.3 Aquatic Ecosystems (Lakes)

This assessment was based on 80 of the 373 lakes in the study area. The results are precautionary because these 80 lakes were biased towards acid sensitivity and areas with higher acidic deposition.

Of these 80 lakes, the assessment results show critical load exceedances for at least 21 of them under all modelled scenarios. Exceedances of critical loads and predicted decreases in pH are highest for lakes north of Kitimat, and much lower in the most southern part of the study area. Based on the number of lakes exceeded and the magnitude of exceedance, the risk for Scenario A_28.2 is categorized as Low, for Scenarios B_51.8, C_57.5 and D_61.8 is High, and for the rest of the scenarios is Critical. The risk categorization ignored any differences in perceived value or importance among these lakes. It also did not exclude the 23 lakes that were estimated to be naturally acidic, since naturally acidic lakes can still lose biological diversity if they experience significant declines in pH. As explained in Section 6.3, the risk categorization for Scenarios E_66.1 through Js/Jm_86.1 would likely change from Critical to High if average deposition levels over 2006, 2008 and 2009 were used instead of just 2008.

Based on a comparison of exceedances and change in pH values under Scenarios Is_83.3, Im_83.3, Js_86.1, and Jm_86.1 with Scenario H_82.6, adding a gas-fired electrical generating facility (with or without NO_X control) to Scenario A_28.2 would not alter its rating of Low risk.

The risk categories were set by the BC Ministry of Environment based on the following rationale. First, the threshold between the High and Critical risk categories is sufficient to protect 94% of the sampled lakes (i.e., 75 of 80 lakes). Given that the lake sampling was intentionally biased toward sensitive lakes, this represents significantly more than 95% protection of all lakes in the study area. Second, the situation in BC is considerably different from that in eastern Canada and Europe where policy is directed at restoring acidified landscapes to 95% protection. A precautionary approach is appropriate to avoid the necessity of restoration efforts. Third, the threshold between the Moderate and High categories (three lakes) is half of the High-Critical threshold (six lakes), consistent with the approach used to determine risk thresholds for human health and soils.

7.4 Observations across Results

Table 7-4 shows the results by colour code for all of the receptors across all of the scenarios, to reveal patterns and facilitate comparisons that might assist decision-makers. There appear to be more horizontal patterns than vertical ones, meaning that there are more differences in risk categories between metrics, methods or receptors than differences between scenarios. Only Scenario A_28.2 appears clearly “best” for the environmental receptors as it is the only scenario for which the risk rating for all environmental receptors is Low. There appears to be no clear “best” scenario for human health across the health metrics. None of the scenarios receive a Green rating for health metrics because of how the colour codes were defined for health. Under the CCME scheme, any addition of SO_2 or NO_X

above background levels would result in a Yellow categorization, so for the health assessment Yellow is the "best" rating for the modelled scenarios. There is no clear "worst" scenario for either health or the environmental receptors. From Scenario G_76.2 through to the highest scenarios assessed (Is/Jm_83.3 for health; Js/Jm_86.1 for environmental receptors), the risk category for each receptor remains constant.

For terrestrial and aquatic ecosystems, most of the risk rating changes occur between Scenarios A_28.2 and B_51.8, and between Scenarios D_61.8 and E_66.1. This corresponds with where very noticeable increases (or 'steps') in exceedances of critical loads occur for acidification of forest soils (Table 5-7) and lakes (Table 6-8), as well as the most noticeable steps in pH change in lakes (Table 6-9). Sulphur deposition forms a much larger fraction of total exceedance (and acidification impacts) than nitrogen deposition (Figure 5-8 and Table 6-13).

For human health metrics, noticeable steps in SO_2 annual average (Figure 3-21), SO_2 hourly 99^{th} percentile (Figure 3-23), and increase in SO_2-related respiratory response (Figure 3-26 and Figure 3-27) are also apparent between Scenarios A_28.2 and B_51.8, and between Scenarios D_61.8 and E_66.1. Some of these steps are reflected in colour category changes at the Service Centre location. The only colour category change in health metrics for NO_2 occurs at the Kitimat location, as a result of selecting a lower background level.

No noticeable steps in assessment metrics, or changes in colour codes, occur between Scenario H_82.6 and either Scenarios Is/Im_83.3 (for any receptors) or Scenarios Js/Jm_86.1 (for environmental receptors, as the Js/Jm scenarios were not assessed for health). This indicates that the incremental addition of emissions from an electrical generating facility (with or without NO_X control) doesn't affect the results of Scenario H_82.6, regardless of whether the facility is sited at the Skeena Substation or the Minette Substation. Results reported in Section 7.2 indicate that for terrestrial acidification, the incremental effect of the electrical generating facility emissions on Scenario A_28.2 remains small, and does not affect the Low risk rating of that scenario. The eutrophication results indicated that either NO_X control or the Skeena site (or both) would keep the four Low risk scenarios from changing to Moderate. The incremental effect of the generating facility emissions on lakes is negligible.

It is important to remember that this was a rapid scoping-level assessment. While the report includes several sensitivity studies to determine the implications of some of the choices regarding modelling and assessment methods and inputs, further investigations into the uncertainties described in the previous sections may be helpful in reaching decisions among particular scenarios. Our layered approach to the air dispersion and deposition modelling also facilitates future investigation into scenarios with emission combinations beyond those assessed in this study.

Table 7-4. Risk colour-code ratings across all receptors and scenarios – bearing in mind that meaning of the colours differs between human health and the environmental receptors. As explained in Section 6.3, the aquatic ecosystems risk categorization for Scenarios E_66.1 to Js/Jm_86.1 would likely change from Critical to High if average deposition levels over 2006, 2008 and 2009 were used instead of only 2008.

	Scenario [a]											
	A_ 28.2	B_ 51.8	C_ 57.5	D_ 61.8	E_ 66.1	F_ 72.6	G_ 76.2	H_ 82.6	Is_ 83.3	Im_ 83.3	Js__ 86.1	Jm_ 86.1
HUMAN HEALTH												
SO_2 annual average, all locations [b]												
NO_2 annual average, all locations												
SO_2 hourly 99th %ile, Near locations [c]												
SO_2 Hourly 99th %ile, Far locations												
NO_2 Hourly 98th %ile, Quesnel background, Near locations												
NO_2 Hourly 98th %ile, Quesnel background, Far locations												
NO_2 Hourly 98th %ile, Kitimat background, Kitimat location												
NO_2 Hourly 98th %ile, Kitimat background, all other locations												
ENVIRONMENTAL RECEPTORS												
Vegetation (SO_2, NO_2)												
Terrestrial ecosystem acidification using Bc:Al												
Terrestrial ecosystem acidification using Ca:Al												
Terrestrial ecosystem eutrophication												
Aquatic ecosystem acidification												

[a] Scenarios Is_83.3, Im_83.3, Js_86.1 and Jm_86.1 represent the addition to Scenario H_82.6 of two alternative locations, and two different treatment levels (with and without NO_X control), for a gas-fired electrical generating facility. Time constraints prevented inclusion of Scenarios Js_86.1 and Jm_86.1 in the health assessment.

[b] For Scenarios E_66.1 through Is_83.3, the Service Centre location is slightly above the Yellow threshold and that location would be characterized as Orange.

[c] For Scenario A_28.2, the Service Centre location is slightly below the Red threshold and that location would be characterized as Orange.

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APPENDIX 1: LARGER SET OF SCENARIOS OF INTEREST TO MOE

The BC Ministry of Environment (MOE) was interested a larger suite of scenarios involving more combinations of facility characteristics, and these are listed below. The eight scenarios chosen for this assessment are indicated in bold and pale grey shading. Emission numbers are estimates based on information available for this study. Actual modelled emissions for scenarios used in this study have been revised somewhat to represent newer data from the proponent or more refined emission estimates.

Scenario Label	#	Smelter	SO_2 t/d	NO_x t/d	LNG	SO_2 t/d	NO_x t/d	Refinery	SO_2 t/d	NO_x t/d	Shipping	SO_2 t/d	NO_x t/d	Total SO_2 t/d	Total NO_x t/d	Total SO_2+NO_x t/d
A_28.2	**1**	**Full Treatment**	**4.2**	**0.86**	**All Electric Drive**	**9.5**	**2.7**	**Off**			**Smelter +LNG**	**0.08**	**1.7**	**13.8**	**5.3**	19.1
	2	Full Treatment	4.2	0.86	Mixed 60/40-NO_X treatment	10.6	3.8	Off			Smelter +LNG	0.08	1.7	14.9	6.4	21.3
	3	Full Treatment	4.2	0.86	Mixed 80/20-NO_X treatment	10.9	4.2	Off			Smelter +LNG	0.08	1.7	15.2	6.8	22.0
	4	Full Treatment	4.2	0.86	Base Case- NO_X treatment	11.2	4.4	Off			Smelter +LNG	0.08	1.7	15.4	7.0	22.4
	9	Full Treatment	4.2	0.86	Mixed 60/40-NO_X treatment	10.6	3.8	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	17.5	8.2	25.7
	10	Full Treatment	4.2	0.86	Mixed 80/20-NO_X treatment	10.9	4.2	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	17.8	8.6	26.4
	11	Full Treatment	4.2	0.86	Base Case-NO_X treatment	11.2	4.4	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	18.1	8.7	26.8
	5	Full Treatment	4.2	0.86	Mixed 60/40	10.6	10.7	Off			Smelter +LNG	0.08	1.7	14.9	13.2	28.1
	6	Full Treatment	4.2	0.86	Mixed 80/20	10.9	13.3	Off			Smelter +LNG	0.08	1.7	15.2	15.9	31.1
	7	Full Treatment	4.2	0.86	Base Case	11.2	14.5	Off			Smelter +LNG	0.08	1.7	15.4	17.1	32.5
	12	Full Treatment	4.2	0.86	Mixed 60/40	10.6	10.7	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	17.5	15.0	32.5
	13	Full Treatment	4.2	0.86	Mixed 80/20	10.9	13.3	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	17.8	17.7	35.5
	14	Full Treatment	4.2	0.86	Base Case	11.2	14.5	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	18.1	18.8	36.9
	16	Partial Treatment	27.3	0.86	Mixed 60/40-NO_X treatment	10.6	3.8	Off			Smelter +LNG	0.08	1.7	38.0	6.4	44.4
	17	Partial Treatment	27.3	0.86	Mixed 80/20-NO_X treatment	10.9	4.2	Off			Smelter +LNG	0.08	1.7	38.3	6.8	45.1
B_51.8	**18**	**Partial Treatment**	**27.3**	**0.86**	**Base Case-NO_X treatment**	**11.2**	**4.4**	**Off**			**Smelter +LNG**	**0.08**	**1.7**	**38.5**	**7.0**	45.5
	22	Partial Treatment	27.3	0.86	Mixed 60/40-NO_X treatment	10.6	3.8	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	40.6	8.2	48.8
	23	Partial Treatment	27.3	0.86	Mixed 80/20-NO_X treatment	10.9	4.2	On	2.6	1.2	Smelter + LNG+	0.10	2.3	40.9	8.6	49.5

Scenario Label	#	Smelter	SO_2 t/d	NO_x t/d	LNG	SO_2 t/d	NO_x t/d	Refinery	SO_2 t/d	NO_x t/d	Shipping	SO_2 t/d	NO_x t/d	Total SO_2 t/d	Total NO_x t/d	Total SO_2+NO_x t/d
											Refinery					
	24	Partial Treatment	27.3	0.86	Base Case- NO_X treatment	11.2	4.4	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	41.2	8.7	49.9
C_57.5	**19**	**Partial Treatment**	**27.3**	**0.86**	**Mixed 60/40**	**10.6**	**10.7**	**Off**			**Smelter +LNG**	**0.08**	**1.7**	**38.0**	**13.2**	51.2
	20	Partial Treatment	27.3	0.86	Mixed 80/20	10.9	13.3	Off			Smelter +LNG	0.08	1.7	38.3	15.9	54.2
D_61.8	**21**	**Partial Treatment**	**27.3**	**0.86**	**Base Case**	**11.2**	**14.5**	**Off**			**Smelter +LNG**	**0.08**	**1.7**	**38.5**	**17.1**	55.6
	25	Partial Treatment	27.3	0.86	Mixed 60/40	10.6	10.7	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	40.6	15.0	55.6
	26	Partial Treatment	27.3	0.86	Mixed 80/20	10.9	13.3	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	40.9	17.7	58.6
	27	Partial Treatment	27.3	0.86	Base Case	11.2	14.5	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	41.2	18.8	60.0
	28	Base Case	42.0	0.86	Mixed 60/40-NO_X treatment	10.6	3.8	Off			Smelte r+LNG	0.08	1.7	52.7	6.4	59.1
	31	Base Case	42.0	0.86	Mixed 60/40	10.6	10.7	Off			Smelter +LNG	0.08	1.7	52.7	13.2	65.9
	29	Base Case	42.0	0.86	Mixed 80/20-NO_X treatment	10.9	4.2	Off			Smelter +LNG	0.08	1.7	53.0	6.8	59.8
	32	Base Case	42.0	0.86	Mixed 80/20	10.9	13.3	Off			Smelter +LNG	0.08	1.7	53.0	15.9	68.9
E_66.1	**30**	**Base Case**	**42.0**	**0.86**	**Base Case-NO_X treatment**	**11.2**	**4.4**	**Off**			**Smelter +LNG**	**0.08**	**1.7**	**53.2**	**7.0**	**60.2**
G_76.2	**33**	**Base Case**	**42.0**	**0.86**	**Base Case**	**11.2**	**14.5**	**Off**			**Smelter +LNG**	**0.08**	**1.7**	**53.2**	**17.1**	**70.3**
	34	Base Case	42.0	0.86	Mixed 60/40-NO_X treatment	10.6	3.8	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	55.3	8.2	63.5
	37	Base Case	42.0	0.86	Mixed 60/40	10.6	10.7	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	55.3	15.0	70.3
	35	Base Case	42.0	0.86	Mixed 80/20-NO_X treatment	10.9	4.2	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	55.6	8.6	64.2
	38	Base Case	42.0	0.86	Mixed 80/20	10.9	13.3	On	2.6	1.2	Smelter + LNG+ Refinery	0.10	2.3	55.6	17.7	73.3
F_72.6	**36**	**Base Case**	**42.0**	**0.86**	**Base Case-NO_X treatment**	**11.2**	**4.4**	**On**	**2.6**	**1.2**	**Smelter + LNG+ Refinery**	**0.10**	**2.3**	**55.9**	**8.7**	64.6
H_82.6	**39**	**Base Case**	**42.0**	**0.86**	**Base Case**	**11.2**	**14.5**	**On**	**2.6**	**1.2**	**Smelter + LNG+ Refinery**	**0.10**	**2.3**	**55.9**	**18.8**	74.7

APPENDIX 2: INDIVIDUAL RECEPTORS

Table A2-1: Individual Receptors for Lakes.

Lake Site ID	Lake Name	UTM NAD 27 [a] Easting (km)	Northing (km)
DCAS17A	Robinson Lake	529.252	5986.160
MOE3	N/A	515.325	5991.167
LAK028	N/A	519.235	5993.224
LAK030	N/A	518.760	5989.951
DCAS01A	N/A	506.677	6070.612
DCAS01B	N/A	507.608	6069.962
DCAS02C	N/A	531.677	6050.628
DCAS03A	N/A	537.222	6057.821
DCAS03B	N/A	539.389	6053.730
DCAS04A	N/A	479.380	5921.754
DCAS04B	N/A	478.355	5925.182
DCAS05A	N/A	490.281	5928.966
DCAS05B	N/A	492.091	5930.073
DCAS06A	N/A	484.315	5946.946
DCAS06C	N/A	482.950	5945.445
DCAS07A	N/A	486.073	5953.802
DCAS07B	N/A	486.802	5953.253
DCAS08A	N/A	480.747	5939.709
DCAS08B	N/A	481.489	5938.639
DCAS09A	N/A	500.959	5975.201
DCAS09B	N/A	500.477	5975.176
DCAS10A	N/A	507.616	6004.715
DCAS10B	N/A	508.279	6005.011
DCAS11A	N/A	506.856	5926.510
DCAS11B	N/A	504.548	5927.614
DCAS12A	Pine Lake	519.112	6051.592
DCAS13A	Kitsumkalum Lake	514.128	6064.876
DCAS14A	Alastair Reference Lake	488.266	5994.696
DCAS15A	Onion Lake	529.722	6018.103
DCAS16A	Williams Creek Reference Lake	543.107	6025.929
LAK001	Hai Lake	524.997	6029.829
LAK002	Herman Lake	526.262	6029.423
LAK003	N/A	523.968	6006.059
LAK004	N/A	521.591	6017.787
LAK005	N/A	523.592	6017.369
LAK006	End Lake	524.251	6020.459
LAK007	Clearwater Lakes	528.866	6017.826
LAK008	N/A	526.468	6019.284
LAK011	N/A	520.593	6018.223
LAK012	N/A	524.241	6020.826
LAK013	N/A	528.125	6029.247
LAK014	Ena Lake	524.970	6021.913
LAK015	N/A	524.485	6003.635
LAK016	N/A	523.443	6018.041
LAK017	N/A	527.447	6008.578
LAK018	Clearwater Lakes	528.973	6017.081
LAK022	N/A	524.280	6022.594
LAK023	West Lake	522.846	6018.648
LAK024	Lakelse Lake	528.691	6025.835
LAK027	Bowbyes Lake	518.328	5995.192
LAK032	N/A	521.331	6046.906
LAK034	N/A	525.481	6049.387
LAK035	N/A	533.025	6047.953
LAK037	N/A	529.900	6047.581
LAK038	N/A	531.371	6046.886
LAK039	N/A	530.995	6048.011
LAK041	N/A	510.269	6048.377
LAK042	N/A	521.006	6048.160
LAK044	N/A	522.637	6050.119
LAK045	N/A	509.159	6016.148
LAK047	N/A	512.375	6016.634
LAK049	N/A	514.577	6017.169
LAK050	N/A	511.866	6020.475
LAK051	N/A	513.522	6030.191
LAK053	Jesse Lake	507.993	5970.356
LAK054	N/A	509.521	5967.349
LAK055	N/A	509.774	5970.059
LAK056	N/A	509.222	5968.547
LAK057	N/A	509.928	5969.312
NC178	N/A	489.540	5924.727
NC171	N/A	495.656	5916.131
LARCH	N/A	498.710	5918.482
LARCH	N/A	498.710	5918.482
NC179	N/A	505.193	5925.267
LOWER	N/A	480.758	5919.309
UPPER LK	N/A	478.588	5920.320
NC180	N/A	481.335	5926.575
CAPONERO	N/A	481.137	5935.647
ARKELLE	N/A	489.527	5940.599
BARDON	N/A	493.328	5942.676
EVELYN	N/A	504.712	5939.067
EVELYN	N/A	504.712	5939.067
NC194	N/A	522.216	5949.414
NC184	N/A	512.418	5933.131

a. All Universal Transverse Mercator (UTM) coordinates are in North American Datum (NAD) 27, Zone 9.

Table A2-2: Individual Receptors for Soils.

Soil Site ID	UTM NAD 27 [a] Easting (km)	Northing (km)
CA004	520.998	5987.986
QM001	523.287	5981.974
QM003	523.258	5981.533
SSS001	523.910	5979.965
SSS002	521.117	5994.473
QM002	523.921	5984.128
QM005	523.323	5983.179
CA001	519.987	5992.768
QD015	526.685	5988.386
DCAS21	514.945	5985.010
DCAS23	525.048	5976.650
DCAS27	523.277	5987.163
DCAS28	519.435	5989.140
CA008	523.409	6031.020
GR001	508.826	6020.548
GR002	520.465	6031.980
GR003	520.979	6032.467
GR005	508.860	6022.034
LM006	522.915	6034.567
LM009	522.390	6035.032
LM010	522.207	6035.034
QD006	526.949	6026.458
QD007	524.518	6014.564
S001	520.042	6048.491
S011	520.408	6049.498
S022	520.468	6049.018
SSS004	527.389	6025.147
SSS005	510.037	6028.066
SSS006	520.888	6048.523
VA012	518.458	6045.497
VC001	522.598	6033.706
VC002	511.436	6032.923
VC005	523.482	6033.513
VC003	523.040	6033.087
S002	516.718	6049.030
GD003	530.034	6021.048
GD009	532.532	6020.069
VA006	518.533	6041.357
LM001	536.991	6041.691
VA001	518.663	6041.935
GD013	532.087	6036.023
GD012	535.590	6010.017
CA011	521.164	6030.045
VA002	518.684	6044.084
S006	519.065	6047.962
QD012	527.370	6025.144
G0026	516.402	6011.661
OG009	508.999	6018.643
G0027	516.389	6011.889
G0008	517.052	6010.482
OG010	508.934	6018.764
SSS003	517.370	5995.517
OG001	509.100	6018.089
G0028	515.933	6011.082
OG003	508.853	6025.117
DCAS01-01	503.636	5917.578
DCAS01-02	501.454	5917.133
DCAS02	497.814	5924.019
DCAS04	481.573	5929.981
DCAS08-01	539.494	6053.789
DCAS08-02	540.574	6059.085
DCAS08-03	520.757	6056.088
DCAS08-04	525.128	6057.395
DCAS09-01	511.468	6068.476
DCAS09-02	511.154	6068.500
DCAS10-01	537.646	6072.135
DCAS10-02	538.326	6073.340
DCAS12	483.213	5919.701
DCAS13	489.131	5915.086
DCAS14	480.743	5916.423
DCAS16	504.848	5936.711
DCAS18	503.022	5944.014
DCAS19-01	487.128	5945.454
DCAS19-02	479.437	5944.709
DCAS20	489.326	5942.618
DCAS24-01	505.958	6072.358
DCAS24-02	508.244	6069.834
DCAS25	528.548	6033.442
DCAS26	526.000	6016.107
DCAS29	521.375	5996.965

a. All Universal Transverse Mercator (UTM) coordinates are in North American Datum (NAD) 27, Zone 9.

APPENDIX 3: MODELLING SOURCE PARAMETERS

This section removed from report to protect proprietary information of proponent/permit holder.

APPENDIX 4: MODELLING QA/QC LOG

Facility	CALPUFF File Names							
	A	D	E	F	30	33	G	H
RTA - Point	RTA_A.*	RTA_D.*	RTA_D.*	RTA_D.*	RTA_H.*	RTA_H.*	RTA_H.*	RTA_H.*
RTA - Line	RTA_POT.*	RTA_POT.*	RTA_POT.*	RTA_POT.*	RTA_POT.*	RTA_POT.*	RTA_POT.*	RTA_POT.*
LNG Canada	LNGC_A.*	LNGC_D.*	LNGC_E.*	LNGC_H.*	LNGC_D.*	LNGC_H.*	LNGC_D.*	LNGC_H.*
Douglas Channel	DCH_A.*	DCH_D.*	DCH_E.*	DCH_H.*	DCH_D.*	DCH_H.*	DCH_D.*	DCH_H.*
Triton	TRTN_A.*	TRTN_D.*	TRTN_E.*	TRTN_H.*	TRTN_D.*	TRTN_H.*	TRTN_D.*	TRTN_H.*
KM LNG	KMLNG_A.*	KMLNG_D.*	KMLNG_E.*	KMLNG_H.*	KMLNG_D.*	KMLNG_H.*	KMLNG_D.*	KMLNG_H.*
Kitimat Clean Refinery	Off	Off	Off	Off	Off	Off	REF_H.*	REF_H.*
Shipping	SHIP_A.*	SHIP_A.*	SHIP_A.*	SHIP_A.*	SHIP_A.*	SHIP_A.*	SHIP_H.*	SHIP_H.*

Facility	Description							
	A	D	E	F	30	33	G	H
RTA - Point	Full Treatment	Partial Treatment	Partial Treatment	Partial Treatment	Base Case	Base Case	Base Case	Base Case
RTA - Line	Base	Base	Base	Base	Base	Base	Base	Base
LNG Canada	All Electric	NOx Treatment	60/40	Base Case	NOx Treatment	Base Case	NOx Treatment	Base Case
Douglas Channel	All Electric	NOx Treatment	60/40	Base Case	NOx Treatment	Base Case	NOx Treatment	Base Case
Triton	All Electric	NOx Treatment	60/40	Base Case	NOx Treatment	Base Case	NOx Treatment	Base Case
KM LNG	All Electric	NOx Treatment	60/40	Base Case	NOx Treatment	Base Case	NOx Treatment	Base Case
Kitimat Clean Refinery	Off	Off	Off	Off	Off	Off	On	On
Shipping	RTA, LNG	RTA, LNG	RTA, LNG	RTA, LNG	RTA, LNG	RTA, LNG	TA, LNG, Refine	RTA, LNG, Refinery

			CALPUFF Input Files					Post-Processing & Results v1.0					Post-Processing & Results v2.0					Post-Processing & Results v3.0					Post-Processing & Results v4.0				
Scenario	New Scenario	Facility	File Name	Set up Status	Modeler	QA Status	QA'er	File/task	Set up Status	Modeler	QA Status	QA'er	File/task	Set up Status	Modeler	QA Status	QA'er	File/task	Set up Status	Modeler	QA Status	QA'er	File/task	Set up Status	Modeler	QA Status	QA'er
A	A	RTA - Point	RTA_A.*	1/23/2014	ACH	1/29/2014	AVJ	CALSUM	1/31/2014	BB	1/31/2014	HC	~~CALSUM~~	NA	NA	NA	NA	~~CALSUM~~	NA	NA	NA	NA					
A	A	RTA - Line	RTA_POT.*	1/23/2014	ACH	1/29/2014	AVJ	CALPOST	1/30/2014	BB	1/30/2014	AH	CALPOST	2/18/2014	BB	2/19/2014	HC	CALPOST	3/5/2014	BB	3/5/2014	HC					
A	A	LNG Canada	LNGC_A.*	1/23/2014	ACH	1/29/2014	AVJ	POSTUtil	1/30/2014	BB	1/30/2014	AH	~~POSTUtil~~	NA	NA	NA	NA	~~POSTUtil~~	NA	NA	NA	NA					
A	A	Douglas Channel	DCH_A.*	1/23/2014	ACH	1/29/2014	AVJ	Append	1/31/2014	BB	1/31/2014	HC	~~Append~~	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA					
A	A	Triton	TRTN_A.*	1/23/2014	ACH	1/29/2014	AVJ	Veg Results_A_2014-0124	1/31/2014	BB	1/31/2014	HC	Veg Results_A_2014-0124	2/18/2014	BB	2/19/2014	HC	ResTSeries(Far update)	3/6/2014	BB	3/7/2014	HC					
A	A	KM LNG	KMLNG_A.*	1/23/2014	ACH	1/29/2014	AVJ	Total Deposition_A_2014-0	1/31/2014	BB	1/31/2014	AH	(updated receptors and format)					Veg Results_A_2014-0124	3/5/2014	BB	3/5/2014	HC					
A	A	Kitimat Clean Refinery	Off	NA	NA	NA	NA						ResTSeries(Near update)	1/30/2014	BB	1/31/2014	AH	(GS update)									
A	A	Shipping	SHIP_A.*	1/23/2014	ACH	1/29/2014	AVJ																				
D	B	RTA - Point	RTA_D.*	2/11/2014	ACH	2/17/2014	BB	CALSUM	2/17/2014	BB	2/18/2014	HC	~~CALSUM~~	NA	NA	NA	NA										
D	B	RTA - Line	RTA_POT.*	NA	NA	NA	NA	CALPOST	2/17/2014	BB	2/18/2014	HC	CALPOST	3/7/2014	BB	3/7/2014	HC										
D	B	LNG Canada	LNGC_D.*	2/11/2014	ACH	2/17/2014	BB	POSTUtil	2/17/2014	BB	2/18/2014	HC	~~POSTUtil~~	NA	NA	NA	NA										
D	B	Douglas Channel	DCH_D.*	2/11/2014	ACH	2/17/2014	BB	~~Append~~	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA										
D	B	Triton	TRTN_D.*	2/11/2014	ACH	2/17/2014	BB	Veg Results_D_2014-0211	2/17/2014	BB	2/18/2014	HC	ResTSeries(Far update)	3/6/2014	BB	3/7/2014	HC										
D	B	KM LNG	KMLNG_D.*	2/11/2014	ACH	2/17/2014	BB	Total Deposition_D_2014-0	2/17/2014	BB	2/18/2014	HC	Veg Results_D_2014-0211	3/6/2014	BB	3/7/2014	SW										
D	B	Kitimat Clean Refinery	Off	NA	NA	NA	NA						(GS update)														
D	B	Shipping	SHIP_A.*	NA	NA	NA	NA																				
E	C	RTA - Point	RTA_D.*	NA	NA	NA	NA	CALSUM	2/20/2014	BB	2/20/2014	HC	~~CALSUM~~	NA	NA	NA	NA										
E	C	RTA - Line	RTA_POT.*	NA	NA	NA	NA	CALPOST	2/20/2014	BB	2/20/2014	HC	CALPOST	3/7/2014	BB	3/7/2014	HC										
E	C	LNG Canada	LNGC_E.*	2/18/2014	BB	2/18/2014	ACH	POSTUtil	2/20/2014	BB	2/20/2014	HC	~~POSTUtil~~	NA	NA	NA	NA										
E	C	Douglas Channel	DCH_E.*	2/18/2014	BB	2/18/2014	ACH	~~Append~~	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA										
E	C	Triton	TRTN_E.*	2/18/2014	BB	2/18/2014	ACH	Veg Results_E_2014-0218	2/20/2014	BB	2/20/2014	HC	ResTSeries(Far update)	3/6/2014	BB	3/7/2014	HC										
E	C	KM LNG	KMLNG_E.*	2/18/2014	BB	2/18/2014	ACH	Total Deposition_E_2014-02	2/20/2014	BB	2/20/2014	HC	Veg Results_E_2014-0218	3/7/2014	BB	3/7/2014	SW										
E	C	Kitimat Clean Refinery	Off	NA	NA	NA	NA						(GS update)														
E	C	Shipping	SHIP_A.*	NA	NA	NA	NA																				
F	D	RTA - Point	RTA_D.*	NA	NA	NA	NA	CALSUM	2/18/2014	BB	2/19/2014	HC	~~CALSUM~~	NA	NA	NA	NA										
F	D	RTA - Line	RTA_POT.*	NA	NA	NA	NA	CALPOST	2/18/2014	BB	2/19/2014	HC	CALPOST	3/7/2014	BB	3/7/2014	HC										
F	D	LNG Canada	LNGC_H.*	NA	NA	NA	NA	POSTUtil	2/18/2014	BB	2/19/2014	HC	~~POSTUtil~~	NA	NA	NA	NA										
F	D	Douglas Channel	DCH_H.*	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA										
F	D	Triton	TRTN_H.*	NA	NA	NA	NA	Veg Results_F_2014-0218	2/18/2014	BB	2/19/2014	HC	ResTSeries(Far update)	3/6/2014	BB	3/7/2014	HC										
F	D	KM LNG	KMLNG_H.*	NA	NA	NA	NA	Total Deposition_F_2014-02	2/18/2014	BB	2/19/2014	HC	Veg Results_F_2014-0218	3/7/2014	BB	3/7/2014	SW										
F	D	Kitimat Clean Refinery	Off	NA	NA	NA	NA						(GS update)														
F	D	Shipping	SHIP_A.*	NA	NA	NA	NA																				
30	E	RTA - Point	RTA_H.*	NA	NA	NA	NA	CALSUM	2/17/2014	BB	2/18/2014	HC	~~CALSUM~~	NA	NA	NA	NA										
30	E	RTA - Line	RTA_POT.*	NA	NA	NA	NA	CALPOST	2/17/2014	BB	2/18/2014	HC	CALPOST	3/7/2014	BB	3/7/2014	HC										
30	E	LNG Canada	LNGC_D.*	NA	NA	NA	NA	POSTUtil	2/17/2014	BB	2/18/2014	HC	~~POSTUtil~~	NA	NA	NA	NA										
30	E	Douglas Channel	DCH_D.*	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA										
30	E	Triton	TRTN_D.*	NA	NA	NA	NA	Veg Results_30_2014-0213	2/17/2014	BB	2/18/2014	HC	ResTSeries(Far update)	3/6/2014	BB	3/7/2014	HC										
30	E	KM LNG	KMLNG_D.*	NA	NA	NA	NA	Total Deposition_30_2014-(	2/17/2014	BB	2/18/2014	HC	Veg Results_30_2014-0213	3/7/2014	HC	3/7/3014	SW										
30	E	Kitimat Clean Refinery	Off	NA	NA	NA	NA						(GS update)														
30	E	Shipping	SHIP_A.*	NA	NA	NA	NA																				
33	G	RTA - Point	RTA_H.*	NA	NA	NA	NA	CALSUM	2/13/2014	BB	2/17/2014	SW	~~CALSUM~~	NA	NA	NA	NA	~~CALSUM~~	NA	NA	NA	NA					
33	G	RTA - Line	RTA_POT.*	NA	NA	NA	NA	CALPOST	2/13/2014	BB	2/17/2014	SW	CALPOST	3/7/2014	BB	3/7/2014	HC	~~CALPOST~~	NA	NA	NA	NA					
33	G	LNG Canada	LNGC_H.*	NA	NA	NA	NA	POSTUtil	2/13/2014	BB	2/17/2014	SW	~~POSTUtil~~	NA	NA	NA	NA	~~POSTUtil~~	NA	NA	NA	NA					
33	G	Douglas Channel	DCH_H.*	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA					
33	G	Triton	TRTN_H.*	NA	NA	NA	NA	Veg Results_33_2014-0213	2/17/2014	SW	2/17/2014	BB	ResTSeries(Far update)	3/6/2014	BB	3/7/2014	HC	Veg Results_33_2014-0213	3/14/2014	BB	3/14/2014	HC					
33	G	KM LNG	KMLNG_H.*	NA	NA	NA	NA	Total Deposition_33_2014-(	2/17/2014	SW	2/17/2014	BB	Veg Results_33_2014-0213	3/7/2014	HC	3/7/2014	SW	(Far results update)									
33	G	Kitimat Clean Refinery	Off	NA	NA	NA	NA						(GS update)														
33	33	Shipping	SHIP_A.*	NA	NA	NA	NA																				
G	F	RTA - Point	RTA_H.*	NA	NA	NA	NA	CALSUM	2/18/2014	BB	2/20/2014	HC	~~CALSUM~~	NA	NA	NA	NA										
G	F	RTA - Line	RTA_POT.*	NA	NA	NA	NA	CALPOST	2/18/2014	BB	2/20/2014	HC	CALPOST	3/7/2014	BB	3/7/2014	HC										
G	F	LNG Canada	LNGC_D.*	NA	NA	NA	NA	POSTUtil	2/18/2014	BB	2/20/2014	HC	~~POSTUtil~~	NA	NA	NA	NA										
G	F	Douglas Channel	DCH_D.*	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA										
G	F	Triton	TRTN_D.*	NA	NA	NA	NA	Veg Results_G_2014-0218	2/18/2014	BB	2/20/2014	HC	ResTSeries(Far update)	3/6/2014	BB	3/7/2014	HC										
G	F	KM LNG	KMLNG_D.*	NA	NA	NA	NA	Total Deposition_G_2014-0	2/18/2014	BB	2/20/2014	HC	Veg Results_G_2014-0218	3/7/2014	HC	3/7/2014	SW										
G	F	Kitimat Clean Refinery	REF_H.*	NA	NA	NA	NA						(GS update)														
G	F	Shipping	SHIP_H.*	NA	NA	NA	NA																				
H	H	RTA - Point	RTA_H.*	1/28/2014	ACH	2/3/2014	BB	CALSUM	1/31/2014	BB	2/3/2014	HC&ACH	~~CALSUM~~	NA	NA	NA	NA	~~CALSUM~~	NA	NA	NA	NA	~~CALSUM~~	NA	NA	NA	NA
H	H	RTA - Line	RTA_POT.*	NA	NA	NA	NA	CALPOST	1/30/2014	BB	2/3/2014	HC	~~CALPOST~~	NA	NA	NA	NA	~~CALPOST~~	NA	NA	NA	NA	CALPOST	3/5/2014	BB	3/5/2014	HC
H	H	LNG Canada	LNGC_H.*	1/28/2014	ACH	2/3/2014	BB	POSTUtil	1/30/2014	BB	2/3/2014	HC	~~POSTUtil~~	NA	NA	NA	NA	~~POSTUtil~~	NA	NA	NA	NA	~~POSTUtil~~	NA	NA	NA	NA
H	H	Douglas Channel	DCH_H.*	1/28/2014	ACH	2/3/2014	BB	~~Append~~	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA	~~Append~~	NA	NA	NA	NA	Append	NA	NA	NA	NA
H	H	Triton	TRTN_H.*	1/28/2014	ACH	2/3/2014	BB	Veg Results_H_2014-0127	1/31/2014	BB	2/3/2014	HC	Veg Results_H_2014-0127	2/13/2014	BB	2/14/2014	SW	Veg Results_H_2014-0127	2/18/2014	BB	NA	NA	ResTSeries(Far update)	3/6/2014	BB	3/7/2014	HC
H	H	KM LNG	KMLNG_H.*	1/28/2014	ACH	2/3/2014	BB	Total Deposition_H_2014-0	1/31/2014	BB	2/3/2014	HC	(exclude receptors)					(reformat)					Veg Results_H_2014-0127	3/5/2014	BB	3/5/2014	HC
H	H	Kitimat Clean Refinery	REF_H.*	1/28/2014	ACH	2/3/2014	BB																(GS update)				
H	H	Shipping	SHIP_H.*	1/28/2014	ACH	2/3/2014	BB																				
33-C	33-C		CPUF_Combined	1/31/2014	ACH	24-Feb	BB	NA	NA	NA	NA	NA	CALPOST	2/25/2014	BB	2/25/2014	HC	Append	3/11/2014	HC	3/13/2014	BB					
33-C	33-C		CPUF_Combined	1/31/2014	ACH	24-Feb	BB	NA	NA	NA	NA	NA	POSTUtil	2/25/2014	BB	2/25/2014	HC	CALPOST	3/11/2014	HC	3/13/2014	BB					
33-C	33-C		CPUF_Combined	1/31/2014	ACH	24-Feb	BB	NA	NA	NA	NA	NA	Veg Results_33_2014-0213	2/25/2014	BB	2/25/2014	HC	Veg Results_33_2014-0213	3/11/2014	HC	3/13/2014	BB					
33-C	33-C												Total Deposition_33_2014-(	2/25/2014	BB	2/25/2014	HC	(SHIP emission rates update)									
Im	Im	RTA - Point	RTA_H.*	NA	NA	NA	NA	CALPOST	3/7/2014	BB	3/7/2014	HC															
Im	Im	RTA - Line	RTA_POT.*	NA	NA	NA	NA	POSTUtil	3/7/2014	BB	3/7/2014	HC															
Im	Im	LNG Canada	LNGC_H.*	NA	NA	NA	NA	Veg Results_Im_2014-0226	3/7/2014	BB	3/7/2014	SW															
Im	Im	Douglas Channel	DCH_H.*	NA	NA	NA	NA	Total Deposition_Im_2014-(	3/7/2014	BB	3/7/2014	SW															
Im	Im	Triton	TRTN_H.*	NA	NA	NA	NA	ResTSeries(Far update)	3/6/2014	BB	3/7/2014	HC															
Im	Im	KM LNG	KMLNG_H.*	NA	NA	NA	NA																				
Im	Im	Kitimat Clean Refinery	REF_H.*	NA	NA	NA	NA																				
Im	Im	Shipping	SHIP_H.*	NA	NA	NA	NA																				
Im	Im	BC Hydro Minette	BCHM_NEAR.*	2/26/2014	BB	2/26/2014	ACH																				
Is	Is	RTA - Point	RTA_H.*	NA	NA	NA	NA	CALPOST	3/7/2014	BB	3/7/2014	HC															
Is	Is	RTA - Line	RTA_POT.*	NA	NA	NA	NA	POSTUtil	3/7/2014	BB	3/7/2014	HC															
Is	Is	LNG Canada	LNGC_H.*	NA	NA	NA	NA	Veg Results_Is_2014-0226	3/7/2014	HC	3/7/2014	SW															
Is	Is	Douglas Channel	DCH_H.*	NA	NA	NA	NA	Total Deposition_Is_2014-0	3/7/2014	HC	3/7/2014	SW															
Is	Is	Triton	TRTN_H.*	NA	NA	NA	NA	ResTSeries(Far update)	3/6/2014	BB	3/7/2014	HC															
Is	Is	KM LNG	KMLNG_H.*	NA	NA	NA	NA																				
Is	Is	Kitimat Clean Refinery	REF_H.*	NA	NA	NA	NA																				
Is	Is	Shipping	SHIP_H.*	NA	NA	NA	NA																				
Is	Is	BC Hydro Skeena	BCHS_NEAR.*	2/26/2014	BB	2/26/2014	ACH																				

APPENDIX 5: MARINE EMISSION CALCULATIONS

This section removed from report to protect proprietary information of proponent/permit holder.

APPENDIX 6: CONCENTRATION AND DEPOSITION MAPS FOR REMAINING SCENARIOS

This appendix contains the following maps in a separate file: ESSA_Kitimat Airshed Emissions Effects Assessment Report_Final_Appendix 6_April 25 2014.pdf.

Scenario A Plots
Scenario A, NO_2 Concentrations, Annual Average
Scenario A, SO_2 Concentrations, Annual Average

Scenario B Plots
Scenario B, 98th Percentile NO_2 Concentrations, 1-hour Average
Scenario B, NO_2 Concentrations, 1-hour Average
Scenario B, NO_2 Concentrations, Annual Average
Scenario B, Total N Deposition
Scenario B, 99th Percentile SO_2 Concentrations, 1-hour Average
Scenario B, SO_2 Concentrations, Growing Season, 3-hour Average
Scenario B, SO_2 Concentrations, Annual Average
Scenario B, SO_2 Concentrations & Exceedances, Growing Season, 3-hour Average
Scenario B, Total S Deposition

Scenario C Plots
Scenario C, 98^{th} Percentile NO_2 Concentrations, 1-hour Average
Scenario C, NO_2 Concentrations, 1-hour Average
Scenario C, NO_2 Concentrations, Annual Average
Scenario C, Total N Deposition
Scenario C, 99^{th} Percentile SO_2 Concentrations, 1-hour Average
Scenario C, SO_2 Concentrations, Growing Season, 3-hour Average
Scenario C, SO_2 Concentrations, Annual Average
Scenario C, SO_2 Concentrations & Exceedances, Growing Season, 3-hour Average
Scenario C, Total S Deposition

Scenario D Plots
Scenario D, 98^{th} Percentile NO_2 Concentrations, 1-hour Average
Scenario D, NO_2 Concentrations, 1-hour Average
Scenario D, NO_2 Concentrations, Annual Average
Scenario D, Total N Deposition
Scenario D, 99^{th} Percentile SO_2 Concentrations, 1-hour Average
Scenario D, SO_2 Concentrations, Growing Season, 3-hour Average
Scenario D, SO_2 Concentrations, Annual Average
Scenario D, SO_2 Concentrations & Exceedances, Growing Season, 3-hour Average
Scenario D, Total S Deposition

Scenario E Plots
Scenario E, 98^{th} Percentile NO_2 Concentrations, 1-hour Average
Scenario E, NO_2 Concentrations, 1-hour Average

Scenario E, NO_2 Concentrations, Annual Average
Scenario E, Total N Deposition
Scenario E, 99th Percentile SO_2 Concentrations, 1-hour Average
Scenario E, SO_2 Concentrations, Growing Season, 3-hour Average
Scenario E, SO_2 Concentrations, Annual Average
Scenario E, SO_2 Concentrations & Exceedances, Growing Season, 3-hour Average
Scenario E, Total S Deposition

Scenario F Plots
Scenario F, 98th Percentile NO_2 Concentrations, 1-hour Average
Scenario F, NO_2 Concentrations, 1-hour Average
Scenario F, NO_2 Concentrations, Annual Average
Scenario F, Total N Deposition
Scenario F, 99th Percentile SO_2 Concentrations, 1-hour Average
Scenario F, SO_2 Concentrations, Growing Season, 3-hour Average
Scenario F, SO_2 Concentrations, Annual Average
Scenario F, SO_2 Concentrations & Exceedances, Growing Season, 3-hour Average
Scenario F, Total S Deposition

Scenario G Plots
Scenario G, 98th Percentile NO_2 Concentrations, 1-hour Average
Scenario G, NO_2 Concentrations, 1-hour Average
Scenario G, NO_2 Concentrations, Annual Average
Scenario G, Total N Deposition
Scenario G, 99th Percentile SO_2 Concentrations, 1-hour Average
Scenario G, SO_2 Concentrations, Growing Season, 3-hour Average
Scenario G, SO_2 Concentrations, Annual Average
Scenario G, SO_2 Concentrations & Exceedances, Growing Season, 3-hour Average
Scenario G, Total S Deposition

Scenario H Plots
Scenario H, NO_2 Concentrations, Annual Average
Scenario H, SO_2 Concentrations, Annual Average

Scenario Im Plots
Scenario Im, NO_2 Concentrations, 1-hour Average
Scenario Im, NO_2 Concentrations, Annual Average
Scenario Im, Total N Deposition
Scenario Im, 99th Percentile SO_2 Concentrations, 1-hour Average
Scenario Im, SO_2 Concentrations, Growing Season, 3-hour Average
Scenario Im, SO_2 Concentrations, Annual Average
Scenario Im, SO_2 Concentrations & Exceedances, Growing Season, 3-hour Average
Scenario Im, Total S Deposition

Scenario Is Plots
Scenario Is, NO_2 Concentrations, 1-hour Average
Scenario Is, NO_2 Concentrations, Annual Average
Scenario Is, Total N Deposition

Scenario Is, 99th Percentile SO_2 Concentrations, 1-hour Average
Scenario Is, SO_2 Concentrations, Growing Season, 3-hour Average
Scenario Is, SO_2 Concentrations, Annual Average
Scenario Is, SO_2 Concentrations & Exceedances, Growing Season, 3-hour Average
Scenario Is, Total S Deposition

Scenario Jm Plots
Scenario Jm, NO_2 Concentrations, 1-hour Average
Scenario Jm, NO_2 Concentrations, Annual Average
Scenario Jm, Total N Deposition

Scenario Js Plots
Scenario Js, NO_2 Concentrations, 1-hour Average
Scenario Js, NO_2 Concentrations, Annual Average
Scenario Js, Total N Deposition

BC Hydro Plots
BC Hydro Minette with SCR Control, NO_2 Concentrations, Annual Average
BC Hydro Skeena with SCR Control, NO_2 Concentrations, Annual Average

APPENDIX 7: TEN YEAR METEOROLOGICAL DATA ANALYSIS

This appendix summarizes Trinity Consultants' assessment of meteorological conditions in the Kitimat airshed. The analysis was conducted with the primary aim of comparing the years that we have modelled with CALPUFF (2006, 2008, and 2009) to longer-term averages (2003-2012) in order to understand the extent to which the modelled years are representative of typical or worst-case years in the area.

7.1 Introduction

Background and Scope

Atmospheric air pollution is a combined result of emissions from natural and anthropogenic sources, atmospheric conditions, source to receptor relationships, and any atmospheric sinks (such as chemical reactions, deposition, etc.). Among the most important meteorological drivers of pollutant concentrations in the atmosphere are wind speed and atmospheric stability. Of course, wind direction is also important, but in the context of the Kitimat airshed, wind direction is a secondary driver more specific in resolving a source to receptor situation. As such, we focused our analysis primarily on wind speed and atmospheric stability. In the Kitimat airshed, one particular phenomenon of concern related to, and characteristic of, atmospheric stability is the presence of temperature inversions. A temperature inversion may be defined generally as an increase in temperature with altitude (rather than the decrease in temperature with altitude that occurs under normal daytime and day-night transitional period conditions).[39] During the daytime, the ground-based temperature is warmer than the air aloft due to surface heating by the sun which results in cooler temperatures at higher altitudes. During the nighttime, the opposite is true due to surface cooling (via long wave radiation from the earth) and temperatures are warmer aloft, i.e., inverted from the daytime (hence, inversion). Temperature inversions commonly occur at night and break up during the morning hours as the sun warms the ground (and the ground warms the air that is adjacent to it). However, due to land cover, snow cover, time of year and other factors, an inversion event can last through the daytime hours and sometimes persist over a period of several weeks. This is especially true when the inversion is related to mesoscale atmospheric conditions such as a high-pressure system with associated subsidence of air aloft forming a non-ground based inversion. These are common along the Front Range of the Rocky Mountains. For ground-based inversions, a common cause for an inversion is when radiation from the surface (long wave) exceeds radiation from the sun (short wave), and results in a surface-based inversion. This is more common in the winter, especially in the northern regions where snow cover and low sun angles can mask effective surface heating. A warmer air mass moving over a colder one also commonly causes an inversion, referred to as a frontal inversion.

A particular concern regarding inversions in the Kitimat airshed relates to inversions causing a restriction of daytime convection at the surface (limited mixing) that can result in stagnant wind conditions and can trap pollutants in the lower layer. This assessment focuses on identifying conditions that may be

[39] Quantitatively, an inversion is treated as an event at which an elevated temperature is strictly greater than a less elevated temperature. This definition agrees with the criterion used by Emslie (1979). Similar definitions are given in Holzworth (1974) and Morgan and Bornstein (1977).

indicative of surface-based inversions. No analysis was performed to assess the climatological reoccurrence of high-pressure systems and potential formation of subsidence inversions or of frontal inversions specifically.

Period Evaluated

We have performed detailed, multi-scenario modelling of pollutant dispersion in the Kitimat airshed using the CALPUFF model for a meteorological data set for the year 2008. This 2008 year of data was used because of its completeness and availability as compared to other years up to and including 2012. Given the potential extent of natural climate variability and the importance of meteorological conditions in determining pollutant distribution, a comparison of 2008 meteorological conditions in the airshed to long-term average conditions is an efficient way of estimating how concentrations in other (including future) years are likely to compare to the concentrations modelled for 2008. We have also performed some CALPUFF modelling for 2006 and 2009. As such, meteorological conditions in these years will also be examined and compared to long-term averages.

In determining a representative long-term average of meteorological concentrations, a period of at least five years is commonly used to capture most of the natural variation in conditions at a site[40], with a longer period being better. In this case, a 10-year period (2003-2012) was used as a compromise between using a longer period and data availability. This should provide a sufficient time period to draw meaningful conclusions.

This document is organized into four main sections. Each section focuses on one of the four primary methods used to compare the modelled years of 2006, 2008, and 2009 to the 2003-2012 average. Within each section, the methodology used for the analysis and the comparative results are presented. The four sections are as follows:

1. Analysis of general wind patterns, including variations in both wind speed and direction
2. Analysis of atmospheric stability conditions using the Pasquill-Gifford stability classification system
3. Analysis of temperature inversion frequency, particularly daytime inversion frequency, using measures of average wind speed and temperature increase as a surrogate for daytime temperature inversions
4. Investigation of the applicability of an inversion assessment technique using the methodology of Emslie (1979), which was referenced by the Orenda pulp and paper Environmental Impact Assessment[41]

7.2 Wind Patterns

A wind pattern analysis, assessing the frequency of occurrence of each combination of wind speed and direction, is useful in the context of this study for two primary reasons:

1. By comparing patterns of wind direction, it can be determined whether the distribution of pollutants in the modelled year is likely to be representative of long-term and future pollutant distributions.

[40] U.S. Code of Federal Regulations: Chapter 40, Part 51, Appendix W (2009).

[41] Environmental Impact Assessment for Orenda's Kitimat-Terrace pulp and paper mill.

2. Because low wind speeds are frequently correlated with higher pollutant concentrations, comparing patterns of wind speed provides insight into whether a modelled year is likely to under- or overestimate the pollutant concentrations in a typical or future year.

We obtained 10 years of hourly wind speed data from the Terrace Airport meteorological station for this purpose. The 10-year distribution of wind patterns was compared to the patterns in 2008, 2006, and 2009 by calculating the percentage of each period during which a given wind speed and direction combination were observed. We grouped wind directions using 36 10-degree directions, and wind speeds were grouped into seven wind speed categories (including a "calm" category) based on an augmented version of the categories used in the Pasquill-Gifford stability classification system (Pasquill 1961). The results of this analysis are summarized by the wind roses shown below in Figure A7-1 (2003-2012), Figure A7-2 (2008), Figure A7-3 (2006), and Figure A7-4 (2009).

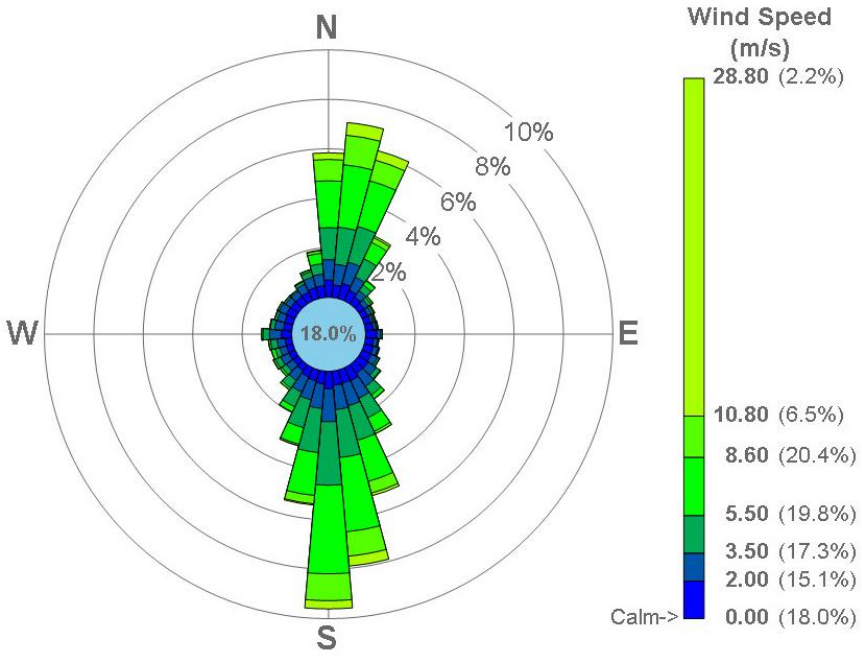

Figure A7-1. Terrace Airport wind rose: 2003-2012.

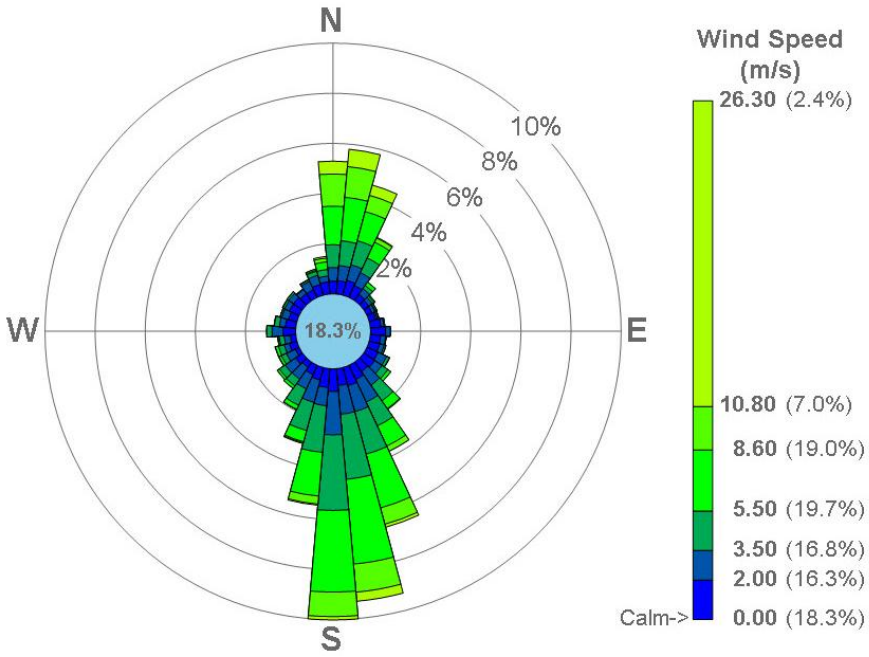

Figure A7-2. Terrace Airport wind rose: 2008.

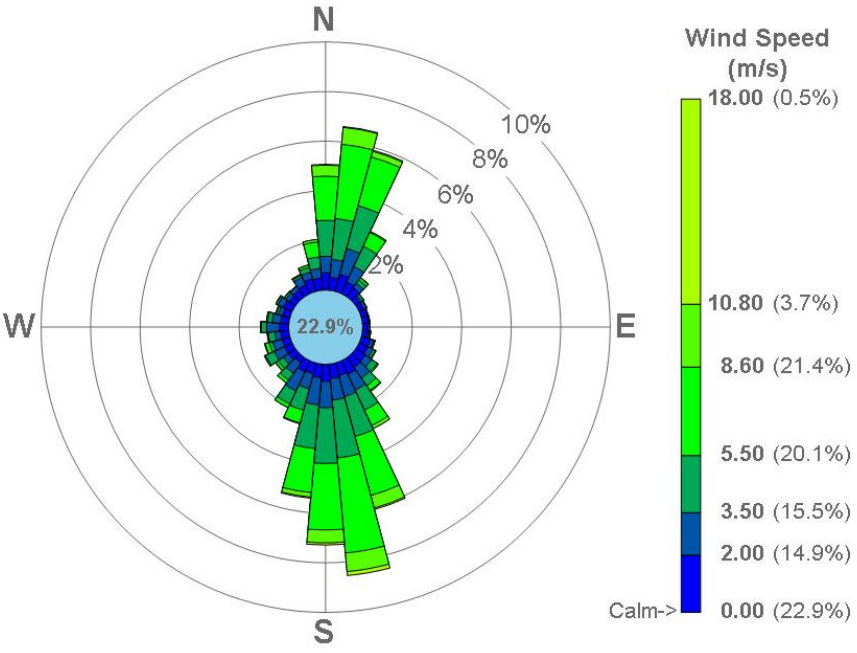

Figure A7-3. Terrace Airport wind rose: 2006.

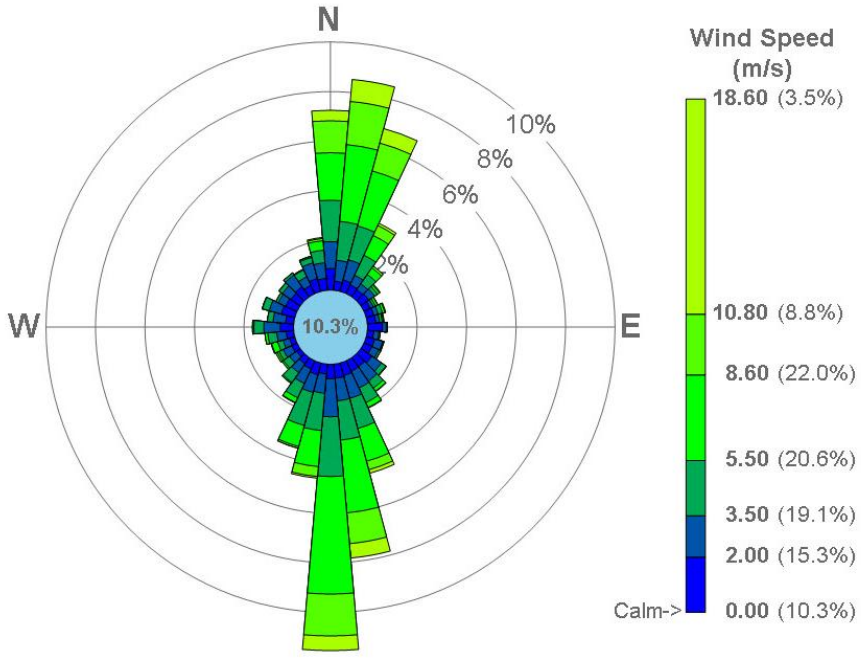

Figure A7-4. Terrace Airport wind rose: 2009.

Wind Direction Analysis

The distribution of wind directions in all four sample periods was broadly similar, with the most common prevailing winds being from the S/SSE and to a lesser extent the N/NNE. The patterns in 2008 and 2009 are a particularly close match to the long-term pattern. The most notable difference is a slightly higher frequency of S/SSE winds in 2008 and a corresponding slightly lower frequency of N/NNE winds compared to 2003-2012. This shift is clearly seen in the lowest wind speed categories as well as in the overall directional patterns.

The 2009 directional pattern is also very similar to the 2003-2012 pattern, though this is somewhat obscured by the lower frequency of calm winds (no measurable directional component) in 2009 versus the 10-year period. 2006 shows the largest difference from the 2003-2012 pattern, with SSE winds being more common and S winds being less common than in the 10-year period.

Wind Speed Analysis

More variation is noted between years in terms of frequency of occurrence of different wind speed categories. 2008 is the closest match to the 2003-2012 period in this regard, with similar frequencies of occurrence for all wind speed categories. Focusing on the low wind speeds that can be particularly consequential for dispersion modelling and are frequently associated with inversion conditions, the frequency of calm wind conditions (indicated in Figure A7-1 to Figure A7-4 by the percentage shown in the blue circle in the center of each wind rose) was 18.3% for 2008, compared to 18.0% for 2003-2012. 2008 shows slightly higher frequency than 2003-2012 in the lowest non-calm wind speed category, (0.1-2.0 m/s), with 16.3% of hours in 2008 falling into that category, versus 15.1% for 2003-2012.

The wind speed distributions in 2006 and 2009 are less similar to the 2003-2012 period. 2006 experienced more frequent calm winds than 2003-2012 (22.9%), but slightly less frequent winds in the 0.1-2.0 m/s category (14.9%). Calm winds were substantially less frequent in 2009 (10.3%) than in 2003-2012 as a whole, but the frequency of 0.1-2 m/s winds was similar (15.3%) to the overall 10-year period.

Because low wind speeds are associated with lower dilution of pollutants, the findings for 2008 indicate that that year likely included a slightly higher number of low-dilution (high-concentration) events than an average year in the region, but is generally close to the average. 2009 may have slightly greater-than-average occurrence of low-dilution events, while 2006 may have slightly lower-than-average occurrence of such events.

7.3 Atmospheric stability

Atmospheric stability is the primary regulator of the amount of vertical motion and vertical and horizontal turbulence in the atmosphere, and thus the amount of dispersion and pollutant concentrations. As such, stability is a critical parameter in this analysis of the Kitimat airshed.

The Pasquill-Gifford stability classification system was used to quantify the frequency of occurrence of stable and unstable conditions in 2003-2012, as well as in the individual years 2008, 2006, and 2009. Stability and vertical motion in the lower atmosphere are determined primarily by the amount of mechanical and buoyant turbulence, which is in turn determined primarily by wind speed and the net flux of radiation (incoming solar radiation minus outgoing long-wave radiation) at the earth's surface. The Pasquill-Gifford system is a commonly used tool for summing both effects (wind- and radiation-driven turbulence) to provide a concise overall assessment of whether the atmosphere is likely to be stable (as in the case of a low-level temperature inversion), unstable (as on a clear, sunny day), or neutral. A letter between A (extremely unstable) and F (extremely stable) is assigned in this system as shown in Figure A7-5 based on wind speed, cloud cover, and solar radiation intensity. Solar radiation intensity is calculated as a function of cloud cover and solar angle (determined from time and date).

Key to Stability Categories					
Surface Wind Speed (at 10m) m/s	Day			Night	
	Incoming Solar Radiation			Thinly Overcast or ≥ 4/8 Low Cloud	≤ 3/8 Cloud
	Strong	Moderate	Slight		
< 2	A	A - B	B		
2 - 3	A-B	B	C	E	F
3 - 5	B	B-C	C	D	E
5 - 6	C	C-D	D	D	D
> 6	C	D	D	D	D

The neutral class, D, should be assumed for overcast conditions during day or night.

Figure A7-5. Pasquill-Gifford Stability classification methodology.

Atmospheric Stability Analysis

Table A7-1, Table A7-2, Table A7-3 and Table A7-4 show the average stability class for the 10-year period of 2003-2012, 2006, 2008, and 2009, respectively. These results are based upon a stability analysis that

was performed on the 2003-2012 data from Terrace Airport. Based on this analysis, D (neutral) stability dominates in all years with about 78% of all hours falling into this category. In comparison, E (stable) and F (extremely stable) conditions are more frequent than A-C (unstable) conditions in all years.

Focusing on years 2006, 2008, and 2009, year 2006 has an above-average frequency of stable conditions, year 2008 is comparable to average, and year 2009 has a below-average frequency of stable conditions. This observation is consistent with the wind speed analysis described in the section above.

Table A7-1. Terrace Airport stability class and wind speed categories: 2003-2012.

2003-2012	<2 m/s	2.1-3.5 m/s	3.6-5.5 m/s	5.6-8.6 m/s	8.7-10.8 m/s	>10.8 m/s	All Wind Speeds
A	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.8%*
B	3.1%	1.3%	0.3%	0.0%	0.0%	0.0%	*4.6%*
C	4.8%	1.5%	1.8%	0.1%	0.0%	0.0%	*8.2%*
D	14.4%	9.0%	15.9%	20.5%	6.5%	2.2%	*68.6%*
E	0.0%	3.9%	2.1%	0.0%	0.0%	0.0%	*6.0%*
F	10.1%	1.7%	0.0%	0.0%	0.0%	0.0%	*11.8%*
All Stability Classes	*33.2%*	*17.4%*	*20.0%*	*20.7%*	*6.5%*	*2.2%*	

Table A7-2. Terrace Airport stability class and wind speed categories: 2006.

2006	<2 m/s	2.1-3.5 m/s	3.6-5.5 m/s	5.6-8.6 m/s	8.7-10.8 m/s	>10.8 m/s	All Wind Speeds
A	1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	*1.3%*
B	4.6%	1.2%	0.3%	0.0%	0.0%	0.0%	*6.1%*
C	5.6%	1.8%	1.9%	0.1%	0.0%	0.0%	*9.4%*
D	13.2%	7.0%	15.6%	21.5%	3.8%	0.5%	*61.6%*
E	0.0%	3.8%	2.5%	0.0%	0.0%	0.0%	*6.4%*
F	13.5%	1.8%	0.0%	0.0%	0.0%	0.0%	*15.3%*
All Stability Classes	*38.2%*	*15.6%*	*20.3%*	*21.6%*	*3.8%*	*0.5%*	

Table A7-3. Terrace Airport stability class and wind speed categories: 2008.

2008	<2 m/s	2.1-3.5 m/s	3.6-5.5 m/s	5.6-8.6 m/s	8.7-10.8 m/s	>10.8 m/s	All Wind Speeds
A	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.7%*
B	2.7%	1.0%	0.1%	0.0%	0.0%	0.0%	*3.9%*
C	5.0%	1.0%	1.5%	0.1%	0.0%	0.0%	*7.6%*
D	16.4%	9.2%	16.3%	19.0%	7.1%	2.4%	*70.5%*
E	0.0%	4.0%	1.8%	0.0%	0.0%	0.0%	*5.8%*
F	9.9%	1.7%	0.0%	0.0%	0.0%	0.0%	*11.6%*
All Stability Classes	*34.8%*	*16.8%*	*19.8%*	*19.1%*	*7.1%*	*2.4%*	

Table A7-4. Terrace Airport stability class and wind speed categories: 2009.

2009	<2 m/s	2.1-3.5 m/s	3.6-5.5 m/s	5.6-8.6 m/s	8.7-10.8 m/s	>10.8 m/s	All Wind Speeds
A	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.3%*
B	2.4%	1.9%	0.4%	0.0%	0.0%	0.0%	*4.7%*
C	3.7%	1.3%	2.4%	0.2%	0.0%	0.0%	*7.6%*
D	10.8%	9.8%	15.3%	21.8%	8.9%	3.5%	*70.1%*
E	0.0%	4.1%	2.6%	0.0%	0.0%	0.0%	*6.6%*
F	8.5%	2.2%	0.0%	0.0%	0.0%	0.0%	*10.7%*
All Stability Classes	*25.7%*	*19.2%*	*20.7%*	*22.0%*	*8.9%*	*3.5%*	

7.4 Temperature Inversions

Ideally, temperature inversions are diagnosed directly using temperature difference data from a tower instrumented at multiple heights, Sodar, or other system. In the absence of such a system in the Kitimat airshed, less direct methods can be used to diagnose when an inversion is likely to have occurred. Two such methods were explored for this study.

Emslie Inversion Method

The first method explored was that proposed by Emslie (1979). In Emslie's study, surface stations were paired based on their relative proximity and their elevation difference, such that the difference in recorded temperature between the stations could reasonably be attributed to a change of temperature with elevation. These pairs are referred to as "valley-ridge pairs." For each day of data taken at the pairs, Emslie concluded that a temperature inversion was occurring if the maximum or minimum daily temperature at the lower station was less than the corresponding temperature at the higher station.

We attempted to apply this method to the 2004-2012 period in the Kitimat airshed. 2003 was not considered because the January-September 2003 data were not available. The Kitimat Haul Road and Kitimat Whitesail stations were identified as a suitable valley-ridge pair (5.9 km horizontal separation, 82 m elevation difference). However, this method revealed patterns that are not physically reasonable and

contradict the atmospheric stability indicated by wind data, such as a near-100% occurrence of afternoon inversion conditions for the years 2003 and 2004, but less than 10% occurrence in 2010-2012.

Based on this evidence, we concluded that differences in instrumentation, calibration, instrument exposure, or other factors likely play a dominant role in the erratic results. Typically, temperature difference-based analyses require precise calibration of a matching pair of instruments, and have much lower tolerances for error than single temperature measurements (US EPA 2000). Because this level of uniformity is not commonly devoted to temperature measurements that are not specifically meant to be used together, the results of this effort are perhaps not surprising.

Effects-Based Inversion Diagnosis Method

In light of the issues described in the previous section related to applying the Emslie method, we elected to use a method based on single rather than paired surface stations. The Kitimat Haul Road site was used for this analysis. Because inversions cannot be diagnosed directly without using temperature measurements at multiple levels, this method sought to identify conditions in single-level wind and temperature data that were likely to occur in the presence of a temperature inversion. Low wind speeds are the most common feature associated with inversion conditions, and thus are an important part of this method, though examination of low wind speeds alone will likely tend to overpredict the frequency of inversions since some low wind speed conditions are driven simply by low synoptic-scale pressure gradient forces. Hosler (1969) states that nighttime winds typically associated with stable conditions are winds less than 7 mph (3.13 m/s). Thus, winds at or below that threshold are considered "low" for the purposes of this analysis. To diagnose daytime temperature inversions, which are of particular concern in the Kitimat area, days were identified in which, in addition to low wind speeds, the temperature increase between 8 AM and 4 PM was less than five degrees Celsius. Because sufficient surface heating will at least raise the height of a temperature inversion, if not cause it to break up altogether, identifying days of low surface temperature increase is potentially useful in determining likely daytime inversion occurrences.

Results obtained using this method are shown in Figure A7-6, Figure A7-7, and Figure A7-8. Based on the results, 2008 is similar to the 10-year average for the number of days with wind speed below 3.13 m/s from 8 AM to 4 PM (Figure A7-6). 2008 is also similar to average in terms of the number of days with wind speed less than 3.13 m/s and 8 AM to 4 PM temperature increase of 5°C or less (Figure A7-7). In comparison, 2006 is less inversion-prone than average based on both of these metrics.

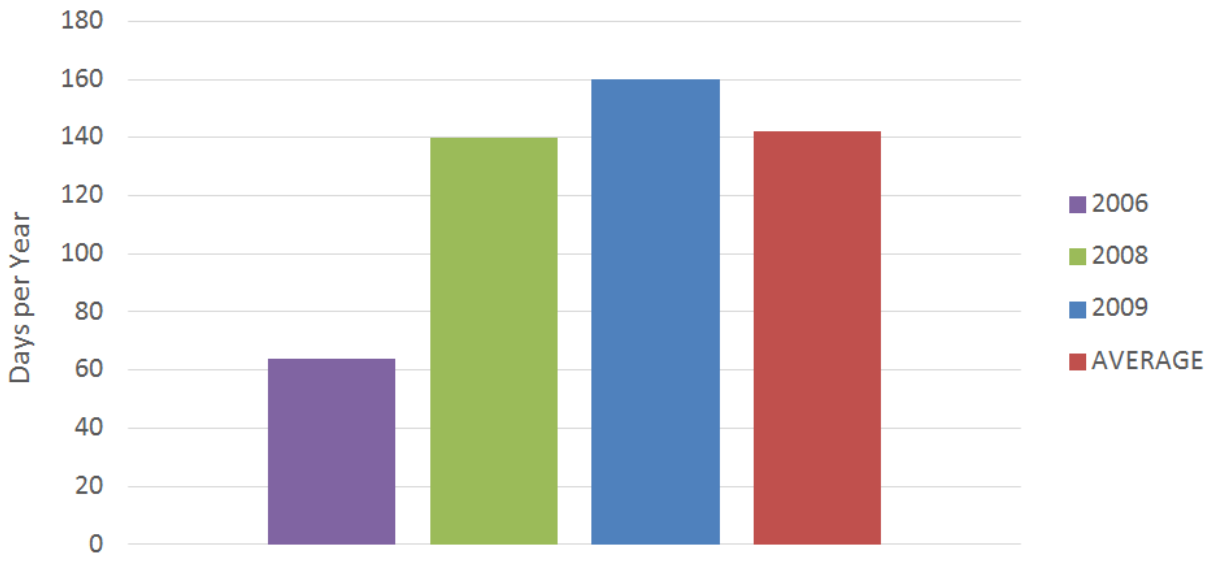

Figure A7-6. Number of days per year with low wind speed at all hours from 8 AM - 4 PM.

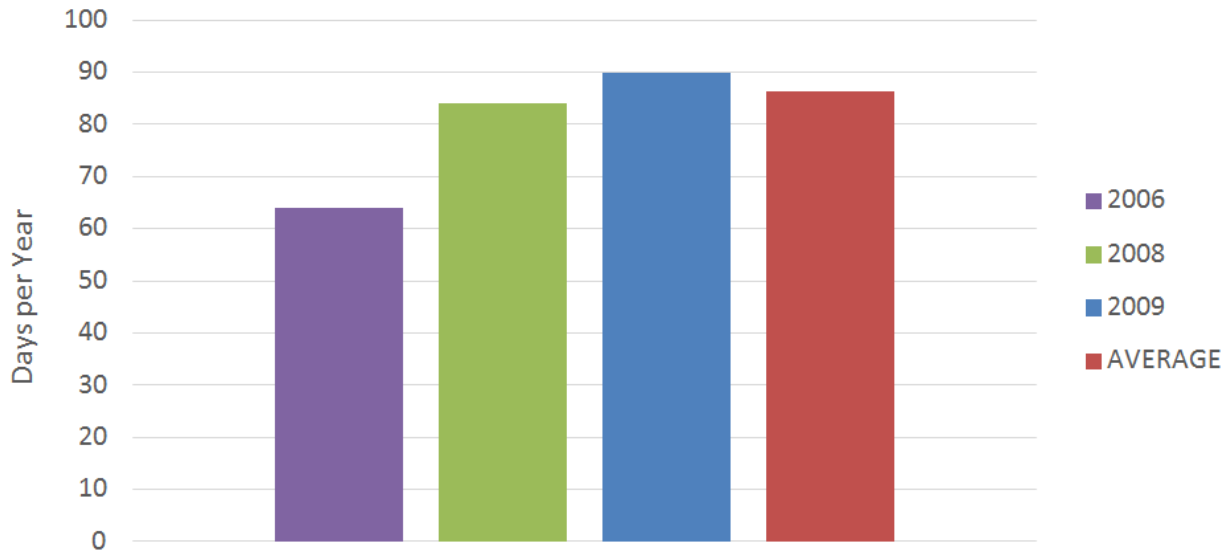

Figure A7-7. Number of days per year with low wind speed at all hours from 8 AM - 4 PM and <5°C Temperature increase from 8 AM - 4PM.

Figure A7-8 shows the number of multi-day inversion events per year, using the classification logic of Figure A7-7 (inversion day = low wind speed for all hours from 8 AM - 4 PM and temperature increase during that time of 5°C or less). As shown in this figure, 2008 had fewer than average 2-day inversion events, had near-average for 3- and 4-day events, and had above average for 5- and 6-day events. 2008 had a total of 14 multi-day events, which is close to the average of 16.7. 2006 was slightly below average in total multi-day events (12). 2009 was well above average for total multi-day events (21), but no events in 2009 lasted longer than 4 days.

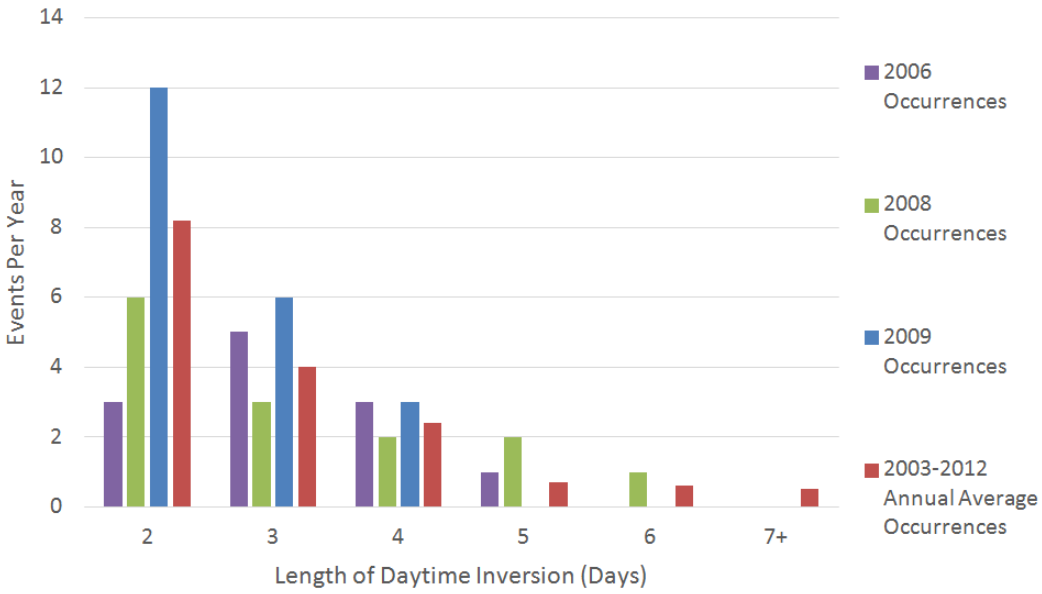

Figure A7-8. Number of multi-day inversion events per year.

An analysis of the seasonal variations between 2006, 2008, 2009, and the average was also performed. These results may be seen in Figure A7-9 and Figure A7-10. Figure A7-9 shows the number of days per season with low wind speeds at all hours between 8 AM and 4 PM. Based on this metric, 2006 tends to be below or just at average in all seasons, whereas 2009 tends to be above average or just at average. 2008 is below average in Winter and Summer but above average in Fall and near average in Spring. Figure A7-10 shows the number of days with wind speed less than 3.13 m/s with 8 AM to 4 PM temperature increase of 5°C or less. In this figure, 2006 is below average during all seasons while 2008 and 2009 are about average in Spring and above average in Summer and Fall. During the Winter, 2008 is below average whereas 2009 is just at average.

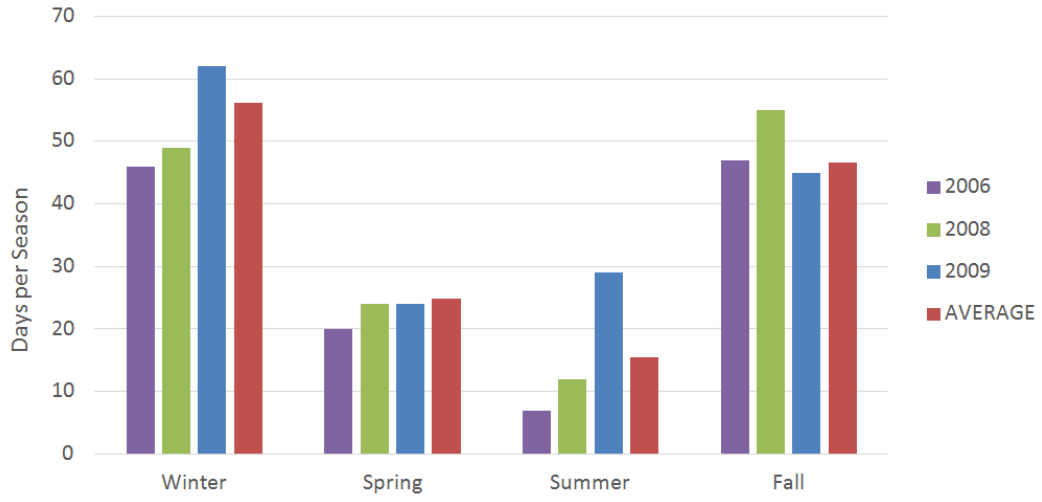

Figure A7-9. Seasonal breakdown of number of days per year with low wind speed at all hours from 8 AM - 4 PM.

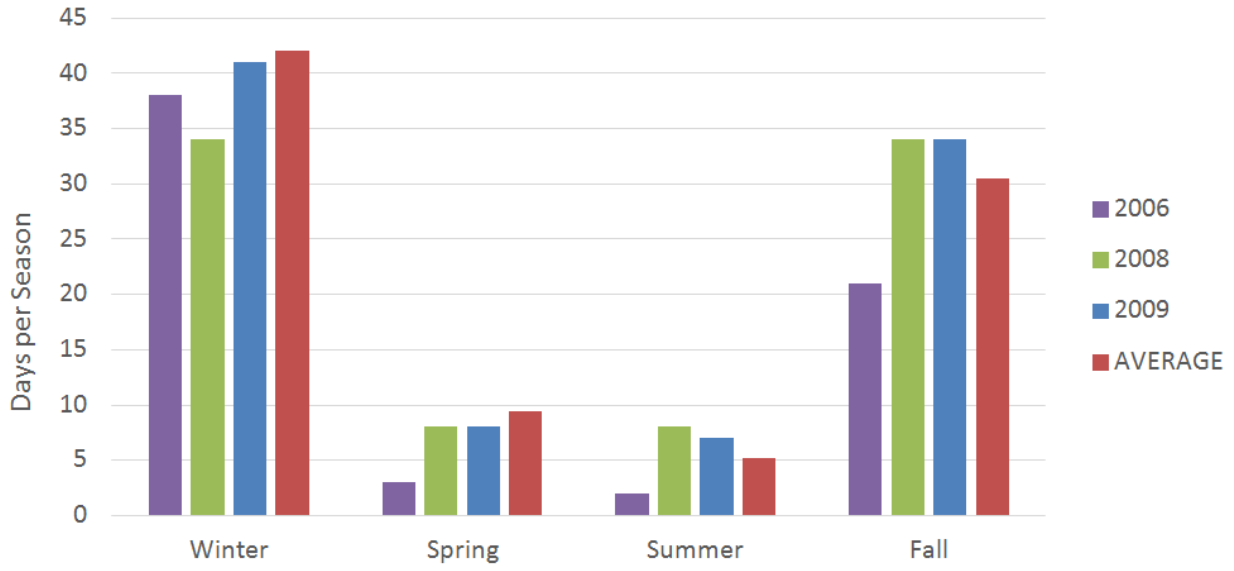

Figure A7-10. Seasonal breakdown of number of days per year with low wind speed at all hours from 8 AM - 4 PM and <5°C temperature increase from 8 AM - 4PM.

A similar analysis was performed using data from the Terrace Airport. Conclusions for 2008 were broadly similar to the Kitimat results described above, with 2008 being similar to the long-term average. 2006 results from Terrace Airport were also broadly similar to the Kitimat results, with below-average occurrence of low wind and inversion-like conditions, but 2009 results using Terrace Airport showed a pattern different from that found using Kitimat data: below-average low wind/inversion-like conditions at Terrace in 2009 compared to above-average frequencies at Kitimat. This suggests that year-to-year variations in inversion conditions are not likely to be uniform across the entire airshed. However, it is noteworthy that for 2008, a similar pattern (close to average conditions) was observed at both locations.

7.5 Conclusions

Kitimat airshed meteorological data from years 2008, 2006, and 2009 were compared to conditions over the 2003-2012 period. The years were compared based on wind patterns (speed and direction), atmospheric stability, and occurrence of conditions likely to indicate a daytime atmospheric temperature inversion situation. The 2008 year of meteorological data appeared to be broadly representative of an average year in the 2003-2012 period considered and may reasonably be assumed to be representative of a typical year in the near future. Years 2006 and 2009 showed more deviation from the 10-year norm.

The average nature of 2008 appeared to be consistent across all metrics and when comparing results from two different sites in the airshed (Kitimat Haul Road and Terrace Airport meteorological stations). 2006 and 2009 showed a less consistent pattern, with 2006 having a higher-than-average frequency of low wind speed and stable atmosphere conditions, but a lower-than-average frequency of inversion-like events. 2009 showed the opposite general tendency: below-average occurrences of low wind speed and stable atmosphere conditions, but above-average occurrences of inversion-like conditions.

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APPENDIX 8: SENSITIVITY STUDY OF 2006 AND 2009 METEOROLOGICAL DATA SETS

This appendix contains the following plots.

2006 Scenario G Tables
SO_2 Vegetation Concentration Results
NO_2 Vegetation Concentration Results
SO_2 and NO_2 Concentration Results for All Near-Field Receptors

2009 Scenario G Tables
SO_2 Vegetation Concentration Results
NO_2 Vegetation Concentration Results
SO_2 and NO_2 Concentration Results for All Near-Field Receptors

Scenario G Plots
Scenario G, NO_2 Concentrations, 1-hour Average, 2006
Scenario G, NO_2 Concentrations, 1-hour Average, 2009
Scenario G, 98th Percentile Daily Peak NO_2 Concentrations, 1-hour Average, 2006
Scenario G, 98th Percentile Daily Peak NO_2 Concentrations, 1-hour Average, 2009
Scenario G, 99th Percentile Daily Peak SO_2 Concentrations, 1-hour Average, 2006
Scenario G, 99th Percentile Daily Peak SO_2 Concentrations, 1-hour Average, 2009
Scenario G, SO_2 Concentrations, Growing Season, 3-hour Average, 2006
Scenario G, SO_2 Concentrations, Growing Season, 3-hour Average, 2009
Scenario G, NO_2 Concentrations, Annual Average, 2006
Scenario G, NO_2 Concentrations, Annual Average, 2009
Scenario G, SO_2 Concentrations, Annual Average, 2006
Scenario G, SO_2 Concentrations, Annual Average, 2009

Kitimat Airshed Emissions Effects Assessment
Scenario G_76.2 - Base Case without Refinery

2006 SO_2 Concentration Results

Averaging Period	Rank	2006 Maximum Concentrations [a] ($\mu g/m^3$)	% Change from 2008	BC Pollution Control Objectives [b] ($\mu g/m^3$)		WHO Guidelines [b,c] ($\mu g/m^3$)	US EPA Secondary Standards [d] ($\mu g/m^3$)	Maximum Date and Time	
				Minimum	Maximum			Julien Day	Time
1-hour	1st	1,713	-2%	450	900	500		290	900
1-hour	2nd	1,553	19%	450	900	500		282	900
3-hour	1st	953	10%	375	665	N/A		286	900
3-hour	2nd	737	17%	375	665	N/A	1300	286	900
24-hour	1st	270	21%	160	260	20		337	0
24-hour	2nd	229	13%	160	260	20		285	0
Annual	Mean	34	-27%	25	75	N/A			
Annual Growing Season [e]	Mean	49							

[a] Modelled concentrations represent the maximum of the 2006 meteorological year modelled, and include a background concentrations corresponding to the appropriate to the averaging period. Maximum modelled concentrations exclude receptors located on RTA's property and those on the channel. Background concentrations are based on monitoring data at the nearby Kitamaat Village monitoring station, as follows:

1.5 ppb	3.92 $\mu g/m^3$	for 1 hour and 3 hour averaging period
1.2 ppb	3.13 $\mu g/m^3$	for 24 hour averaging period
0.4 ppb	1.07 $\mu g/m^3$	for Annual averaging period

[b] Comparisons to the PCO and WHO thresholds do not provide conclusions related to impacts on the environment or human health.

[c] The SO_2 1-hr standard in the WHO Guidelines is based on a 10-minute mean. The form of the standard is conservatively assumed to apply for a 1-hour averaging

[d] Secondary National Ambient Air Quality Standard (NAAQS) define the levels that protect the public welfare from any known or anticipated adverse effects of a pollutant. The secondary standard for the 3-hour averaging period is not to be exceeded more than once per calendar year. Therefore, results are compared to the second high.

[e] Growing Season is from April 15 through September 15. Daylight hours are between 0700-1900 PDT. The annual background concentration is applied to these concentrations.

Kitimat Airshed Emissions Effects Assessment
Scenario G_76.2 - Base Case without Refinery

2006 NO_2 Concentration Results

Averaging Period	Rank	2006 Maximum Concentrations [a] ($\mu g/m^3$)	% Change from 2008	Canada Air Quality Objectives [b] ($\mu g/m^3$)			US EPA Secondary Standards [c] ($\mu g/m^3$)	Maximum Date and time	
				MDL	MAL	MTL		Julien Day	Time
1-hour	1st	328	6%		400	1000		81	0
1- hour	2nd	267	8%		400	1000		92	2300
3-hour	1st	214	1%					114	0
3-hour	2nd	193	0%					49	2100
24-hour	1st	99	5%		200	300		339	0
24-hour	2nd	94	6%		200	300		337	0
Annual	Mean	27	-16%	60	100		100		
Annual Growing Season [d]	Mean	31							

[a] Modelled concentrations represent the maximum of the 2006 meteorological year modelled. Maximum modelled concentrations exclude receptors located on RTA's property and those on the channel. For short term averaging periods, the maximum NOx concentration is scaled to assume 80% of NOx is NO_2, then a background concentrations is added as determined by the 98th percentile of NO_2 data from three years in Quesnel. For the annual averaging period, the maximum NOx concentration is scaled to assume 75% of NOx is NO_2, then a background concentration is added as determined by Quesnel annual average data. Therefore the model output (MO) is updated as follows MO * NOx/NO_2 Ratio + Background = Reported Result

30.6 ppb	57.53 $\mu g/m^3$	80% NOx is NO_2	for 1 hour and 3 hour averaging period
23.9 ppb	44.93 $\mu g/m^3$	80% NOx is NO_2	for 24 hour averaging period
9.4 ppb	17.74 $\mu g/m^3$	75% NOx is NO_2	for Annual averaging period

[b] Comparisons to the PCO and WHO thresholds do not provide conclusions related to impacts on the environment or human health. MDL=Maximum Desirable Level, MAL=Maximum Acceptable level, MTL=Maximum Tolerable level.

[c] Secondary National Ambient Air Quality Standard (NAAQS) define the levels that protect the public welfare from any known or anticipated adverse effects of a pollutant.

[d] Growing Season is from April 15 through September 15. Daylight hours are between 0700-1900 PDT. The annual background concentration is applied to these concentrations.

Kitimat Airshed Emissions Effects Assessment

Scenario G_76.2 - Base Case without Refinery

** Note all values below do not have the background concentration or NOx/NO2 ratio applied*

SO2 Concentration Comparison. Scenario G_76.2: 2006 vs 2008 meteorological data									
	SO_2 Concentration Difference				SO_2 Concentration % Difference				
	1 hr	3 hr	24 hr	Annual	1 hr	3 hr	24 hr	Annual	Annual
	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$					(Absolute)
All Near Field Receptors									
Minimum	-1600	-1061	-157	-9	-511%	-380%	-205%	-91%	0.02%
Average	150	73	41	5	24%	20%	39%	53%	58.23%
Maximum	1144	532	213	19	93%	86%	88%	81%	90.60%
Service Center, Kitimat, and Kitamaat Village Receptors Only									
Minimum	-459	-309	-40	-2	-140%	-169%	-83%	-18%	0%
Average	181	87	48	6	32%	26%	47%	62.4%	62.6%
Maximum	1144	532	213	19	84%	82%	88%	81%	81%

NO2 Concentration Comparison. Scenario G_76.2: 2006 vs 2008 meteorological data									
	NO_x Concentration Difference				NO_x Concentration % Difference				
	1 hr	3 hr	24 hr	Annual	1 hr	3 hr	24 hr	Annual	Annual
	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$					(Absolute)
All Near Field Receptors									
Minimum	-446	-127	-27	-6	-365%	-384%	-212%	-104%	0.07%
Average	21	15	8	1	18%	19%	30%	47%	55.305%
Maximum	199	176	43	5	84%	85%	83%	80%	104.25%
Service Center, Kitimat, and Kitamaat Village Receptors Only									
Minimum	-52	-88	-23	-2	-69%	-159%	-147%	-57%	0%
Average	26	19	9	2	23%	25%	36%	57.0%	57.4%
Maximum	170	112	43	5	74%	70%	83%	80%	80%

Kitimat Airshed Emissions Effects Assessment
Scenario G_76.2 - Base Case without Refinery

2009 SO_2 Concentration Results

Averaging Period	Rank	2009 Maximum Concentrations [a] ($\mu g/m^3$)	% Change from 2008	BC Pollution Control Objectives [b] ($\mu g/m^3$)		WHO Guidelines [b,c] ($\mu g/m^3$)	US EPA Secondary Standards [d] ($\mu g/m^3$)	Maximum Date and Time	
				Minimum	Maximum			Julien Day	Time
1-hour	1st	1,925	9%	450	900	500		026	1200
1-hour	2nd	1,662	24%	450	900	500		324	1,100
3-hour	1st	1,149	26%	375	665	N/A		157	2,100
3-hour	2nd	785	22%	375	665	N/A	1300	157	2,100
24-hour	1st	216	1%	160	260	20		033	0
24-hour	2nd	182	-10%	160	260	20		032	0
Annual	Mean	36	-17%	25	75	N/A			
Annual Growing Season [e]	Mean	52							

[a] Modelled concentrations represent the maximum of the 2009 meteorological year modelled, and include a background concentrations corresponding to the appropriate to the averaging period. Maximum modelled concentrations exclude receptors located on RTA's property and those on the channel. Background concentrations are based on monitoring data at the nearby Kitamaat Village monitoring station, as follows:

1.5 ppb	3.92 $\mu g/m^3$	for 1 hour and 3 hour averaging period
1.2 ppb	3.13 $\mu g/m^3$	for 24 hour averaging period
0.4 ppb	1.07 $\mu g/m^3$	for Annual averaging period

[b] Comparisons to the PCO and WHO thresholds do not provide conclusions related to impacts on the environment or human health.

[c] The SO_2 1-hr standard in the WHO Guidelines is based on a 10-minute mean. The form of the standard is conservatively assumed to apply for a 1-hour averaging period.

[d] Secondary National Ambient Air Quality Standard (NAAQS) define the levels that protect the public welfare from any known or anticipated adverse effects of a pollutant. The secondary standard for the 3-hour averaging period is not to be exceeded more than once per calendar year. Therefore, results are compared to the second high.

[e] Growing Season is from April 15 through September 15. Daylight hours are between 0700-1900 PDT. The annual background concentration is applied to these concentrations.

Kitimat Airshed Emissions Effects Assessment
Scenario G_76.2 - Base Case without Refinery

2009 NO_2 Concentration Results

Averaging Period	Rank	2009 Maximum Concentrations [a] ($\mu g/m^3$)	% Change from 2008	Canada Air Quality Objectives [b] ($\mu g/m^3$)			US EPA Secondary Standards [c] ($\mu g/m^3$)	Maximum Date and time	
				MDL	MAL	MTL		Julien Day	Time
1-hour	1st	293	-5%		400	1000		246	400
1- hour	2nd	273	10%		400	1000		283	2300
3-hour	1st	231	8%					283	1800
3-hour	2nd	206	7%					277	2100
24-hour	1st	97	3%		200	300		277	0
24-hour	2nd	90	2%		200	300		167	0
Annual	Mean	29	-8%	60	100		100		
Annual Growing Season [d]	Mean	34							

[a] Modelled concentrations represent the maximum of the 2009 meteorological year modelled. Maximum modelled concentrations exclude receptors located on RTA's property and those on the channel. For short term averaging periods, the maximum NOx concentration is scaled to assume 80% of NOx is NO_2, then a background concentrations is added as determined by the 98th percentile of NO_2 data from three years in Quesnel. For the annual averaging period, the maximum NOx concentration is scaled to assume 75% of NOx is NO_2, then a background concentration is added as determined by Quesnel annual average data. Therefore the model output (MO) is updated as follows MO * NOx/NO_2 Ratio + Background = Reported Result

30.6 ppb	57.53 $\mu g/m^3$	80% NOx is NO_2	for 1 hour and 3 hour averaging period
23.9 ppb	44.93 $\mu g/m^3$	80% NOx is NO_2	for 24 hour averaging period
9.4 ppb	17.74 $\mu g/m^3$	75% NOx is NO_2	for Annual averaging period

[b] Comparisons to the PCO and WHO thresholds do not provide conclusions related to impacts on the environment or human health. MDL=Maximum Desirable Level, MAL=Maximum Acceptable level, MTL=Maximum Tolerable level.

[c] Secondary National Ambient Air Quality Standard (NAAQS) define the levels that protect the public welfare from any known or anticipated adverse effects of a pollutant.
[d] Growing Season is from April 15 through September 15. Daylight hours are between 0700-1900 PDT. The annual background concentration is applied to these concentrations.

Kitimat Airshed Emissions Effects Assessment

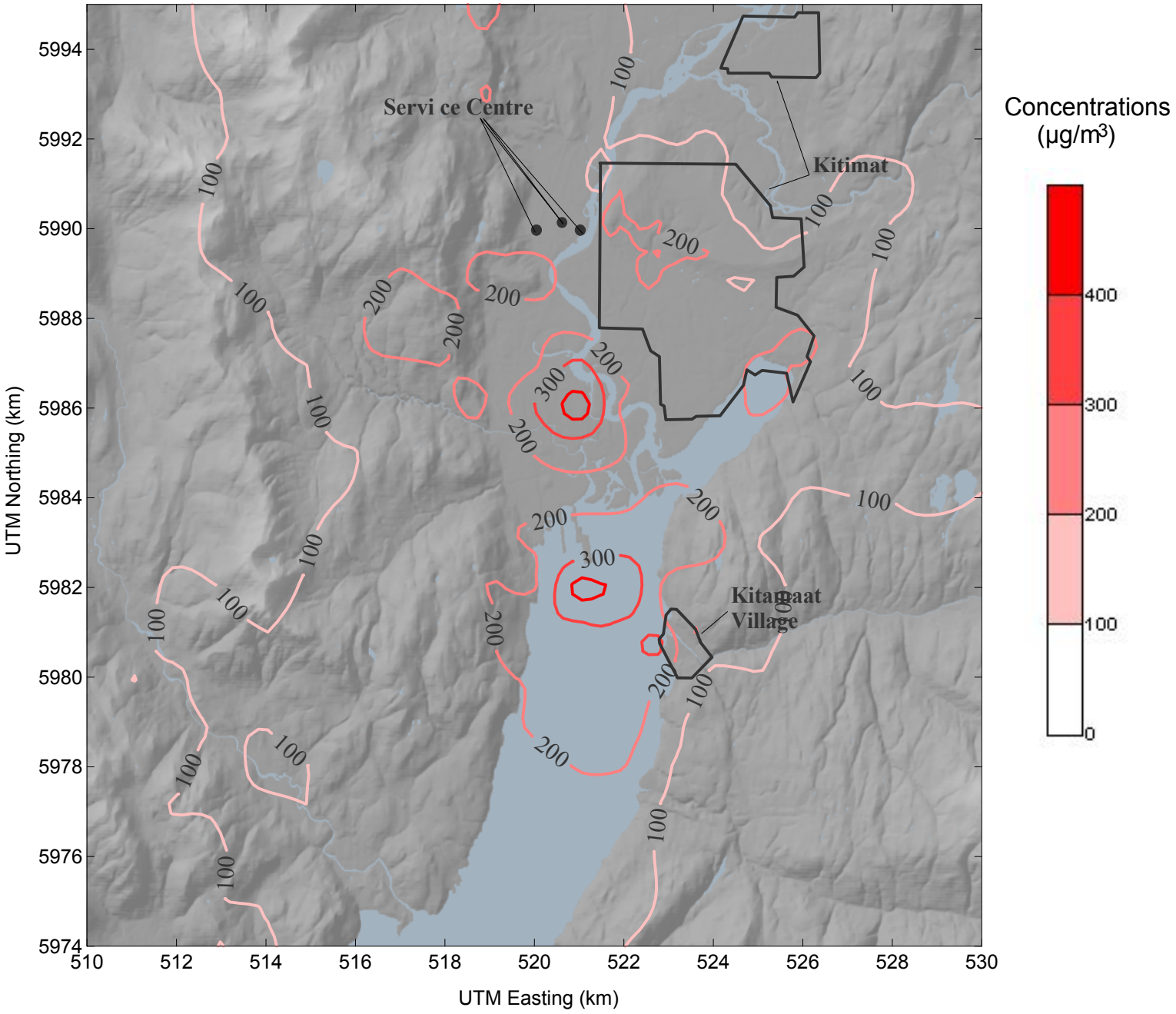
Scenario G_76.2 - Base Case without Refinery

** Note all values in this tab do not have the background concentration or NOx/NO2 ratio applied*

SO2 Concentration Comparison. Scenario G_76.2: 2009 vs 2008 meteorological data									
	SO_2 Concentration Difference				SO_2 Concentration % Difference				
	1 hr	3 hr	24 hr	Annual	1 hr	3 hr	24 hr	Annual	Annual
	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$					(Absolute)
All Near Field Receptors									
Minimum	-1315	-1088	-151	-7	-285%	-344%	-357%	-52%	0.01%
Average	123	38	11	0	19%	10%	13%	1%	17.39%
Maximum	1304	742	136	7	96%	97%	94%	76%	75.77%
Service Center, Kitimat, and Kitamaat Village Receptors Only									
Minimum	-326	-344	-54	-3	-283%	-344%	-357%	-52%	0%
Average	127	33	11	0	19%	8%	12%	-0.3%	16%
Maximum	1146	332	107	3	73%	73%	79%	61%	61%

NO2 Concentration Comparison. Scenario G_76.2: 2009 vs 2008 meteorological data									
	NO_x Concentration Difference				NO_x Concentration % Difference				
	1 hr	3 hr	24 hr	Annual	1 hr	3 hr	24 hr	Annual	Annual
	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$					(Absolute)
All Near Field Receptors									
Minimum	-179	-113	-23	-3	-118%	-198%	-122%	-59%	0.00%
Average	31	12	3	0	24%	17%	13%	-6%	16.854%
Maximum	827	274	49	2	93%	93%	94%	78%	78.16%
Service Center, Kitimat, and Kitamaat Village Receptors Only									
Minimum	-91	-113	-23	-2	-84%	-198%	-104%	-59%	0%
Average	33	13	3	0	26%	18%	13%	-6.9%	14%
Maximum	212	150	38	1	84%	81%	83%	58%	59%

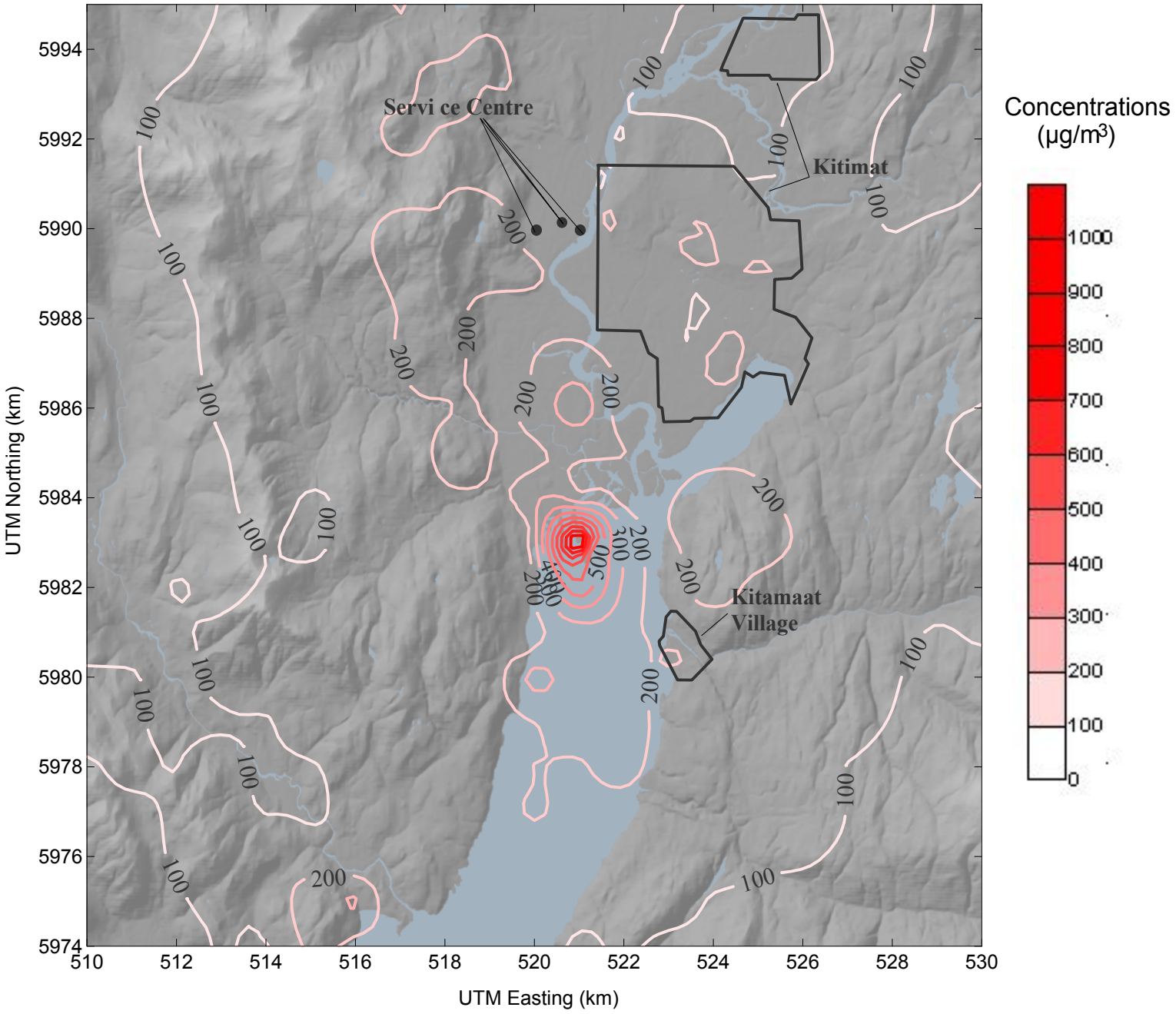
Maximum NO_2 Concentrations, 1 hour Average
2006 Meteorological Year
Scenario G_76.2



-x.x- = NO_2 Concentration (µg/m³)

* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m³.

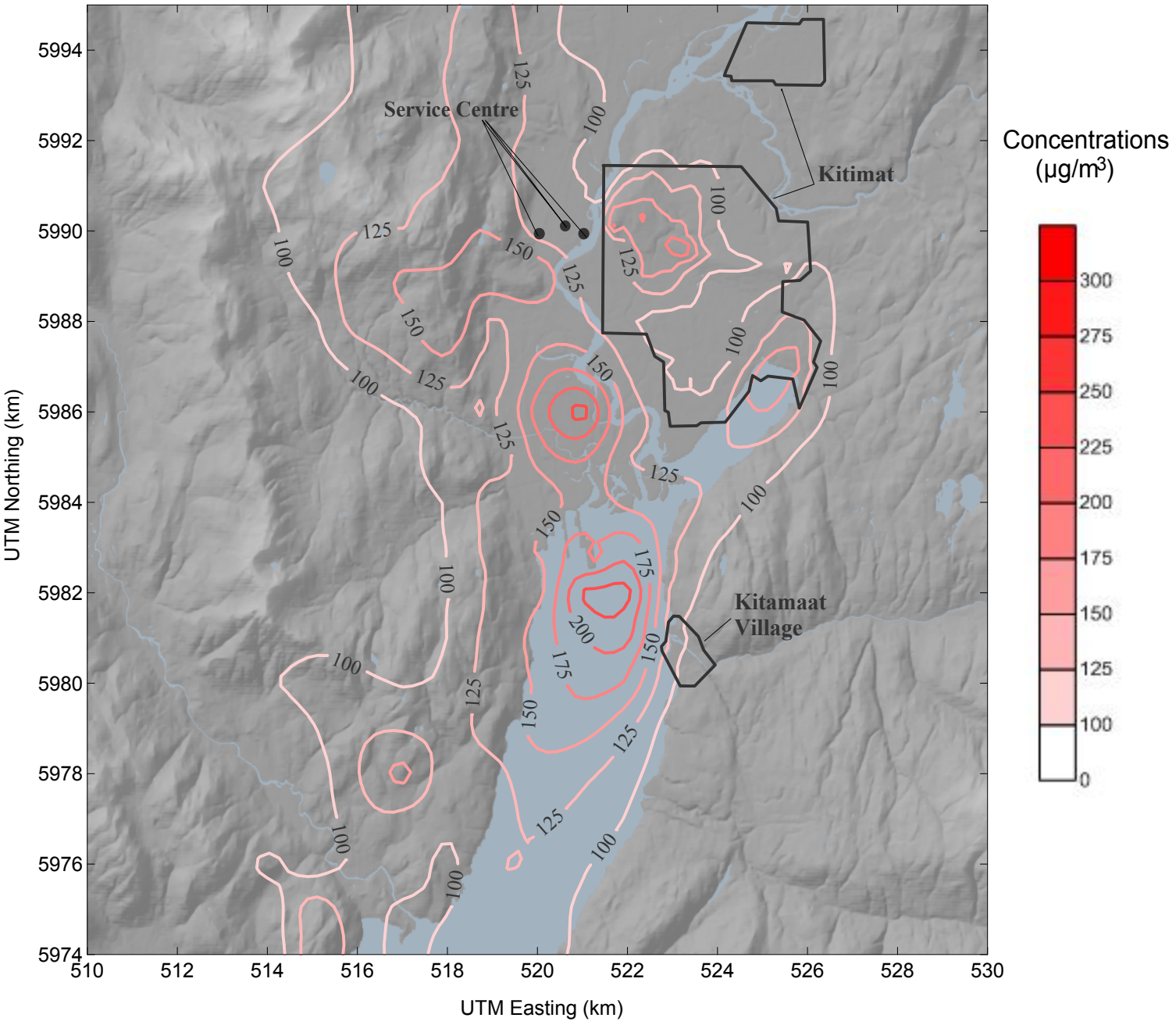
Maximum NO_2 Concentrations, 1 hour Average
2009 Meteorological Year
Scenario G_76.2



-x.x- = NO_2 Concentration (µg/m³)

* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m³.

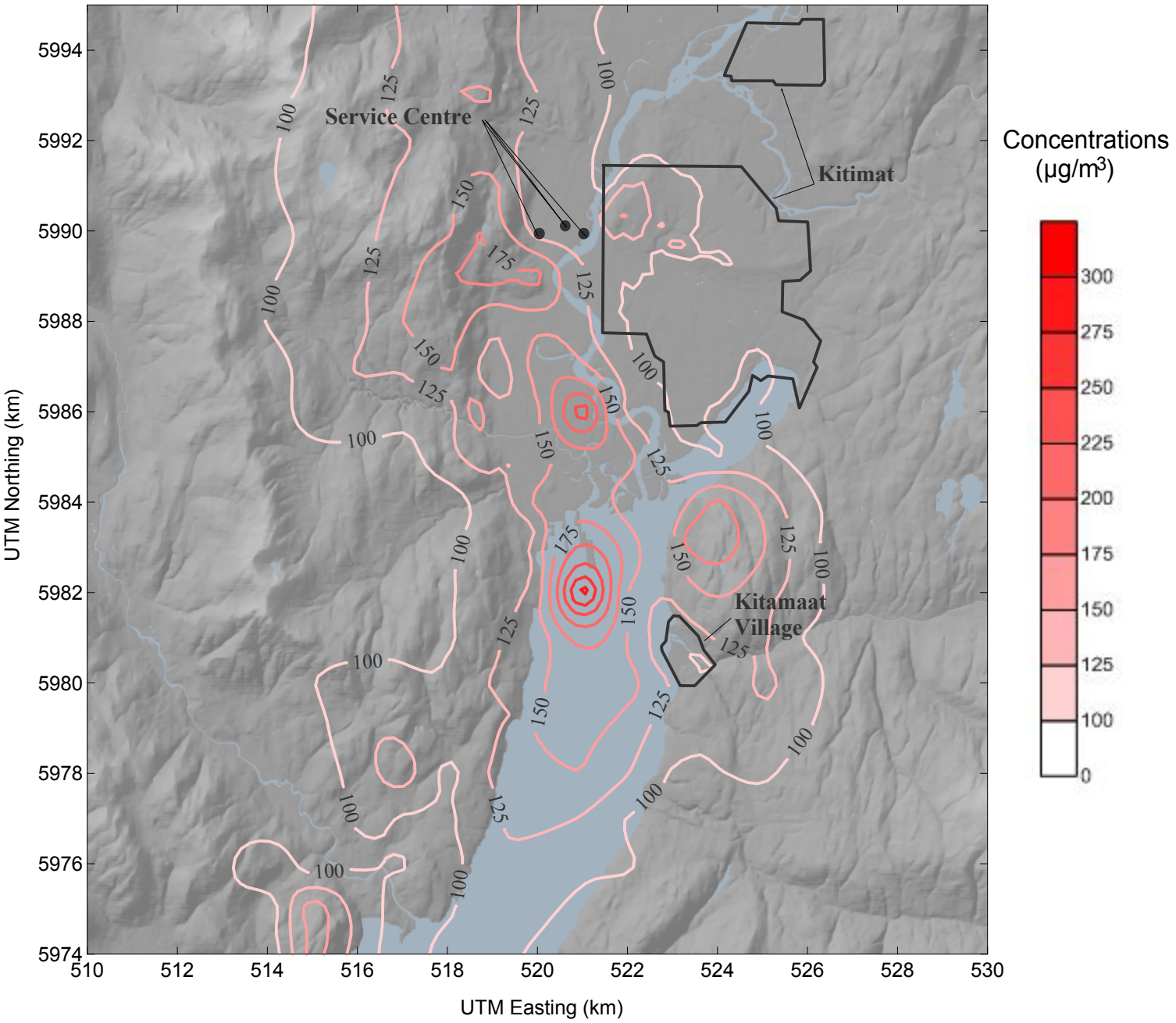
98th Percentile Daily Peak NO_2 Concentrations, 1 hour Average
2006 Meteorological Year
Scenario G_76.2



-x.x- = NO_2 Concentration (µg/m^3)

* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m^3), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m^3.

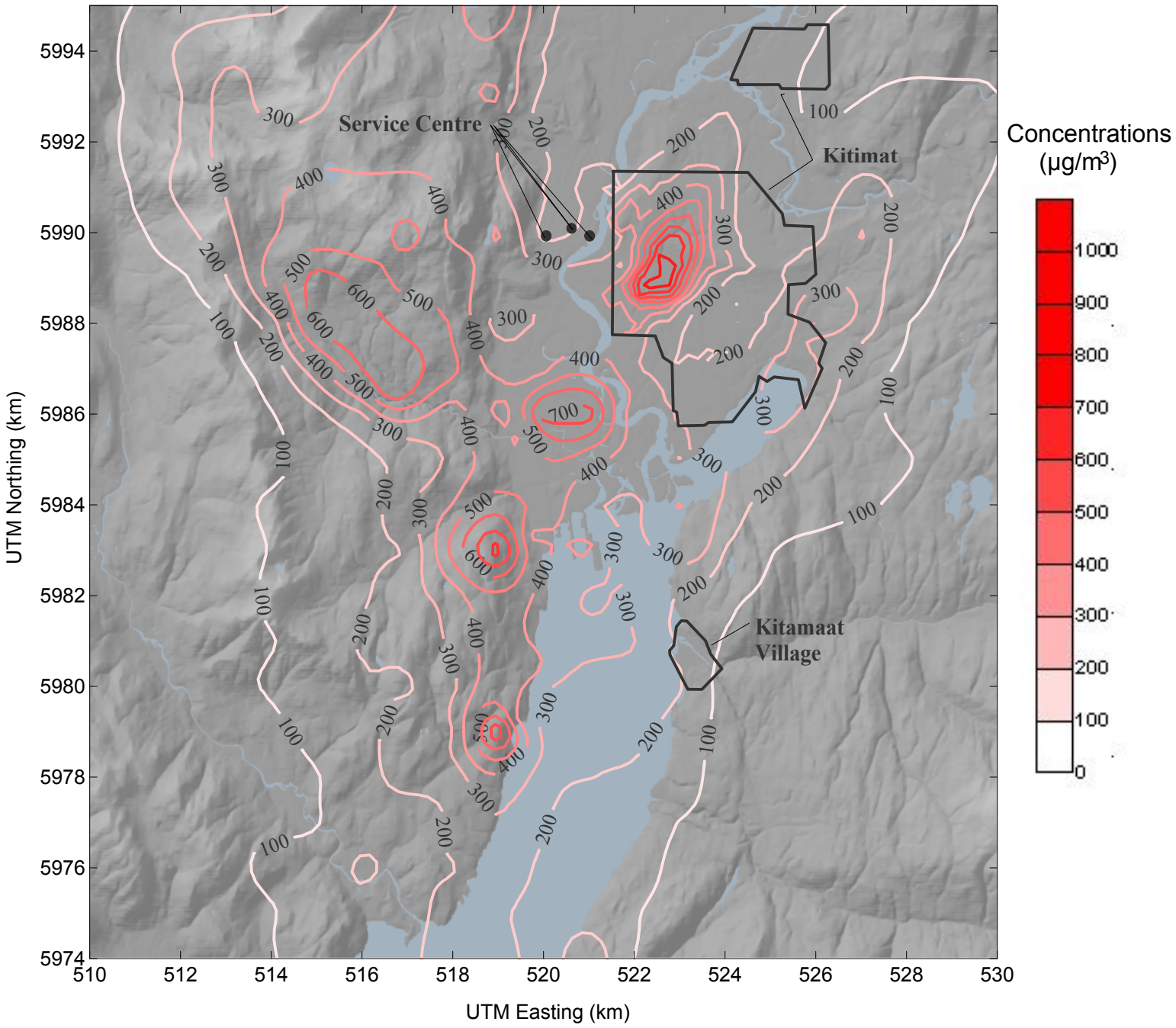
98th Percentile Daily Peak NO_2 Concentrations, 1 hour Average
2009 Meteorological Year
Scenario G_76.2



-x.x- = NO_2 Concentration (µg/m^3)

* The modelled NOx concentrations are scaled to assume 80% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 30.6 ppb NO_2 (57.53 µg/m^3), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 57.53 µg/m^3.

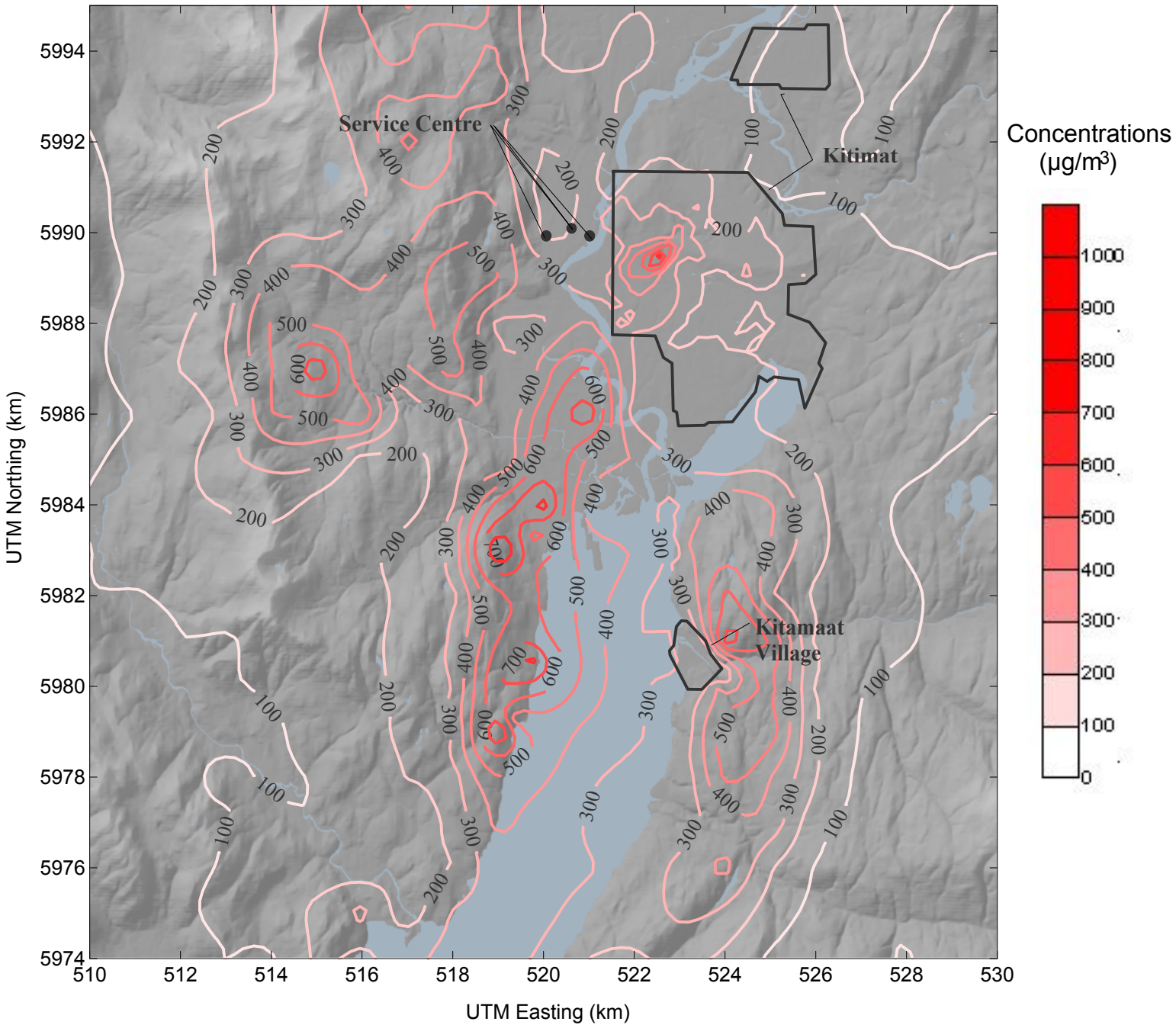
99th Percentile Daily Peak SO_2 Concentrations, 1 hour Average
2006 Meteorological Year
Scenario G_76.2



-x.x- = SO_2 Concentration (µg/m³)

* A background concentration of 1.5 ppb SO_2 (3.92 µg/m³), is added based on data from Kitamaat Village monitoring station. Therefore, all locations have a minimum SO_2 concentration of 3.92 µg/m³.

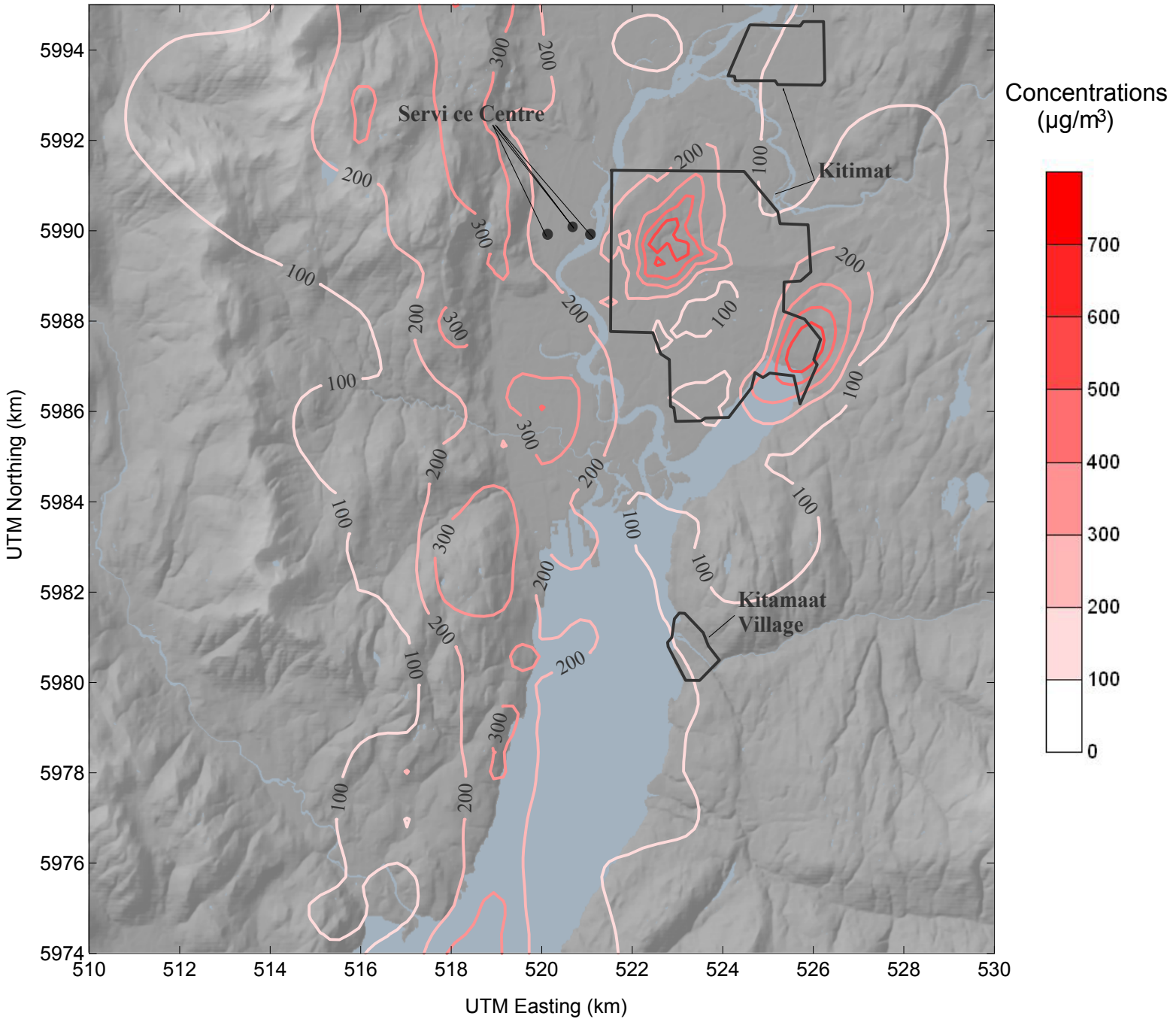
99th Percentile Daily Peak SO_2 Concentrations, 1 hour Average
2009 Meteorological Year
Scenario G_76.2



-x.x- = SO_2 Concentration (µg/m³)

* A background concentration of 1.5 ppb SO_2 (3.92 µg/m³), is added based on data from Kitamaat Village monitoring station. Therefore, all locations have a minimum SO_2 concentration of 3.92 µg/m³.

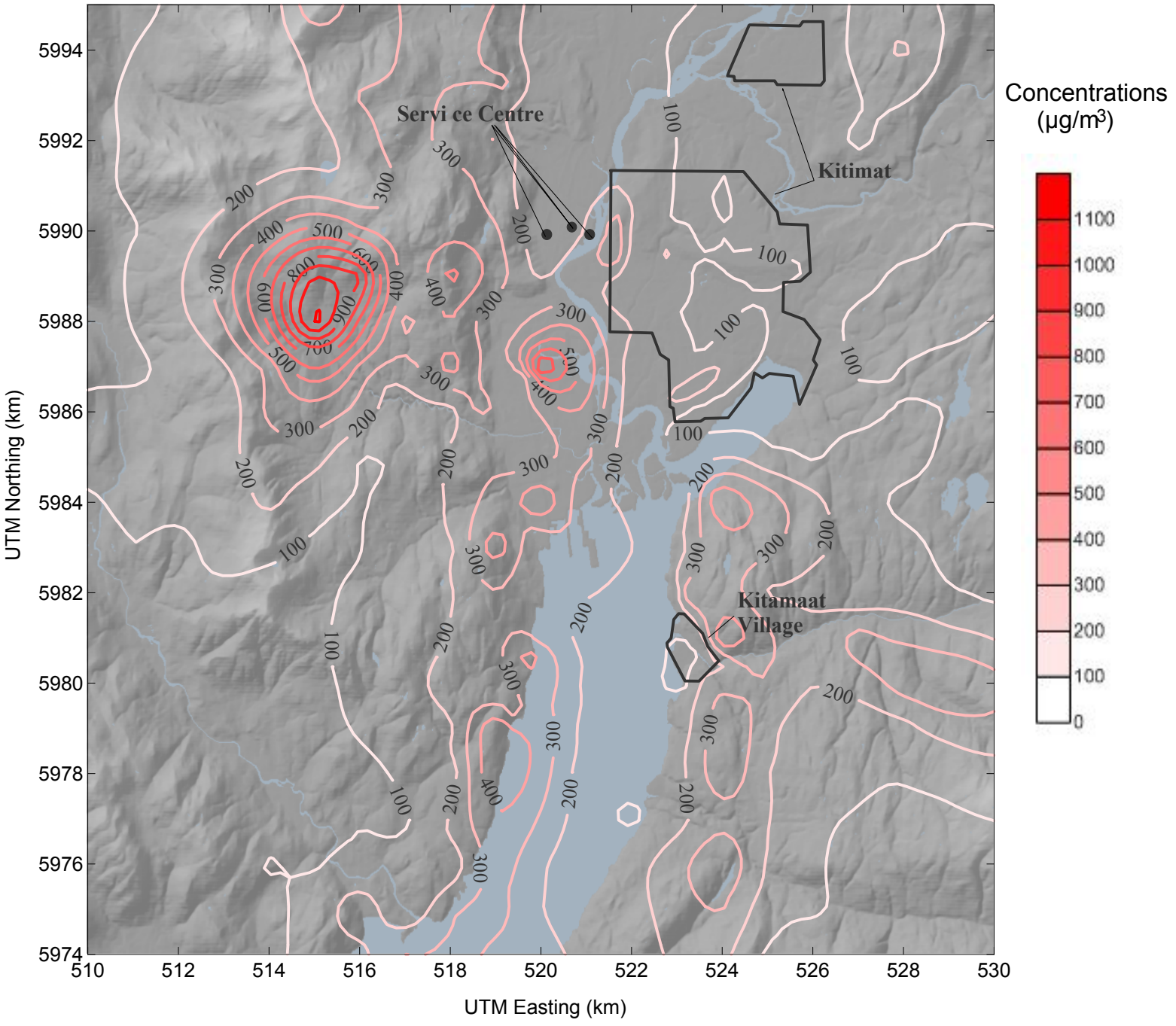
Maximum SO_2 Concentrations, 3 hour Average
2006 Meteorological Year, Growing Season (April 15 to September 15)
Scenario G_76.2



-x.x- = SO_2 Concentration (µg/m³)

* A background concentration of 1.5 ppb SO_2 (3.92 µg/m³), is added based on data from Kitamaat Village monitoring station. Therefore, all locations have a minimum SO_2 concentration of 3.92 µg/m³.

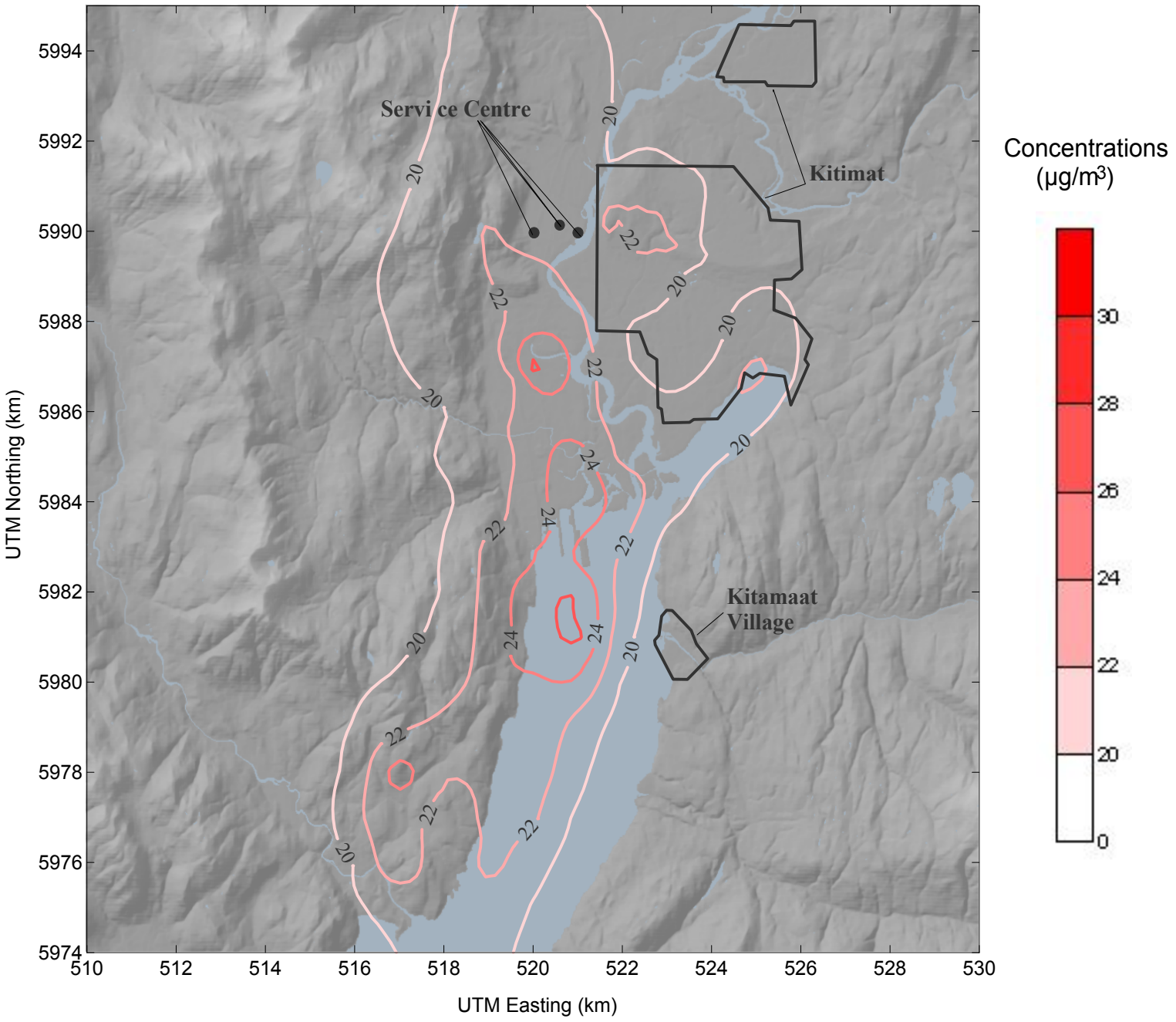
Maximum SO_2 Concentrations, 3 hour Average
2009 Meteorological Year, Growing Season (April 15 to September 15)
Scenario G_76.2



-x.x- = SO_2 Concentration (µg/m³)

* A background concentration of 1.5 ppb SO_2 (3.92 µg/m³), is added based on data from Kitamaat Village monitoring station. Therefore, all locations have a minimum SO_2 concentration of 3.92 µg/m³.

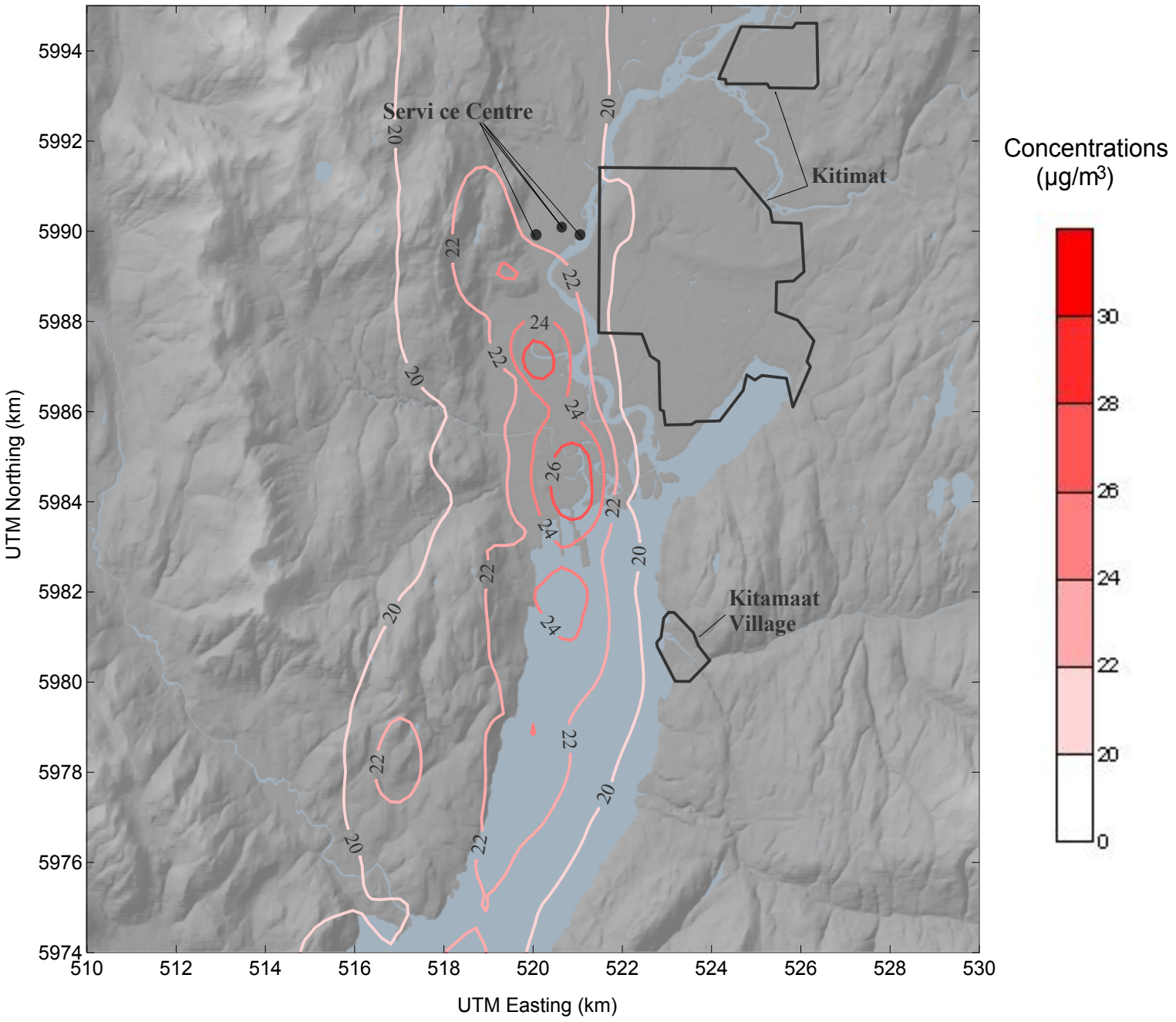
NO_2 Concentrations, Annual Average
2006 Meteorological Year
Scenario G_76.2



-x.x- = NO_2 Concentration (µg/m³)

* The modelled NOx concentrations are scaled to assume 75% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 9.4 ppb NO_2 (17.74 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 17.74 µg/m³.

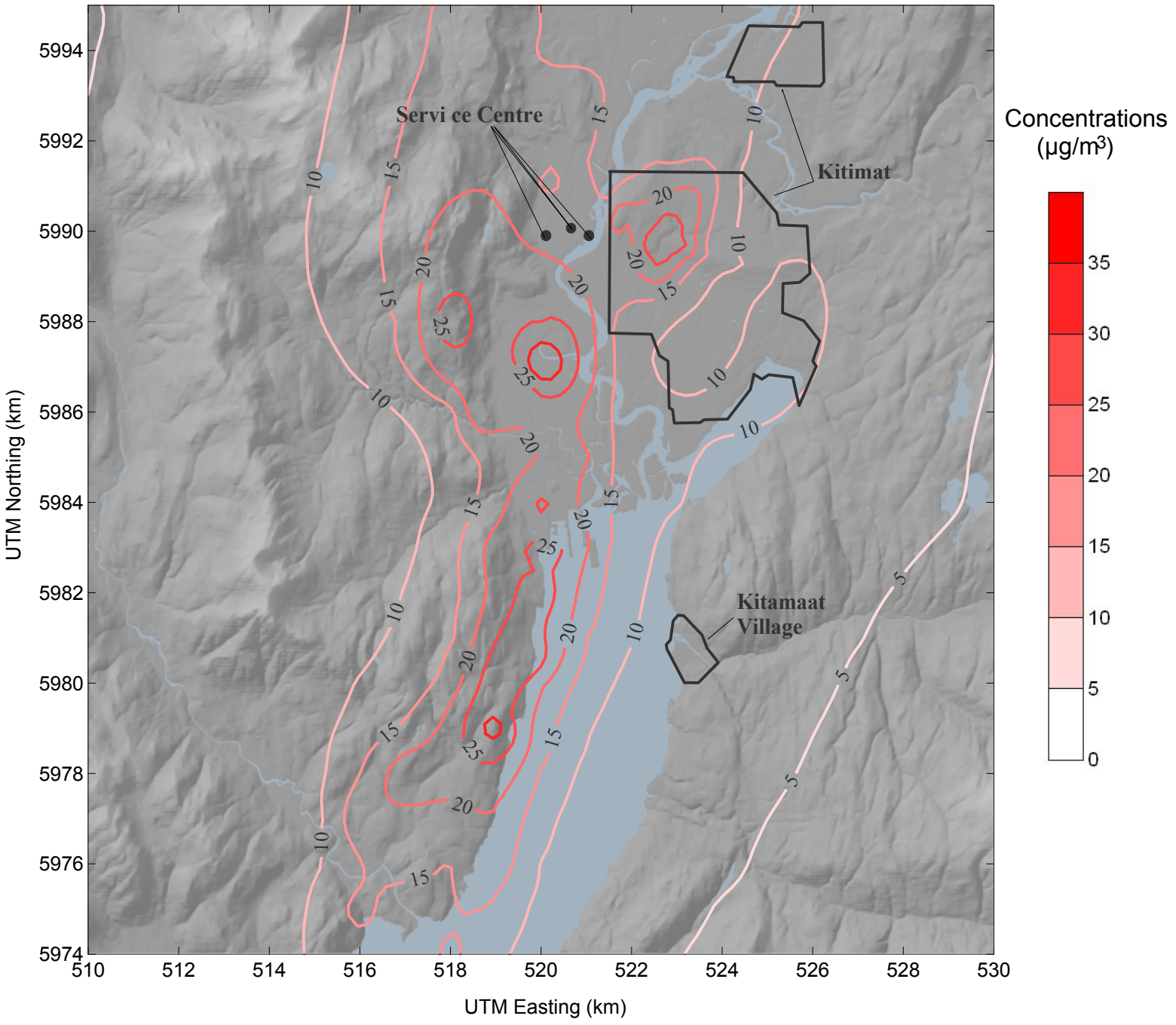
NO_2 Concentrations, Annual Average
2009 Meteorological Year
Scenario G_76.2



-x.x- = NO_2 Concentration (µg/m³)

* The modelled NOx concentrations are scaled to assume 75% of NOx is NO_2, based on USEPA guidance (June 28, 2010 and March 1, 2011). Additionally, a background concentration of 9.4 ppb NO_2 (17.74 µg/m³), is added based on data from Quesnel monitoring station. Therefore the minimum annual NO_2 concentration is 17.74 µg/m³.

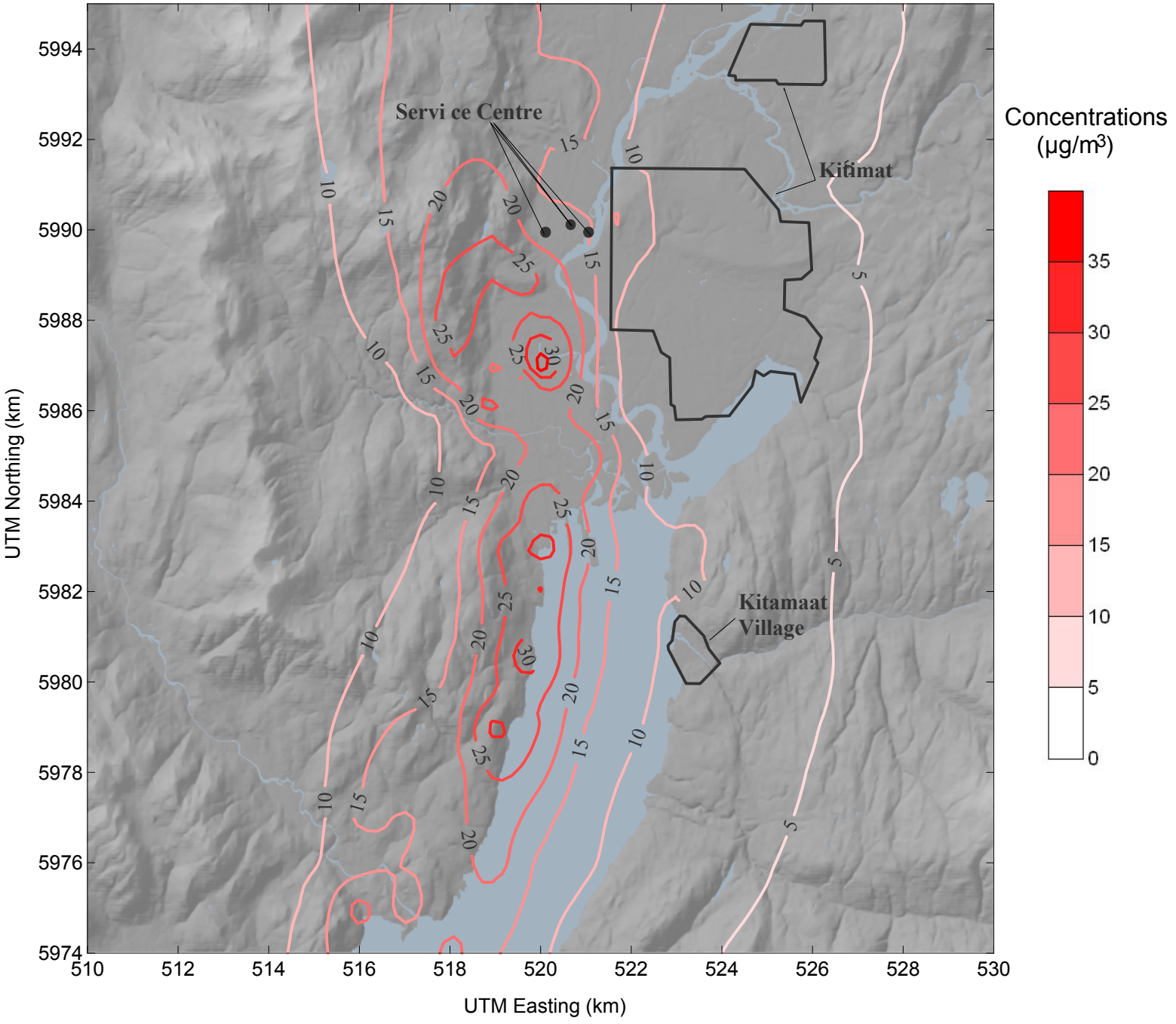
SO_2 Concentrations, Annual Average
2006 Meteorological Year
Scenario G_76.2



-x.x- = SO_2 Concentration (µg/m³)

* A background concentration of 0.4 ppb SO_2 (1.07 µg/m³), is added based on data from Kitamaat Village monitoring station. Therefore, all locations have a minimum SO_2 concentration of 1.07 µg/m³.

SO_2 Concentrations, Annual Average
2009 Meteorological Year
Scenario G_76.2



-x.x- = SO_2 Concentration (µg/m³)

* A background concentration of 0.4 ppb SO_2 (1.07 µg/m³), is added based on data from Kitamaat Village monitoring station. Therefore, all locations have a minimum SO_2 concentration of 1.07 µg/m³.

APPENDIX 9: SENSITIVITY STUDY OF PRECIPITATION ON DEPOSITION

As noted in Section 2.1.3.2, the precipitation data from surface station observations are not available on an hourly scale in the meteorological domain, and the MM5 dataset is used for precipitation information in CALMET processing and consequently in the CALPUFF modelling. Studies (such as Box et. al. 2006) show that MM5 tends to overestimate precipitation in coastal areas. Figure A9-1 compares the 2008 monthly cumulative MM5 precipitation data with observations at Kitimat and Terrace, BC, Canada. As is shown in Figure A9-1, MM5 overestimates precipitation at these two locations substantially. Therefore, there is need to evaluate the precipitation impact on deposition in CALPUFF modelling.

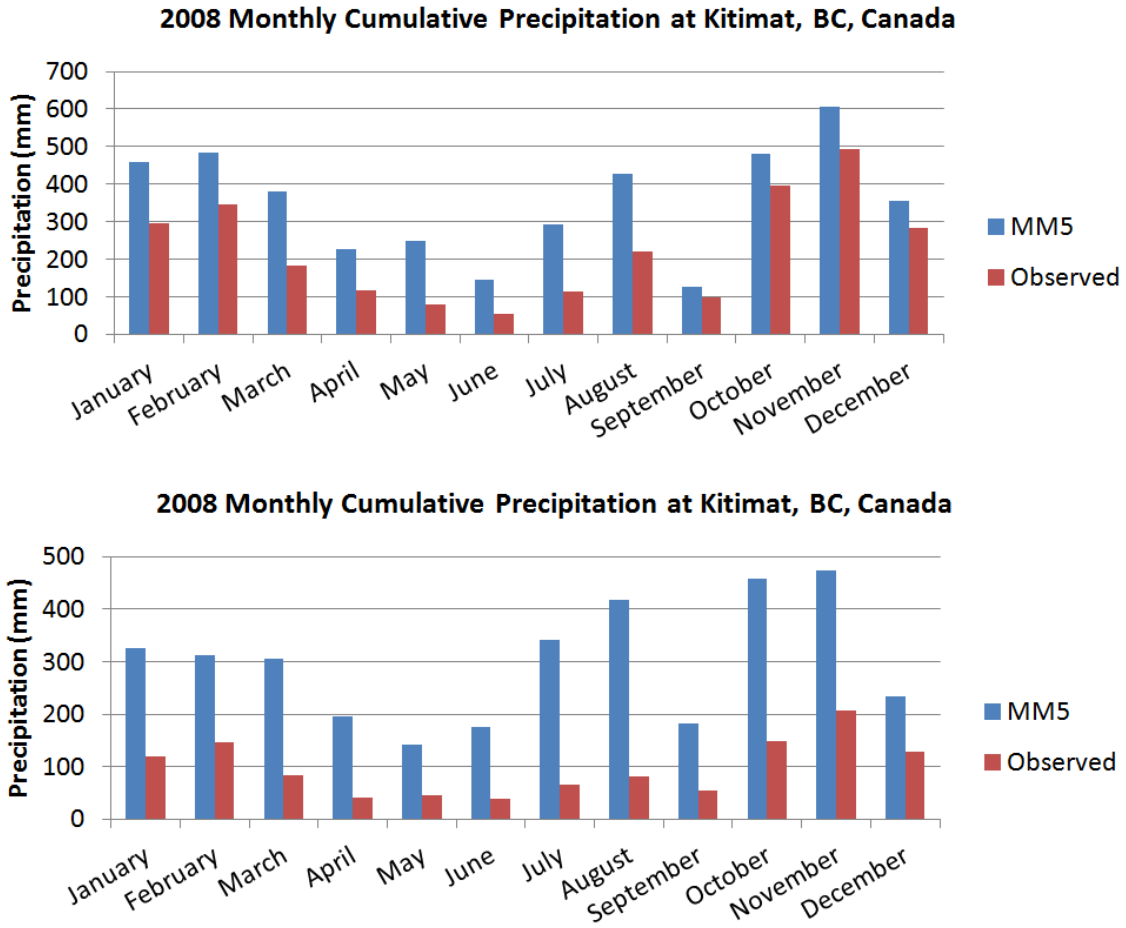


Figure A9-1. Comparison of MM5 predicted and observed 2008 monthly cumulative precipitation data at selected locations.

June and November in 2008 were selected as the driest month and wettest month respectively (according to 2008 data in Figure A9-1), and were therefore chosen for the sensitivity study of precipitation on deposition. Precipitation data in the CALPUFF-ready meteorological files were increased by a factor of 2 and decreased by a factor 0.17 for the two months respectively. These two factors are based on Figure A9-1 and 30-year historical precipitation data at Kitimat and Terrance with

consideration of climate change. All other parameters in the meteorological files were kept the same. The modified meteorological files were then used as inputs to conduct CALPUFF modelling for Scenario G_76.2. The sulphur deposition results at far- and near-source receptors from CALPUFF simulations with modified precipitation data were then compared with those from CALPUFF simulations with unmodified MM5 precipitation data (Base Case).

Figure A9-2 shows the partition of wet and dry S deposition for the base case simulation in the modelling domain. Generally speaking, in the wettest month, wet S deposition is higher than dry S deposition, especially when both are relatively high; while in the driest month, wet S deposition is lower than dry S deposition when both are relatively low.

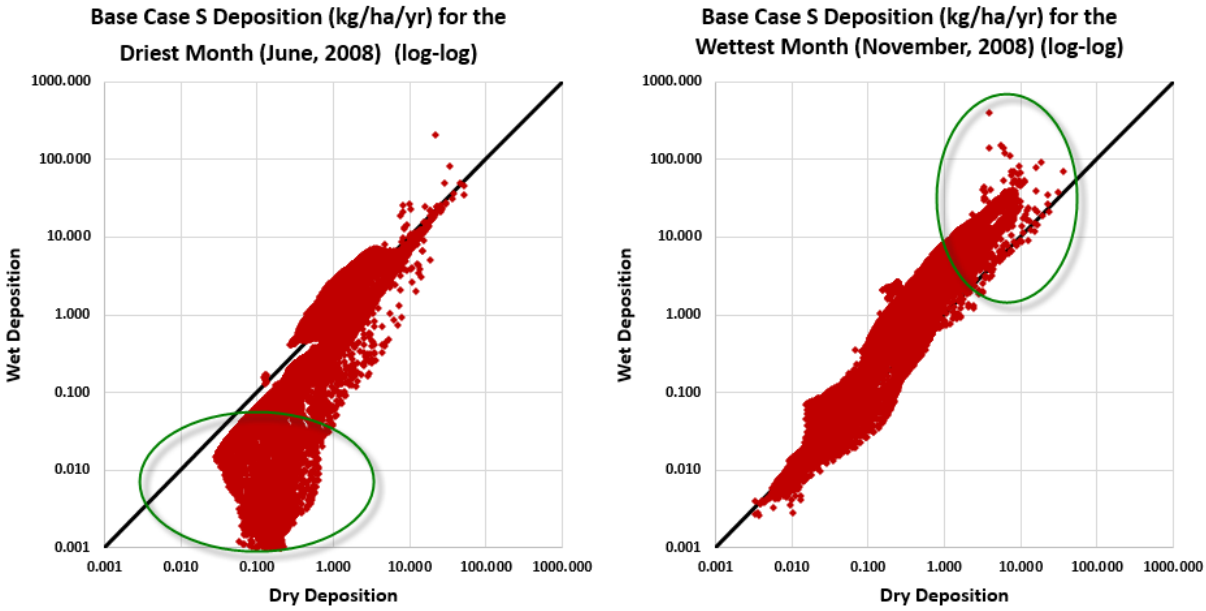


Figure A9-2. Partition of dry and wet S deposition for the base case simulation.

As expected, Figure A9-3 shows that precipitation has nearly no impact on the dry S deposition.

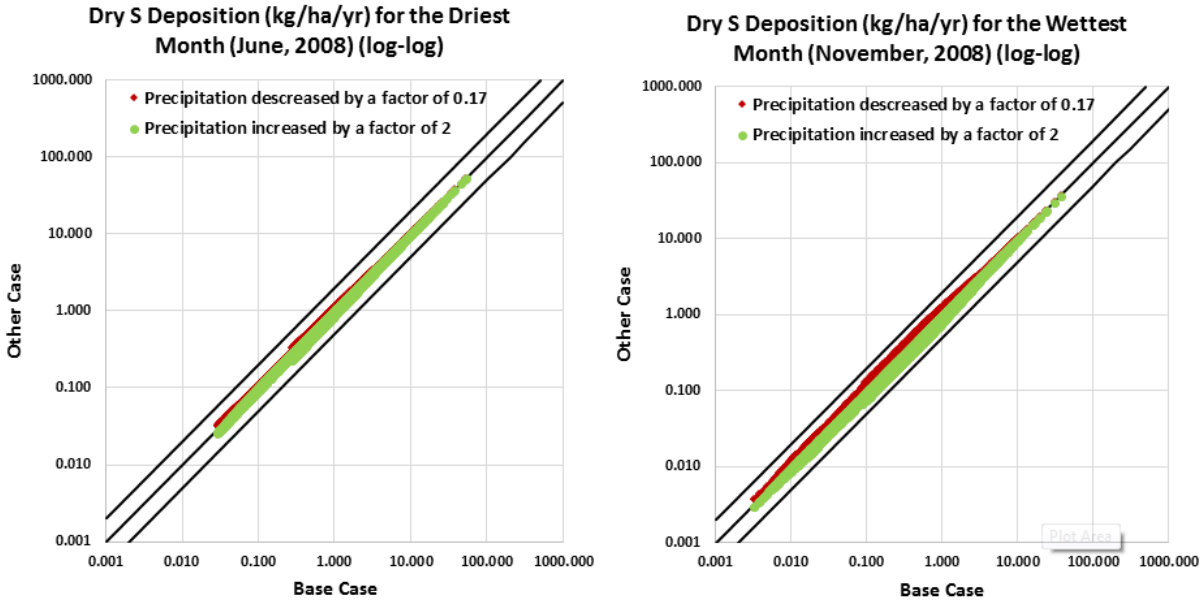


Figure A9-3. Precipitation impact on dry S deposition.

Figure A9-4 shows a dramatic precipitation impact on wet S deposition, especially when the wet S deposition is high: wet S deposition increases by a factor of 2 when precipitation increases by a factor 2; and wet S deposition decreases by a factor of 0.17 when precipitation decreases by a factor of 0.17. In the driest month, the decreasing precipitation tends to have a uniform decreasing impact on wet S deposition.

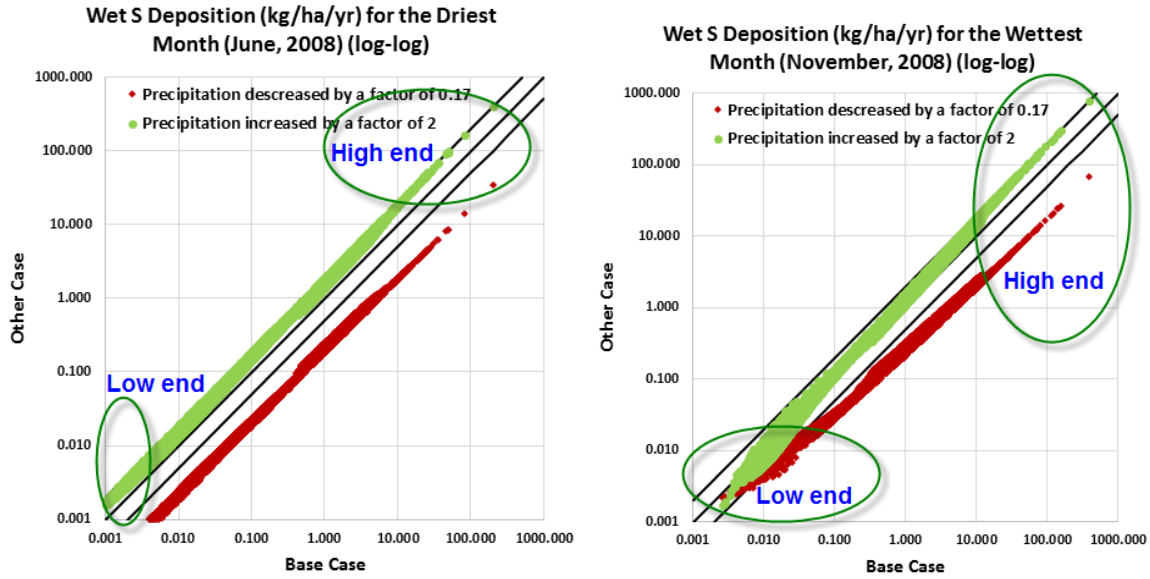


Figure A9-4. Precipitation impact on wet S deposition.

Figure A9-5 and Figure A9-6 show the total S deposition contours for the driest month and wettest month respectively.

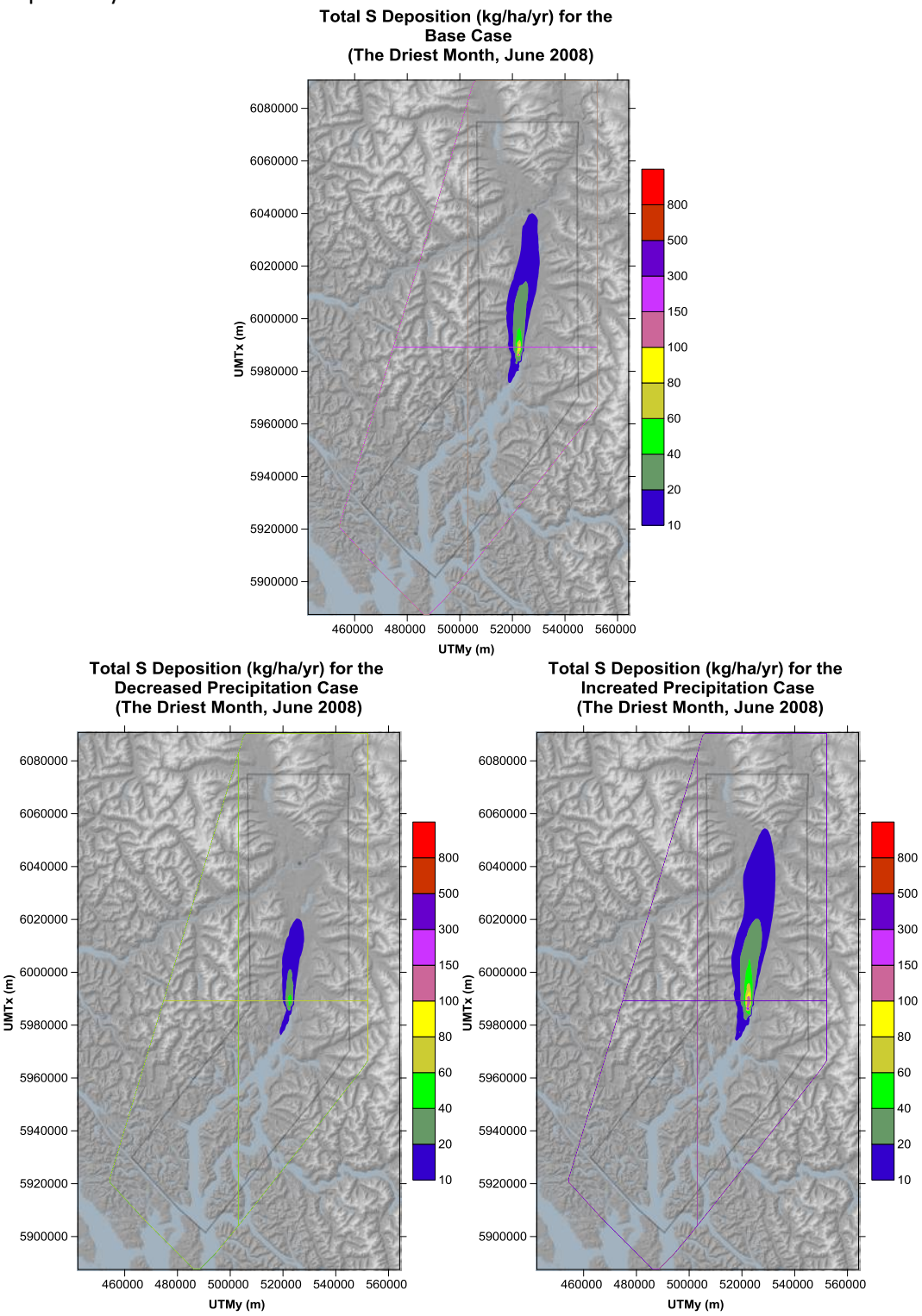


Figure A9-5. Total S deposition contour for the driest month.

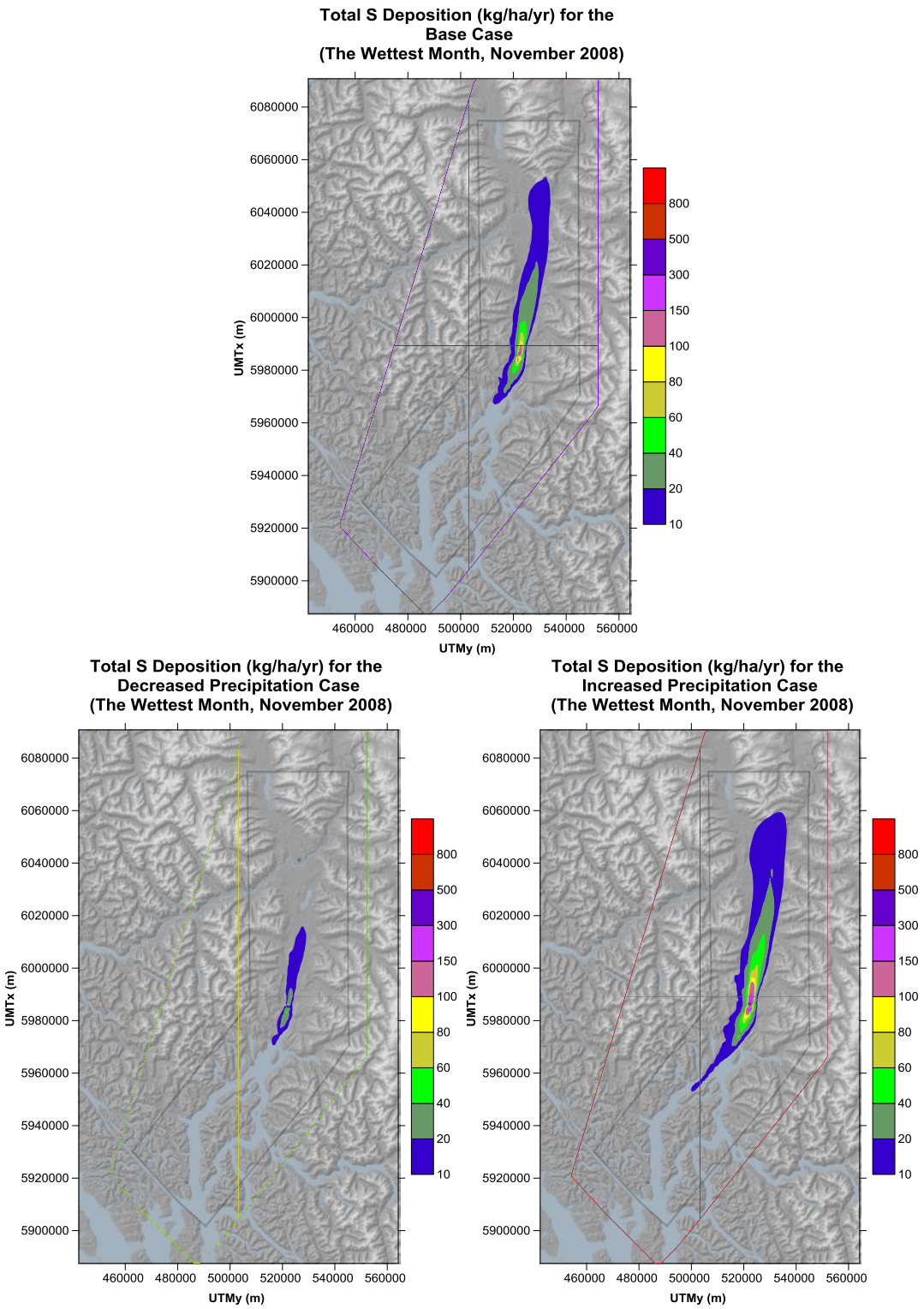


Figure A9-6. Total S deposition contour for the wettest month.

Compared with Figure A9-4, Figure A9-7 shows a much smaller impact of precipitation on monthly-averaged SO_2 concentration than on wet S deposition for both the driest month and the wettest month.

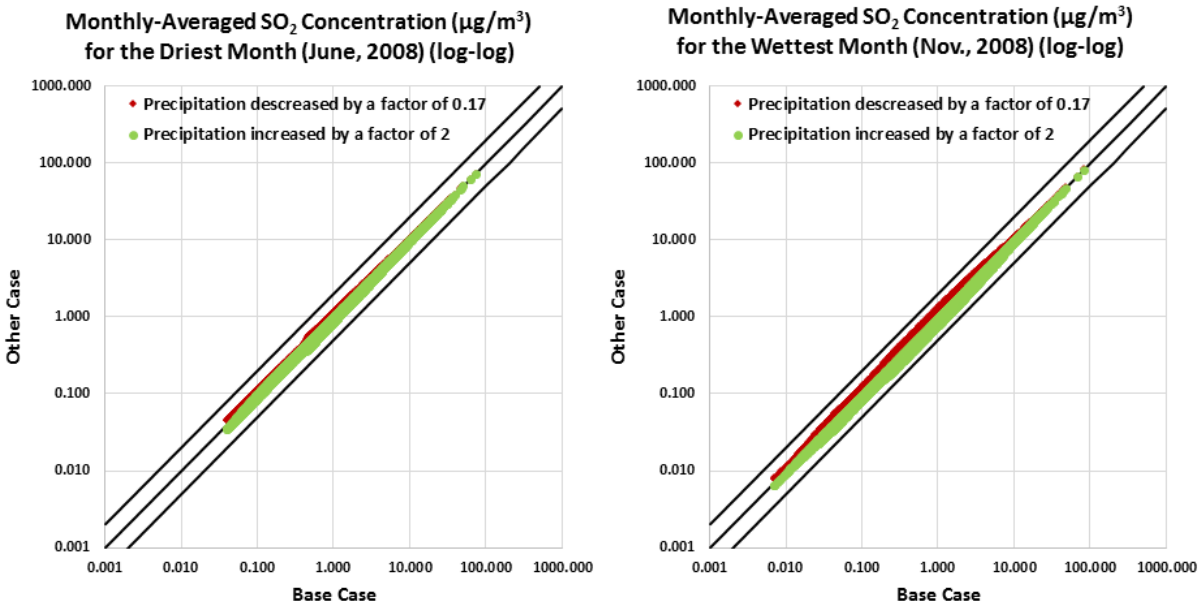


Figure A9-7. Precipitation impact on SO_2 concentration.

Figure A9-8 and Figure A9-9 show the monthly-averaged SO_2 concentration contours for the driest month and wettest month respectively.

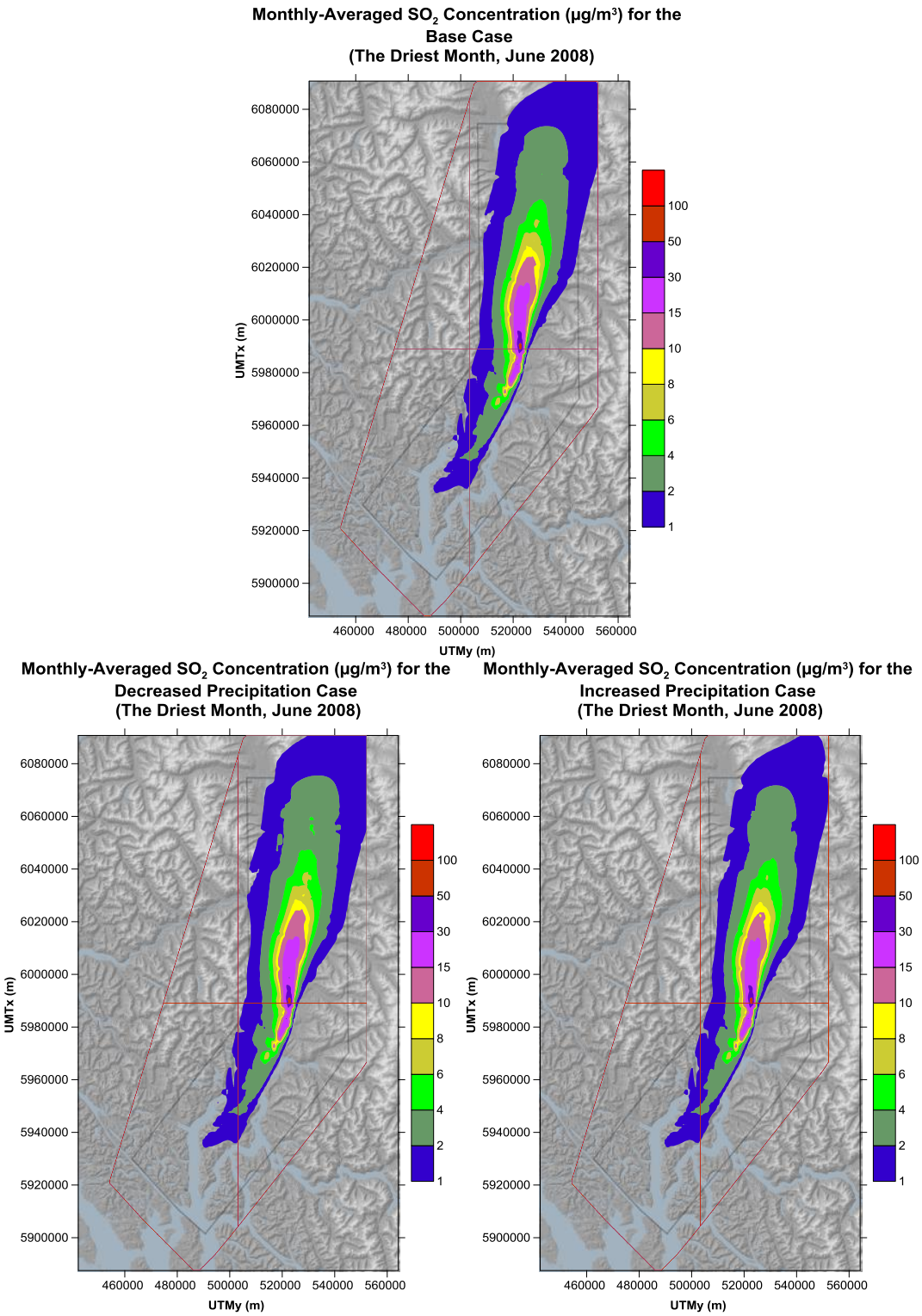


Figure A9-8. Monthly-averaged SO_2 concentration contour for the driest month.

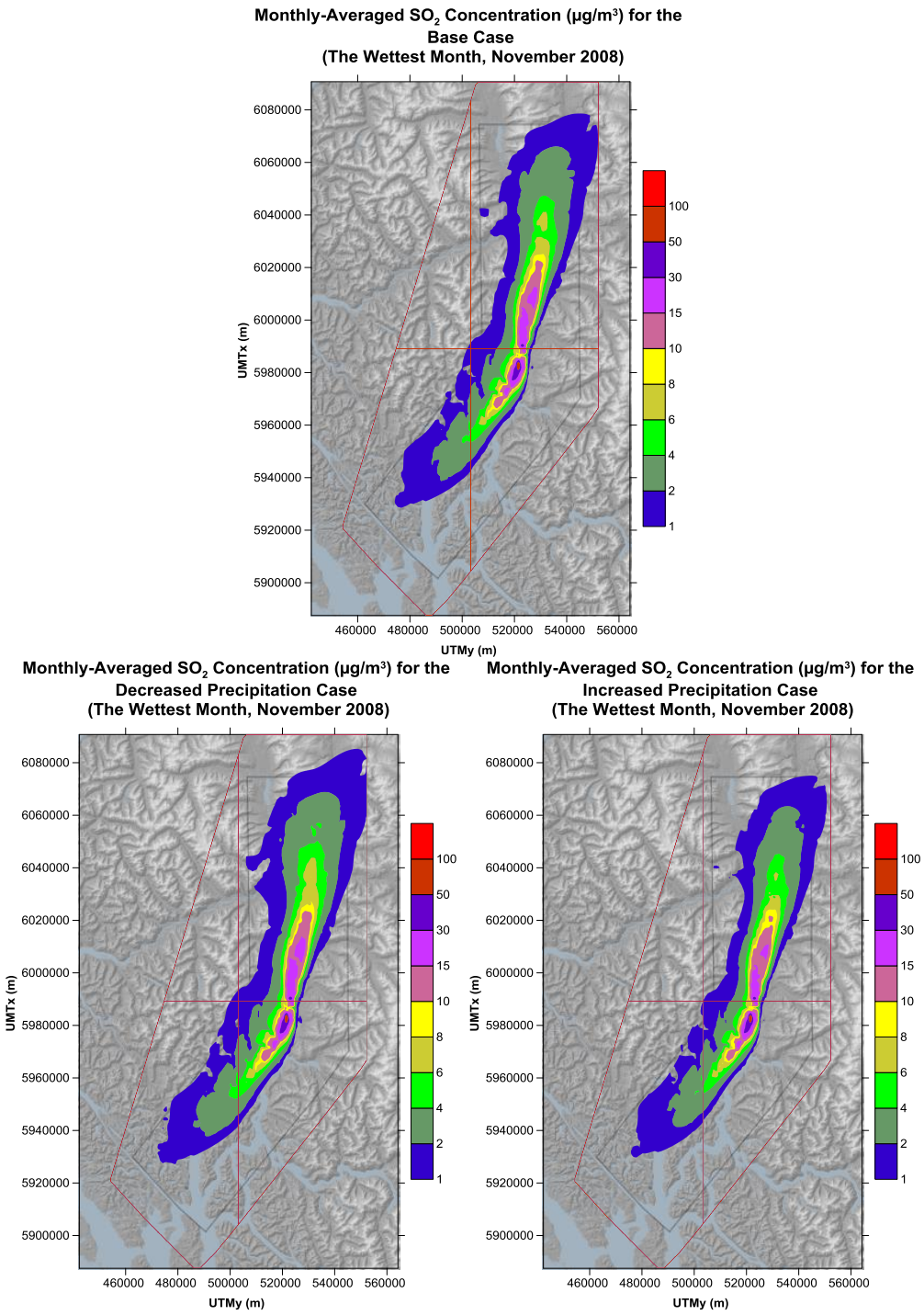


Figure A9-9. Monthly-averaged SO_2 concentration contour for the wettest month.

References Cited

Box, J.E., D.H. Bromwich, B.A. Veenhuis, L.-S. Bai, J.C. Stroeve, J.C. Rogers, K. Steffen, T. Haran, and S.-H. Wang. 2006. Greenland Ice Sheet Surface Mass Balance Variability (1988-2004) from Calibrated Polar MM5 Output. Journal of Climate 19(12).

APPENDIX 10: COMPARISON OF LAYERING-METHOD VERSUS SCENARIO-SPECIFIC-METHOD MODEL RUNS

List of Tables

List of Figures

Scenario G_76.2 - Base Case without Refinery

** Note all values in this tab do not have the background concentration or NOx/NO2 ratio applied*

SO2 Concentration Comparison. Scenario G_76.2: Layered minus Scenario-Specific									
	SO_2 Concentration Difference				SO_2 Concentration % Difference				
	1 hr	3 hr	24 hr	Annual	1 hr	3 hr	24 hr	Annual	Annual
	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$					(Absolute)
Minimum	-41.86	-30.53	-10.31	-3.69	-10%	-20%	-11%	-17%	0.00%
Average	0.12	0.011	-0.013	-0.001	0.05%	0.031%	0.01%	-0.04%	0.14%
Maximum	47.57	13.15	2.34	1.35	28%	9%	9%	7%	16.70%

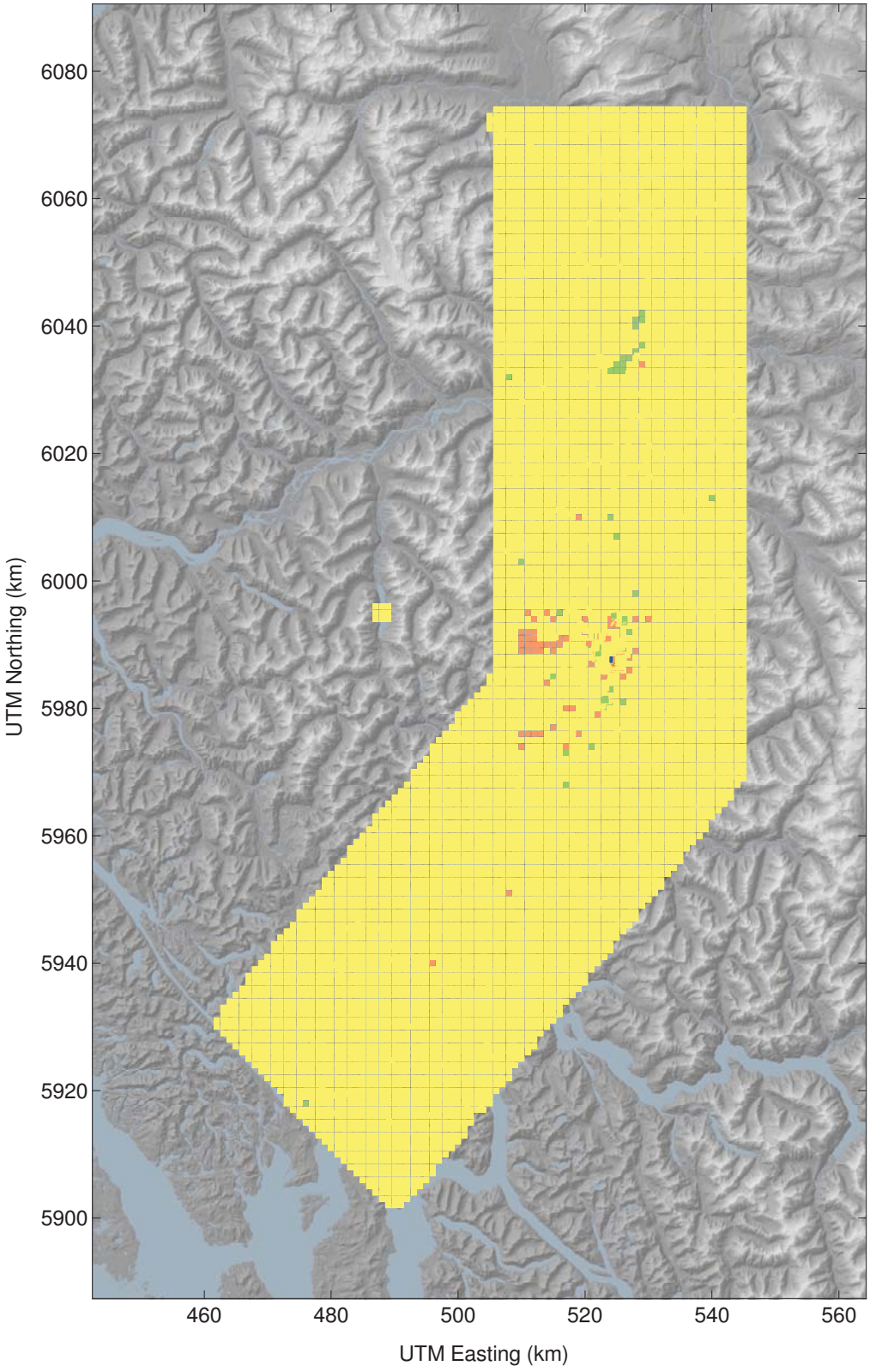
NOX Concentration Comparison. Scenario G_76.2: Layered minus Scenario-Specific									
	NO_x Concentration Difference				NO_x Concentration % Difference				
	1 hr	3 hr	24 hr	Annual	1 hr	3 hr	24 hr	Annual	Annual
	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$					(Absolute)
Minimum	-3.02	-1.26	-0.72	-0.01	-6%	-3%	-4%	-0.3%	0.00%
Average	0.00	0.000	0.00	0.000	0.00%	0.00%	-0.01%	-0.01%	0.015%
Maximum	4.47	0.41	1.05	0.04	6%	0.42%	3%	0.6%	0.64%

Scenario G_76.2 - Base Case without Refinery
Layered minus Scenario-Specific
** Note all values in this tab do not have the background concentration or NOx/NO2 ratio applied*

Sulpur Deposition Comparison. Scenario G_76.2: Layered minus Scenario-Specific			
	Sulfur Deposition Difference	Sulfur Deposition % Difference	% Difference
	(kg SO4/ha/yr)		(Absolute)
Min	-1.80	-5.9%	0.00%
Average	-0.0079	-0.22%	0.28%
Max	1.71	4.6%	5.90%

Nitrogen Deposition Comparison. Scenario G_76.2: Layered minus Scenario-Specific			
	Nitrogen Deposition Difference	Nitrogen Deposition % Difference	% Difference
	(kg Nitrogen/ha/yr)		(Absolute)
Min	-0.12	-20.1%	0.53%
Average	-0.018	-6.4%	6.41%
Max	0.00	-0.5%	20.09%

Maximum NO_x Concentration Difference, 1 hour Average
2008 Meteorological Year
Scenario G_76.2: Layered minus Scenario-Specific

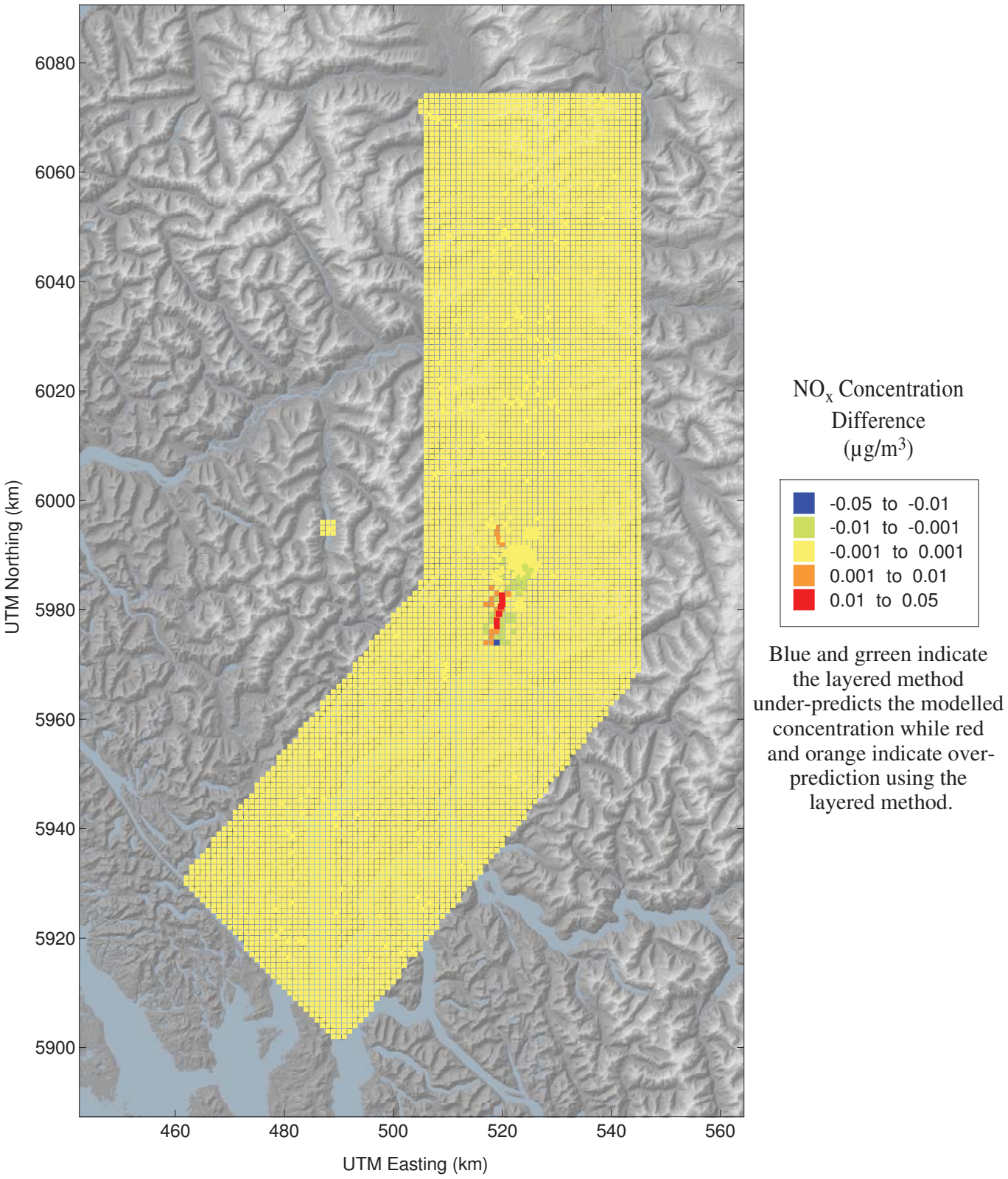


NO_x Concentration Difference ($\mu g/m^3$)

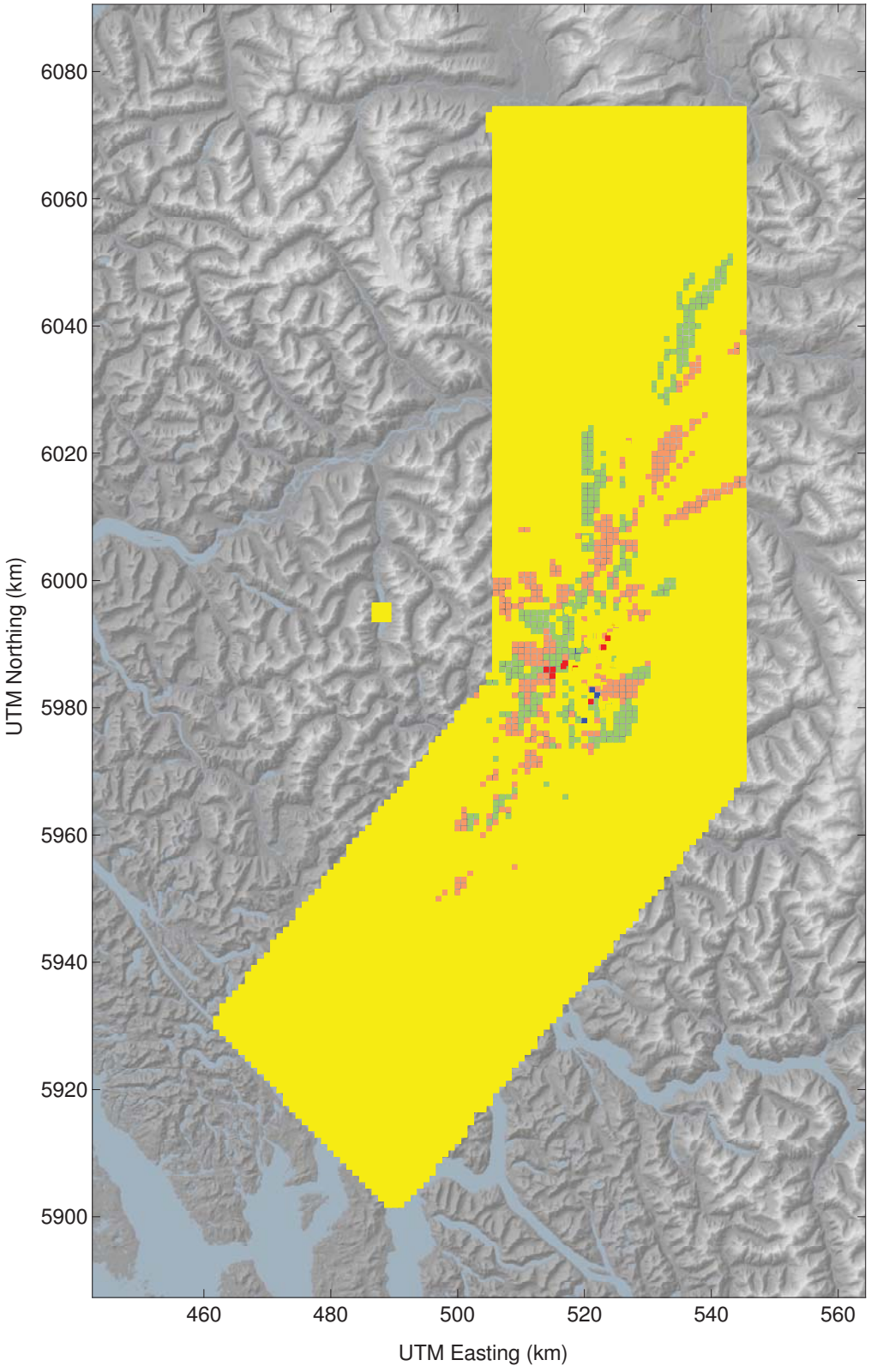
- -3.02 to -1
- -1 to -0.001
- -0.001 to 0.001
- 0.001 to 0.99
- 1 to 6

Blue and grreen indicate the layered method under-predicts the modelled concentration while red and orange indicate over-prediction using the layered method.

NO_x Concentration Difference, Annual Average
2008 Meteorological Year
Scenario G_76.2: Layered minus Scenario-Specific



Maximum SO_2 Concentration Difference, 1 hour Average
2008 Meteorological Year
Scenario G_76.2: Layered minus Scenario-Specific

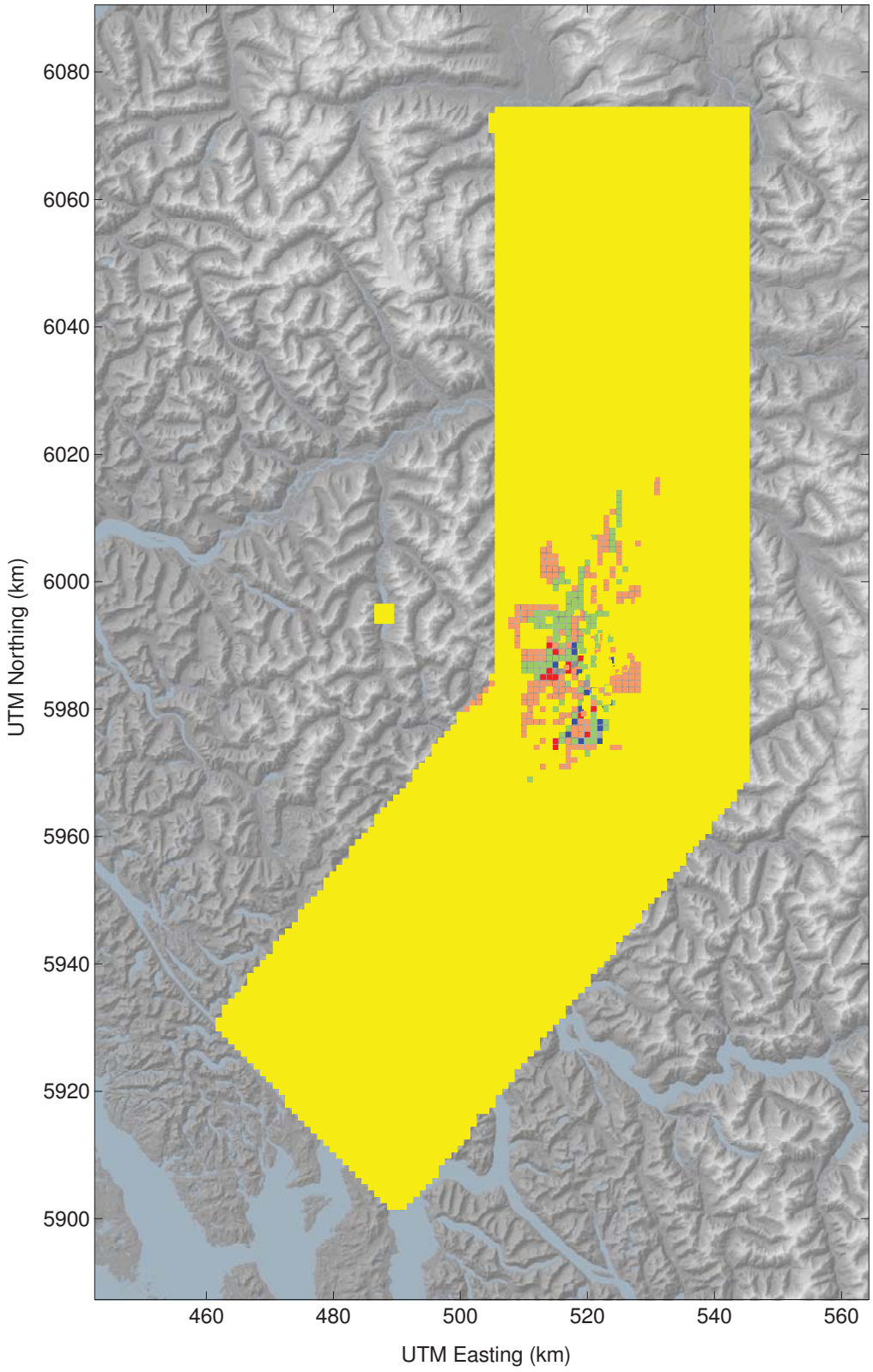


SO_2 Concentration Difference ($\mu g/m^3$)

- -42 to -10
- -10 to -0.3
- -0.3 to 0.3
- 0.3 to 10
- 10 to 48

Blue and grreen indicate the layered method under-predicts the modelled concentration while red and orange indicate over-prediction using the layered method.

Maximum SO_2 Concentration Difference, Annual Average
2008 Meteorological Year
Scenario G_76.2: Layered minus Scenario-Specific

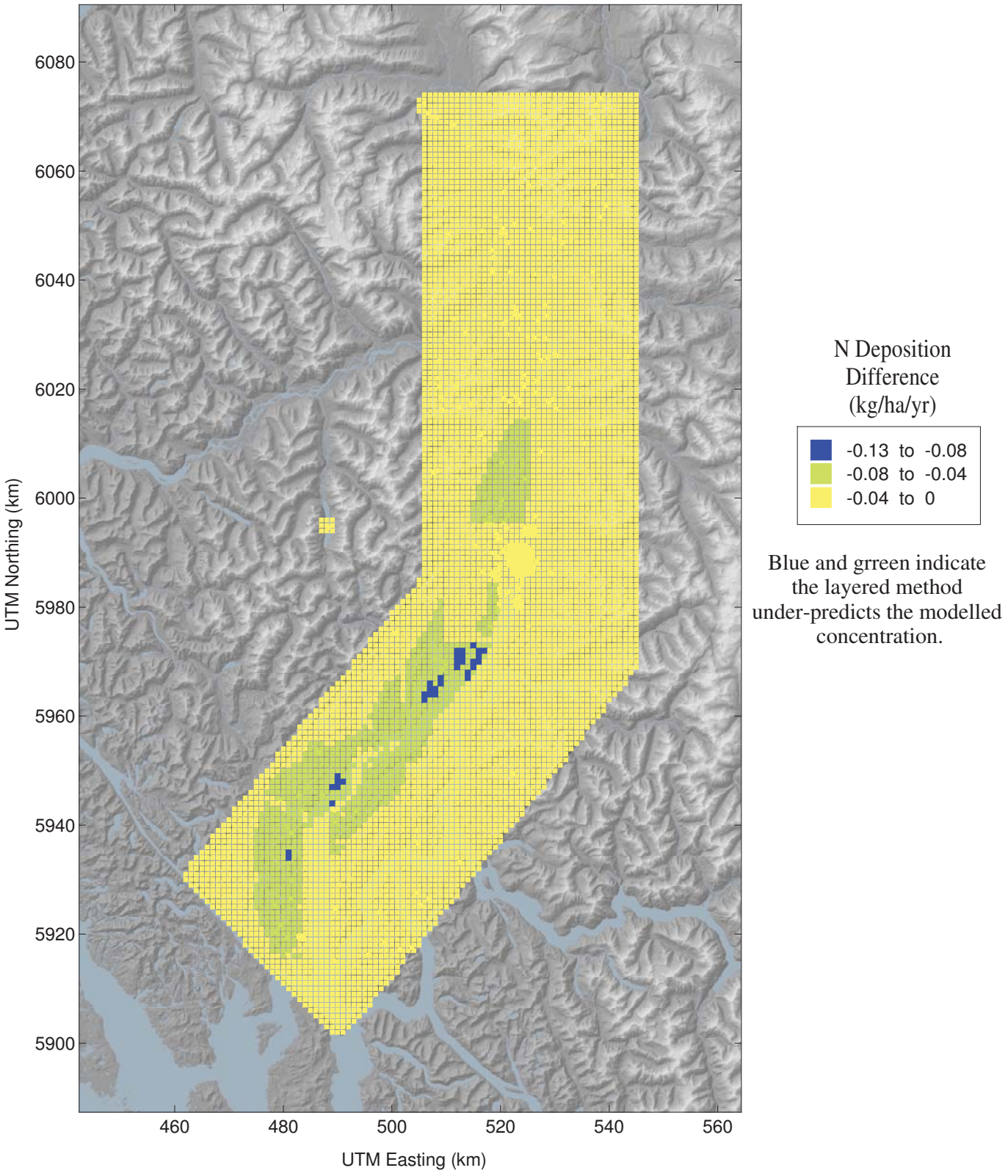


SO_2 Concentration Difference ($\mu g/m^3$)

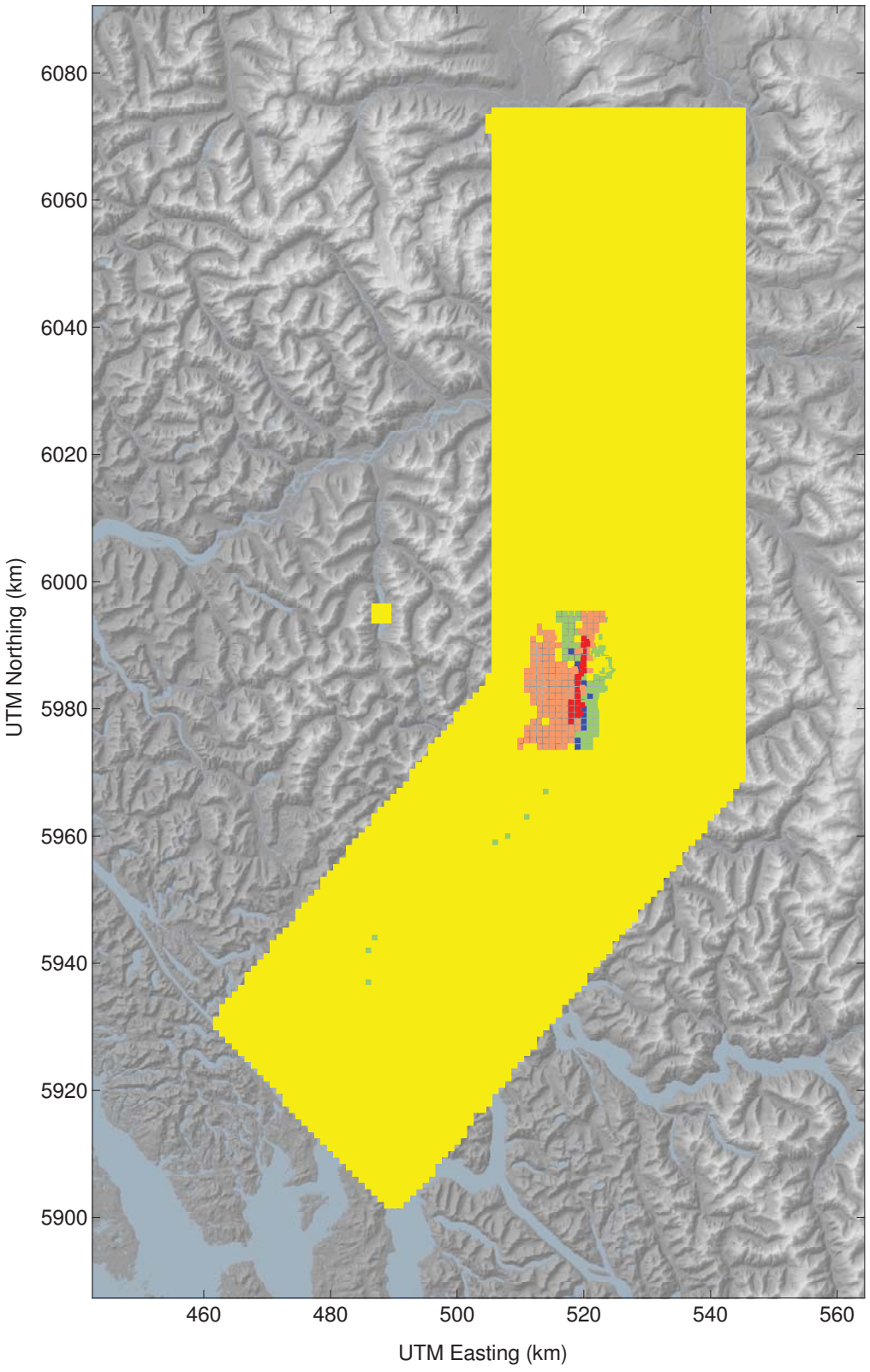
- -4 to -1
- -1 to -0.1
- -0.1 to 0.1
- 0.1 to 1
- 1 to 2

Blue and grreen indicate the layered method under-predicts the modelled concentration while red and orange indicate over-prediction using the layered method.

Nitrogen Deposition Difference, Annual Average
2008 Meteorological Year
Scenario G_76.2: Layered minus Scenario-Specific



SO_4 Deposition Difference, Annual Average
2008 Meteorological Year
Scenario G_76.2: Layered minus Scenario-Specific



SO_4 Deposition Difference (kg/ha/yr)

- -1.9 to -0.5
- -0.5 to -0.04
- -0.04 to 0.04
- 0.04 to 0.5
- 0.5 to 1.8

Blue and grreen indicate the layered method under-predicts the modelled concentration while red and orange indicate over-prediction using the layered method.

APPENDIX 11: RECENT CANADIAN STUDIES ON AMBIENT SULPHUR OXIDES, NITROGEN OXIDES, AND HEALTH

11.1 Methods

Peer-reviewed articles published between 2008 and March 17, 2014 were identified from the following sources:

1. Studies conducted in Canada on health effects of sulphur dioxide were selected from a Reference Manager Database created in October 2012 for the KMP SO_2 Technical Assessment (ESSA et al. 2013).
2. The literature on health effects of sulphur oxides was updated on March 17, 2014 using the US National Library of Medicine (PubMed) database. The following search was used: ((sulfur dioxide[MeSH Terms]) AND Canada) AND ("2012/10/01"[Date - Publication] : "3000"[Date - Publication]).
3. The reference list was used from the US EPA *Integrated Science Assessment for Oxides of Nitrogen – Health Criteria* (First External Review Draft), 2013 (http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=259167).
4. A PubMed search was conducted on March 17, 2014: ((Nitrogen Oxides[MeSH Terms]) AND Canada) AND ("2008/01/01"[Date - Publication] : "3000"[Date - Publication]).

11.2 Results

Short-term Exposure and Respiratory Morbidity

Burra et al. (2009) studied physician visits for asthma in Toronto. Data on physician visits between January 1992 and 31 December 2001 were obtained from the Ontario Health Insurance Plan (OHIP) database. Socioeconomic status (SES) was determined on the basis of a residential postal code. Air pollution data (NO_2, SO_2, O_3, $PM_{2.5}$) were obtained from six monitoring stations in the area. The mean daily NO_2 concentration was 39.2 ppb, and mean SO_2 concentration was 9.7 ppb. Single-pollutant models were used, and meteorological data were accounted for in the analyses. The associations were estimated using pollution levels on the day of the visit as well as using 2-day, 3-day, 4-day, and 5-day moving averages. Physician visits for asthma were significantly associated with SO_2 and NO_2 for most lag-structures. Estimated SO_2-associated risks for low socioeconomic status females were significantly greater than those for high socioeconomic status group. No effect of socioeconomic status on NO_2-related risks was seen. The authors discuss the following limitations: lack of individual-level SES data; unavailability of data on emergency department visits for asthma; “limited network of air pollution sampling stations to generate city-wide estimates of exposure”; and inability to account for fluctuations induced by seasonal allergies and changes in transportation patterns.

Cakmak et al. (2011) studied S association between air pollution (NO_2, $PM_{2.5}$, O_3) measured on the day of the survey, spirometry (FEV1 and FVC), heart rate and blood pressure in 5,604 subjects aged 6 to79 years who participated in the Canadian Health Measures Survey. The subjects were recruited from 15 sites grouped into five regions: British Columbia, the Prairies, Ontario, Quebec, and the Atlantic

provinces. Analyses were adjusted for age, sex, income, education, smoking, temperature and relative humidity. Mean 24-h average NO_2 concentration was 12.6 ppb. An interquartile increase in NO_2 (12.6 ppb) was associated with significantly lower FEV1 (-1.021% of predicted FEV1) and decreased FEV1/FVC ratio (-0.48% of predicted). See Cakmak et al. (2011) below for data on heart rate and blood pressure.

Dales et al. (2009) measured morning and evening FEV1 for 28 consecutive days in 182 asthmatic elementary school students in Windsor, Ontario. Hourly air pollution concentrations (NO_2, SO_2, $PM_{2.5}$ and O_3) were obtained from two fixed-site monitors. Analyses were adjusted for day of the week, number of hours spent outdoors, sex and study period, temperature and relative humidity. Single- and two-pollutant models were used. Mean SO_2 concentration was 6.0 ppb, mean NO_2 concentration was 19.1 ppb. Neither SO_2 nor NO_2 was significantly associated with FEV1 in single-or two-pollutant analyses.

In May-August 2010, Dales et al. (2013) conducted a randomized cross-over study of air pollution and lung function among 61 young, healthy non-smoking adults in Sault Ste. Marie, Ontario. The subjects were randomized to spend five consecutive, 8-hour days in a residential area approximately 0.9 km from a steel plant, or approximately 4.5 km away at a college campus. There was a nine-day washout period between the two exposure periods. FEV1, FVC, forced expiratory flow between 25% and 75% of the forced vital capacity (FEF25–75), total lung capacity (TLC), functional residual capacity (FRC), residual volume (RV), were measured. Hourly concentrations of pollutants (NO_2, SO_2, O_3) were measured by the Air Pointer®. The model for lung function analysis included temperature, humidity, and barometric pressure. Significant decreases in FEF25-75, TLC and RV were associated with an interquartile range increase (3.8 ppb) in SO_2. Significant decreases in FEV1, FEF25-75 and TLC were associated with an interquartile range increase in NO_2 (4.2 ppb).

Liu et al. (2009) measured lung function, markers of oxidative stress in breath condensate of 182 asthmatic children nine to 14 years of age in Windsor, Ontario. The measurements were performed once a week for four weeks. Levels of NO_2, SO_2, O_3 and $PM_{2.5}$ were obtained from two monitoring stations. Analyses were adjusted for testing period to reduce the impact of seasonality, for temperature and relative humidity. Because the subjects served as their own controls, there was no need to adjust for factors that were constant during the study period (age, sex, family history of asthma, family income). Single- and multi-pollutant analyses were used. Interquartile range increases in 3-day average SO_2 (5.4 ppb) and NO_2 (6.8 ppb) were associated with decreases in forced expiratory flow between 25% and 75% of forced vital capacity (FEF25-75%): -3.1% (95% CI: -5.8, -0.3%) and -2.8% (95% CI: -4.8, -0.8%), respectively. Interquartile range increases in SO_2 and NO_2 were associated with significant increase in markers of oxidative stress (TBARS) in breath condensate: 36.2% (95% CI: 15.7, 57.2%) and 21.8% (95% CI: 8.2, 36.0%), respectively.

Stieb et al. (2009) analyzed emergency department (ED) visits for respiratory and cardiac conditions in seven Canadian cities (Montreal, Ottawa, Edmonton, Saint John, Halifax, Toronto and Vancouver) during the 1990s and early 2000s. Air pollution data were obtained from the National Air Pollution Surveillance (NAPS) system, and weather data (temperature and relative humidity) from Environment Canada weather archive. ED visit data were obtained from participating institutions in each city. Daily average SO_2 levels were (ppb, mean±SD): Montreal 4.8±3.0, Ottawa 3.9±3.0, Edmonton 2.6±1.8, Saint John 7.7±7.0, Halifax 10.0±6.6 ppb, Toronto 4.2±2.6 ppb, Vancouver 2.6±1.5 ppb. Daily average NO_2 concentrations (ppb, mean±SD) were: Montreal 19.4±7.6, Ottawa 18.8±8.8, Edmonton 21.9±9.4, Saint John 9.3±5.5, Halifax 17.5±5.8, Toronto 22.7±7.6 and Vancouver 18.7±4.6. In a single-pollutant analysis, ED visits for asthma, chronic obstructive pulmonary disease or respiratory infections were not significantly linked with SO_2 or NO_2 concentrations lagged zero, one or two days. Results on ED visits for cardiac conditions are summarized in a relevant section below.

ED visits for asthma in relation to air pollution in Edmonton were studied by Szyszkowicz (2008a). Capital Health, academic-based health system of all the five hospitals in Edmonton, provided data on ED visits between 1992 and 2002. Environment Canada provided data on levels of SO_2, NO_2, O_3, CO, $PM_{2.5}$ and PM_{10} and on weather condition (temperature and relative humidity). Analyses were also adjusted for day of the week and were conducted by season, sex and age (<10 years and ≥10 years). The current day, 1-day and 2-day lagged exposures were used in the analyses. Mean concentrations were 2.6 ppb (SO_2) and 21.9 ppb (NO_2). In children under 10 years of age, a significant increase in relative risk for ED visits was associated with NO_2 exposure lagged two days in the period between April and September in males, females and both sexes and for the whole year in males. In the older age group, a significant increase in relative risk for ED visits was associated with NO_2 exposure lagged two days in the period between April and September in females. No significant associations were seen for SO_2. The authors discuss limitations "typical of this type of research", which include exposure measurement error and possible misclassification of the outcome (asthma diagnosis).

Short-term Exposure and Cardiovascular Morbidity

Cakmak et al. (2011) studied the association between air pollution (NO_2, $PM_{2.5}$, O_3) measured on the day of the survey, heart rate, blood pressure and spirometry in 5,604 subjects aged six to 79 years who participated in the Canadian Health Measures Survey. The subjects were recruited from 15 sites grouped into five regions: British Columbia, the Prairies, Ontario, Quebec, and Atlantic provinces. Analyses were adjusted for age, sex, income, education, smoking, temperature and relative humidity. Mean 24-h average NO_2 concentration was 12.6 ppb. An interquartile range increase in NO_2 (12.6 ppb) was associated with higher resting diastolic (+1.33) and systolic (+1.108) blood pressure.

Goldberg et al. (2008) monitored for two months oxygen saturation, pulse rate, weight and temperature in 31 subjects (aged 50 to 85 years) with congestive heart failure in Montreal. Data on air pollution (NO_2, SO_2, CO, O_3, $PM_{2.5}$) and weather conditions were obtained from fixed-site monitoring stations. The models included: consumption of salt; intake of fluids and being ill the day before; and weather variables (maximum temperature and relative humidity, changes in barometric pressure from the previous day). The authors did not use multi-pollutant models. Air pollutant concentrations lagged zero or one day and 3-day means were used. Neither oxygen saturation nor pulse rate was associated with NO_2 concentrations using any lag. Daily average SO_2 concentration lagged one day (interquartile range 8.6 $\mu g/m^3$) was significantly positively associated with pulse rate and significantly negatively associated with oxygen saturation.

Liu et al. (2011) conducted a randomized controlled crossover study of cardiovascular physiology in the group of 61 young adults in Sault Ste. Marie, Ontario described by Dales et al. (2013) (see section on short-term exposure and respiratory health above). The subjects were involved daily in 30-minute moderate intensity exercise. Blood pressure and pulse rate were measured daily and post exercise. Flow-mediated endothelium-dependent vasodilation (FMD) was measured using a Vivid i BT09 portable ultrasound machine. Outside temperature, relative humidity, barometric pressure, wind speed, day-of-the-week, and sex were considered as confounders; covariates that were significant at $p < 0.20$ were included in the model. Interquartile range increases in NO_2 (5 ppb) and SO_2 (2.9 ppb) measured on the same day were associated with small increases in pulse rate; NO_2 was also associated with a small decrease in FMD. No significant associations were seen for SO_2 or NO_2 with 1-day lag. After a 30-minute exercise, SO_2 concentration measured during exercise (interquartile range increase 3.6 ppb) was significantly associated with an increase in pulse rate. NO_2 was not associated with parameters of cardiovascular physiology during exercise. The authors discuss a lack of data on noise levels at the study sites (potential confounder) and the possibility of some statistically significant associations occurring by chance when multiple associations are tested.

Thompson et al (2010) studied blood markers of systemic inflammation that are risk factors for cardiovascular disease. Study participants were 45 healthy non-smoking adults in Toronto. Hourly and daily moving averages were calculated for SO_2, NO_2, O_3 and $PM_{2.5}$. All models were adjusted for age, sex, body mass index (BMI), asthma, day of the week, season, and temperature. An increase in interleukin-6, was linked with increased 4-day and 5-day moving average SO_2 concentrations No link was seen between SO_2 and fibrinogen. NO_2 was not associated with either marker of inflammation.

Weichenthal et al. (2011) conducted a crossover study in 42 healthy non-smoking volunteers to examine the relationship between traffic pollution and acute changes in heart rate variability (HRV). The participants were randomly assigned to cycle for one hour along a high-traffic route, along a low-traffic route or indoors. The three cycling periods were at least five days apart. HRV and respiratory measures (FEV1, FVC, FEF25–75) were collected at baseline and one to four hours after the start of cycling. One-hour average ambient O_3, NO_2, SO_2 concentrations were obtained from a fixed monitoring station in downtown Ottawa for the duration of each cycling period. Demographic data, medical histories (e.g., allergies, recent medication use and/or illness), information on alcohol and caffeine consumption, and recent exposure to environmental tobacco smoke were obtained from questionnaires. Analyses were not conducted for SO_2 because of its low levels and little variation between the study days. If an association was detected in a single-pollutant model, two-pollutant analyses were performed. NO_2 levels were associated with significantly increased FEV1 two hours and three hours after the start of cycling. NO_2 levels were inversely associated with the standard deviation of normal-to-normal intervals (β = –10 msec; 95% CI, –20 to –0.34 msec) and positively associated with the ratio of low-frequency to high-frequency power (β = 1.4; 95% CI, 0.35 to 2.5) two hours after the start of cycling. The authors concluded that exposure to traffic-related air pollution "may contribute to altered autonomic modulation of the heart in the hours immediately after cycling." The authors discuss the following limitations of their study: inability to control for exposures experienced en route to the study site; inability to adjust for the effects of respiration on HRV; small sample of subjects; and lack of personal exposure measures for NO_2.

Emergency department visits/hospital admissions for cardiovascular diseases

In a time-stratified case-crossover analysis, Chen et al. (2013a) found a positive, significant association between air concentration of NO_2 and the number of emergency department (ED) visits for ischemic stroke during April-September. The measures of association were adjusted for temperature and relative humidity. Associations between SO_2 and ED visits for stroke were also analyzed. At the time of this review, the full text of the article was not available. Because the data for SO_2 were not reported in the abstract, it can be assumed that no significant association between SO_2 and ED visits for stroke was seen.

Stieb et al. (2009) analyzed emergency department (ED) visits for respiratory and cardiac conditions in seven Canadian cities (Montreal, Ottawa, Edmonton, Saint John, Halifax, Toronto and Vancouver) during the 1990s and early 2000s. Information on data sources, and mean pollutant concentrations are described in the section on short-term exposure and respiratory health above. Only single-pollutant analysis was conducted. An 18.4 ppb increase in NO_2 with zero lag was associated with 2.6% increase (95% CI: 0.2%, 5.0%) in ED visits for angina/myocardial infarction and with 4.7% increase (95% CI: 1.2%, 8.4%) in ED visits for heart failure. An 18.4 ppb increase in NO_2 (1-day lag) was associated with a 2.7% increase (95% CI: 0.2%, 5.3%) in ED visits for angina/myocardial infarction. No associations were seen between NO_2 (any lag) and ED visits for dysrhythmia. A 5.1 ppb increase in SO_2 concentration lagged one day was associated with a 2.1% increase (95% CI: 0.2%, 4.0%) in ED visits for angina/myocardial infarction. No significant increase in ED visits for angina/myocardial infarction was associated with

increased SO_2 concentration lagged zero or two days. SO_2 concentrations (any lag) were not significantly linked with emergency department visits for dysrhythmia/conduction disturbance or for heart failure.

Daily ED visits for ischemic stroke in relation to air pollution in Edmonton were studied by Szyszkowicz (2008b). Data on ED visits between 1992 and 2002 were supplied by Capital Health, an academic-based health system of all five hospitals in Edmonton. Environment Canada provided data on levels of SO_2, NO_2, O_3, CO, PM_{10}, $PM_{2.5}$ and on weather condition (temperature and relative humidity). Mean SO_2 concentration was 2.6 ppb, mean NO_2 concentration was 21.9 ppb. Analyses were conducted by season, gender and age (20 to 64 years and ≥65 years). In the older age group, an interquartile range increase in NO_2 was associated with an 8.2% increase in ED visit for both genders (95% CI: 0.4%–16.7%) in the warm season. An interquartile range increase in SO_2 was associated with a 9.1% increase in ED visits (95% CI: 2.2%–16.4%) for males in the warm season, and with a 6.0% increase (95% CI: 0.5–11.8) for females in the cold season (lag 1 day). In the younger age group, the excess risk for NO_2 was 6.3% (95% CI: 0.2%–12.8%) for both genders and all seasons, and 13.8% (95% CI: 2.1%–26.7%) for females in the cold season. One-day lagged SO_2 was associated with a 10.3% increase in ED visits (95% CI: 0.7%–20.9%) for females in the cold season. The authors discuss limitations "typical for this type of research", namely exposure measurement error and possible misclassification of the outcome.

Szyszkowicz et al. (2012a) applied a case-crossover design to analyze ED visits for hypertension for the period 1992-2002 in Edmonton. Methods are not described in detail. Lag periods from zero to seven days were examined. Marginally significant associations were seen for SO_2 and NO_2 with a 3-day lag; odds ratios (ORs) were 1.04 (95% CI: 1.00-1.08) and 1.06 (95% CI: 1.00-1.08), respectively. The authors discuss limitations, in particular fixed-site monitors not fully reflecting inter-individual differences in exposure. In a case-crossover study each patient serves as his own control, which reduces or eliminates the confounding effects from factors that are constant in time. The authors note that confounding was still possible from time-varying characteristics, such as higher traffic level which may correlate with some pollutants.

In a single-pollutant analysis of data on SO_2 and emergency department visits for ischemic stroke in Vancouver, Szyszkowicz et al. (2012b) found no significant associations for NO_2 and a significant positive association with SO_2 concentrations lagged zero days in female patients. No significant associations were seen for longer lags (up to six days) in female patients or for any lag in male patients. In two-pollutant analyses of all patients, emergency department visits for ischemic stroke were significantly positively linked with SO_2 concentrations after adjustment for O_3 (lag 3 days) and for CO (lag three days). After both O_3 and CO were included in the model, the link was still significant. Results of analyses adjusted for other co-pollutants ($PM_{2.5,}$ PM_{10}, and NO_2) are not reported. Mean SO_2 concentration in this study was 2.5 ppb (SD 1.5 ppb).

Villeneuve et al. (2012) conducted a time-stratified case-crossover analysis of data on ED admissions for stroke from 10 hospitals in Edmonton. The outcome included hemorrhagic stroke, ischemic stroke and transient ischemic attacks. Daily average concentrations of NO_2, $PM_{2.5}$, CO, and SO_2 were calculated using hourly concentrations obtained from monitoring stations in Edmonton. Analyses were stratified by season, stroke subtype, and patient characteristics (history of heart disease, history of stroke, and medication use). Single-pollutant and two-pollutant models were used. Analyses were adjusted for temperature and relative humidity. For all strokes combined, there was no significant association with either SO_2 or NO_2 in any season. No significant associations were seen between the air pollutants and either hemorrhagic stroke or transient ischemic attacks. ED visits for ischemic stroke during the warm season were significantly associated with 1-day lagged and 3-day average NO_2 concentrations; ORs associated with interquartile range increases in NO_2 were 1.37 (95% CI: 1.10-1.71) and 1.50 (95% CI: 1.12-2.01), respectively. The association between NO_2 and ischemic stroke in the warm season remained

significant after inclusion of SO_2 in the model: OR=1.49 (95% CI: 1.11-2.00). However, it lost significance after adjustment for O_3, CO or $PM_{2.5}$. No associations were seen for SO_2 and for NO_2 during the cold season. Associations between NO_2 and ischemic stroke were stronger for those with a history of stroke, heart disease, and taking medication for diabetes.

Johnson et al. (2011) conducted a retrospective study in a cohort of 336 stroke patients in Edmonton to investigate the validity of two elements of case-crossover studies: (1) using the day of presentation at an emergency department or hospitalization as the day of onset of stroke; and (2) the use of the patient's place of residence to assign exposure. Data on NO_2 and $PM_{2.5}$ were used in these analyses. The authors reached the following conclusion: "Our data suggest that day of presentation and residential location data obtained from administrative records reasonably captures the time and location of stroke onset for most patients. Under these conditions, any associated errors are unlikely to be an important source of bias when estimating air pollution risks in this population."

Short-term Exposure and Morbidity other than Respiratory or Cardiovascular

Kaplan et al. (2012) used a case-crossover analysis to investigate associations between ED visits for non-specific abdominal pain and air pollution in Edmonton and Montreal. Data on air pollutants (NO_2, SO_2, CO, O_3, $PM_{2.5}$, PM_{10}) were supplied by Environment Canada from fixed monitoring stations. OR associated with an interquartile range increase in a daily average pollutant level served as a measure of effect after adjustment for temperature and relative humidity. Significant associations between ED visits and same-day NO_2 concentrations were seen among 15 to 24-year old individuals in Edmonton, and among 15 to 24 and 45 to 64-year olds in Montreal. Significant associations with same-day SO_2 were seen in individuals aged >64 years in Edmonton and in most age groups in Montreal. All the observed associations were modest in size (the highest OR was 1.17 for SO_2 in 15 to 24-year olds). Lag periods of 1 and 2 days were also examined and the results are presented in supplementary tables (unavailable). Although cases served as their own controls in this case-crossover study, the authors cannot rule out residual confounding. The authors also note the probability of observing significant findings by chance due to multiple comparisons (several pollutants, lag periods and age groups).

In a case-crossover analysis, Kaplan et al. (2009) found a significant positive relationship between 3-day, 5-day and 7-day average concentrations of SO_2 and NO_2 (levels not reported) and the incidence of appendicitis during summer months in the Calgary Health Region, Canada. Cases of appendicitis were ascertained from the hospital discharge database. Analysis by sex showed that the associations were significant only for men. In a model including both pollutants, NO_2 was significant but SO_2 was not. ORs for SO_2 were above 1.00 but not significant in two-pollutant models with CO, O_3, $PM_{2.5}$, PM_{10}. OR for NO_2 was above 1.0 and significant in models including CO and $PM_{2.5}$, but lost significance in models with O_3 and PM_{10}. The authors discuss limitations of their study: use of regional estimates of air pollution from fixed monitoring stations; differences between dates of disease onset and date of hospitalization; availability of data only on adult patients; and multiple comparisons and related probability of observing statistically significant findings by chance.

Applying a case-crossover analytical technique, Zemec et al. (2010) estimated the effects of air pollution on ED visits for otitis media in children one to three years of age in Edmonton. Data on ED visits for 1992-2002 were based on discharge diagnosis and were obtained from five hospitals. Air pollution data (NO_2, SO_2, O_3, CO, $PM_{2.5}$ and PM_{10}) were from fixed monitors covering the city and were obtained from the National Air Pollution Surveillance System. Mean levels were 2.6 ppb and 21.9 for SO_2 and NO_2, respectively. Data on temperature and relative humidity were provided by Environment Canada weather archive. Same-day exposures (0-lag), exposures for up to four days before the visit (lagged one

to four days) and average levels for two to five days preceding the visit were considered. Analyses were stratified by sex and season. Single-and multi-pollutant models were used. No effect of SO_2 on ED visits for otitis media was detected. NO_2 exposure lagged two days was associated with increased number of ED visits in warm months and cold months: OR per interquartile range increase in NO_2 (12.8 ppb) was 1.10 (95% CI: 1.02- 1.19) and 1.03 (95% CI: 1.00-1.07), respectively. In warm months, NO_2 exposure lagged three days was also associated with increased ED visits: OR 1.08; 95% CI: 1.00-1.17). Analysis by sex showed that these increases were mainly due to female patients. The other pollutant that produced similar associations was CO. The models including both NO_2 and CO produced higher effect estimates for CO and significant negative associations for NO_2. Because CO and NO_2 were negatively correlated with O_3 (for which same-day exposure and 1-day lagged exposure were positively associated with ED visits), the authors believe that "a negative association with NO_2 may indicate a positive association with high O_3 on a preceding day". The authors concluded that the models that include two collinear pollutants were not reliable. Multiple comparisons that could produce significant associations due to random variation or chance, inability to determine when the ED visit occurred in relation to the onset of otitis symptoms, the use of pollutant concentrations averaged over three monitoring stations that did not reflect local exposures, and the error in estimating personal exposure from fixed-site monitors were discussed as limitations of this study.

In a single-pollutant analysis of data on emergency department visits for seizure in Vancouver, Szyszkowicz et al. (2012b) found no significant associations with NO_2 and a significant positive association with SO_2 concentrations lagged one or two days in female patients (see Szyszkowicz et al. 2012a in section on ED visits for cardiovascular diseases for more details).

Several studies on possible links between air pollution and ED visits for migraine/other headaches were conducted in different Canadian cities by Szyszkowicz et al. (2008c,d; 2009a,b,c) and Szyszkowicz and Porada 2012). Some of these studies were focused on SO_2, others examined SO_2 and other pollutants. The analyses used various lag structures, some were stratified by sex and age, and several positive associations were reported for both SO_2 and NO_2. In all studies, only single-pollutant analyses were used.

A multi-city study in Canada (Szyszkowicz et al. 2009a) and a study in Edmonton (Szyszkowicz et al. 2009d) suggest a link between SO_2, NO_2 and depression, and a study in Vancouver demonstrated statistical associations between SO_2, NO_2 and the risk of suicide attempts (Szyszkowicz et al. 2010).

Short-term Exposure and Mortality

Goldberg et al. (2013) used a time series approach to analyze daily mortality for 1990-2003 among residents of Montreal who were aged 65 years or older and who were diagnosed with major health conditions one year before death. Deceased subjects were identified from the computerized provincial database of death certificates, and were linked to billing and prescription data from the Quebec Health Insurance Plan to identify health conditions included in the analysis: respiratory, cardiovascular diseases, cancer, diabetes mellitus, and some combinations of these conditions. Daily average concentrations of NO_2, SO_2, CO, O_3 and $PM_{2.5}$ were calculated using data from air monitoring stations. Mean SO_2 concentration was 13.48 µg/m^3 and mean NO_2 concentration was 37.90 µg/m^3. For both pollutants the means were slightly higher during the cold season (October to March). A measure of the outcome was percent change in the mean number of daily deaths (MPC) for an increase in concentration of each pollutant across its interquartile range. Each pollutant was modelled separately with adjustment for weather conditions. Positive associations between daily non-accidental mortality and SO_2 were found

among persons having any form of cardiovascular disease, atrial fibrillation, hypertension, cancer. Positive associations between daily non-accidental mortality and NO_2 were found among persons with any form of cardiovascular disease, congestive heart failure, acute coronary artery disease, diabetes, atrial fibrillation, hypertension, cancer. The authors discuss possible inaccuracy of their classification of the underlying health conditions resulting from the use of administrative databases as a data source, inability to control for disease epidemics, and possible misclassification of exposure.

The aim of Shin et al. (2012) was to illustrate the application of a Bayesian hierarchical two-level model to estimate mortality risks. For this purpose, mortality and NO_2 data for 21 years (1984-2004) in 24 Canadian cities across the country were used. Administrative databases were used as data sources: National Air Pollution Surveillance (NAPS) Network operated by Environment Canada for data on daily average concentrations of NO_2 as a marker of traffic-related air pollution; and National Mortality Database for data on daily non-accidental mortality. Calendar time, daily mean temperature (from Environment Canada) and day of the week were used as potential confounders. NO_2-associated risks for cardiopulmonary (CP) mortality were slightly lower than for non-CP mortality. For both groupings, NO_2-associated risks were higher in the warm season than in the cold season. There was no strong evidence for time trends in NO_2 risk at national or regional levels. In view of the focus of this study (to illustrate a new method), and the use of NO_2 as a marker of traffic pollution, the results cannot be used to infer causal associations between NO_2 and mortality.

Stieb et al. (2008) obtained data on 3-hour maximum concentrations of NO_2, SO_2, CO, O_3, $PM_{2.5}$ and PM_{10} from National Air Pollution Surveillance (NAPS), weather data from Environment Canada archive, and mortality data from the National Mortality Database maintained by Statistics Canada to construct an Air Quality Health Index (AQHI). As part of this work, the authors conducted a time-series analysis to estimate percent increases in mortality at the mean concentration of each pollutant for 1981-2000 in 12 Canadian cities from single-pollutant and multi-pollutant models. In the single-pollutant analyses, associations were significant at all lags for NO_2 and at lag one for the other pollutants. The percent increase in mortality associated with the mean concentration was 2.08 (95% CI 0.90–3.28) for NO_2 (33.6 ppb) and 0.55 (95% CI 0.22–0.88) for SO_2 (13.7 ppb). Significant heterogeneity of effect estimates between cities was seen for NO_2. Associations for SO_2 were less robust in the multi-pollutant models. NO_2 was significant in all but a five-pollutant model with PM_{10}, in which it was of borderline significance. A linear function fitted best for NO_2.

A cross-sectional analysis of the weather type, air pollution, and mortality for 1981-1999 was conducted by Vanos et al. (2013) in 10 Canadian cities. Daily non-accidental mortality data were obtained from the Canadian Institute for Health Information. National Air Pollution Surveillance Network air pollution data (NO_2, SO_2, O_3, CO) were supplied by Environment Canada. Data on daily synoptic weather types were obtained from the spatial synoptic classification (SSC) website. The weather types were: dry moderate (DM), dry polar (DP), dry tropical (DT), moist moderate (MM), moist polar (MP), moist tropical (MT), and a transitional (TR) category representing a shift from one weather type to another. Mortality risk estimates were significantly increased due to exposure to NO_2 and SO_2 and modified by the weather type and age. Later, Vanos et al. (2014) showed that associations between air pollutants and mortality were significantly modified by weather type, season, and cause of death (respiratory or cardiovascular): 61% of the relative risk estimates for respiratory-related mortality were significantly higher than those for cardiovascular-related mortality.

Long-term Exposure and Health

Respiratory health

Carlsten et al. (2011a) recruited 272 infants from Vancouver at high risk for asthma defined as having a first-degree relative with allergic diseases. Exposure to NO, NO_2 and $PM_{2.5}$ during the birth year (1995) was estimated by land use regression on the basis of residential address. Asthma status was assessed at seven years of age by a paediatric allergist and by methacholine-based measurements of airway reactivity. Twenty-three children were diagnosed with asthma and 68 with bronchial hyper-reactivity. The mean NO concentration was 35.7 $\mu g/m^3$; the mean NO_2 concentration was 32.6 $\mu g/m^3$. NO and NO_2 were correlated (R=0.8). There was no significant association between asthma and NO or NO_2. The OR for an interquartile range increase in NO (12.7 $\mu g/m^3$) was 1.2 (95% CI: 0.9-1.7), and the OR for an interquartile range increase in NO_2 (7.2 $\mu g/m^3$) was 1.5 (95% CI: 0.9-2.5). The authors discuss possible changes in pollutant levels over the 7-year study period as a limitation of their study.

The same research group (Carlsten et al. 2011b) demonstrated that co-exposure to elevated indoor NO_2 and to dog allergen early in life increased the risk of asthma at seven years of age as compared to having neither such exposure in 545 high-risk children recruited in Vancouver and Winnipeg. The high risk for asthma was also defined as having relatives with allergic diseases.

Chen et al. (2008) recruited 73 children (nine to 18 years of age) with asthma from Vancouver and estimated their exposure to NO_2 (as a marker of air pollution) using residential address and a land use regression model. The mean estimated level of NO_2 was 16.5 ppb. Measures of outcome were asthma symptoms, Peak Expiratory Flow Rate (PEFR) and immunological parameters: complete and differential blood counts; total serum immunoglobulin E (IgE); and levels of interleukin (IL)-4, IL-5, IL-13. These parameters were measured at baseline and six months later. NO_2 levels were not associated with levels of interleukins, IgE, eosinophil counts, or PEFR. Children in high pollution areas had higher child-reported daily symptoms and parent-reported symptoms. For many of these parameters, there was a significant interaction between air pollution and chronic family stress, indicating that vulnerability to asthma is increased in children with higher chronic stress. NO_2 in this study was estimated as a single indicator of traffic-related air pollution; no other pollutants were estimated.

Clark et al. (2010) followed a cohort of 37,401 children born in southwestern British Columbia in 1999 and 2000 for the incidence of asthma. The follow-up continued for three to four years using outpatient and hospitalization records. Traffic-related exposure to pollutants (CO, NO, NO_2, PM_{10}, SO_2, and black carbon) was estimated for the gestational period and for the first year of life by land use regression (LUR) models. Exposures from industrial point sources were estimated by an inverse distance-weighted (IDW) summation of emissions from point sources within 10 km. The estimates were assigned using residential history (postal codes). Birth weight and gestational length data were obtained from the Vital Statistics Clinical Birth Data. Maternal smoking during pregnancy, maternal age, number of siblings, and intention to breast-feed were obtained from the BC Perinatal Database Registry. Individual-level socioeconomic data were not available; census dissemination area data on income quintiles and maternal education level quartiles were assigned. Single-pollutant and mutually-adjusted models were used. Increases in IDW exposure estimates for NO, NO_2 and SO_2 (both in utero and in the first year of life) were associated with elevated risk of asthma diagnosis. Associations for LUR estimates were less consistent: NO exposure in utero and NO_2 exposure in the first year of life were associated with increased risk of asthma. There was no LUR estimate for SO_2, and SO_2 was analyzed only in a single-pollutant model. The authors discuss lack of individual-level data on risk factors and the use of administrative databases as limitations of their study.

Dales et al. (2008) conducted a cross-sectional study in Windsor, Ontario of air pollution and lung function (FVC and FEV1) in 2,328 children aged nine to 11 years. Exhaled nitric oxide was measured as a marker of airway inflammation. Exposures to air pollutants (NO_2, SO, $PM_{2.5}$ and coarse PM, black smoke) were estimated on the level of the child's neighborhood using land use regression modelling. Analyses were adjusted for ethnicity, passive smoking, pets at home, acute respiratory diseases and any medication for wheezing/asthma taken in the preceding two weeks. To account for seasonal variability, the models included a variable to represent each month during the study period. Covariates were retained in the model if they were significant and/or changed the coefficient for exposure by 10%. Mean estimated NO_2 concentration was 13.58 ppb, mean SO_2 concentration 5.39 ppb. It appears that only single-pollutant analysis was conducted. Ambient concentrations of NO_2 or SO_2 were not associated with lung function parameters or exhaled nitric oxide.

Gan et al. (2013) studied chronic obstructive pulmonary disease (COPD) hospitalization and mortality in a cohort of 467,994 residents of Metropolitan Vancouver. The cohort was assembled using the health insurance system of British Columbia. The participants were aged 45 to 85 years and had no coronary heart disease (CHD) at baseline. The study had two periods: a 5-year exposure period (1994-1998) and a 4-year follow-up period (1999-2002). Exposures to pollutant (NO_2, NO, $PM_{2.5}$, black carbon) were estimated by land use regression models. Changes in residence during the exposure period were taken into account. Mean estimated NO_2 concentration was 32.2 $\mu g/m^3$, and mean NO concentration was 32.1 $\mu g/m^3$. COPD morbidity data were obtained from provincial hospitalization records, and mortality data were available from provincial death registration records. The statistical models included age, sex, pre-existing comorbidities (asthma, diabetes, and hypertensive heart disease), neighborhood socioeconomic status (SES), and co-pollutants. Neither single-pollutant analysis nor analysis including $PM_{2.5}$ and black carbon showed significant associations between NO or NO_2 and hospitalizations for COPD or mortality from COPD. Limitations of this study, as discussed by the authors, include lack of data on smoking, availability of only neighborhood data on SES, inability to evaluate accuracy of COPD diagnoses, and inability of modeling to precisely reflect individual exposures.

Neupane et al. (2010) conducted a case-control study in Hamilton, Ontario to assess the effect of long-term exposure to air pollutants (NO_2, SO_2 and $PM_{2.5}$) on hospitalization for community-acquired pneumonia in individuals aged ≥65 years. Cases were 345 patients hospitalized between July 2003 and April 2005, and controls were 494 individuals of the same age selected from the community by random-digit dialing. Annual average exposures to air pollutants were estimated by inverse distance weighting (IDW), bicubic splined (SPL) and land use regression (LUR) methods, and assigned to subjects using residential addresses. Mean NO_2 levels ranged from 15.00 to 20.14 ppb for different estimation methods, and mean SO_2 ranged from 4.65 to 5.80 ppb. Health data and information on potential confounders were collected by trained interviewers using the same questionnaire for cases and controls. Sex, age, history of smoking, history of occupational exposures to gases, fumes, and chemicals were included in the model. NO_2 was significantly associated with hospitalization for community-acquired pneumonia (IDW estimate: OR=2.30, 95% CI: 1.25-4.21, P=0.007; SPL estimate: OR=2.19; 95% CI: 1.25-3.83, P=0.006; LUR estimate: OR=1.70, 95% CI: 1.00-2.89, P=0.049). There was no significant link between estimated SO_2 and hospitalizations.

Sahsuvaroglu et al. (2009) studied associations between air pollution and asthma prevalence in 1,467 children of Hamilton. The study population was defined in 1994-1995 within the framework of the International Study of Asthma and Allergies in Child (ISAAC), using a standardized questionnaire to assess asthma and respiratory symptoms in children aged six to seven, and 13 to 14 years. Questionnaires for younger children were filled out by parents. Exposure to air pollution was estimated by four techniques:

1. Using distance from major roadways as a proxy for traffic pollution exposure
2. Using deterministic interpolators applied to three-year averages corresponding to the time of enrolment in the study; specifically, exposures to NO_X, SO_2, O_3 and PM_{10} were derived by Theissen polygons, bi-cubic spline and inverse distance weighted (IDW) interpolation techniques
3. Pollution surface estimation method based on data for a two-week period in 2002 from 107 monitoring stations throughout Hamilton (NO_2 only)
4. Land use regression (LUR) modelling based on the same NO_2 monitoring data

Because individual-level data on confounding were limited, neighbourhood proxies were used, such as income, deprivation index, the percentage of smokers, percent of houses built before 1946 and rate of repair of housing to approximate exposure to mold and damp conditions. To be included in the model as a confounder, a variable had to meet three criteria: 1) to be associated with asthma; 2) to be associated with pollution exposure; and 3) to change the regression coefficient for the relation between asthma and pollution by >10%. There were no significant associations between pollution exposures and asthma in the whole population. When the population was stratified by age, sex and atopy, asthma was associated with NO_2 (LUR estimate) in all girls and older girls without hayfever. The association remained significant in two- and multi-pollutant analyses. The ORs from the co-pollutant models were 1.85 (95% CI: 0.92–3.73) for all girls and 2.98 (95% CI: 0.98–9.02) for older girls. SO_2 was not the focus of this study. Tables show only ORs for SO_2 estimated by the Theissen technique, from which it follows that there were no significant associations with asthma prevalence. The authors comment on the following limitations of their study: lack of individual data on confounders; identification of atopy was based on associated symptoms (hayfever) rather than on objective evidence (skin prick tests for IgE mediated sensitizations to common allergens); and "temporal discontinuity" between ascertainment of the health outcome (1994-1995) and data for NO_2 estimation (2002). Regarding the latter, the authors note little change in pollution levels and their spatial patterns within this time period. Sensitivity of the effect estimates to the method of exposure estimation was also pointed out.

Deger et al. (2012) conducted a cross-sectional study to examine associations between exposure to SO_2 emissions from petroleum refineries located in Montreal and the prevalence of active asthma and poor asthma control among children. A respiratory health survey of Montreal children six months to 12 years of age was conducted in 2006. Of 7,964 eligible households, 842 children lived in an area impacted by emissions. Annual SO_2 levels were estimated using dispersion modelling. Analyses were adjusted for age, sex, parental history of atopy and exposure to smoking at home. There was no significant association between SO_2 and active asthma: the Prevalence Ratio (PR) per interquartile range increase in modelled SO_2 was 1.14 (95% CI: 0.94-1.39). The effect of SO_2 on poor asthma control was greater: PR=1.39 (95% CI: 1.00-1.94). The full text of this article is not available.

Cardiovascular effects

Beckerman et al. (2012) studied associations between prevalence of ischemic heart disease (IHD) and exposure to traffic-related air pollution, in particular NO_2 modelled using land use regression and residential postal code. Median exposure was 22.9 ppb, interquartile range was 4.0 ppb. The study population included 2,360 patients with respiratory complaints referred between 1992 and 1999 to the Toronto Western Hospital. Data on IHD were extracted from Ontario Physician Billing Database. Gender, age, smoking, BMI, diabetes status, and deprivation index were included in the model. Other modelled pollutants were $PM_{2.5}$ and O_3. Adjusted Relative Risk (RR) for NO_2 was 1.26 (95% CI: 1.14, 1.4). Adding O_3 and $PM_{2.5}$ reduced the effect estimate to 1.15 (95% CI: 1.01, 1.31). Neither O_3 nor $PM_{2.5}$ were associated with IHD. The authors discuss the following limitations: 1) this was a cross-sectional study of prevalent IHD; it was not clear whether the exposure preceded the disease; 2) inability to control for some risk factors for IHD such as cholesterol levels, blood pressure and genetic factors; 3) patients with

respiratory problems might represent a sensitive subpopulation; and 4) traffic-related stressors such as noise could play a role in the development of IHD.

Gan et al. (2011) studied coronary heart disease (CHD) hospitalizations and mortality in a cohort of 452,735 residents of Metropolitan Vancouver. The cohort was assembled using the health insurance system of British Columbia. The participants were aged 45 to 85 years and had no CHD at baseline. The study had two periods: a 5-year exposure period (1994-1998) and a 4-year follow-up period (1999-2002). Exposures to pollutants (NO_2, NO, $PM_{2.5}$, black carbon) were estimated by land use regression models. Changes in residence during the exposure period were taken into account. Mean estimated NO_2 concentration was 32.1 $\mu g/m^3$, and mean NO concentration was 32.0 $\mu g/m^3$. CHD morbidity data were obtained from provincial hospitalization records, and mortality data were available from provincial death registration records. Analyses were adjusted for age, sex, pre-existing diseases (diabetes, COPD, or hypertensive heart disease), neighborhood income quintiles and SES, and co-pollutants. Neither single-pollutant nor multi-pollutant analysis showed a significant association between NO or NO_2 and hospitalizations for CHD. CHD mortality was significantly associated with both NO and NO_2 in a single-pollutant analysis. However, when two other pollutants were included in the model, the association lost statistical significance. The authors discuss limitations of their study including lack of data on smoking, availability of only neighbourhood-level data on SES, possible confounding from traffic-related noise, inability to evaluate accuracy of CHD diagnoses in the administrative databases, and the inability of modelling to precisely reflect individual exposures.

Johnson et al. (2013) conducted a case-control study to evaluate associations between ambient NO_2 as a marker of traffic-related pollution, and ED visits for stroke. Cases were 4,696 events of acute ischemic stroke, hemorrhagic stroke, or transient ischemic attack presented to an ED in Edmonton between 2007 and 2009. Controls (n=37,723) were presented to the same hospitals for conditions thought to be unrelated to air pollution (injuries). NO_2 levels were estimated by land-use regression models and assigned to the place of residence. The spatial resolution was less than 50 meters. The mean estimated NO_2 concentration was 15.4 ppb. Because individual-level socio-economic data were unavailable, neighborhood measures for education and income were constructed on the basis of the 2006 Canadian Census data. Statistical models included age, sex and the neighborhood SES variables. There were no statistically significant associations between NO_2 and all strokes combined or any type of stroke. Adjusted ORs in relation to an interquartile range increase in ambient NO_2 (5 ppb) ranged from 1.01 to 1.07. The associations did not differ by sex: the ORs for all strokes were 0.99 and 1.03 for women and men, respectively. The OR for individuals aged >65 years was 0.98. The authors consider lack of individual data on risk factors for stroke as a major limitation of their study.

Developmental effects

Brauer et al. (2008) evaluated the effects of air pollution (SO_2, NO, NO_2, O_3, CO, $PM_{2.5}$ and PM_{10}) on infant birth weight in Vancouver. Using administrative databases, 70,249 singleton births (1999–2002) were identified. Residential exposures by month of pregnancy were estimated using nearest and inverse-distance weighting (IDW) of study area monitors, land use regression (LUR) models and proximity to major roads. Effect estimates were adjusted for infant sex, First Nations status, parity, maternal age, maternal smoking during pregnancy, month-year of birth, income (neighborhood-level data), and maternal education (neighborhood-level data). A statistical association approaching significance was seen between SO_2 and babies that were small for their gestational age (SGA): OR per 1 $\mu g/m^3$ in SO_2 (IDW estimate) was 1.01 (95% CI: 1.00–1.02). No significant association was seen between SO_2 and babies with low full-term birth weights (LBW). There was no statistically significant association between estimated SO_2 exposure and preterm births. Mean SO_2 concentrations were 5.7 $\mu g/m^3$ (estimated by nearest monitor) and 5.3 $\mu g/m^3$ (estimated by inverse-distance weighting approach). NO

and NO_2 (IDW estimates) were significantly associated with SGA: ORs per 10 µg/m^3 increase were 1.05 (95% CI: 1.03–1.08) and 1.14 (95% CI: 1.09–1.18), respectively. NO_2 (IDW) was significantly associated with LBW: OR per 10 µg/m^3 increase was 1.11 (95% CI: 1.01–1.23). NO (IDW) was significantly associated with preterm birth (<30 weeks): OR per 10 µg/m^3 increase was 1.26 (95% CI: 1.08–1.47). The authors discuss limitations related to their use of data from administrative databases. In particular, they defined growth restriction as a weight below the 10th percentile for gestational age, and this definition did not make a distinction among fetuses who were constitutionally small, growth restricted and small, and growth restricted but not small. Lack of data on maternal ethnicity (other than First Nation Status), nutrition and prenatal care, of individual-level socioeconomic data, and "imperfect" accounting for residential mobility were also listed as weaknesses of the study.

Mortality

Chen et al. (2013b) followed for cardiovascular mortality a cohort of 205,440 adults aged 35 to 85 years, who lived in Toronto, Hamilton, or Windsor between 1982 and 1986. The follow-up continued to 2004. Mortality from cardiovascular diseases was ascertained from the Canadian Mortality Database. Annual estimates of exposure to air pollution were obtained by land use regression models, and estimated NO_2 levels were linked to subjects' residential addresses. Analyses were adjusted for age, sex, individual-level data on income, marital status, area-level variables (derived from the 1981 Canadian Census) characterizing education, percentage of immigrants, unemployment rate and household income. The impact of unmeasured tobacco smoking and obesity was assessed by Monte Carlo sensitivity analyses. An increase in NO_2 of 5 ppb was associated with a significant increase in mortality from all cardiovascular diseases: RR=1.12 (95% CI: 1.07-1.17) and ischemic heart disease; RR=1.15 (95% CI: 1.08-1.21). There was no significant association with mortality from cerebrovascular diseases: RR=0.99 (95% CI: 0.91-1.08). The authors discuss the following limitations: 1) the use of death certificates for cause of death ascertainment; 2) characterization of exposure towards the end of study (exposure for the earlier period might not be adequately characterized); and 3) lack of individual-level data on risk factors for cardiovascular diseases. Also, data on air pollutants other than NO_2 were not used in the analyses.

Gan et al. (2011) demonstrated that CHD mortality was significantly associated with both NO and NO_2 in a single-pollutant analysis but not after inclusion of $PM_{2.5}$ and black carbon in the model.

Jerrett et al. (2009) studied possible associations between traffic-related air pollution and mortality for a period 1992-2002 in a cohort of 2,360 subjects from a respiratory clinic in Toronto. Data on underlying health conditions for these subjects were obtained by linkage to the OHIP physician billing database and the Ontario hospital discharge database. Height, weight, results of lung function testing, and smoking history were obtained from the clinic's database. Cause of death was ascertained from the Ontario Mortality Registry. Land use regression models were used to predict levels of NO_2; levels of $PM_{2.5}$ and O_3 were predicted using interpolations. Models were adjusted for age, sex, BMI, lung function, smoking, neighborhood deprivation index. An interquartile range increase in NO_2 (4 ppb) was associated with a significant increase in all-cause mortality (OR=1.17; 95% CI: 1.01-1.35), and mortality from circulatory diseases (OR=1.45; 95% CI: 1.11–1.91). There was no significant association between NO_2 and mortality from respiratory diseases and no significant associations with other pollutants. The authors discuss study limitations, such as potential confounding from traffic noise, unavailability of individual SES data, questionable generalizability of the results due to high prevalence of chronic diseases in this cohort as compared to the general population, and small sample size.

Cancer

Crouse et al. (2010) conducted a case-control study of breast cancer in Montreal. Cases were 383 postmenopausal women with incident invasive breast cancer, and controls were 416 women with other

cancers. NO_2 concentrations across Montreal were estimated by land use regression models for 2006 and were extrapolated to 1996 and 1985 (approximately the time of diagnosis and 10 years before the diagnosis). The exposure estimates were linked to subjects' residential addresses at the time of their interview. Analyses were controlled for age at diagnosis, family history of breast cancer, education, ethnicity, age at bilateral oophorectomy, age at menarche, age at first full-term pregnancy, alcohol consumption, and duration of hormonal replacement therapy, oral contraceptive use, smoking, total duration of breast-feeding, body mass index. Census data from 1996 were used for assigning indicators of deprivation to subjects. In the fully adjusted model, ORs for postmenopausal breast cancer per 5 ppb increase were all above 1.0 but only OR for exposure estimate extrapolated to 1996 approached significance: 1.31 (95% CI: 1.00-1.71). When analyses were restricted to subjects who had resided at the same address for at least 10 years (195 cases, 213 controls), the ORs were above 1.0 but none of the increases was significant. NO_2 was the only pollutant estimated as a marker of traffic-related air pollution.

Hystad et al. (2013) conducted a case-control study of lung cancer incidence in relation to long-term exposure to NO_2, O_3, $PM_{2.5}$ and proximity to major roads. The analyses included 2,390 histologically confirmed lung cancer cases diagnosed between 1994 and 1997, and 3,507 randomly selected population controls from eight Canadian provinces. Controls were frequency matched to cases for sex and 5-year age intervals. Data on personal characteristics, occupational exposures and residential histories were collected from questionnaires. Annual residential exposures to air pollutants were estimated over a 20-year exposure period (1975-1994) using spatiotemporal models and were assigned to study participants based on their residential history. Mean estimated NO_2 concentration was 15.4 ppb. Measures of association were adjusted for age, sex, education, household income, smoking and second-hand smoke exposure, alcohol and meat consumption, occupational lung hazards. Geographical covariates included province, residential radon concentrations, and neighborhood deprivation index. The adjusted OR for a 10 ppb increase in NO_2 was 1.11 (95% CI: 1.00–1.24). In joint models for NO_2 and O_3, the OR increased to 1.14 and reached statistical significance (95%CI: 1.02-1.28). When exposure data from surveillance monitors within 50 km of residential postal codes were used, the OR for a 10 ppb increase in NO_2 was 1.34 (95% CI: 1.07–1.69). Analysis by NO_2 exposure quintile demonstrated elevated ORs in all quintiles relative to the lowest (<7.1 ppb), but there was no exposure-response relationship. Analysis by histological type showed the strongest association between NO_2 and adenocarcinoma: OR=1.17 (95% CI: 1.01-1.35). The authors discuss limitations, including: potential for response and recall bias (response rates were 62% for cases and 67% for controls); uneven distribution of populations across geographic communities, which could result in a random sample of the population not being a random sample of all places; and lack of exposure-response which could be due to a relatively narrow range of exposures.

A case–control study by Parent et al. (2013) included 803 men with histologically confirmed incident prostate cancer diagnosed in 11 French hospitals in Montreal between September 2005 and June 2008. Control subjects (n=969) were selected from the provincial electoral French-speaking list and frequency-matched to cases by 5-year age groups. Information about socio-demographic characteristics, lifestyle factors, a prostate cancer screening history and occupational histories were obtained at face-to-face interviews. NO_2 was used as a marker of traffic-related air pollution. Air samplers were deployed at 133 locations across the Island of Montreal on three occasions (in spring, summer, winter) to obtain 2-week integrated samples. A land use regression model was used to predict mean annual concentrations of NO_2 for 2005-2006 for residential locations at the time of diagnosis or at the time of interview for controls. The estimates were back extrapolated to 1996 using measurements from fixed monitoring stations to determine location-specific ratios. Mean estimated NO_2 concentrations were ≈12 ppb in 2006 and ≈17-18 ppb in 1996. Individual-level covariates (age, family history of prostate cancer, family

income, body mass index and education) and some neighborhood-level ("ecological") socio-economic characteristics were considered for inclusion in the model as potential confounders and were included if significant. The OR per 5 ppb increase in NO_2 estimated in 2006 was 1.44 (95% CI: 1.21-1.75). It was lower but still significant when the neighborhood-level socio-economic variables were included in the model: 1.27 (95% CI: 1.03-1.58). The OR per 5 ppb increase in NO_2 back-extrapolated to 1996 was from 1.35 to 1.49 depending on extrapolation method (all significantly greater than 1.00). Inclusion of ecological covariates reduced the ORs to 1.23-1.38 but all were significantly greater than 1.00. These data suggest increased risk of prostate cancer among men exposed to higher concentrations of NO_2. Because NO_2 was used as a marker of traffic-related air pollution, these data cannot be used to infer causality. The authors point out that the exposure estimates did not take into account time spent outdoors, or population mobility.

Other effects

The association between air pollution and physician visits for otitis media was studied among 45,513 children born in southwestern British Columbia in 1999-2000 (MacIntyre et al. 2011). The children were followed until the age of two years. Exposures to NO, NO_2, SO_2, O_3, $PM_{2.5}$, PM_{10} in the two months preceding the visit were estimated by land use regression (LUR) models. Exposures from industrial point sources were estimated by inverse distance-weighting (IDW). Exposures were assigned to participants based on their place of residence. Analyses were stratified by sex, aboriginal status, maternal smoking, older siblings, otitis media season (a 4-level categorical variable based on the otitis media rate in each study month), neighborhood income and neighborhood female education. Adjusted relative risks for the association between physician visits and NO (LUR and IDW estimates) were consistently elevated. Relative risks for NO_2 were significantly elevated or significantly decreased depending on which adjustment variables were included in the model. Adjusted relative risks for the association between physician visits and SO_2 (IDW estimate only) were significantly below 1.0. The authors discuss the use of administrative databases to create the cohort, to obtain residential histories and ascertain the outcome as a limitation of their study.

Seven hundred and seventy-four residents of "Chemical Valley", Sarnia, Ontario self-assessed their annoyance due to air pollution odours on an 11-point annoyance scale from 0 ("no disturbance at all") to 10 ("intolerable disturbance") (Atari et al. 2009). Land use regression modelling was used to estimate exposures to NO_2 and SO_2 based on 6-digit postal codes. Indoor exposures were assessed by asking respondents about indoor appliances. Self-reported health status, chronic conditions and emotional distress were also accounted for in the analyses. Individual level measurements were participants' scoring of annoyance or estimated exposure. Census tract level measurements were mean values of all individual annoyance scores or estimated individual exposures in each census tract (a subdivision of a county). Odour annoyance was significantly correlated with modelled pollutants at the individual (NO_2, $r = 0.15$; SO_2, $r = 0.13$) and census tract (NO_2, $r = 0.56$; SO_2, $r = 0.67$) levels. Later, it was demonstrated that the degree of odour annoyance in this population was significantly correlated with modelled concentrations of volatile organic compounds (Atari et al. 2013). Thus, the annoyance was not likely to be related to any specific pollutant but rather it reflected "within-area variability of ambient pollution", and questionnaire-based odour annoyance scores could be used as a proxy for assessing the air quality (Atari et al. 2009, 2013).

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APPENDIX 12: TERRESTRIAL ECOSYSTEMS

12.1 Soil Data

Table A12-1. Physico-chemical characteristics for soil samples (n = 80) indicating site ID, sampling location, elevation (ALT), and profile average estimates of coarse fragment (CFG) by volume, bulk density (Db), loss-on-ignition (LOI), particle size (sand, silt and clay) and soil pH (H_2O) at the 40–50 cm depth.

Site ID	Easting m	Northing m	ALT m	CFG %v	Db g/cm^3	LOI %	pH H_2O	Sand %	Silt %	Clay %
CA008	523313	6031222	98	0.3	1.34	5.17	5.01	34.3	61.2	4.5
GR001	508730	6020750	505	15.1	0.65	24.37	4.95	53.7	43.6	2.7
GR002	520369	6032182	133	2.4	0.78	4.75	5.52	61.8	34.8	3.4
GR003	520883	6032669	108	0.1	0.99	4.28	6.26	37.4	56.7	5.9
GR005	508764	6022236	476	8.1	0.68	13.06	5.16	27.6	61.8	10.6
CA004	520902	5988188	18	0.3	1.09	4.11	5.27	32.0	63.7	4.3
LM006	522819	6034769	142	13.9	0.85	4.30	5.74	47.9	44.0	8.1
LM009	522294	6035234	142	14.7	0.80	5.60	5.71	56.3	41.4	2.3
LM010	522111	6035236	135	0.3	0.89	3.48	5.66	30.4	60.4	9.1
QD006	526853	6026660	155	10.6	1.11	5.24	4.89	54.4	42.6	3.0
QD007	524422	6014766	203	7.0	0.40	16.91	4.87	43.1	49.1	7.8
QM001	523191	5982176	134	10.6	0.43	23.52	5.64	61.0	35.6	2.8
QM003	523162	5981735	67	1.6	0.99	2.33	5.17	58.5	36.3	4.1
S001	519946	6048693	212	3.3	0.73	5.22	6.07	68.3	28.3	3.0
S011	520312	6049700	214	0.7	0.86	4.34	6.00	38.4	54.0	7.5
S022	520372	6049220	218	4.5	0.82	3.52	5.52	29.1	63.9	7.0
SSS001	523814	5980167	104	3.1	0.21	15.58	4.91	24.9	65.2	9.9
SSS004	527293	6025349	75	0.6	1.18	3.76	6.46	24.0	65.2	10.8
SSS005	509941	6028268	41	25.7	0.93	5.69	5.56	27.0	59.7	13.3
SSS006	520792	6048725	208	1.2	0.86	5.46	5.38	26.1	67.3	6.6
VA012	518362	6045699	178	1.6	0.67	8.72	5.26	59.2	36.6	2.2
VC001	522502	6033908	92	0.6	1.06	4.34	5.92	71.7	23.9	1.8
VC002	511340	6033125	78	1.7	0.84	10.51	5.54	50.7	43.4	2.9
VC005	523386	6033715	119	1.2	0.85	5.82	5.35	85.9	12.5	1.6
VC003	522944	6033289	116	1.6	0.74	6.77	5.34	61.0	35.8	2.2
S002	516622	6049232	557	8.1	0.22	24.77	4.04	38.6	50.4	11.0
GD003	529938	6021250	135	3.7	0.85	6.86	5.70	29.6	61.3	9.0
SSS002	521021	5994675	39	1.4	0.50	13.06	5.09	32.0	62.9	5.0
GD009	532436	6020271	312	14.9	0.57	13.01	5.64	20.3	72.4	7.3
VA006	518437	6041559	71	1.2	0.84	4.96	5.88	55.5	41.1	3.4
LM001	536895	6041893	391	4.9	0.19	34.13	4.97	58.4	12.8	27.8
VA001	518567	6042137	21	6.9	0.79	7.95	6.29	25.5	64.5	10.0
GD013	531991	6036225	195	33.4	0.79	2.81	6.03	30.6	63.2	6.2
GD012	535494	6010219	144	2.4	1.02	15.90	.	20.9	67.6	11.4
QM002	523825	5984330	57	10.6	0.55	25.19	4.93	49.8	46.1	4.0
QM005	523227	5983381	126	3.4	0.67	17.33	5.12	68.2	29.8	1.7
CA011	521068	6030247	33	0.4	0.86	7.05	5.36	30.0	65.6	4.4
VA002	518588	6044286	217	1.6	0.39	16.01	6.43	57.7	39.6	2.7
S006	518969	6048164	192	13.9	1.08	2.66	5.76	31.6	62.6	5.8
CA001	519891	5992970	68	1.0	0.92	6.50	4.92	38.4	57.6	3.9

Site ID	Easting m	Northing m	ALT m	CFG %v	Db g/cm^3	LOI %	pH H_2O	Sand %	Silt %	Clay %
QD012	527274	6025346	86	0.3	0.93	4.96	5.42	75.5	20.1	1.4
QD015	526589	5988588	146	14.7	0.45	26.90	5.36	33.8	58.0	8.2
G0026	516306	6011863	373	4.1	0.14	58.78	4.76	61.3	36.1	2.2
OG009	508903	6018845	599	7.1	0.12	15.68	5.79	63.9	33.0	2.3
G0027	516293	6012091	394	12.6	0.65	8.82	6.04	92.6	6.5	0.9
G0008	516956	6010684	174	10.3	0.34	10.81	6.63	39.5	50.6	9.9
OG010	508838	6018966	602	35.0	0.67	34.15	5.26	57.1	39.8	1.9
SSS003	517274	5995719	406	8.8	0.19	36.29	5.00	52.5	44.6	2.9
OG001	509004	6018291	661	35.0	0.85	8.28	5.48	40.3	56.7	3.0
G0028	515837	6011284	204	9.0	0.64	10.99	5.55	20.6	69.4	10.0
OG003	508757	6025319	448	2.2	0.40	30.96	5.29	33.9	60.8	5.3
DCAS01-01	503540	5917780	495	7.7	1.03	11.24	4.71	79.9	18.7	0.6
DCAS01-02	501358	5917335	125	4.1	0.69	7.77	4.74	79.2	20.1	0.4
DCAS02	497718	5924221	464	2.9	1.03	3.97	4.75	81.4	18.4	0.1
DCAS04	481477	5930183	6	10.8	0.56	8.80	4.78	80.4	19.3	0.4
DCAS08-01	539398	6053991	373	9.9	0.73	14.05	5.17	58.9	38.2	2.8
DCAS08-02	540478	6059287	236	21.6	0.73	6.53	5.24	54.0	43.4	2.6
DCAS08-03	520661	6056290	352	38.1	1.47	4.76	5.23	62.5	31.9	2.4
DCAS08-04	525032	6057597	584	16.2	0.59	13.51	4.85	75.9	22.6	1.0
DCAS09-01	511372	6068678	206	2.0	0.93	4.26	5.30	48.2	48.7	3.0
DCAS09-02	511058	6068702	232	24.2	0.55	5.00	5.88	58.5	38.6	2.8
DCAS10-01	537550	6072337	1040	16.9	0.62	13.53	4.69	63.3	33.5	2.6
DCAS10-02	538230	6073542	678	17.1	0.45	30.90	4.64	51.6	46.3	2.0
DCAS12	483117	5919903	12	1.8	0.85	9.50	4.47	71.0	28.3	0.6
DCAS13	489035	5915288	15	45.4	0.65	9.20	5.69	76.2	22.2	0.9
DCAS14	480647	5916625	25	8.9	0.63	8.83	5.16	77.6	18.1	0.5
DCAS16	504752	5936913	343	4.3	0.88	5.66	4.81	83.8	15.8	0.4
DCAS18	502926	5944216	302	7.3	0.59	6.84	4.48	75.0	24.0	1.0
DCAS19-01	487032	5945656	63	9.0	0.71	10.52	4.83	69.8	28.4	1.8
DCAS19-02	479341	5944911	28	24.9	0.75	7.81	4.52	78.4	20.4	1.1
DCAS20	489230	5942820	23	3.1	0.72	8.57	4.92	78.6	21.2	0.2
DCAS21	514849	5985212	379	7.7	0.73	8.96	5.05	57.7	39.8	2.5
DCAS23	524952	5976852	420	12.6	0.61	11.39	6.06	71.9	26.5	1.6
DCAS24-01	505862	6072560	316	19.1	0.68	10.79	5.63	59.0	38.8	2.2
DCAS24-02	508148	6070036	907	24.0	1.51	13.52	5.16	72.0	25.8	1.2
DCAS25	528452	6033644	242	39.7	1.25	3.77	5.83	41.9	52.2	5.3
DCAS26	525904	6016309	209	15.0	0.47	13.93	4.97	61.4	34.8	3.8
DCAS27	523181	5987365	153	4.3	0.67	7.37	5.40	42.7	53.2	4.1
DCAS28	519339	5989342	202	16.5	0.42	15.57	5.28	65.8	31.8	2.4
DCAS29	521279	5997167	10	12.0	0.80	8.27	5.27	65.0	32.6	2.4

Table A12-2. Average major oxide content and loss-on-ignition per soil profiles (n = 80) used for the determination of soil mineralogy and base cation weathering rate. See Table A12-1 for further details on sampling location.

Site ID	SiO2 %	TiO2 %	Al2O3 %	Fe2O3 %	MnO %	MgO %	CaO %	K2O %	Na2O %	P2O5 %	LOI %
CA008	57.41	0.86	16.60	7.29	0.12	1.77	0.60	1.52	1.78	0.12	11.52
GR001	48.53	0.42	11.74	4.70	0.06	1.01	2.83	1.15	2.32	0.10	26.62
GR002	56.94	0.90	16.62	7.47	0.09	1.66	1.01	1.48	2.23	0.19	11.13
GR003	59.28	0.87	16.33	6.71	0.11	1.75	1.18	1.52	2.08	0.15	9.75
GR005	56.00	0.72	13.65	5.20	0.06	0.68	2.02	1.95	2.59	0.16	16.15
CA004	58.47	0.72	14.65	6.20	0.12	2.76	4.20	1.44	3.19	0.24	7.63
LM006	58.53	0.87	16.23	6.66	0.06	1.36	1.35	1.34	2.73	0.33	9.69
LM009	63.36	0.69	12.29	7.33	0.04	2.17	0.63	0.69	1.50	0.11	10.37
LM010	62.07	0.93	15.17	6.49	0.08	1.58	1.14	1.34	2.34	0.25	8.35
QD006	60.41	0.80	15.86	4.90	0.06	1.04	1.84	2.10	3.19	0.26	9.12
QD007	50.22	0.79	12.55	6.50	0.06	0.85	0.82	1.09	2.06	0.18	23.76
QM001	44.30	0.46	13.02	4.23	0.15	0.94	2.01	1.11	2.27	0.15	31.01
QM003	70.80	0.19	13.28	1.64	0.04	0.11	0.50	4.71	4.66	0.02	3.71
S001	62.95	0.96	13.59	5.37	0.07	1.50	1.09	1.33	2.00	0.26	10.43
S011	60.07	0.89	15.43	6.63	0.08	1.51	1.13	1.38	2.34	0.30	9.68
S022	62.87	0.89	15.43	5.91	0.10	1.70	1.19	1.63	2.27	0.22	7.61
SSS001	46.31	0.60	12.71	5.35	0.06	1.43	1.53	1.05	1.88	0.08	28.36
SSS004	60.48	0.88	14.81	5.80	0.16	1.36	1.03	1.38	2.76	0.08	10.45
SSS005	60.66	0.52	13.53	5.77	0.13	2.32	2.62	1.42	3.07	0.14	9.10
SSS006	58.48	0.91	15.06	6.70	0.06	1.37	1.13	1.24	2.01	0.41	11.83
VA012	56.99	0.89	15.67	6.16	0.08	1.56	0.81	1.67	1.84	0.22	13.60
VC001	58.42	0.89	17.22	7.20	0.10	1.68	0.50	1.52	1.72	0.15	9.96
VC002	53.32	0.99	14.20	7.46	0.06	1.55	1.64	0.71	2.30	0.52	16.27
VC005	57.61	0.97	15.47	7.24	0.08	1.35	0.87	1.14	2.09	0.19	12.50
VC003	58.12	0.95	15.17	6.91	0.09	1.53	0.73	1.31	1.85	0.21	12.87
S002	50.28	0.87	8.44	6.04	0.03	0.46	0.57	0.76	0.85	0.07	31.39
GD003	59.36	0.85	13.74	6.55	0.07	1.21	1.28	1.22	2.54	0.26	12.08
SSS002	53.96	0.78	14.19	6.97	0.07	1.46	0.92	1.18	1.71	0.12	18.72
GD009	55.13	0.76	13.30	5.36	0.06	0.73	1.88	1.59	2.68	0.11	17.63
VA006	59.40	0.85	15.52	6.48	0.11	1.80	0.98	1.55	2.29	0.17	10.17
LM001	34.23	0.66	10.89	7.53	0.16	1.65	4.64	0.64	1.30	0.42	37.51
VA001	56.79	0.86	15.60	6.30	0.08	1.65	1.02	1.47	2.04	0.21	13.50
GD013	61.33	0.83	14.92	6.78	0.10	1.48	1.31	1.43	2.81	0.38	7.84
GD012	57.99	0.55	11.76	1.53	0.03	0.57	1.70	2.31	3.08	0.09	19.61
QM002	34.23	0.98	11.85	12.80	0.09	5.63	2.01	0.51	0.74	0.08	30.49
QM005	45.41	0.68	14.34	6.41	0.08	1.38	1.02	1.20	1.76	0.14	27.12
CA011	58.82	0.99	14.40	6.38	0.07	1.39	0.92	1.03	2.21	0.42	13.06
VA002	48.33	0.76	13.83	6.30	0.21	1.35	2.16	1.03	2.51	0.23	22.48
S006	65.03	0.60	15.33	4.99	0.07	1.51	1.93	1.75	2.98	0.16	5.45
CA001	58.73	0.93	15.19	6.63	0.09	1.68	0.78	1.47	1.59	0.11	11.91
QD012	61.32	0.91	15.12	6.38	0.11	1.45	0.94	1.46	2.66	0.09	9.03
QD015	43.79	0.63	12.63	5.89	0.07	1.24	2.59	0.98	2.17	0.15	29.52
G0026	22.50	0.30	5.52	2.45	0.03	0.47	1.14	0.73	0.82	0.11	65.58
OG009	58.50	0.71	13.94	3.71	0.08	1.20	3.15	2.07	2.79	0.14	13.24
G0027	56.71	0.72	13.78	7.20	0.08	1.50	2.80	1.84	2.63	0.10	12.16
G0008	50.32	0.51	12.91	10.82	0.69	1.83	2.99	1.36	2.35	0.20	15.80
OG010	34.14	0.55	8.65	3.82	0.05	1.07	2.08	1.04	1.53	0.16	46.41

Site ID	SiO2 %	TiO2 %	Al2O3 %	Fe2O3 %	MnO %	MgO %	CaO %	K2O %	Na2O %	P2O5 %	LOI %
SSS003	25.57	0.41	5.93	2.46	0.05	0.80	1.62	0.60	0.98	0.13	61.10
OG001	58.31	0.44	15.21	4.61	0.12	1.33	3.27	1.98	2.86	0.21	10.86
G0028	58.44	0.65	11.65	4.47	0.06	0.92	2.39	1.63	2.26	0.11	16.73
OG003	42.88	0.59	10.56	4.52	0.05	0.65	1.40	1.37	2.01	0.13	35.41
DCAS01-01	57.32	0.68	14.60	3.12	0.03	0.95	3.47	1.20	4.06	0.10	14.77
DCAS01-02	52.51	0.75	14.47	5.53	0.07	2.00	4.95	0.90	3.49	0.06	15.55
DCAS02	60.19	0.58	14.66	2.18	0.02	0.49	3.28	1.30	4.94	0.04	12.50
DCAS04	55.79	0.67	11.50	5.93	0.09	2.89	4.16	1.20	1.94	0.14	15.87
DCAS08-01	55.38	0.80	12.68	5.99	0.03	0.83	0.90	1.07	2.29	0.11	20.28
DCAS08-02	59.31	0.76	11.46	5.03	0.04	1.04	0.84	1.11	2.39	0.31	18.05
DCAS08-03	59.37	0.69	14.59	5.77	0.10	1.23	1.98	1.76	2.94	0.17	11.61
DCAS08-04	54.54	0.52	13.07	4.03	0.04	0.97	2.38	1.67	2.97	0.16	19.86
DCAS09-01	64.37	0.68	15.21	3.44	0.06	1.19	2.54	2.03	3.20	0.14	7.33
DCAS09-02	56.23	0.59	15.40	5.41	0.08	1.33	2.82	1.92	2.90	0.18	13.43
DCAS10-01	50.86	0.76	14.21	7.45	0.12	2.04	1.85	1.87	1.72	0.19	19.05
DCAS10-02	38.15	0.65	8.79	5.63	0.03	0.66	0.72	1.06	0.91	0.22	43.17
DCAS12	46.15	0.64	10.72	4.24	0.04	1.04	2.73	1.29	2.80	0.05	30.40
DCAS13	60.15	0.65	12.46	3.91	0.06	1.26	2.19	1.34	2.96	0.08	14.61
DCAS14	47.12	0.72	12.77	5.33	0.07	2.11	3.85	1.38	3.01	0.11	23.54
DCAS16	61.57	0.72	15.87	1.65	0.04	0.51	1.05	4.23	5.87	0.05	8.48
DCAS18	59.51	0.65	13.58	4.58	0.07	1.81	4.31	1.34	3.01	0.08	10.87
DCAS19-01	57.59	0.71	12.07	9.00	0.05	2.11	1.08	0.97	0.56	0.10	15.84
DCAS19-02	60.83	0.67	13.41	4.05	0.05	2.41	2.56	1.08	2.98	0.09	11.88
DCAS20	49.82	0.65	11.77	5.83	0.06	2.43	4.30	1.16	2.69	0.05	21.24
DCAS21	61.08	0.70	12.70	5.97	0.07	1.51	3.24	1.06	2.53	0.06	11.28
DCAS23	53.86	0.58	13.75	5.54	0.07	1.23	3.08	1.05	2.81	0.10	18.01
DCAS24-01	48.56	0.52	12.44	4.81	0.07	1.05	1.45	2.00	1.84	0.18	27.12
DCAS24-02	55.32	0.58	13.22	4.55	0.11	1.05	2.42	1.84	2.48	0.19	18.36
DCAS25	60.58	0.82	14.96	6.90	0.07	1.62	1.02	1.46	2.66	0.21	9.96
DCAS26	54.05	1.38	11.10	8.20	0.04	0.96	1.07	0.91	1.78	0.18	20.37
DCAS27	55.00	0.79	14.93	6.30	0.07	2.66	2.79	1.59	2.70	0.24	12.84
DCAS28	50.37	0.77	14.61	6.33	0.07	1.21	1.78	1.26	2.38	0.17	21.17
DCAS29	59.10	0.82	13.10	5.92	0.05	1.24	2.70	1.28	2.76	0.09	13.18

Table A12-3. Average soil mineralogy per soil profile (n = 80) estimated from major oxide content using the A2M solver (Posch and Kurz 2007). See Table A12-1 and Table A12-2 for further details on sampling location and soil oxide content.

Site ID	Apatite %	Calcite %	Chlorite %	Hornblende %	Kaolinite %	K-Feldspar %	Muscovite %	Plagioclase %
CA008	0.32	0.13	11.56	1.95	19.92	13.97	8.12	9.17
GR001	0.32		5.58	7.94	2.63	11.52	7.59	33.60
GR002	0.50		10.16	4.45	18.77	16.45	6.91	12.07
GR003	0.39		8.42	6.17	18.59	15.41	7.38	11.15
GR005	0.45		4.22	8.61	6.14	18.33	11.65	20.55
CA004	0.60	1.31	8.30	11.38	4.44	10.21	8.63	30.48
LM006	0.85		7.73	5.54	16.50	10.68	7.51	21.06
LM009	0.29		12.01	2.84	14.48	5.54	3.90	11.95
LM010	0.63		8.53	4.60	15.82	16.28	5.47	12.30
QD006	0.67		4.84	7.02	7.97	18.83	12.05	21.56
QD007	0.56		8.57	4.19	16.09	17.20	5.06	12.75
QM001	0.51		5.57	10.00	12.43	10.18	9.37	28.93
QM003	0.05		0.53	3.69	0.25	49.04	0.85	20.82
S001	0.68		7.55	4.35	13.93	14.67	6.18	10.88
S011	0.77		8.83	4.25	16.52	16.66	5.87	12.38
S022	0.55		8.01	5.07	14.49	16.35	7.65	12.03
SSS001	0.26		7.23	10.11	17.16	16.76	5.40	14.79
SSS004	0.21		7.12	5.63	13.00	11.09	7.80	21.35
SSS005	0.36		6.83	11.48	4.32	10.91	8.18	28.50
SSS006	1.09		9.12	3.51	18.26	14.82	5.59	10.85
VA012	0.59		9.48	3.14	17.41	15.03	9.37	10.07
VC001	0.39		11.09	1.76	21.48	13.41	8.11	8.70
VC002	1.46		9.52	6.38	18.03	6.12	4.30	21.51
VC005	0.51		9.61	3.70	19.66	15.14	4.69	11.34
VC003	0.56		10.27	2.71	18.35	14.11	6.48	9.87
S002	0.24		8.04	3.50	12.75	8.69	5.33	6.53
GD003	0.69		8.80	4.90	10.60	8.64	8.34	21.82
SSS002	0.34		9.87	4.86	18.39	13.85	6.14	10.44
GD009	0.31		4.97	8.28	7.35	17.38	9.33	21.92
VA006	0.44		9.53	4.40	15.45	16.86	7.28	12.27
LM001	1.57		10.15	16.68	3.98	8.05	4.67	35.15
VA001	0.57		9.24	4.49	17.84	15.77	7.41	11.46
GD013	0.96		9.61	4.07	11.68	16.87	6.85	16.38
GD012	0.26		1.80	3.60	1.15	34.02	6.00	19.71
QM002	0.27		34.68	11.29	10.90	7.04	3.18	11.06
QM005	0.45		9.50	6.40	21.58	15.97	6.96	11.83
CA011	1.12	0.11	9.81	1.65	16.51	8.48	5.96	17.15
VA002	0.69		8.56	10.24	12.01	8.51	7.72	28.37
S006	0.39		5.64	7.57	8.54	16.35	9.34	20.21
CA001	0.29	0.18	10.29	2.84	17.84	12.85	8.18	8.62
QD012	0.23		7.78	5.12	14.78	18.56	5.81	13.59
QD015	0.50		7.85	11.36	8.77	7.85	8.78	31.45
G0026	0.75		5.73	10.46	6.40	15.59	11.17	18.82
OG009	0.38	1.22	4.40	6.53	4.03	20.66	11.26	21.14
G0027	0.27		6.30	12.40	4.89	19.41	8.97	20.66
G0008	0.55		11.94	13.79	5.49	17.21	6.21	19.93
OG010	0.70	0.98	7.96	8.91	6.18	16.70	9.61	20.67

Site ID	Apatite %	Calcite %	Chlorite %	Hornblende %	Kaolinite %	K-Feldspar %	Muscovite %	Plagioclase %
SSS003	0.78		7.00	8.72	3.65	15.23	6.55	24.70
OG001	0.55	1.08	5.76	6.88	6.03	18.80	11.18	22.43
G0028	0.31		4.60	7.03	2.46	18.72	8.01	20.45
OG003	0.47	0.54	6.89	5.79	7.34	15.93	11.97	19.53
DCAS01-01	0.27		2.88	6.15	1.00	13.98	4.00	47.47
DCAS01-02	0.16		3.65	15.41	1.21	9.83	3.69	47.92
DCAS02	0.11		1.01	6.60	0.31	19.62	1.03	50.46
DCAS04	0.38	1.49	8.72	12.86	4.81	13.94	6.09	18.13
DCAS08-01	0.32		7.05	4.82	13.22	9.53	6.70	20.24
DCAS08-02	0.87		8.43	2.28	7.65	8.00	8.33	21.04
DCAS08-03	0.44		5.94	8.40	7.69	17.90	9.48	20.99
DCAS08-04	0.46		4.36	7.17	3.61	20.85	8.21	26.68
DCAS09-01	0.35		3.77	5.88	3.86	19.25	9.71	25.72
DCAS09-02	0.48		5.82	8.16	4.95	17.89	11.03	26.51
DCAS10-01	0.54		11.15	8.58	9.39	14.13	13.48	13.94
DCAS10-02	0.90		10.70	3.76	12.10	10.94	10.91	8.71
DCAS12	0.17		3.00	12.22	1.26	18.15	5.40	34.76
DCAS13	0.22		4.69	6.78	2.58	10.27	8.47	31.29
DCAS14	0.33		5.47	16.19	1.44	17.32	5.84	36.89
DCAS16	0.13	0.40	1.63	2.96	0.69	53.00	2.33	28.60
DCAS18	0.21	1.58	5.19	9.53	3.98	11.99	6.62	31.14
DCAS19-01	0.28		12.97	5.84	15.72	5.74	6.57	4.67
DCAS19-02	0.24		5.89	10.13	6.14	8.31	6.41	30.96
DCAS20	0.15		4.01	19.59	1.10	14.64	4.44	34.62
DCAS21	0.16		5.94	8.56	2.59	8.66	5.84	31.23
DCAS23	0.28		6.71	7.25	3.81	8.05	7.14	37.53
DCAS24-01	0.57		6.55	7.62	6.26	15.71	16.94	15.61
DCAS24-02	0.54		5.28	7.17	3.70	18.62	10.75	22.60
DCAS25	0.54		10.37	3.75	11.93	16.32	7.47	15.67
DCAS26	0.52		10.77	4.91	11.26	12.66	4.74	12.39
DCAS27	0.64		8.47	12.12	8.43	16.83	8.55	21.54
DCAS28	0.50		7.98	8.69	15.18	17.15	6.81	18.32
DCAS29	0.24		6.15	7.68	3.14	9.94	7.68	30.90

12.2 Background Deposition

Modelled sulphur and nitrogen deposition estimates (see Section 2) for this scoping study did not include background deposition estimates. Therefore, the modelled deposition for all scenarios represents the contribution of the stationary and mobile emissions sources (listed in Section 1) to total deposition, rather than total anthropogenic deposition to the study domain. Transboundary atmospheric sources contribute a significant amount of anthropogenic sulphur and nitrogen deposition, as observed by monitoring stations in background regions (see CAPMoN [URL: www.on.ec.gc.ca/natchem], NADP [URL: http://nadp.sws.uiuc.edu] and EMEP [URL: www.nilu.no/projects/ccc]).

Global anthropogenic sulphur emissions during 2010 were approximately 100 Tg[42] SO_2, with China responsible for approximately one third of all global emissions (Klimont et al. 2013). Mean multi-model global predictions of sulphur and nitrogen deposition indicate that shipping and emissions from China are significant sources of transboundary anthropogenic deposition to northern British Columbia (Lamarque et al. 2013). Global model estimates of wet anthropogenic sulphur deposition to north coastal British Columbia during 2000 ranged from 100–200 mg S/m^2/yr (6.3–12.5 meq/m^2/yr); notably global sulphur emissions during 2000 were similar to 2010 (Klimont et al. 2013), although China's contribution to this total was about 20% higher in 2000 than 2010. Global model estimates of wet oxidised nitrogen during 2000 ranged from 50–100 mg N/m^2/yr (3.6–7.1 meq/m^2/yr).

Observations of wet deposition from monitoring stations within the CAPMON, NADP and EMEP networks show similar ranges in background regions, e.g., average non-marine sulphur deposition to three NADP stations in Washington state and two stations in Alaska during the last decade was approximately 5 meq/m^2/yr. Average wet nitrate deposition at the same sites was approximately 3.5 meq/m^2/yr. This suggests that background deposition of sulphur (owing to transboundary sources) in the Kitimat Airshed ranges from 5–10 meq/m^2/yr, and background nitrogen deposition ranges from 3–5 meq/m^2/yr.

There are limited observations of wet deposition in (or close to) the study area, i.e., Lakelse Lake (operated by NADP since February 2014) and Diana Lake Provincial Park (Emili and Price 2013). These sites suggest an average wet sulphate concentration in precipitation of 9 µeq/L and wet nitrate concentration of 2 µeq/L. Assuming constant precipitation concentration across the region, average sulphate wet deposition is 25.8 meq/m^2/yr (range: 8.8–53.7 meq/m^2/yr), and average nitrate wet deposition is 5.7 meq/m^2/yr (range: 1.9–11.9 meq/m^2/yr) using long-term climate normals for precipitation volume (see Section 5, Table 5-1). However, spatial observations are too limited to evaluate the influence of higher rainfall volumes (under increasing altitude) on precipitation concentrations, which may lead to significant overestimates of wet deposition in high rainfall areas.

Based on wider monitoring networks and global modelling studies, we chose a constant sulphur deposition of 10 meq/m^2/yr and nitrogen deposition of 5 meq/m^2/yr to represent background deposition for this scoping study. It is recognised that actual background deposition will vary across the region, and that the selected values represent precautionary estimates of background deposition. We recommend that these values be revised if further information becomes available in the future.

[42] Teragram, which equals 1 million metric tons.

12.3 Sensitivity Analysis: Impact of Deposition Year on Exceedance of Critical Loads of Acidity for Forest Ecosystems

Modelled deposition estimates under this scoping study were based on one meteorological year, i.e., 2008. This year was precautionary from a deposition standpoint, as the 2008 meteorological year had the highest deposition levels of the three years (2006, 2008 and 2009) used in the KMP SO_2 Technical Assessment (ESSA et al. 2013).

The results of the KMP SO_2 Technical Assessment (ESSA et al. 2013) were revisited to evaluate the potential influence of deposition year on predicted exceedance of critical loads of acidity for forest soils under the Kitimat Airshed Emissions Effects Assessment. A sensitivity analysis was carried out comparing modelled KMP exceedance under 2008 with exceedance under the average of 2006, 2008 and 2009 using the KMP SO_2 Technical Assessment data. However, given the significant differences in data sources, regionalisation approaches and critical load methodologies between the two assessments, the results of this analysis can at best be speculatively extended to the Kitimat Airshed Emissions Effects Assessment.

Average modelled sulphur deposition across the KMP study domain during 2008 was 187.4 meq/m^2/yr (range: 2.2–11,677.0 meq/m^2/yr) compared with 163.4 meq/m^2/yr (range: 3.0–8,143.4 meq/m^2/yr) under the 2006, 2008 and 2009 meteorological years. Total modelled deposition[43] to the KMP study domain based on the 2008 meteorological year was 278,619 meq (4,466 kg S) in excess of the average total sulphur deposition for 2006, 2008 and 2009.

In general, higher levels of atmospheric deposition lead to higher levels of exceedance. Under the 2008 meteorological year, 1.32 km^2 (encompassing eleven 500 m × 500 m grids with average exceedance of 156.8 meq/m^2/yr) of forest ecosystems on mineral soil received sulphur deposition in excess of critical loads compared with 0.41 km^2 (encompassing five 500 m × 500 m grids with average exceedance of 161.7 meq/m^2/yr) under the 2006, 2008 and 2009 deposition average (see Figure A12-1).

[43] This is the difference in the sum of modelled KMP deposition to all grids using the 2008 meteorological year compared with the same metric for 2006, 2008 and 2009 which was then averaged across those three years.

Figure A12-1. Exceedance of critical loads of acidity (sulphur) from modelled KMP deposition for forest ecosytems on mineral soils under the average 2006, 2008 and 2009 deposition scenario (orange filled squares) and under the 2008 deposition scenario (orange and yellow filled squares). Note: areal exceedance relates solely to forest coverage within the mapped 500 m × 500 m modelled deposition grids; colours do not represent risk categories.

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APPENDIX 13: DETAILS OF LAKES DATA SETS USED

The three data sets used in this study were selected through the steps outlined below.

1) **Data Set 1** includes 41 lakes sampled in August 2012 by Limnotek and analyzed by ESSA for the KMP SO_2 Technical Assessment (ESSA et al. 2013). The method of selecting these lakes is described in detail in ESSA et al. (2013). Briefly, the 41 lakes included all lakes greater than 1 ha in size within the study area which met a set of lake selection criteria as 'true lakes' and were either in acid-sensitive bedrock geologies, or received levels of sulphate deposition which might potentially cause acidification based on studies in other locations within North America. The 41 sampled lakes spanned four sampling regions:
    a. Twenty-two lakes entirely within the three year average 10 kg SO_4/ha/yr isopleth of total sulphate deposition from KMP (irrespective of the bedrock geology sensitivity of a lake's watershed)
    b. Six lakes north of the isopleth that would be potentially exposed to total KMP sulphate deposition of more than 7.5 kg SO_4/ha/yr based on meteorological conditions in 2008 (irrespective of the bedrock geology sensitivity of a lake's watershed)
    c. Five lakes south of the smelter that would potentially receive SO_4 deposition during wind outflows
    d. Eight lakes within acid sensitivity classes (ASC) 1 and 2, based on Hornung et al. (1995)

2) **Data Set 2** includes 28 lakes sampled by Limnotek in October 2013 under a separate part of the Kitimat Airshed Project (Perrin et al. 2014), shown in Figure 6-1. These 28 lakes were derived from two groups:
    a. Twenty-one lakes were derived from a set of candidate lakes selected by Dr. Julian Aherne of Trent University. Dr. Aherne selected candidate lakes from drainages whose bedrock geologies fell within acid sensitivity classes (ASC) 1 to 3 based on Hornung et al. 1995. Clusters of two to four lakes formed a site group that receives drainage from the same bedrock geology. Up to two lakes within each site group were actually sampled, with the selection made in the field based on access constraints and most direct flight routes. One additional lake that could not be accessed due to weather was omitted.
    b. An additional seven lakes were recommended for sampling by MOE based five criteria: (1) on glaciofluvial landforms; (2) near settlements with human uses; (3) within the inferred emissions plume of industrial activities based upon prevailing wind patterns; (4) previously mentioned as being sensitive to acidification (Swain 1985); and (5) of potential use as reference lakes. One of these seven lakes was sampled in October 2013 as part of the KMP Environmental Effects Monitoring project based on a recommendation from MOE (Perrin et al. 2013).

3) **Data Set 3** includes 13 lakes in the study region sampled by Environment Canada in October 2013. A total of nine lakes were selected by Environment Canada based on their size (> 4 ha) and bedrock weathering classes, typically granites. As with other regions sampled by Environment Canada since 2008 (e.g., Strang et al. 2010), the intent of Environment Canada was to include the most sensitive (e.g., least buffered) lakes in the set of sampled lakes. From the suite of potential lakes, a statistical subset was chosen to represent the range of lake sizes in the study

area. An additional four lakes recommended by MOE were included in the set of lakes sampled by Environment Canada based on the five MOE criteria described above under 2b.

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APPENDIX 14: ANALYSIS OF CHARGE BALANCE AND PREDICTED VS. MEASURED CONDUCTIVITY

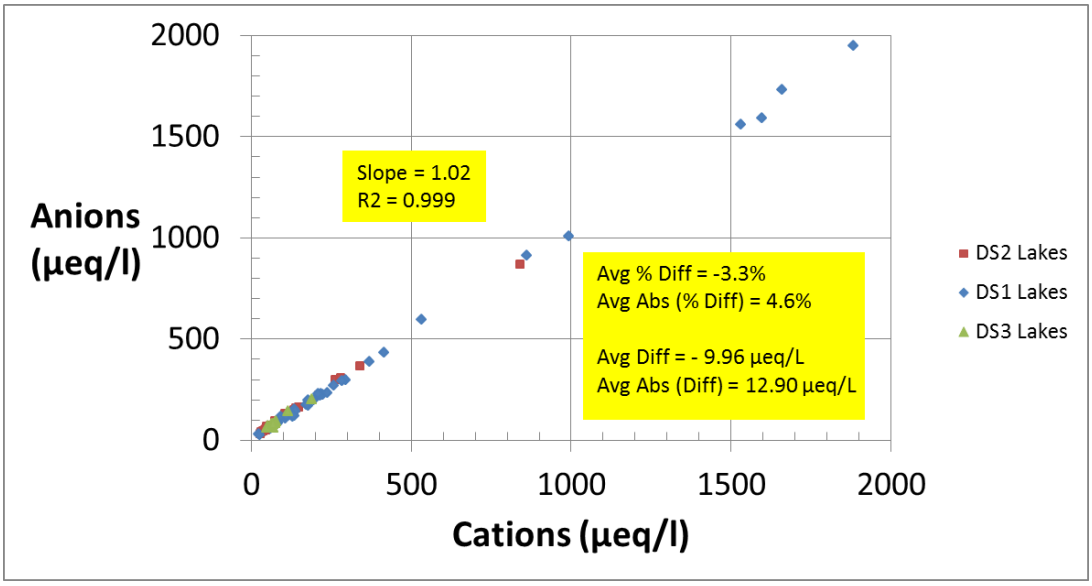

Figure A14-1. Analysis of charge balance. The Y-axis is the sum of all major anions (negatively charged ions); the X-axis the sum of all major cations (positively charged ions).

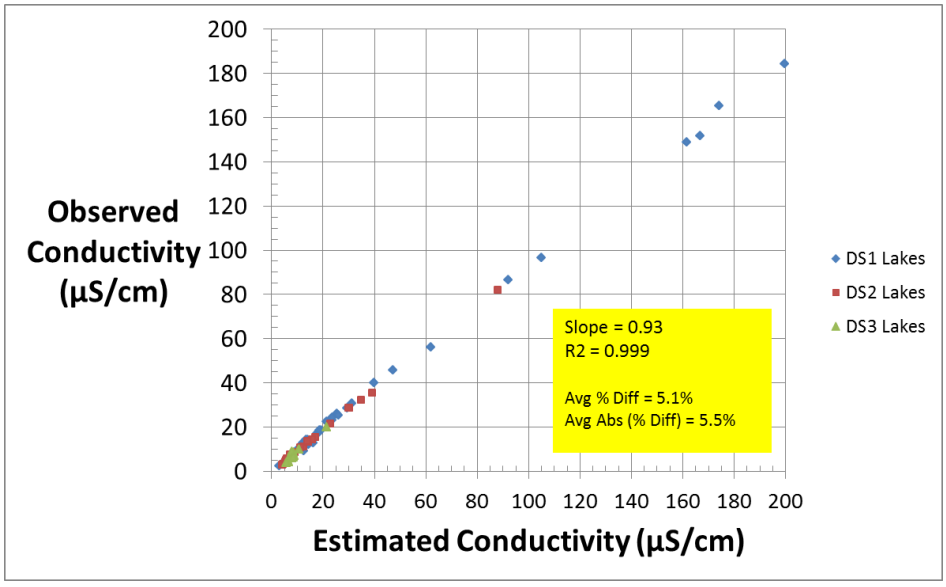

Figure A14-2. Analysis of estimated conductivity (based on laboratory measurements of the concentrations of all ions, and literature values for the conductivity of each ion) vs. conductivity observed in field measurements.

APPENDIX 15: DATA INPUTS FOR CRITICAL LOAD MODELLING

The following water quality parameters are required either as inputs for the SSWC and FAB models, for charge balance and conductivity QA/QC calculations, or to assess the relative importance of different factors on current acid-base water chemistry:

- **Standard water quality parameters providing contextual information on each lake:** dissolved oxygen, conductivity, total dissolved solids, temperature, turbidity
- **Major anions**: chloride, fluoride, nitrate, bicarbonate, carbonate, sulphate (chloride was used to make sea-salt corrections of sulphate, calcium, magnesium, sodium and potassium)
- **Major cations:** calcium, magnesium, sodium, potassium, ammonium, hydrogen (pH)
- **Metals:** aluminum, manganese, iron (only in data sets 1 and 2), indicators of water quality
- **Gran Acid Neutralizing Capacity (Gran ANC):** the capacity of a solution to neutralize strong acids, used to determine the sensitivity of lakes to acidification, and determined by titration to the inflection point of the pH-alkalinity titration curve (only in data sets 1 and 2)
- **Fixed end point alkalinity:** similar to Gran ANC, but more commonly applied in historical studies (thereby allowing comparisons to historical data), and determined by titration to a fixed end point of pH 4.5 (in all 3 data sets)
- **Dissolved organic carbon:** used to estimate the concentration of organic anions, an indicator of influence from wetlands and vegetation on water quality
- **Dissolved inorganic carbon (DIC):** the sum of dissolved carbon dioxide (as CO_2 or H_2CO_3), bicarbonate and carbonate in a solution of water; DIC can be used to determine the proportions of carbonate and bicarbonate ions that are present at a given pH

15.1 Additional Data Required for Calculation of Critical Loads and Exceedances

Other data required for calculating critical loads and exceedance include:

- **Average runoff:** As in the KMP SO_2 Technical Assessment, we acquired average annual runoff values for the 1960-1999 period[44] for the entire study area on a 0.4 km x 0.4 km grid from Joel Trubilowicz (Ph.D. candidate at UBC), applying the Distributed Climate Water Balance Model described in Moore et al. (2012).
- **Watershed areas:** We defined upstream watersheds for each sampled lake primarily using the 1:20K Freshwater Atlas Fundamental Watersheds. The Freshwater Atlas watersheds do not use lake outflows as natural pour points to define the watershed boundaries, so watershed polygons often encompass lakes and result in an area of watershed downstream of the lake. We used flow direction calculated from the Canadian Digital Elevation Data 1:50K digital elevation model (DEM) to identify areas downstream of the lake and remove them from the Freshwater Atlas watershed polygons. The 1:20K Freshwater Atlas stream network was used to enforce

[44] The same time period used in the KMP SO_2 Technical Assessment Report (ESSA et al. 2013).

drainage within the DEM, and ESRI's hydrology toolset was used within ArcMap to define the upstream/downstream areas around the lake outflow.

- **$[ANC]_{limit}$:** We applied the same $[ANC]_{limit}$ that was derived from pH and ANC data from the Kitimat Valley in the KMP SO_2 Technical Assessment (ESSA et al. 2013), namely 26 µeq/L, which will yield a CL sufficient to protect lakes from acidifying below a pH level of 6.0, unless lakes were naturally acidified to below pH 6.0 in pre-industrial times due to organic acids.
- **In-lake retention of N and S**: The lake:watershed area ratio, runoff and mass transfer coefficients are used in FAB to estimate in-lake retention of nitrogen (equation 5.87 in UNECE 2004), and an example application is provided in Aherne et al. (2004). We used the default parameters of S_N=6.5 m/yr and S_S=0.5 m/yr, as per Posch et al. (2012).
- **Lake areas:** Data on lake areas were provided in the KMP SO_2 Technical Assessment Report for data set #1 from the BC Freshwater Atlas (http://ilmbwww.gov.bc.ca/geobc/FWA), and have been provided for data set #2 by the Ministry of Environment.
- **Land cover classes:** the FAB model requires estimates of the areas of grass/heath-land, forested land, peat land (considered equivalent to wetlands) and bare rock within each lake catchment. The fraction of peat land/wetland can be used to estimate the rate of de-nitrification (Posch et al. 1997, as explained in Henriksen and Posch (2001) and UNECE (2004)). Land use and land cover classifications were produced using a combination of provincial and national data sets, as described below.
- **Removal of Base Cations and Nitrogen by Forest Harvesting:** The KMP SO_2 Technical Assessment study area included parts of TFL 1 and TFL 41, three timber supply areas (TSAs) (Kalum, Pacific and Cascadia), and one community forest (Terrace). We built upon the data developed for the SO_2 Technical Assessment, and described on pages 208-209 of Volume 2 of the SO_2 Technical Assessment Report (ESSA et al. 2013).
- **Deposition of S, N, S+N:** Deposition outputs from CALPUFF included S, N, and S+N, at points spread 1 km apart across the study area, with additional points at the centre of each sampled lake. Average deposition across each lake's catchment was estimated from the values at each grid point. As a QA/QC check, we also obtained CALPUFF deposition estimates for the centre points of each lake.
- **Background deposition of S and N:** Anthropogenic deposition unrelated to the Kitimat smelter was estimated by methods described in Appendix 12.2 as 10 meq/m^2/yr of S and 5 meq/m^2/yr of N.

15.2 Land Cover Summary

Land cover data were generated from a combination of data sources to give the best available classification based on accuracy, timeliness, and coverage of the data, as shown in Table A15-1.

Table A15-1. Data sources used to generate land cover data for the project.

Source	Abbreviated name
Vegetation Resource Inventory, 2012 (updated annually). 1:20K vector layer defining polygons of land cover using the BC Land Cover Classification scheme.	VRI
BC Freshwater Atlas, 2008 (updated as needed) 1:20K polygons of lakes, rivers, man-made water bodies, wetlands, and glaciers.	FWA
Land Cover, circa 2000-Vector, c2000 1:50K (approx.) vector layer created from classified aerial and satellite imagery.	LCC2000V
Consolidated cut blocks, 2013 (updated annually). Merger of cut block polygons from VRI, RESULTS, FTEN, and Remote Sensing classification (Landsat imagery), 2013	CCB

The following land cover classes (Table A15-2) were extracted from the above data sets, and were defined by the available classes that can be identified in either the VRI or the LCC2000V or supplemented by the other data sources.

Table A15-2. Land cover classes generated from land cover data sources in Table A15-1.

Coniferous forest	Dense
	Sparse
	Open
Deciduous forest	Dense
	Sparse
	Open
Mixed forest	Dense
	Sparse
	Open
Shrub low (<2m)	(unknown coverage)
	Dense
	Sparse
	Open
Shrub tall (>2m)	(unknown coverage)
	Dense
	Sparse
	Open
Herb	(unknown coverage)
	Dense
	Open
	Sparse
Grassland	
Agricultural land	
Bryoids	

Wetland	Treed
	Shrub
	Herb
	(unknown coverage)
Cut blocks	
Snow/ice	
Exposed land	
Rock/rubble	
Developed land	
Water	
No data/unclassified/unreported	

The primary layer for land cover was the VRI, as this layer provided the most detailed and accurate representation of land cover out of the available data sources. The VRI, however, is unreported for Tree Farm Licence areas (and other areas of private land); for these areas we used the LCC2000V to fill in the gaps. The Freshwater Atlas was used to identify water bodies and wetland areas as well as permanent snow/ice. The consolidated cut blocks layer was used to identify all cut blocks irrespective of their classification in the VRI or LCC2000V as these data sets often classify cut block re-growth as shrub land, herbs, exposed land, or agricultural land. For the purposes of this project, cut blocks were treated as forested land and therefore were identified separately from other vegetation classes. The input data were combined in the following order of precedence: FWA layers, CCB, VRI, LCC2000V.

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APPENDIX 16: APPLICATION OF MODIFIED ESSA/DFO MODEL TO ESTIMATE ORIGINAL, PRE-INDUSTRIAL pH_o AND FUTURE STEADY-STATE pH_∞

The modified ESSA/DFO model is explained in ESSA et al. 2013 (Section 8.6.3.4), and was applied in the KMP SO_2 Technical Assessment to estimate both pH_o and pH_∞. For the Kitimat Airshed Emissions Effects Assessment study, we adjusted this model as follows:

- **Original $[SO_4]_o$.** In the KMP SO_2 Technical Assessment (ESSA et al. 2013), we had a CALPUFF run for the pre-KMP condition (i.e., old Kitimat smelter), and used the modelled pre-KMP deposition (average of 2006, 2008 and 2009) to estimate the original sulphate concentration ($[SO4]_o$) in each lake in data set 1 as follows:

$$[SO4]_o = [SO4]_t - [DEP_{pre\text{-}KMP}/Q], \quad [1]$$

where Q = runoff. This approach worked well in that it gave reasonable, positive estimates of $[SO4]_o$ for most lakes. In a few lakes, equation 1 generated a negative estimate of $[SO4]_o$, which was reset to 0. Lower values of $[SO4]_o$ will generate lower CL estimates, so this approach was precautionary.

For this study, we modified equation [1] as follows:

$$[SO4]_o = [SO4]_t - [DEP_{pre\text{-}KMP} + DEP_{BACKGROUND}] / Q \quad [2]$$

In the KMP SO_2 Technical Assessment, we predicted the future change in Acid Neutralizing Capacity (ΔANC) with KMP, and the steady state ANC (ANC_∞) as follows:

$$ANC_\infty = ANC_t + \Delta ANC_{FUTURE} \quad [3]$$

$$\Delta ANC_{FUTURE} = -1*(1-F)*(DEP_{KMP} - DEP_{pre\text{-}KMP}) / Q \quad [4]$$

where:

- F (F-factor) = proportion of incoming acidity neutralized by cation exchange
- DEP_{KMP} = sulphate deposition (meq/m^2/yr) due to KMP
- $DEP_{pre\text{-}KMP}$ = pre-KMP sulphate deposition due to existing Kitimat smelter (meq/m^2/yr) (average of 2006, 2008, 2009)
- Q = runoff (m)
- ANC = Acid Neutralizing Capacity (µeq/L, or meq/m^3); ANC_t = current ANC measured in 2012; ANC_∞ = eventual steady state ANC

We then used the titration curve based on Small and Sutton (1986), described in Section 8.6.3.4, of ESSA et al. (2013), to estimate the steady state pH (pH_∞) associated with ANC_∞, correcting for the residual in the fit of the curve to 2012 data (i.e., if a pH value was originally below the pH-ANC titration curve, it stayed below the curve). As discussed above, lakes with higher DOC would be expected to fall below the curve.

We estimated each lake's original, pre-industrial pH (pH_o) in the absence of any deposition by setting DEP_{KMP} to zero in equation [2], serving to reflect a *decrease* in current deposition by the amount $DEP_{PRE\text{-}KMP}$. The original, pre-industrial pH_o was estimated from the pre-industrial ANC_o using the titration curve.

- **Prospective prediction of pH_∞.** For this study, we modified equation [4] as follows to estimate future steady state ANC_∞ and pH_∞:

$$\Delta ANC_{FUTURE} = -1*\left[(1-F)*(S\text{-}DEP_{SCEN} - S\text{-}DEP_{pre\text{-}KMP}) + (1-F_N*(N\text{-}DEP_{SCEN} - N\text{-}DEP_{pre\text{-}KMP})\right] / Q \quad [5]$$

where:

  - $S\text{-}DEP_{SCEN}$ and $S\text{-}DEP_{pre\text{-}KMP}$ are the S deposition levels for a given emission scenario, and pre-KMP conditions, respectively, estimated from CALPUFF for 2008.
  - $N\text{-}DEP_{SCEN}$ and $N\text{-}DEP_{pre\text{-}KMP}$ are the N deposition levels for a given emission scenario, and pre-KMP conditions, respectively, estimated from CALPUFF for 2008.
  - F_N is the fraction of N deposition neutralized in the watershed. To reflect the fact that catchments retain more N than S (as shown by the CL functions in Figure 6-10 and conceptually in Figure 6-4), we set $F_N = F * (CLmax(N)/CLmax(S)$, while ensuring that F_N remained bounded between 0 and 1.

Since background S deposition is a component of both $S\text{-}DEP_{SCEN}$ and $S\text{-}DEP_{pre\text{-}KMP}$, it falls out of equation 5 and does not need to be considered. The same is true for background N deposition.

Retrospective prediction of pH_o. We applied the modified ESSA/DFO model retrospectively as follows:

$$ANC_o = ANC_t + \Delta ANC_{PAST} \quad [6]$$

$$\Delta ANC_{PAST} = \left[(1-F)*(S\text{-}DEP_{pre\text{-}KMP} + S\text{-}DEP_{BACK}) + (1-F_N)*(N\text{-}DEP_{pre\text{-}KMP} + N\text{-}DEP_{BACK})\right] / Q \quad [7]$$

where:

  - $S\text{-}DEP_{BACK}$ = background deposition of S (10 meq/m^2/yr); see Appendix 12.2
  - $N\text{-}DEP_{BACK}$ = background deposition of N (5 meq/m^2/yr); see Appendix 12.2

Conversion of ANC_o to pH_o was done as described above for the KMP SO_2 Technical Assessment (ESSA et al. 2013). The inclusion of background deposition led to slight increases in the predicted pH_o, and reduced the number of naturally acidified lakes (defined as having $pH_o < 6$) from 27 to 23.

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ESSA Technologies, J. Laurence, Limnotek, Risk Sciences International, Rio Tinto Alcan, Trent University, Trinity Consultants and University of Illinois. 2013. Sulphur Dioxide Technical Assessment Report in Support of the 2013 Application to Amend the P2-00001 Multimedia Permit for the Kitimat Modernization Project. Volume 2: Final Technical Report. Prepared for Rio Tinto Alcan, Kitimat, B.C. 450 pp.

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APPENDIX 17: EXCLUSION OF ONION LAKE

Onion Lake (DCAS15A) was included in data set 2. Onion Lake had to be excluded from further analyses due to its excessively high chloride levels. As shown in Figure A17-1, the chloride concentration in Onion Lake is almost 8x greater than any other lake, and approximately 24x greater than the average chloride concentration for all other lakes. Given its proximity to the main highway (part of the lake directly abuts the embankment of the roadway), it is likely that the high chloride levels in Onion Lake are due to long-term inputs of road salts in drainage from the highway.

However, an important assumption in the SSWC model is that all chloride in runoff originates from sea salts. This assumption is required in order to use chloride to correct base cation and sulphate concentrations for the influence of sea salts and calculate their non-marine component. A critical load cannot be estimated for Onion Lake because it violates this assumption of the SSWC model.

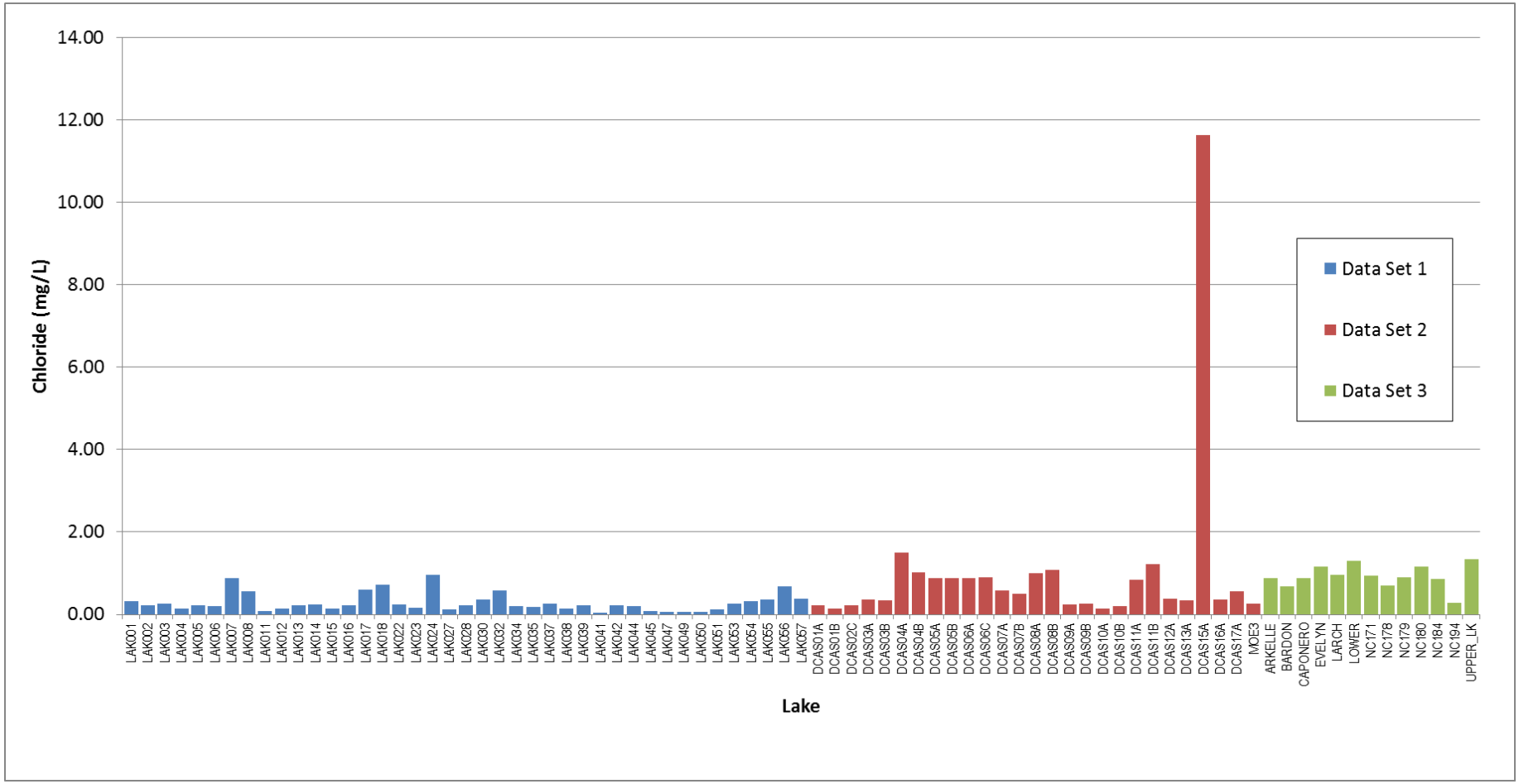


Figure A17-1. Chloride (mg/L) in sampled lakes across all three sets of lakes. The chloride measurements in data sets 2 and 3 are notably higher than for data set 1; however, the chloride measurements for Onion Lake (DCAS015A) are drastically higher than all other lakes.

APPENDIX 18: TOTAL ALKALINITY AND GRAN ANC IN SAMPLED LAKES

In ESSA et al. (2013), a critical ANC of 26.0 µeq/L was calculated based on fitting the Small and Sutton (1986) curve to pH and Gran ANC data for the lakes in data set 1 and determining the ANC where pH=6.0 (see ESSA 2013, Section 9.4.1.1.3). The Gran ANC values for the lakes in data set 2 appear to be consistent with those for data set 1, from which the critical ANC being used in this study was originally derived. Figure A18-1 shows the relationship between pH and Gran ANC for data sets 1 and 2.

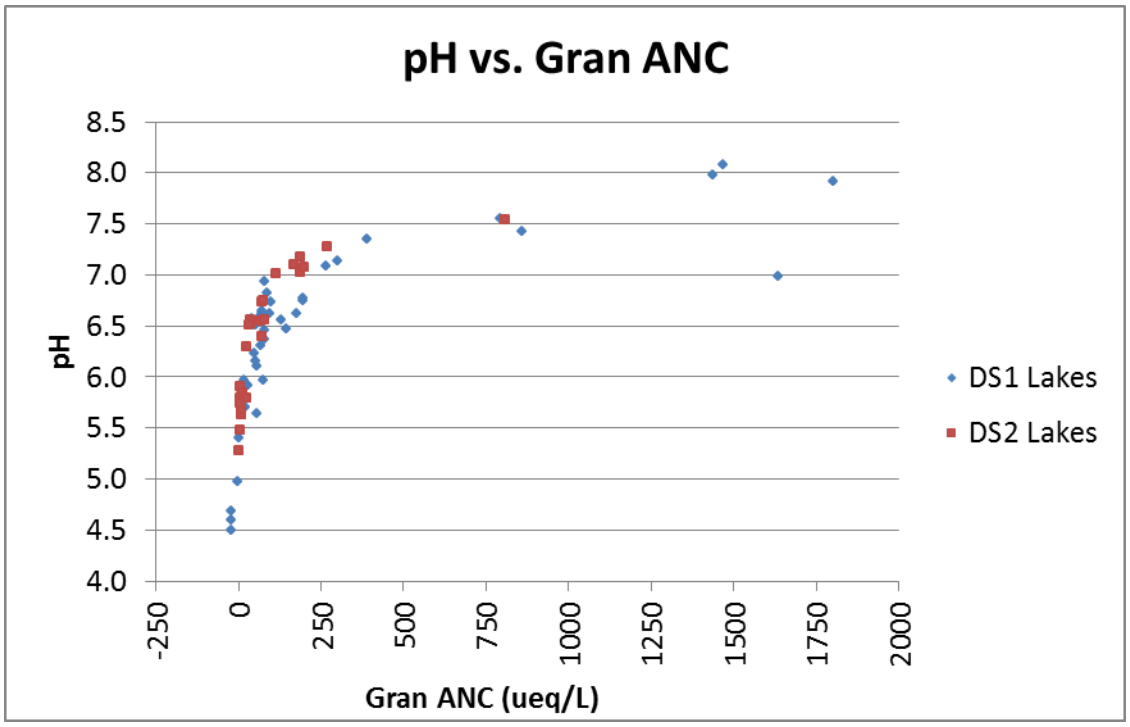


Figure A18-1. pH vs. Gran ANC for data sets 1 and 2. The graph indicates that the data for the lakes in data set 2 appear to be generally consistent with those data from which the critical ANC being used in this study was derived.

Total alkalinity was measured at all lakes, whereas Gran ANC was only measured for data sets 1 and 2. Figure A18-2 shows the relationship between total alkalinity and Gran ANC for those lakes where both were measured (i.e., data sets 1 and 2).

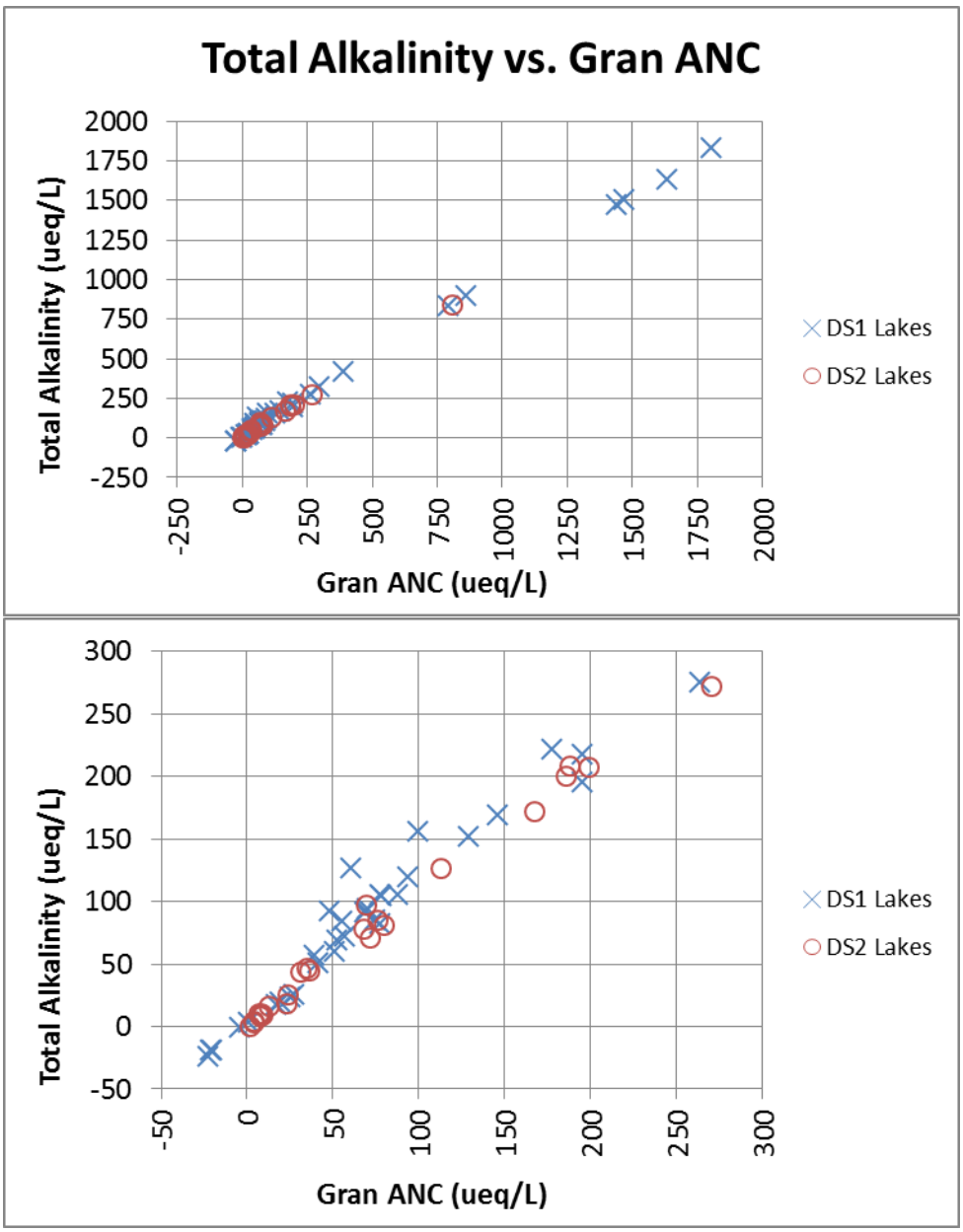


Figure A18-2. Total alkalinity vs. Gran ANC for the lakes in data set 1 (blue crosses) and data set 2 (red circles). Gran ANC was not measured for data set 3. The top and bottom panel use the same data, but the lower panel provides more detail for values <300 µeq/L. A regression based on the combined data determined that Total alkalinity = 1.01 * Gran ANC + 11.59, with R^2 = 0.999.

References Cited

ESSA Technologies, J. Laurence, Limnotek, Risk Sciences International, Rio Tinto Alcan, Trent University, Trinity Consultants and University of Illinois. 2013. Sulphur Dioxide Technical Assessment Report in Support of the 2013 Application to Amend the P2-00001 Multimedia Permit for the Kitimat Modernization Project. Volume 2: Final Technical Report. Prepared for Rio Tinto Alcan, Kitimat, B.C. 450 pp.

Small, M.J., and M.C. Sutton. 1986. A Regional pH-Alkalinity Relationship. Water Research 20(3): 335-343.

APPENDIX 19: REGIONAL DISTRIBUTION OF pH VALUES

Data from geochemical surveys available from the government of British Columbia (Figure A19-1) indicate that there is a significant difference in the pH of streams in the northern and southern halves of the study area. Virtually all streams in the northern portion of the study area have a pH >6.0, and most >6.5, whereas a substantial portion of the streams in the southern portion of the study area have a pH <6.0, with many streams (especially those adjacent to the coast) showing a pH <5.5.

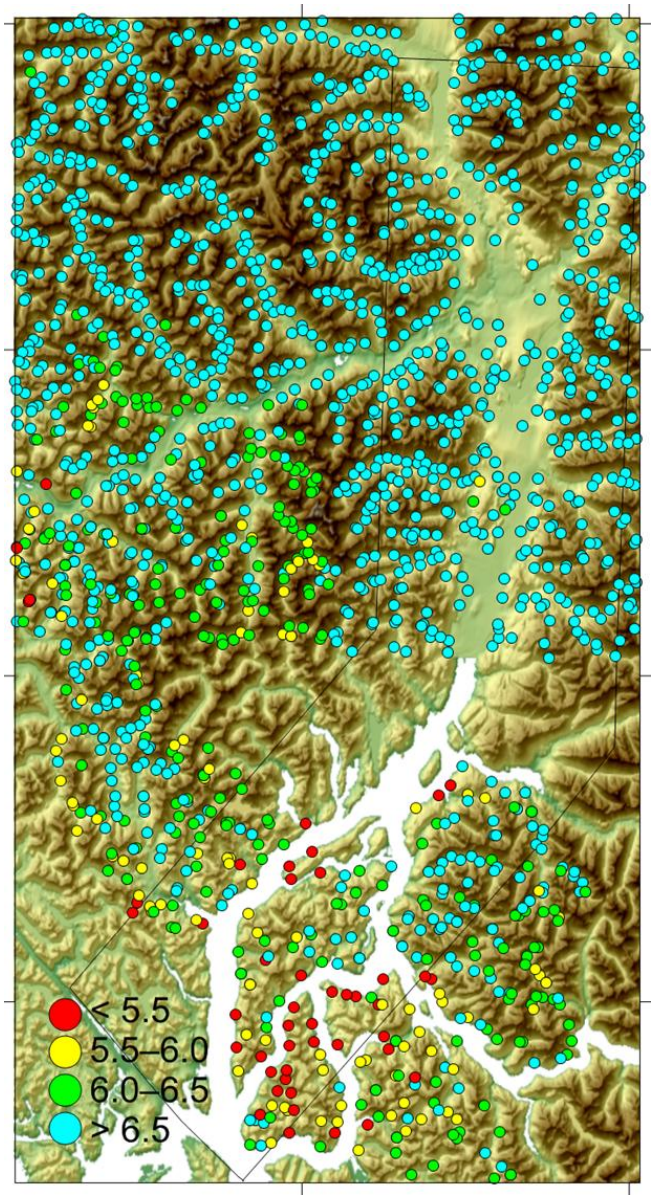


Figure A19-1. Spatial distribution of pH values from geochemical surveys. Source: B.C. Government. http://www.empr.gov.bc.ca/Mining/Geoscience/Geochemistry/RegionalGeochemistry/Pages/default.aspx

APPENDIX 20: ANION COMPOSITION OF SAMPLE LAKES

Anion Composition of All Lakes

These analyses help to determine potential causes of acidification (Marmorek et al. 1989). We assigned the term 'dominated' to an anion which made up more than 50% of the total anions in a sampled lake or stream, and 'influenced' when the anion made up more than 25% of the total anions. A lake can be dominated by one anion and influenced by another, or have up to three influential anions. The key findings (Table A20-1, Table A20-2, Figure A20-1, and Figure A20-2) are as follows.

Table A20-1 and Table A20-2 indicate that:

- The lakes in data set 3 have the lowest % bicarbonate (average of 26%; very low ionic strength waters). Next highest are the lakes in data set 2 (average of 47%), followed by the lakes in data set 1 (average of 60%). This reflects the fact that the lakes in data sets 2 and 3 were deliberately selected from areas with acid-sensitive bedrock geology, whereas more than half of the lakes in data set 1 were selected purely based on levels of sulphate deposition.
- Data sets 2 and 3 had higher % chloride anion composition than the lakes in data set 1 (average of 23% and 32% respectively for data sets 2 and 3 vs. 16% for data set 1), presumably at least partly due to differences in the distances to the ocean (see Figure A20-3). The pie charts of anion influence and dominance (Figure A20-1) illustrate this quite markedly, with more blue pie slices in data sets 2 and 3.
    - The data in Figure A20-3 show that although there is not a clear, consistent relationship between chloride concentration and the distance to the ocean, some patterns emerge. The majority of lakes with moderate chloride concentrations and almost all with high chloride concentrations are relatively close to the ocean (<7 km), and few lakes that are close to the ocean have low chloride levels. The majority of lakes that are not close to the ocean have low chloride concentrations, and only one lake >50 km has a chloride concentration >11 µeq/L.
- All three data sets have similar average percent sulphate composition (14 to 15%); the highest percent sulphate is found in data set 1 (51% maximum) and the lowest in data set 3 (23% maximum).
- Lakes in data sets 1 and 2 have similar average percent organic composition (17% and 14% respectively), both lower than the lakes in data set 3 (26%).
- Nitrate is currently a low percent of the total anions in all lakes (always <6%; average of 1%).
- Flouride is also a low percent of the total anions in all lakes (average of 2%), but reached a level of 18% in one lake in data set 1 and 8% in one lake in data set 2.

The ternary diagrams (Figure A20-2) and anion composition data (Section 6, Table 6-5; Table A20-1) suggest that while lakes in data set 1 with a pH <6 appear to have been acidified by organic anions and/or sulphate, some of the lakes in data set 3 with a pH <6 may have been acidified by a combination of chloride and organic acids. Data set 2 has a smaller proportion of organic-influenced or organic-dominated lakes with pH<6 than data sets 1 and 3 (Section 6, Table 6-5; Table A20-1).

Table A20-1. Anion composition of sampled lakes. Highlighted values indicate anion influence or dominance (≥25%), except for F and NO_3, where highlighting indicates notably elevated levels. Bold lettering indicates anion dominance (≥50%). COND=conductivity (µS/cm), O_2 = dissolved oxygen (mg/L), HCO_3 = bicarbonate, Cl = chloride, SO_4 = sulphate, ORG = organic anions, F = fluoride, NO_3 = nitrate. COND = conductivity (µS/cm). DOC = dissolved organic carbon (mg/L). Red bold lettering indicates pH <6. Lake names are coloured according to their data set (blue = DS1, red = DS2, green = DS3).

Name	COND (lab)	DOC	pH (lab)	% HCO_3	% Cl	%SO_4	% ORG	%F	%NO_3
LAK001	87	3.1	7.56	**91%**	1%	5%	3%	0%	0%
LAK002	19	5.3	6.62	**62%**	3%	13%	20%	2%	0%
LAK003	46	2.8	7.08	**64%**	2%	28%	5%	1%	0%
LAK004	22	4.5	6.47	**75%**	2%	7%	14%	2%	0%
LAK005	17	4.9	6.10	48%	4%	23%	20%	5%	0%
LAK006	7	3.6	**5.79**	34%	8%	17%	34%	6%	0%
LAK007	149	0.6	7.98	**95%**	2%	3%	0%	0%	0%
LAK008	184	0.7	7.92	**94%**	1%	5%	0%	0%	0%
LAK011	11	1.4	6.62	**80%**	2%	8%	9%	1%	0%
LAK012	13	4.6	**5.64**	**61%**	4%	6%	26%	4%	0%
LAK013	97	2.8	7.43	**89%**	1%	8%	2%	0%	0%
LAK014	17	3.8	6.46	**62%**	4%	15%	16%	3%	0%
LAK015	23	7.6	**5.97**	38%	2%	34%	23%	3%	0%
LAK016	18	3.7	6.31	**53%**	4%	23%	15%	5%	0%
LAK017	26	3.2	6.77	**81%**	6%	2%	9%	1%	0%
LAK018	152	0.4	8.08	**95%**	1%	3%	0%	0%	0%
LAK022	11	5.3	**5.92**	24%	7%	29%	35%	6%	0%
LAK023	8	4.2	**5.70**	25%	6%	25%	36%	7%	0%
LAK024	40	1.4	7.14	**83%**	7%	7%	3%	0%	0%
LAK027	25	1.1	6.64	43%	1%	**51%**	4%	1%	0%
LAK028	12	4.9	**4.98**	0%	5%	**51%**	25%	18%	0%
LAK030	56	2.2	7.35	**71%**	2%	21%	3%	3%	1%
LAK032	165	2.5	6.99	**95%**	1%	3%	1%	0%	0%
LAK034	22	4.5	6.74	**69%**	3%	11%	15%	3%	0%
LAK035	14	4.2	6.23	**63%**	4%	12%	20%	1%	0%
LAK037	19	4.1	6.58	**65%**	4%	13%	15%	3%	0%
LAK038	24	5.9	6.56	**66%**	2%	12%	18%	2%	0%
LAK039	14	4.6	6.36	**59%**	5%	10%	24%	3%	0%
LAK041	7	0.4	6.51	**81%**	2%	11%	5%	0%	1%
LAK042	12	13.2	**4.68**	0%	7%	8%	**81%**	4%	0%
LAK044	3	1.7	**5.40**	9%	19%	24%	38%	10%	0%
LAK045	11	0.4	6.93	**93%**	2%	2%	2%	0%	1%
LAK047	3	0.4	**5.96**	**72%**	7%	8%	10%	1%	3%
LAK049	12	0.3	6.82	**91%**	2%	5%	2%	0%	1%
LAK050	9	0.2	6.51	**85%**	2%	10%	2%	1%	1%
LAK051	31	4.1	6.75	**67%**	1%	21%	10%	0%	0%
LAK053	9	0.8	6.57	**66%**	8%	19%	6%	0%	0%
LAK054	9	6.7	**4.59**	0%	16%	18%	**61%**	5%	0%
LAK055	11	5.3	6.16	**51%**	9%	8%	32%	1%	0%
LAK056	13	8.5	**4.50**	0%	26%	15%	**56%**	4%	0%

Name	COND (lab)	DOC	pH (lab)	% HCO_3	% Cl	%SO_4	% ORG	%F	%NO_3
LAK057	29	4.5	6.63	**76%**	4%	9%	11%	1%	0%
DCAS01A	15	0.1	7.01	**78%**	4%	17%	1%	0%	0%
DCAS01B	21	0.3	7.17	**91%**	2%	6%	1%	0%	0%
DCAS02C	11	1.3	6.74	**74%**	5%	11%	7%	3%	0%
DCAS03A	11	4.9	6.40	**57%**	8%	6%	28%	1%	0%
DCAS03B	82	1.1	7.54	**97%**	1%	1%	1%	0%	0%
DCAS04A	9	4.7	**5.48**	4%	**50%**	10%	35%	1%	0%
DCAS04B	8	3.7	**5.63**	13%	41%	10%	35%	1%	0%
DCAS05A	6	3.2	**5.68**	14%	37%	17%	32%	0%	0%
DCAS05B	4	0.8	**5.79**	9%	**58%**	18%	13%	1%	0%
DCAS06A	13	1.0	6.75	**64%**	19%	11%	5%	1%	1%
DCAS06C	14	3.7	6.55	49%	16%	12%	17%	1%	6%
DCAS07A	3	0.6	**5.91**	25%	43%	20%	10%	1%	0%
DCAS07B	3	0.5	**5.81**	28%	43%	18%	10%	1%	1%
DCAS08A	5	1.5	**5.74**	14%	**52%**	14%	19%	2%	0%
DCAS08B	6	1.7	**5.84**	24%	44%	12%	17%	2%	2%
DCAS09A	6	0.2	6.56	**64%**	9%	14%	2%	8%	3%
DCAS09B	5	0.5	6.29	49%	14%	30%	6%	0%	0%
DCAS10A	5	0.4	6.52	**78%**	7%	9%	4%	1%	0%
DCAS10B	4	0.6	6.51	**73%**	10%	9%	7%	1%	0%
DCAS11A	6	3.5	**5.28**	1%	47%	8%	43%	1%	0%
DCAS11B	8	5.1	**5.79**	20%	36%	7%	36%	1%	0%
DCAS12A	13	4.6	6.56	**54%**	7%	14%	22%	2%	0%
DCAS13A	35	0.4	7.28	**74%**	3%	21%	1%	0%	1%
DCAS16A	28	2.8	7.03	**69%**	3%	20%	7%	0%	0%
DCAS17A	29	4.7	7.07	**69%**	5%	14%	12%	0%	0%
MOE3	32	0.4	7.10	**56%**	2%	40%	1%	1%	0%
ARKELLE	7	2.3	6.27	32%	29%	17%	19%	1%	2%
BARDON	6	1.6	6.32	36%	25%	19%	15%	1%	5%
CAPONERO	6	3.3	**5.84**	19%	33%	15%	30%	1%	2%
EVELYN	20	3.7	6.73	43%	16%	23%	13%	1%	3%
LARCH	4	1.1	**5.95**	24%	45%	18%	13%	1%	0%
LOWER	7	0.3	**5.69**	20%	**61%**	15%	3%	1%	1%
NC171	8	5.6	**5.64**	15%	29%	14%	41%	0%	0%
NC178	5	3.1	**5.86**	21%	30%	15%	32%	1%	1%
NC179	9	7.5	**5.35**	6%	31%	6%	**56%**	1%	1%
NC180	6	3.5	**5.59**	14%	44%	11%	31%	0%	0%
NC184	10	11.6	**5.73**	20%	17%	6%	56%	0%	0%
NC194	4	0.7	6.58	**70%**	13%	8%	9%	0%	0%
UPPER_LK	6	2.6	**5.73**	15%	48%	12%	22%	1%	1%

Table A20-2. Summary of analyses of anion composition. {D} = dominated; {I} = influenced. The total number of lakes either dominated or influenced (106) exceeds the number sampled (80) because a lake can be influenced by more than one anion. Analyses of anion composition are summarized across all lakes (top panel) as well as within each of the separate data sets (bottom three panels), which illustrate some differences in composition associated with their differences in geographic coverage and selection criteria.

ALL lakes	Anion					
	HCO_3	Cl	SO_4	ORG	F	NO_3
avg %	51%	15%	14%	18%	2%	1%
min %	0%	1%	1%	0%	0%	0%
max %	97%	61%	51%	81%	18%	6%
# > 50% {D}	45	4	2	5	0	0
# > 25% {I}	12	16	6	16	0	0

Data set 1	Anion					
	HCO_3	Cl	SO_4	ORG	F	NO_3
avg %	60%	5%	15%	17%	3%	0.2%
min %	0%	1%	2%	0%	0%	0%
max %	95%	26%	51%	81%	18%	3%
# > 50% {D}	30	0	2	3	0	0
# > 25% {I}	5	1	4	6	0	0

Data set 2	Anion					
	HCO_3	Cl	SO_4	ORG	F	NO_3
avg %	48%	22%	14%	14%	1%	1%
min %	1%	1%	1%	1%	0%	0%
max %	97%	58%	40%	43%	8%	6%
# > 50% {D}	14	3	0	0	0	0
# > 25% {I}	4	7	2	6	0	0

Data set 3	Anion					
	HCO_3	Cl	SO_4	ORG	F	NO_3
avg %	26%	32%	14%	26%	1%	1%
min %	6%	13%	6%	3%	0%	0%
max %	70%	61%	23%	56%	1%	5%
# > 50% {D}	1	1	0	2	0	0
# > 25% {I}	3	8	0	4	0	0

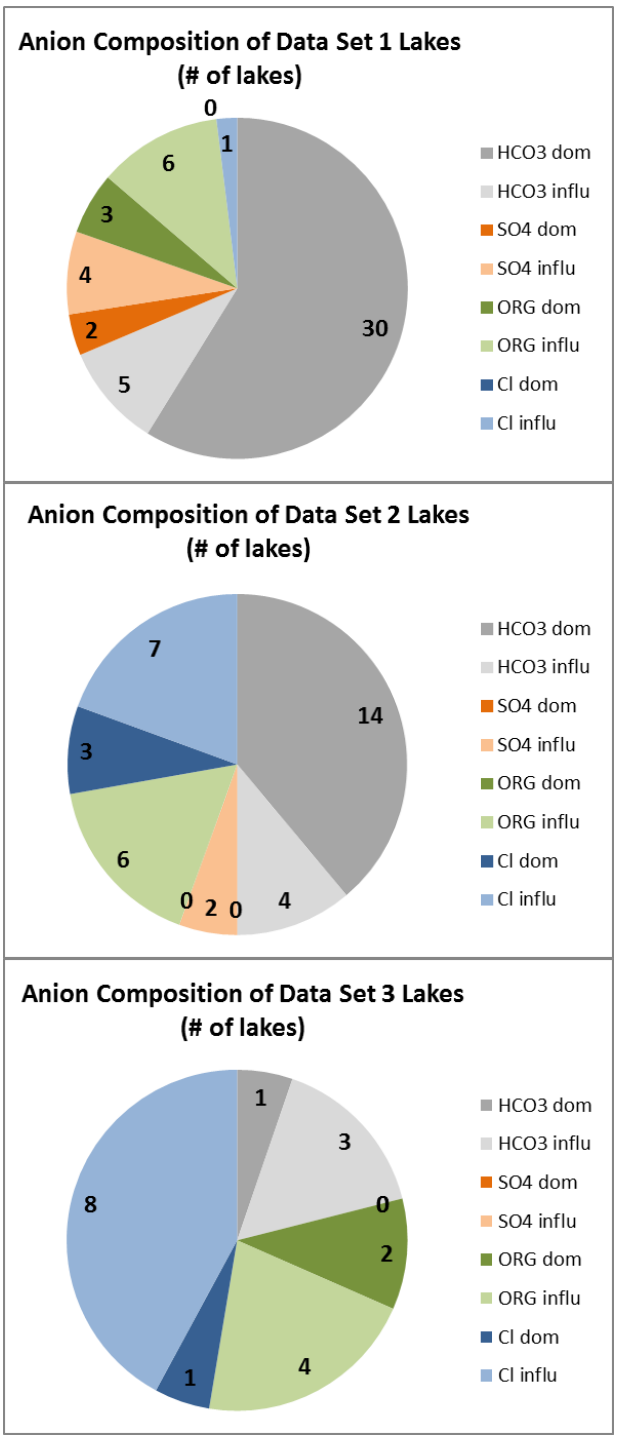


Figure A20-1. Distribution of lakes among types of anion dominance or influence, by data set (Data set 1, upper panel; Data set 2, middle panel; Data set 3, lower panel). For each data set, the total number of lakes either dominated or influenced exceeds the number sampled because a lake can be influenced by more than one anion. HCO_3 = bicarbonate, SO_4 = sulphate, ORG = organic anions, Cl = chloride, dom = dominated, influ = influenced.

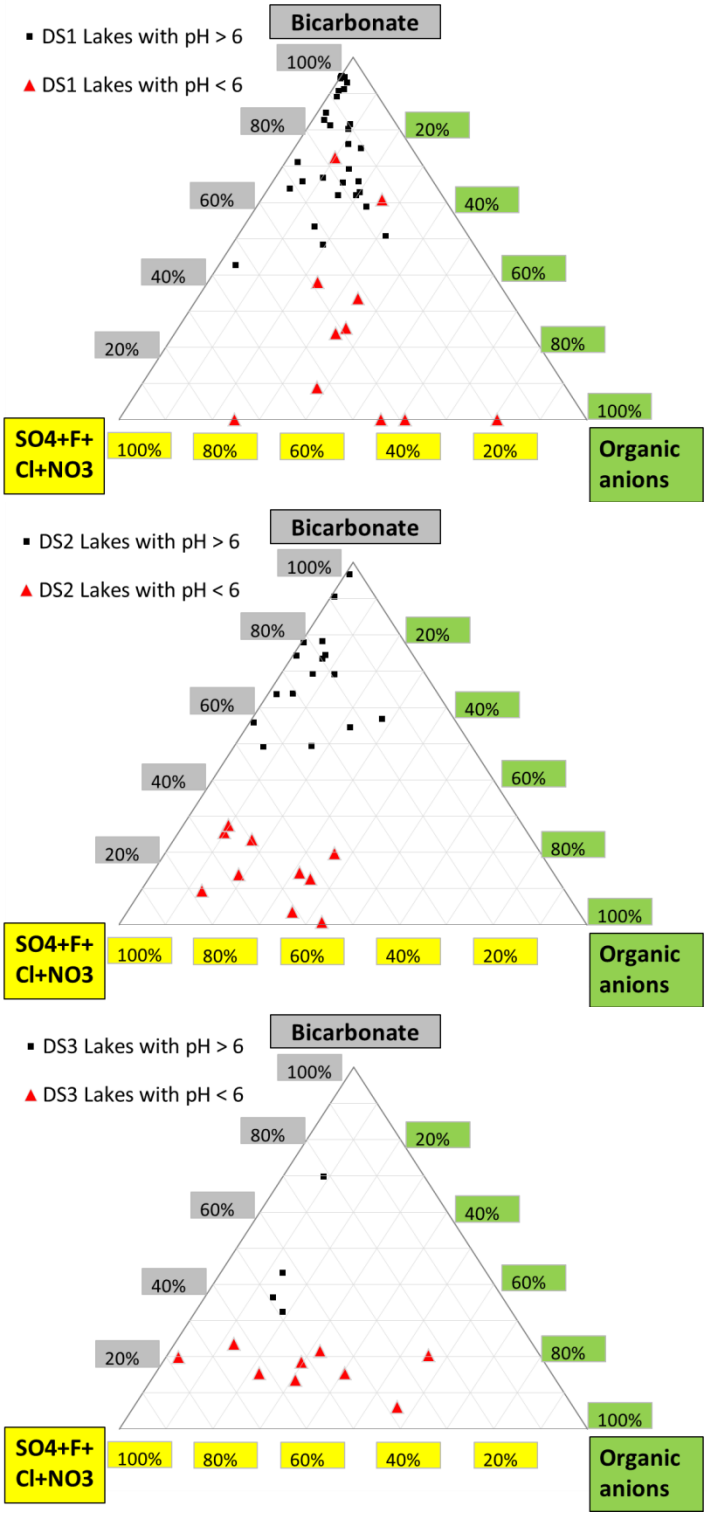


Figure A20-2. Ternary diagram of anion composition of the sampled lakes by data set (data set 1 (DS1), upper panel; data set 2 (DS2), middle panel; data set 3 (DS3), lower panel). Points closest to a corner are dominated by the anion at that corner. Acidification (whether natural or anthropogenic) moves points down the triangle, as bicarbonate is replaced by other anions that accompany hydrogen, as demonstrated by the lakes with pH <6.

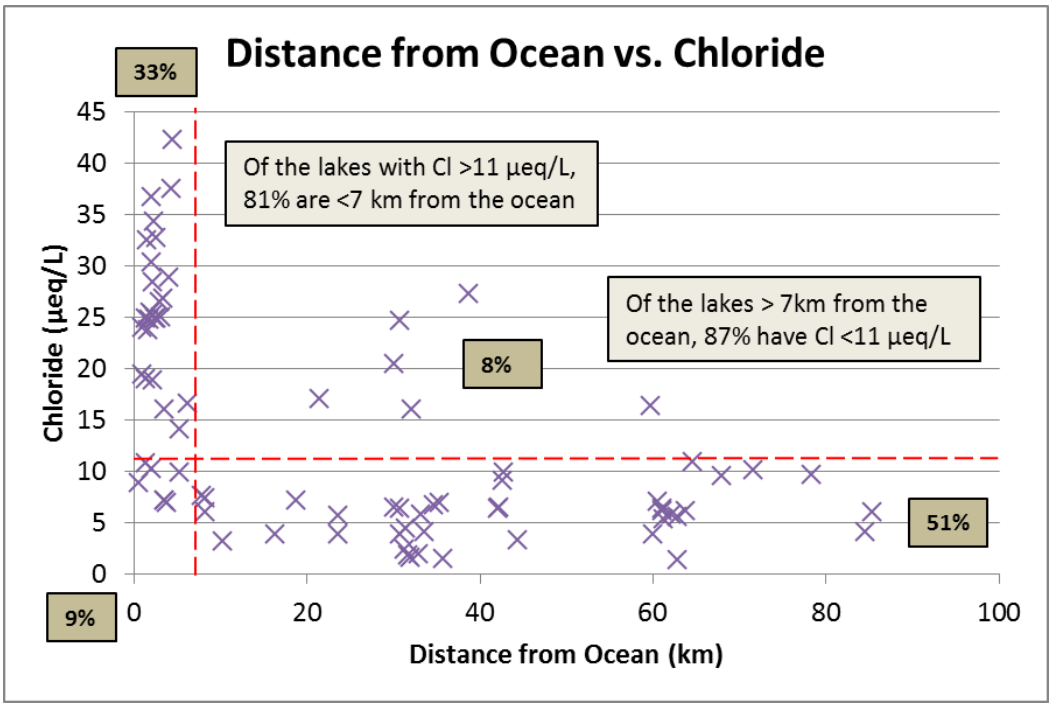


Figure A20-3. Chloride concentration versus distance from the ocean for all sampled lakes. Distance to the ocean was measured as the shortest straight-line distance to Douglas Channel. The two dotted red lines indicate natural breaks based on visual assessment at a chloride concentration of 11 µeq/L and a distance from the ocean of 7 km. The 4 darker boxes indicate the percentage of all lakes that fall within each of the four quadrants created by those two thresholds.

References Cited

Marmorek, D.R., D.P. Bernard, C.H.R. Wedeles, G.D. Sutherland, J.A. Malanchuk, and W.E.Fallon. 1989. A protocol for determining lake acidification pathways. Water Air and Soil Poll. 44: 235-257.

APPENDIX 21: CRITICAL LOADS

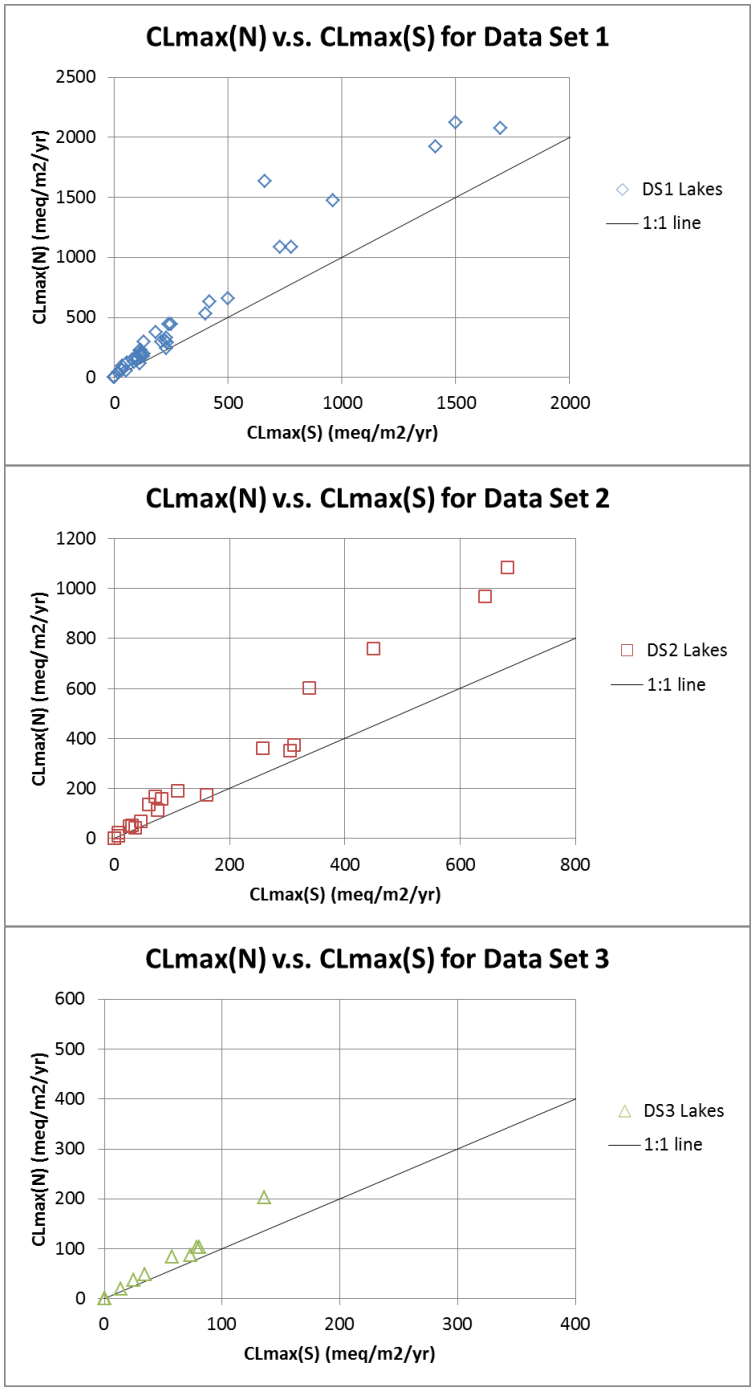


Figure A21-1. CLmax(S) and CLmax(N) for the sampled lakes in each of the data sets (data set 1, upper panel; data set 2, middle panel; data set 3, lower panel). The CLs from the FAB model are, on average, lowest for data set 3, intermediate for data set 2, and highest for data set 3 (e.g., note the differences in scale). Across all of the lakes, CLmax(N) is consistently higher than CLmax(s), indicated by lakes that are above the 1:1 line.

APPENDIX 22: VARIATION IN CRITICAL LOADS WITH BEDROCK GEOLOGY

Acid Sensitivity Classes (ASC) are designed to combine bedrock geologies such that ASC 1 is the most acid-sensitive class, and ASC 4 the least acid sensitive, with ASC 2 and ASC 3 intermediate. The distribution of CLs within each ASC is shown in Figure A22-1 and Table A22-1. The median and mean CLs were lowest in ASC 2, even lower than ASC 1, which is surprising, as is the fact that there was little difference in median and mean CLs between ASC 1 and ASC 3. The maximum CLs were however higher in ASC 3 than ASC 1 and ASC 2. There were not enough lakes in ASC 4 to draw any conclusions. It is possible that the variation in runoff values across the 80 lakes exerts as much influence on CLs as bedrock geology.

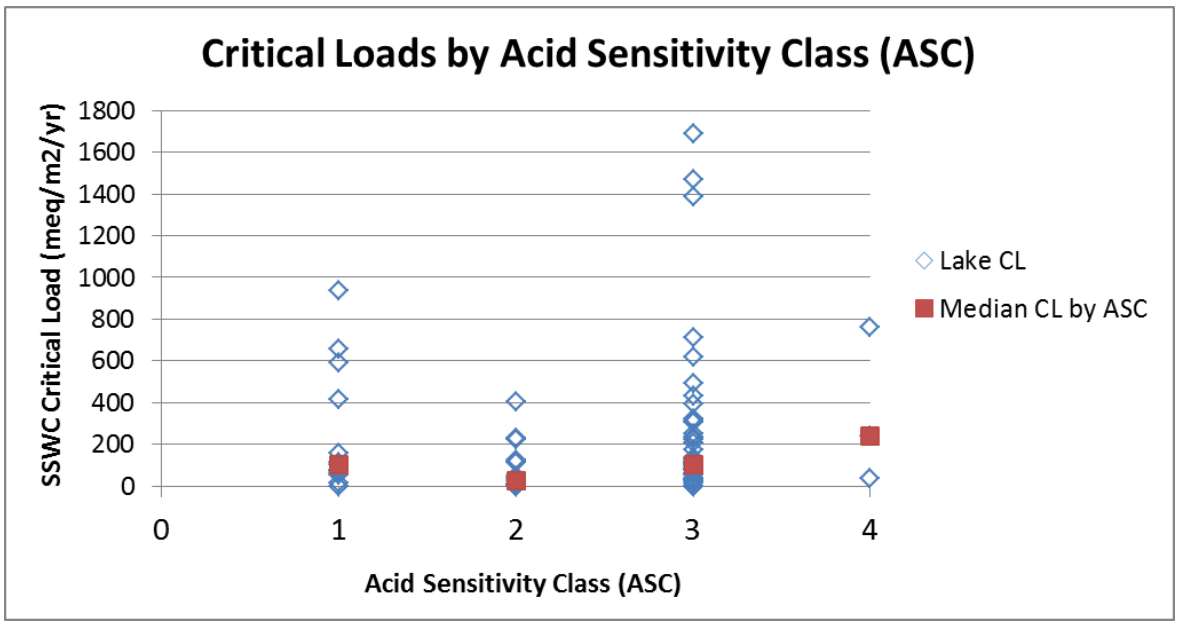


Figure A22-1. Variation in critical load by Acid Sensitivity Class.

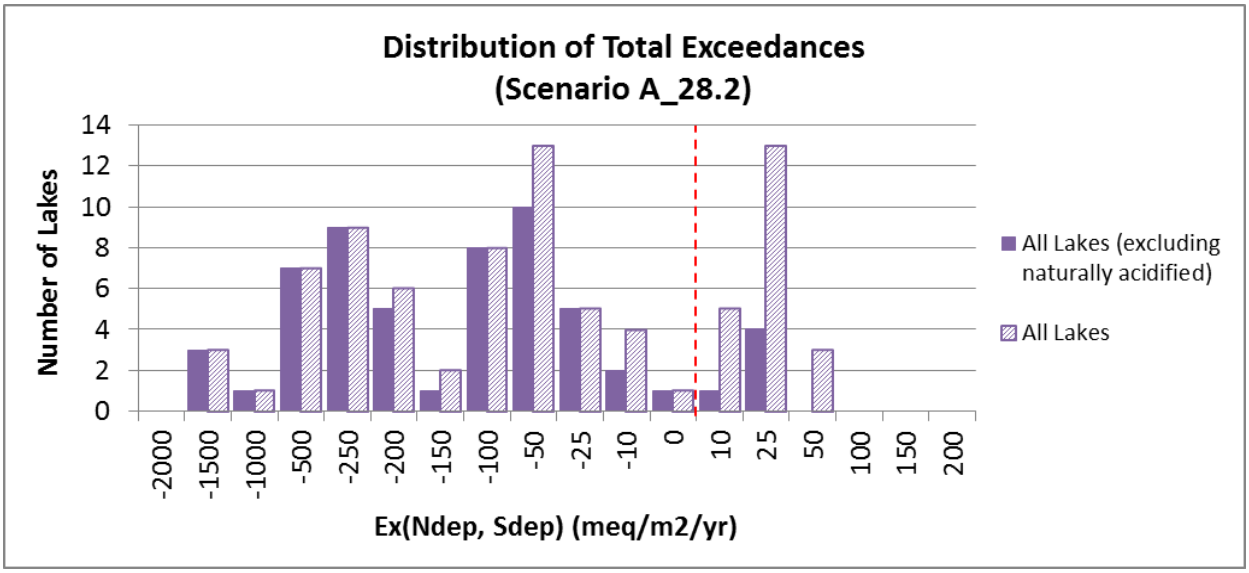
Table A22-1. Statistics on lake critical load values (meq/m^2/yr) by Acid Sensitivity Class (ASC). A critical load of 21 meq/m^2/yr can neutralize 21 meq/m^2/yr of total sulphate deposition (=10 kg/ha/yr) without exceedance.

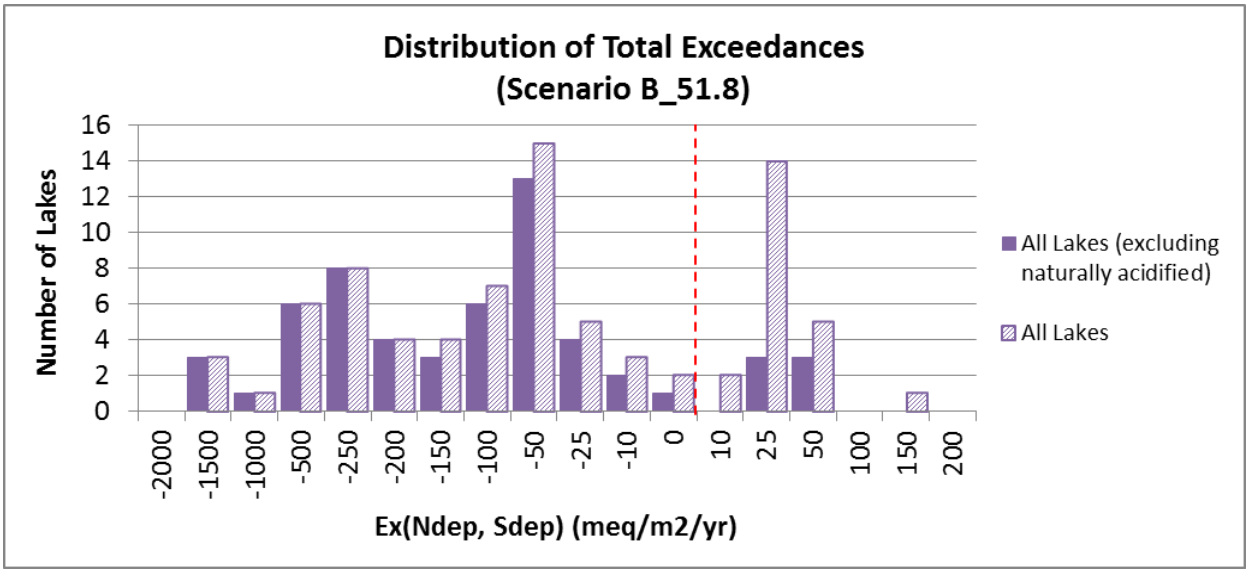
	SSWC Critical Load Statistics (meq/m^2/yr)							
ASC	n	Min	Max	Median	Mean	# < 11	# < 21	SE
1	13	0	939	103	251	1	2	83
2	19	0	406	26	82	9	9	26
3	45	0	1688	99	240	7	8	57
4	3	35	763	237	345	0	0	217
Overall	**80**	**0**	**1688**	**92**	**208**	**17**	**19**	**37**

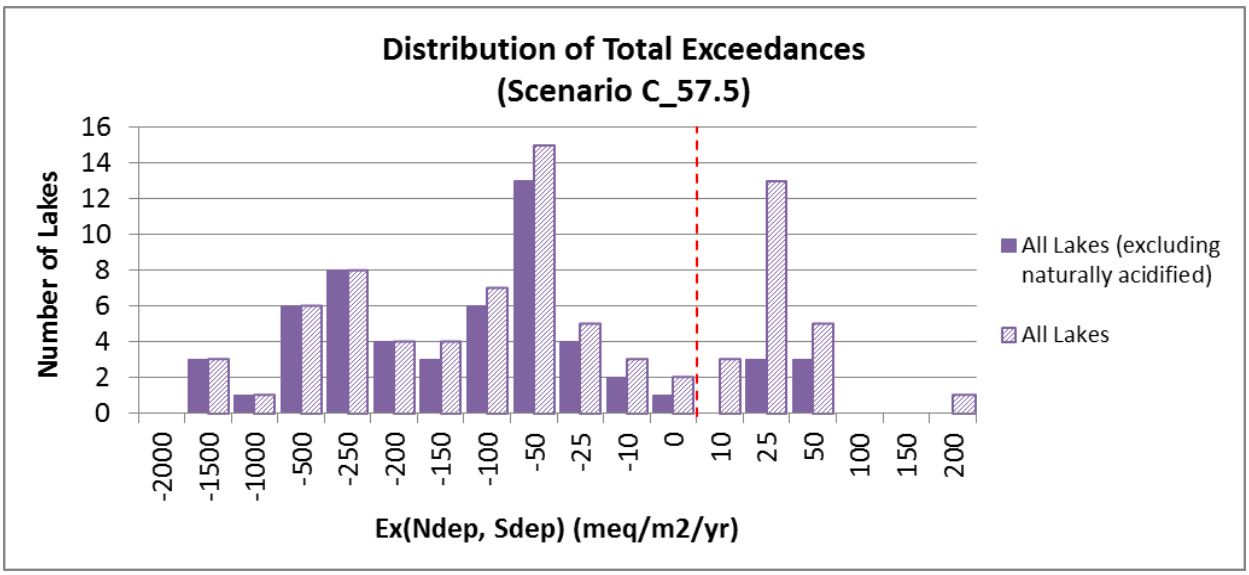
APPENDIX 23: EXCEEDANCES UNDER ALL SCENARIOS

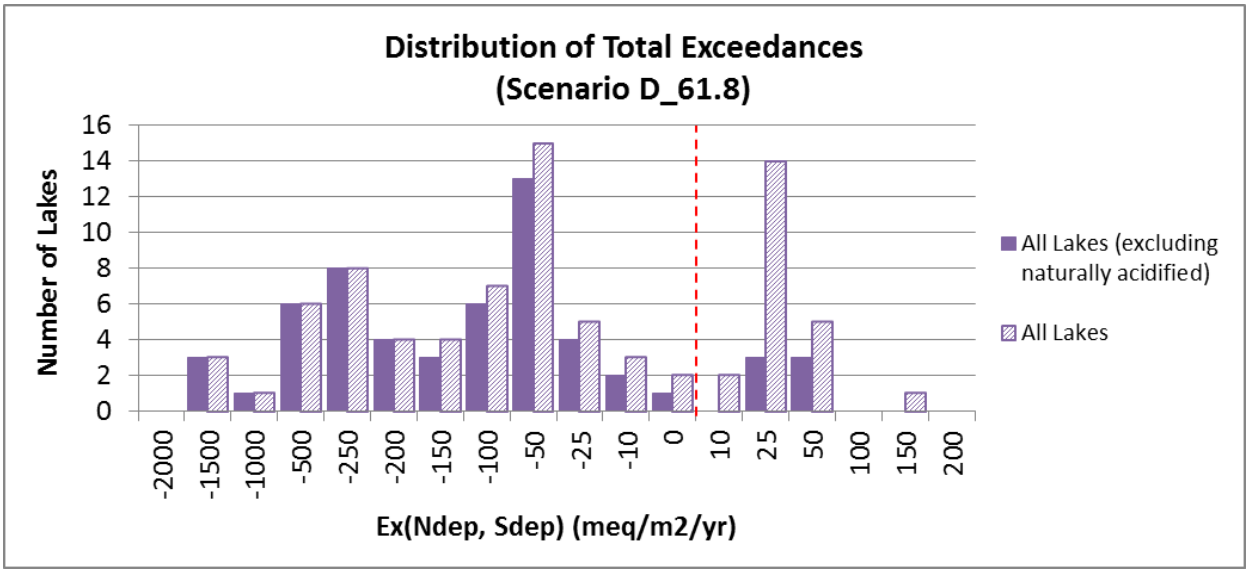
This appendix section contains the histograms and maps of exceedances for all twelve scenarios. Further description is provided in Section 6.2.3.2 of the report.

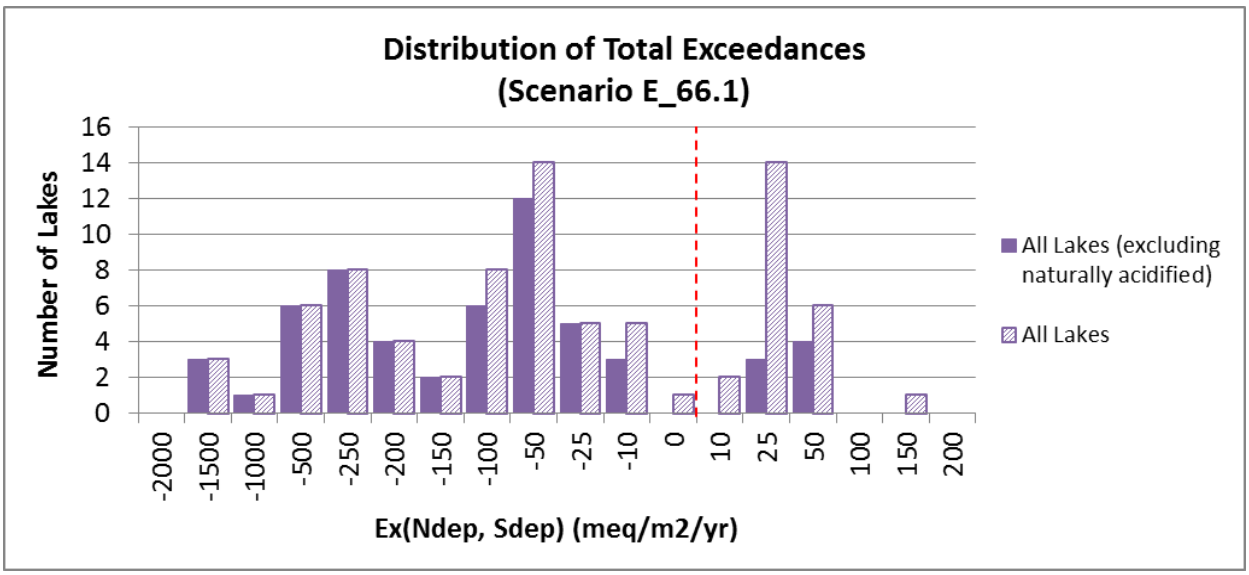
23.1 Distribution of Total Exceedances

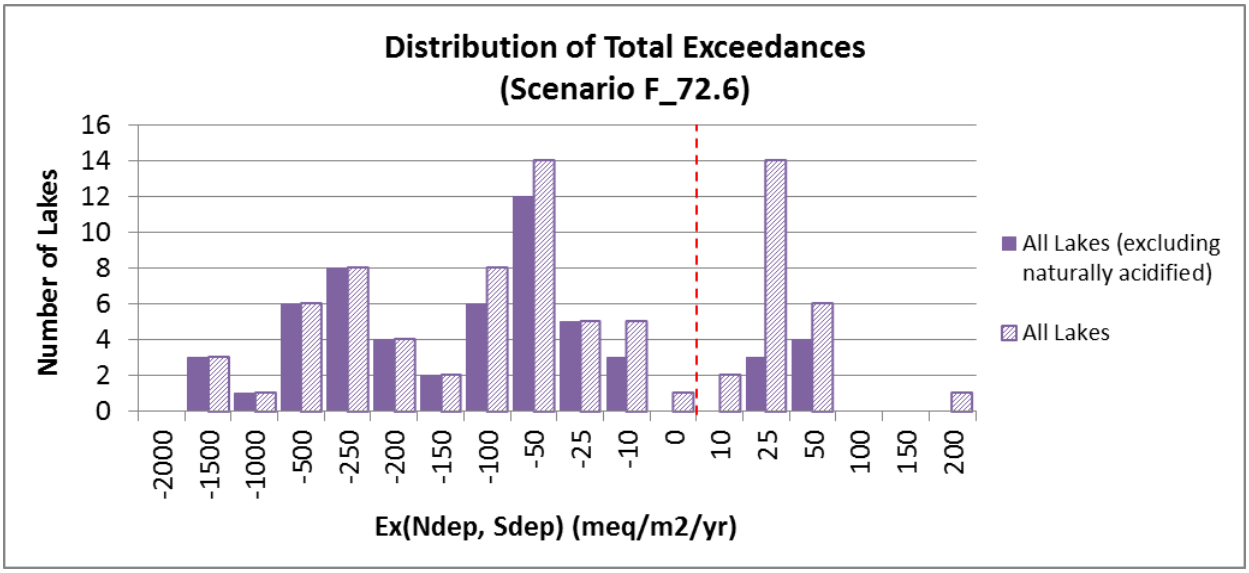


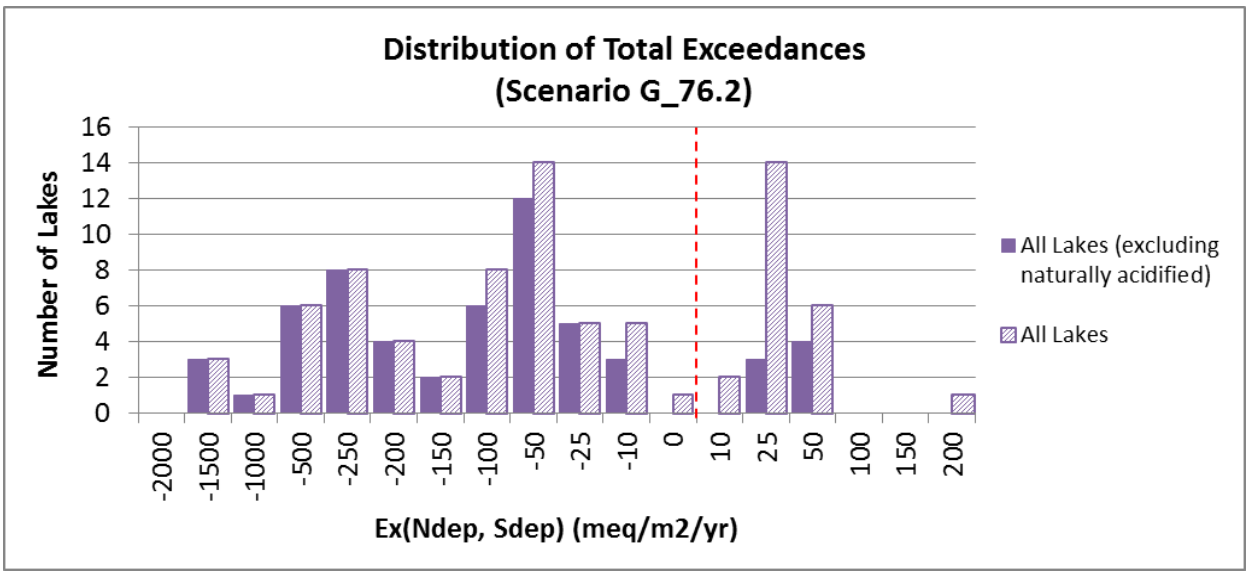


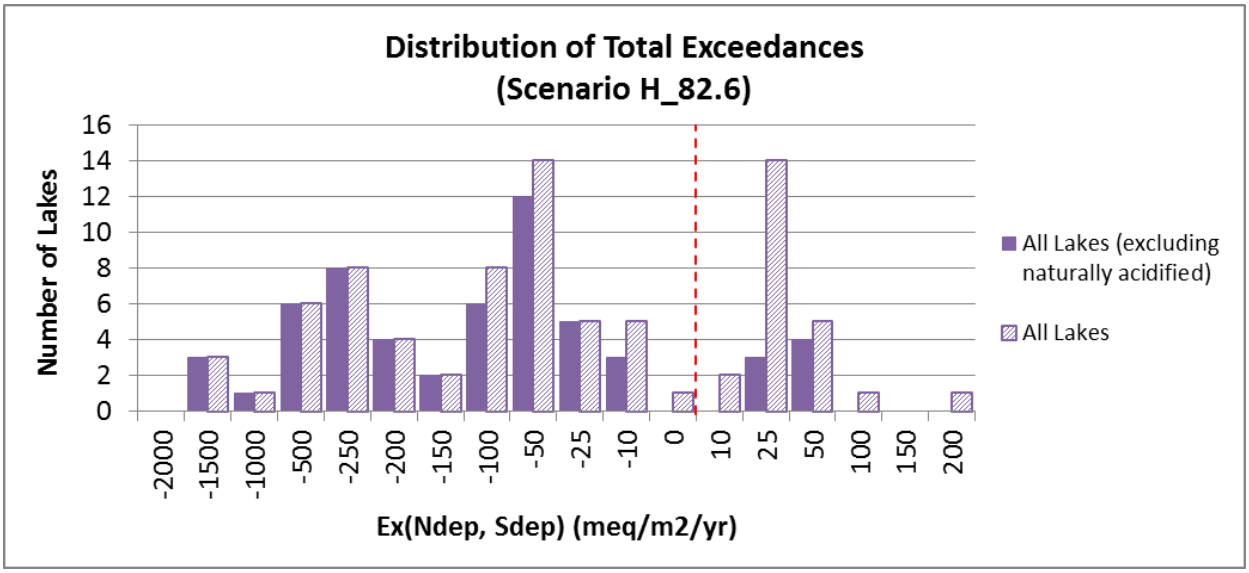

Distribution of Total Exceedances
(Scenario C_57.5)
Number of Lakes
16
14
12
10
8
6
4
2
0
-2000
-1500
-1000
-500
-250
-200
-150
-100
-50
-25
-10
0
10
25
50
100
150
200
Ex(Ndep, Sdep) (meq/m2/yr)
All Lakes (excluding naturally acidified)
All Lakes

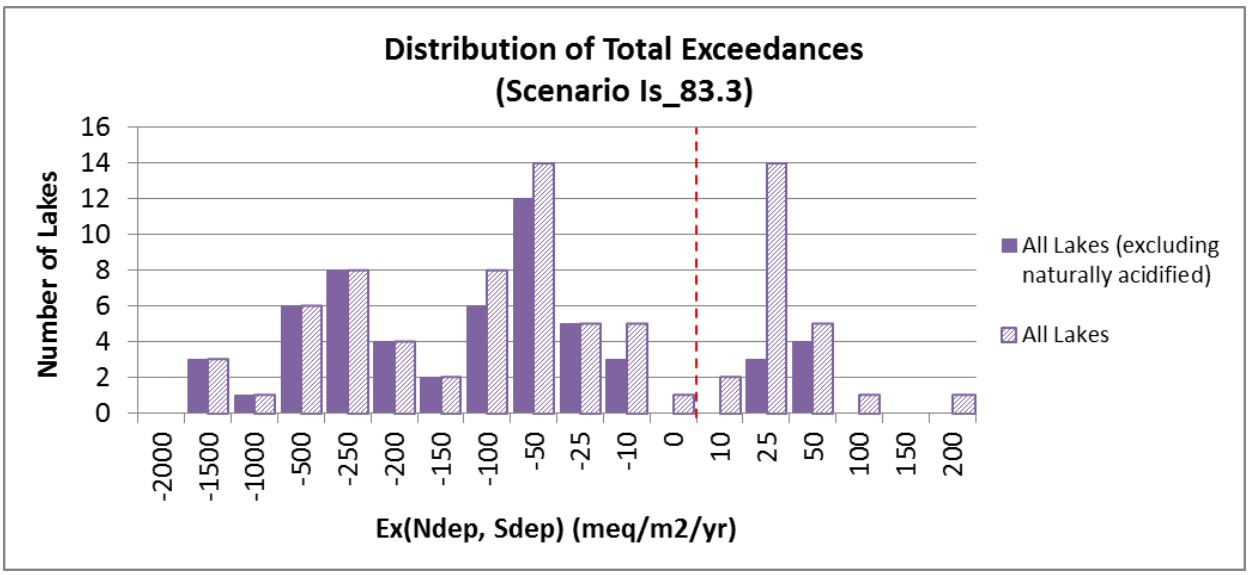

Distribution of Total Exceedances
(Scenario D_61.8)
Number of Lakes
16
14
12
10
8
6
4
2
0
-2000
-1500
-1000
-500
-250
-200
-150
-100
-50
-25
-10
0
10
25
50
100
150
200
Ex(Ndep, Sdep) (meq/m2/yr)
All Lakes (excluding naturally acidified)
All Lakes

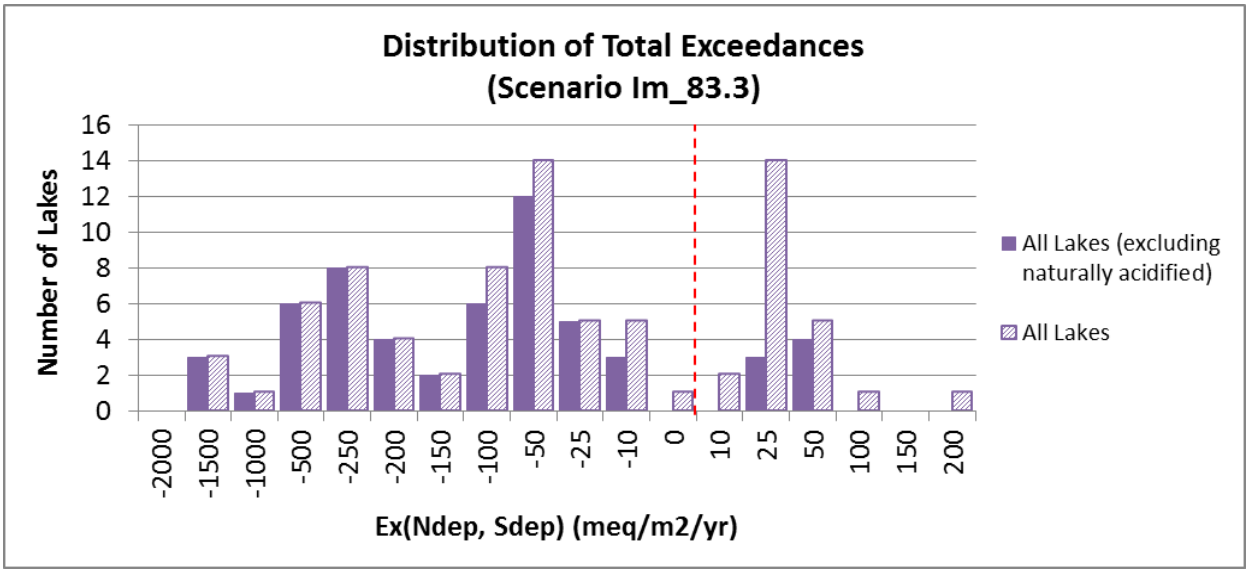

Distribution of Total Exceedances
(Scenario E_66.1)
Number of Lakes
16
14
12
10
8
6
4
2
0
-2000
-1500
-1000
-500
-250
-200
-150
-100
-50
-25
-10
0
10
25
50
100
150
200
Ex(Ndep, Sdep) (meq/m2/yr)
All Lakes (excluding naturally acidified)
All Lakes

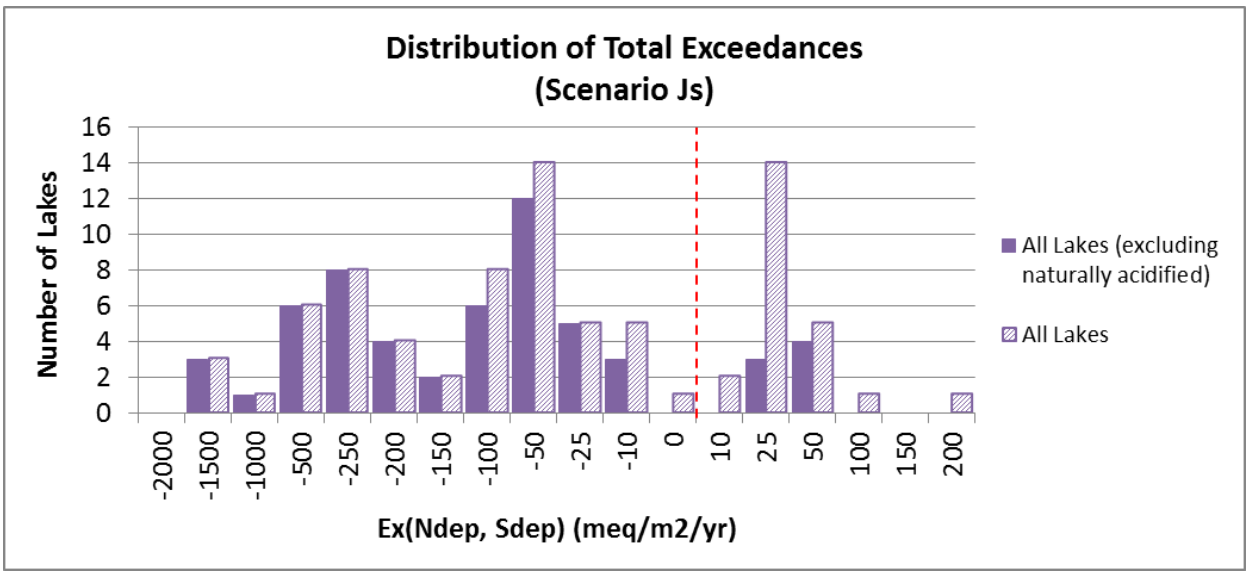

Distribution of Total Exceedances
(Scenario F_72.6)
Number of Lakes
16
14
12
10
8
6
4
2
0
-2000
-1500
-1000
-500
-250
-200
-150
-100
-50
-25
-10
0
10
25
50
100
150
200
Ex(Ndep, Sdep) (meq/m2/yr)
All Lakes (excluding naturally acidified)
All Lakes

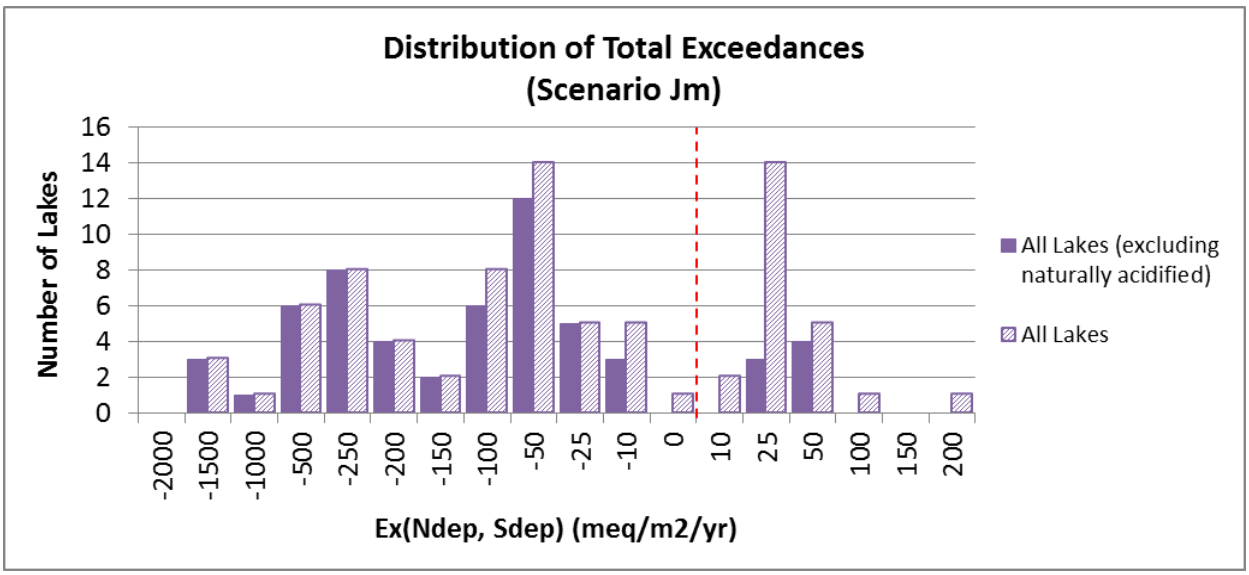

Distribution of Total Exceedances
(Scenario G_76.2)
Number of Lakes
16
14
12
10
8
6
4
2
0
-2000
-1500
-1000
-500
-250
-200
-150
-100
-50
-25
-10
0
10
25
50
100
150
200
Ex(Ndep, Sdep) (meq/m2/yr)
All Lakes (excluding naturally acidified)
All Lakes


Distribution of Total Exceedances
(Scenario H_82.6)
Number of Lakes
16
14
12
10
8
6
4
2
0
-2000
-1500
-1000
-500
-250
-200
-150
-100
-50
-25
-10
0
10
25
50
100
150
200
Ex(Ndep, Sdep) (meq/m2/yr)
All Lakes (excluding naturally acidified)
All Lakes

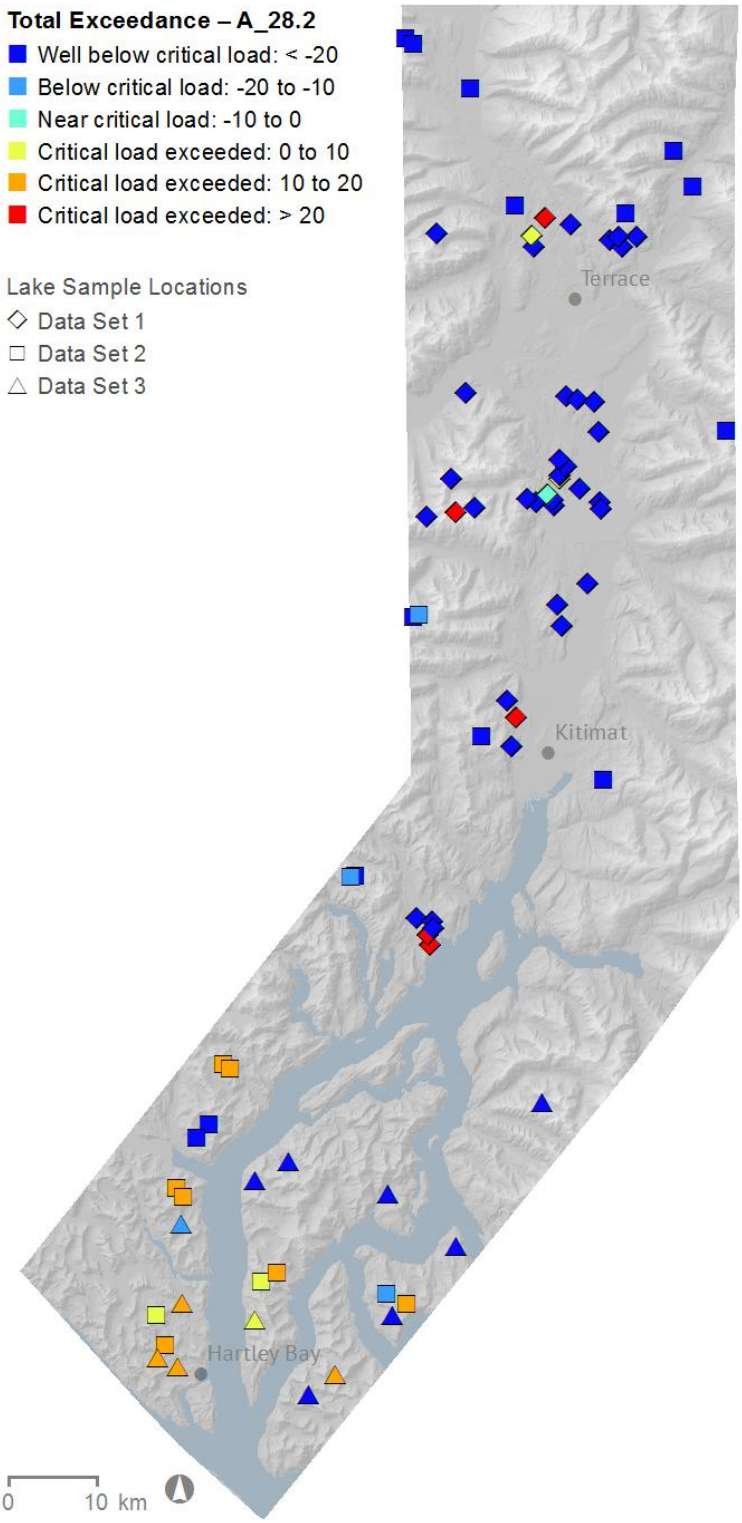

Distribution of Total Exceedances
(Scenario Is_83.3)
Number of Lakes
16
14
12
10
8
6
4
2
0
-2000
-1500
-1000
-500
-250
-200
-150
-100
-50
-25
-10
0
10
25
50
100
150
200
Ex(Ndep, Sdep) (meq/m2/yr)
All Lakes (excluding naturally acidified)
All Lakes

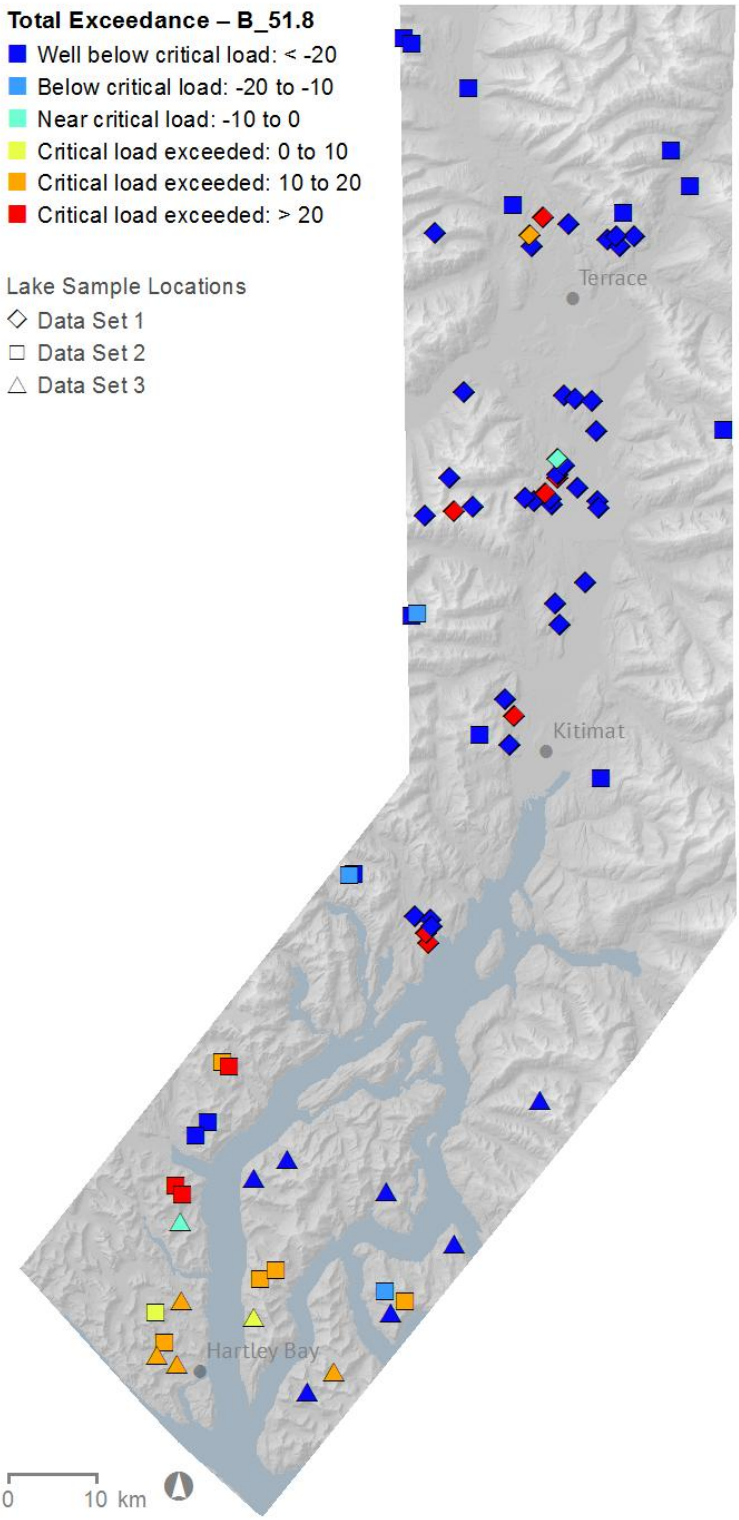

Distribution of Total Exceedances
(Scenario Im_83.3)
Number of Lakes
16
14
12
10
8
6
4
2
0
-2000
-1500
-1000
-500
-250
-200
-150
-100
-50
-25
-10
0
10
25
50
100
150
200
Ex(Ndep, Sdep) (meq/m2/yr)
All Lakes (excluding naturally acidified)
All Lakes

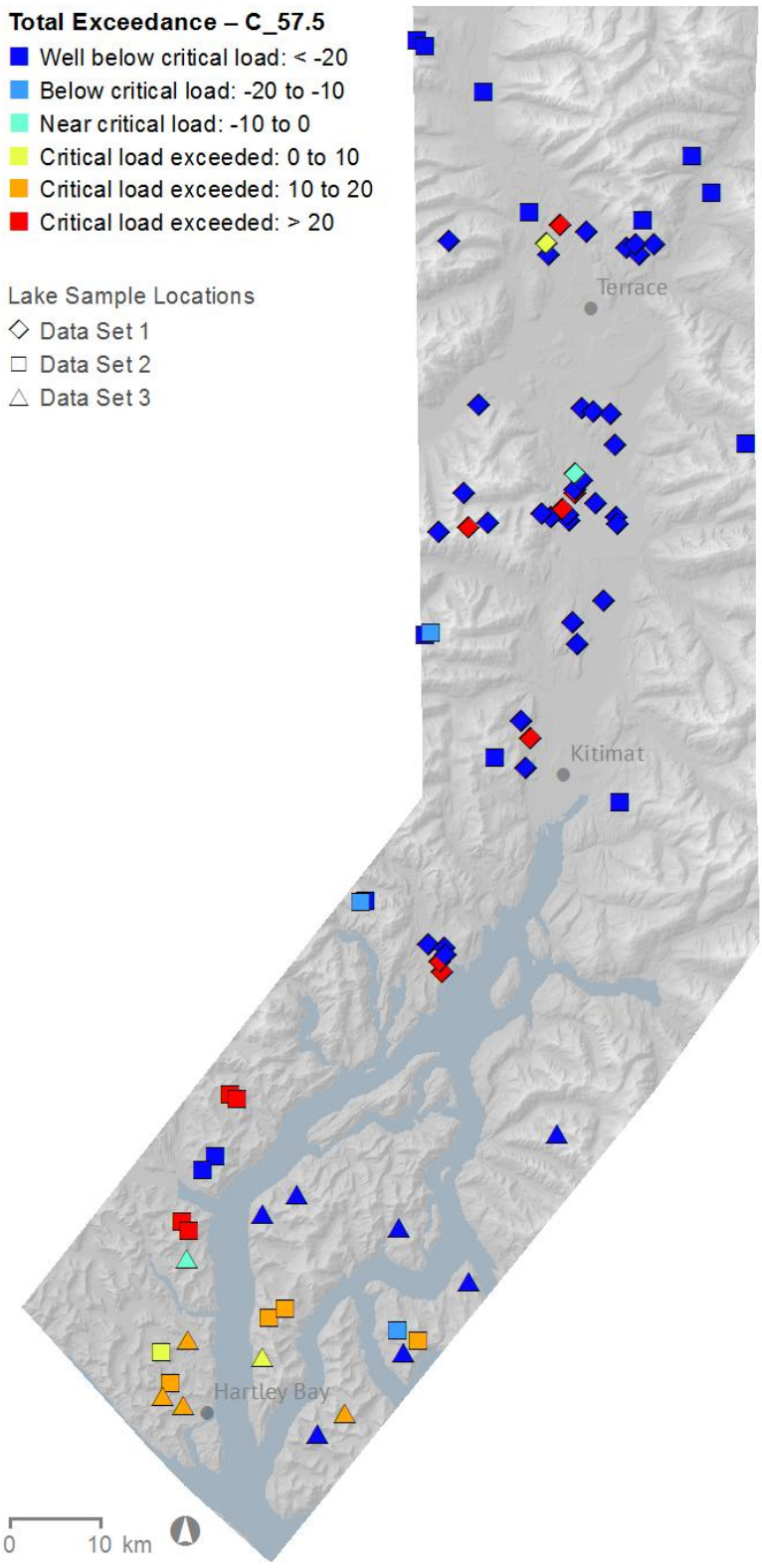

Distribution of Total Exceedances
(Scenario Js)
Number of Lakes
16
14
12
10
8
6
4
2
0
-2000
-1500
-1000
-500
-250
-200
-150
-100
-50
-25
-10
0
10
25
50
100
150
200
Ex(Ndep, Sdep) (meq/m2/yr)
All Lakes (excluding naturally acidified)
All Lakes

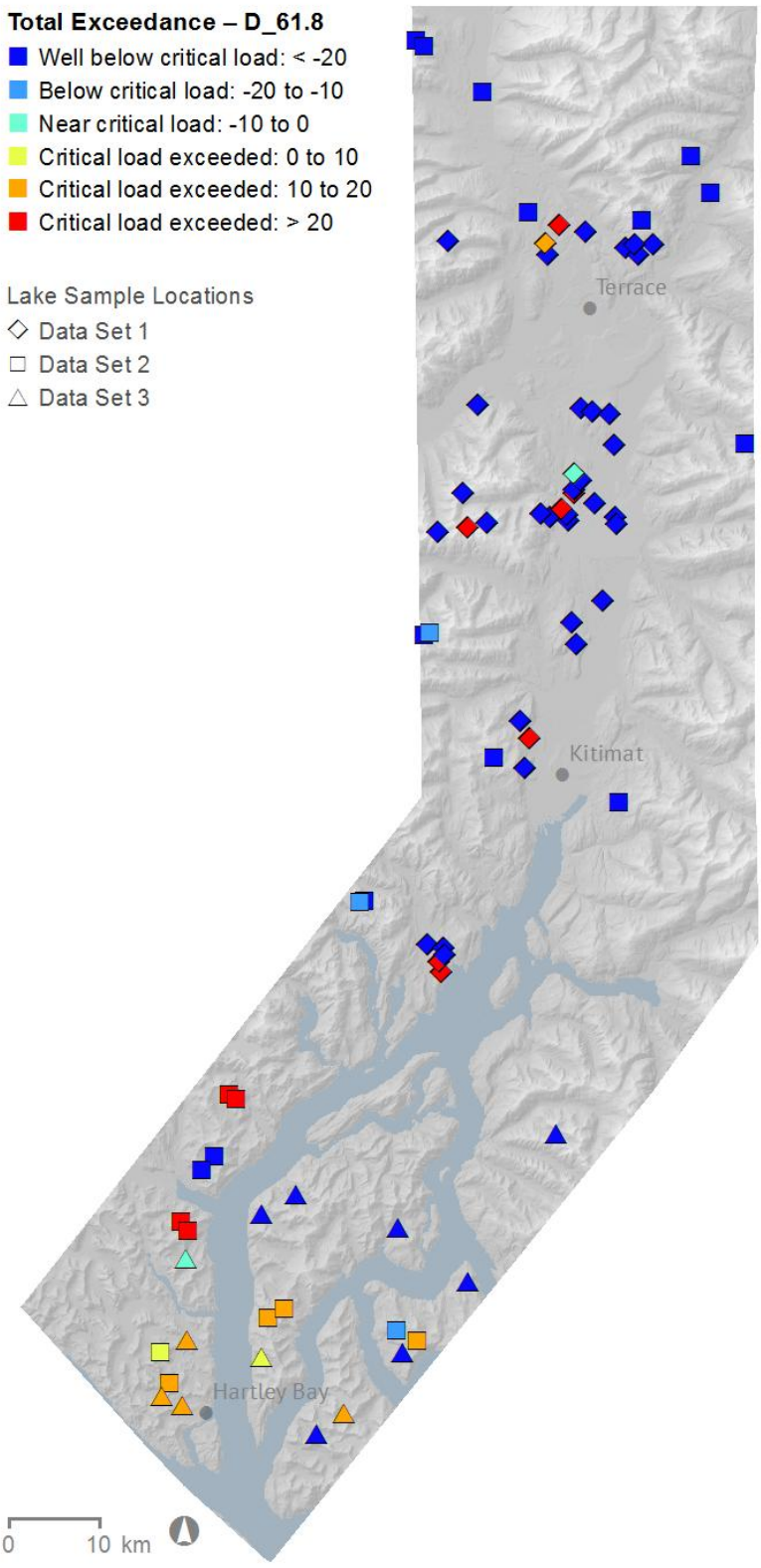

Distribution of Total Exceedances
(Scenario Jm)
Number of Lakes
16
14
12
10
8
6
4
2
0
-2000
-1500
-1000
-500
-250
-200
-150
-100
-50
-25
-10
0
10
25
50
100
150
200
Ex(Ndep, Sdep) (meq/m2/yr)
All Lakes (excluding naturally acidified)
All Lakes

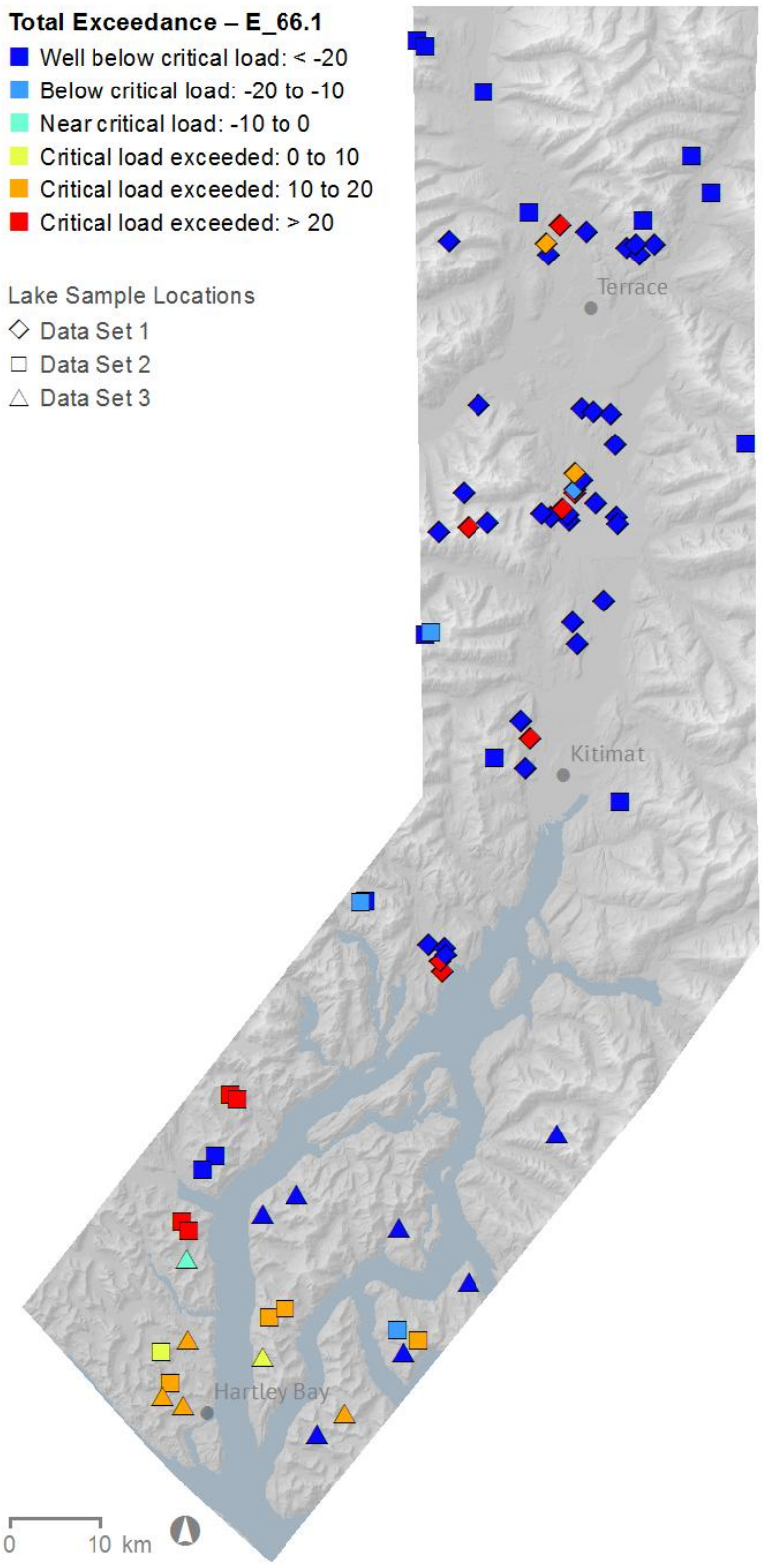
23.2 Maps of Total Exceedances

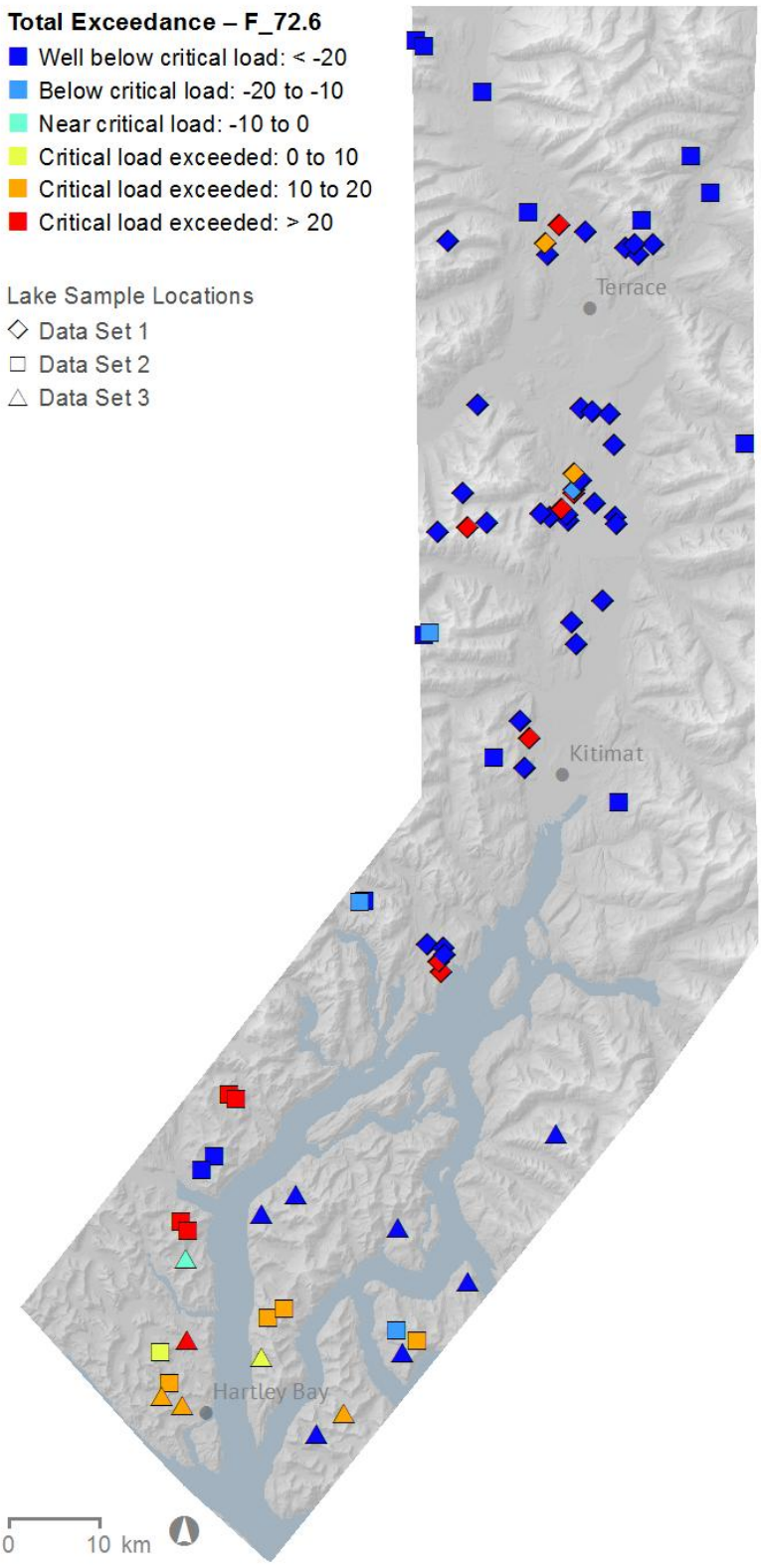


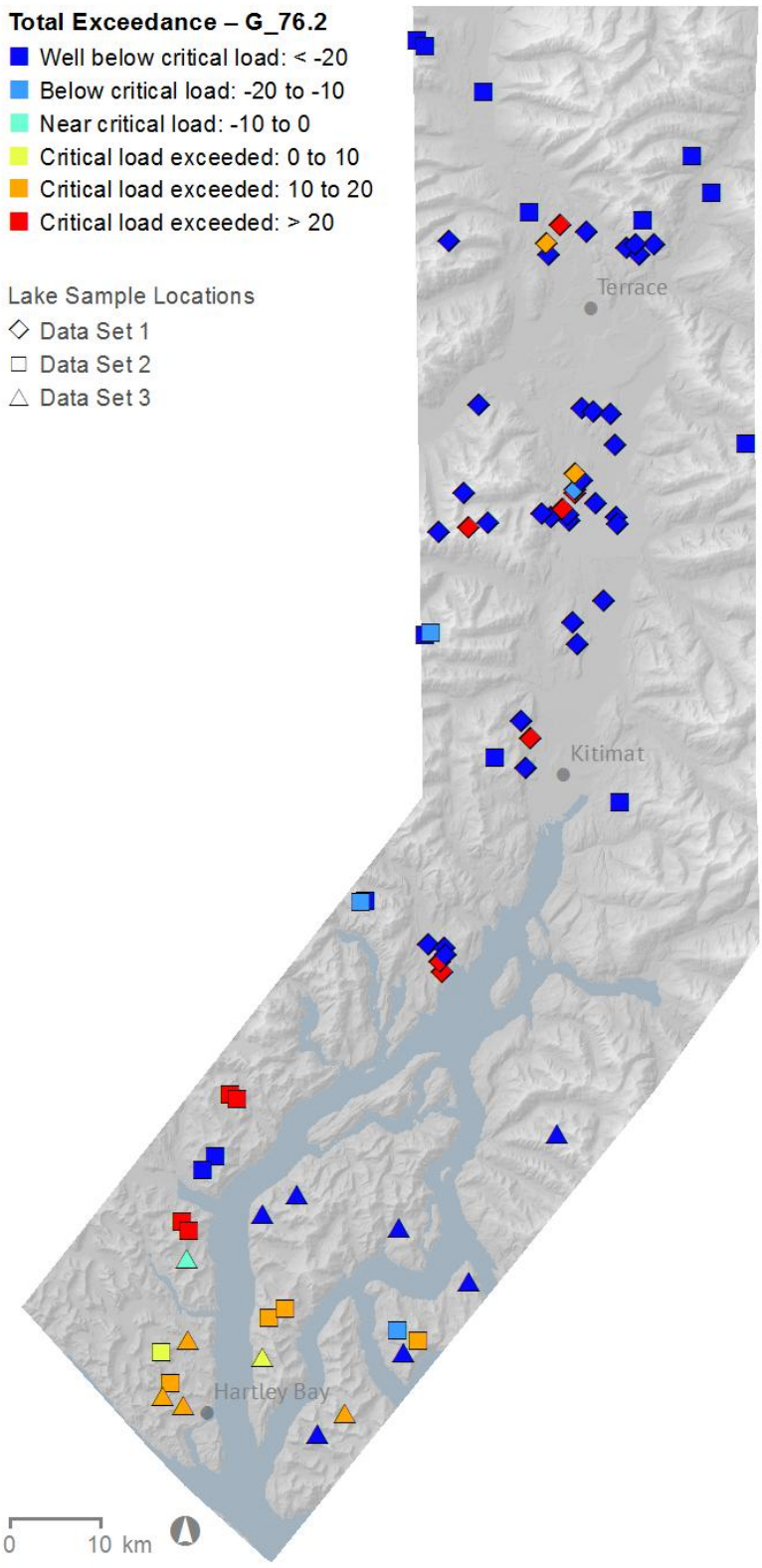

Total Exceedance – B_51.8
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km

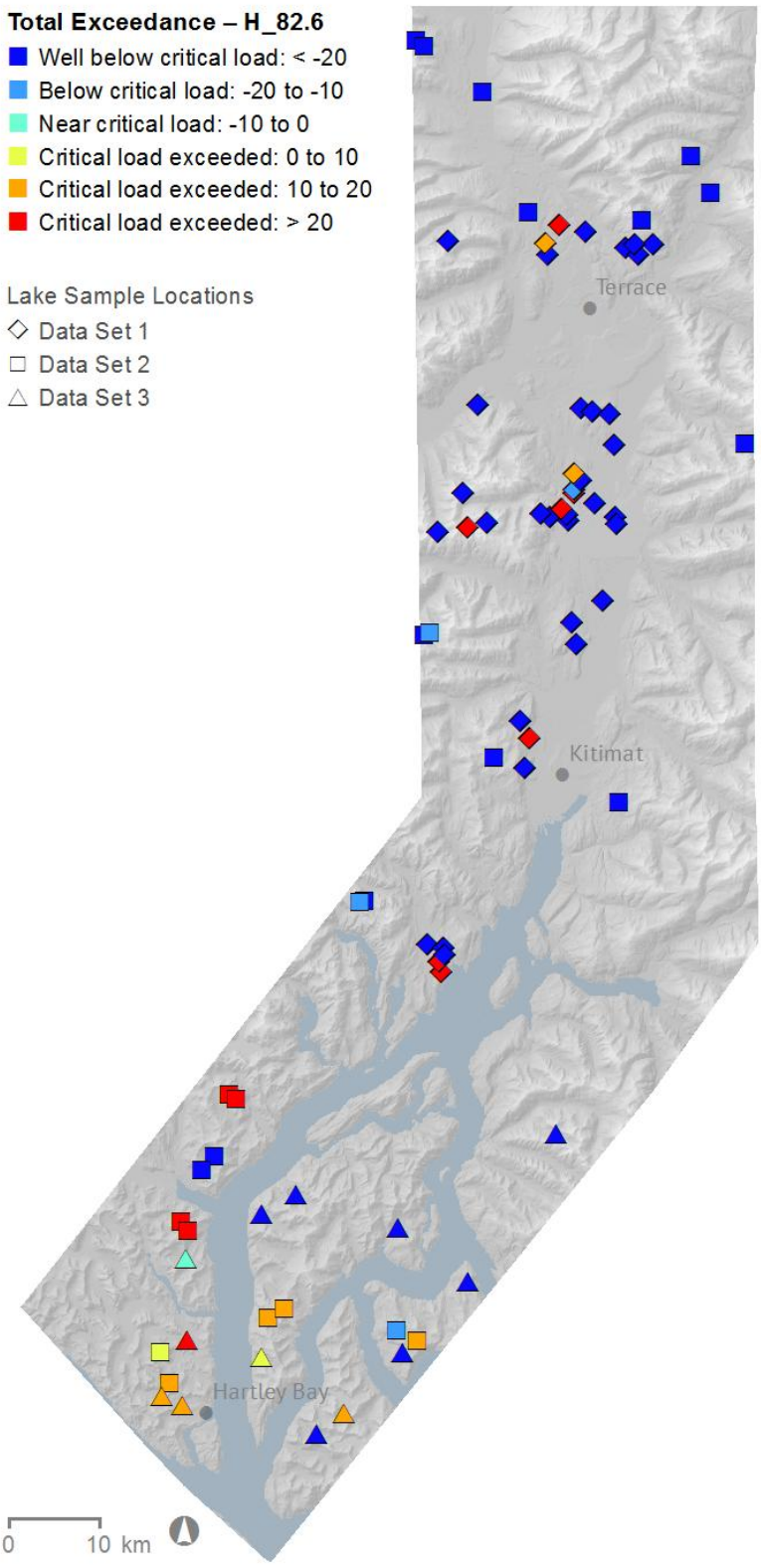

Total Exceedance – C_57.5
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km

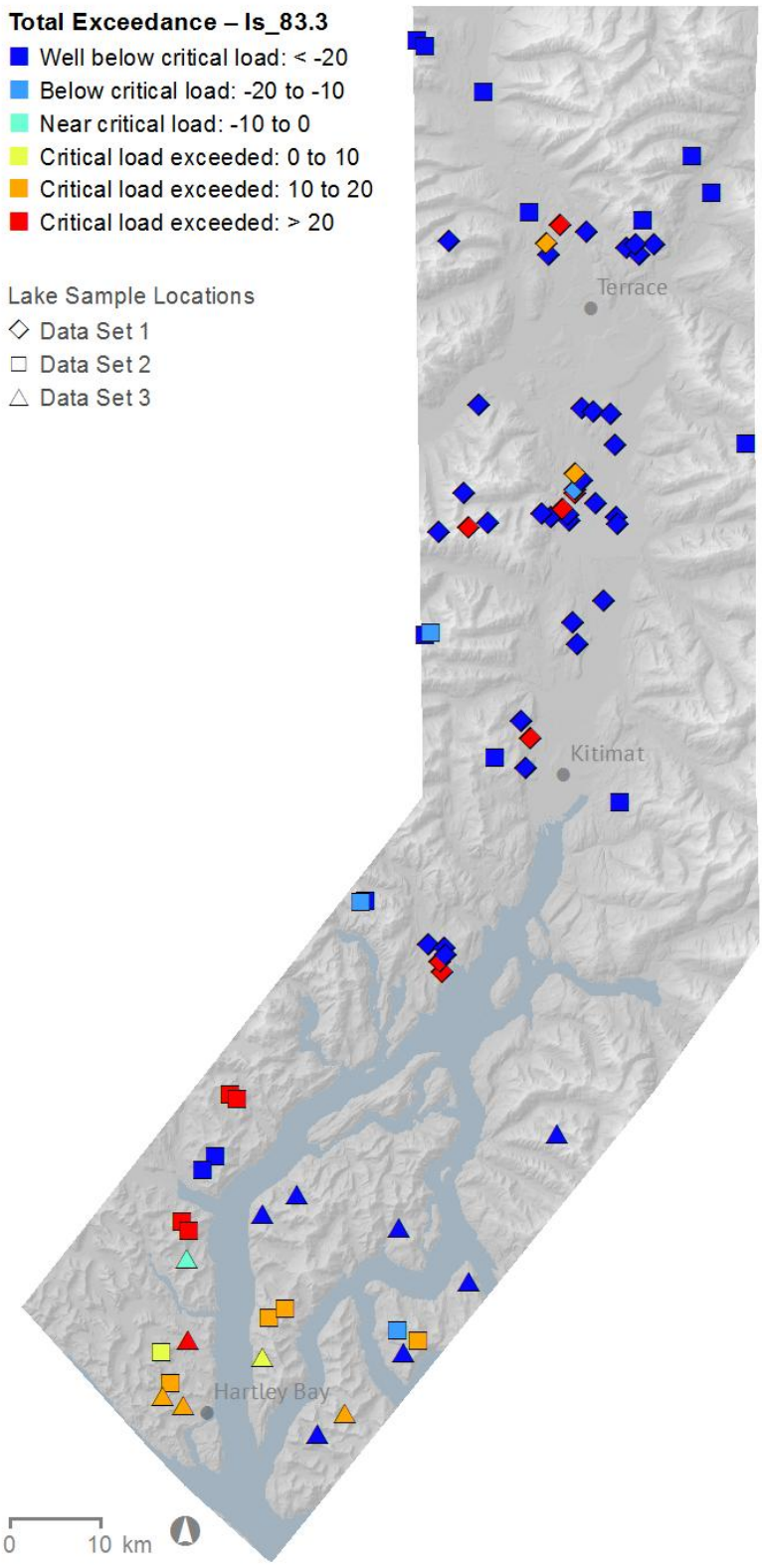

Total Exceedance – D_61.8
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km

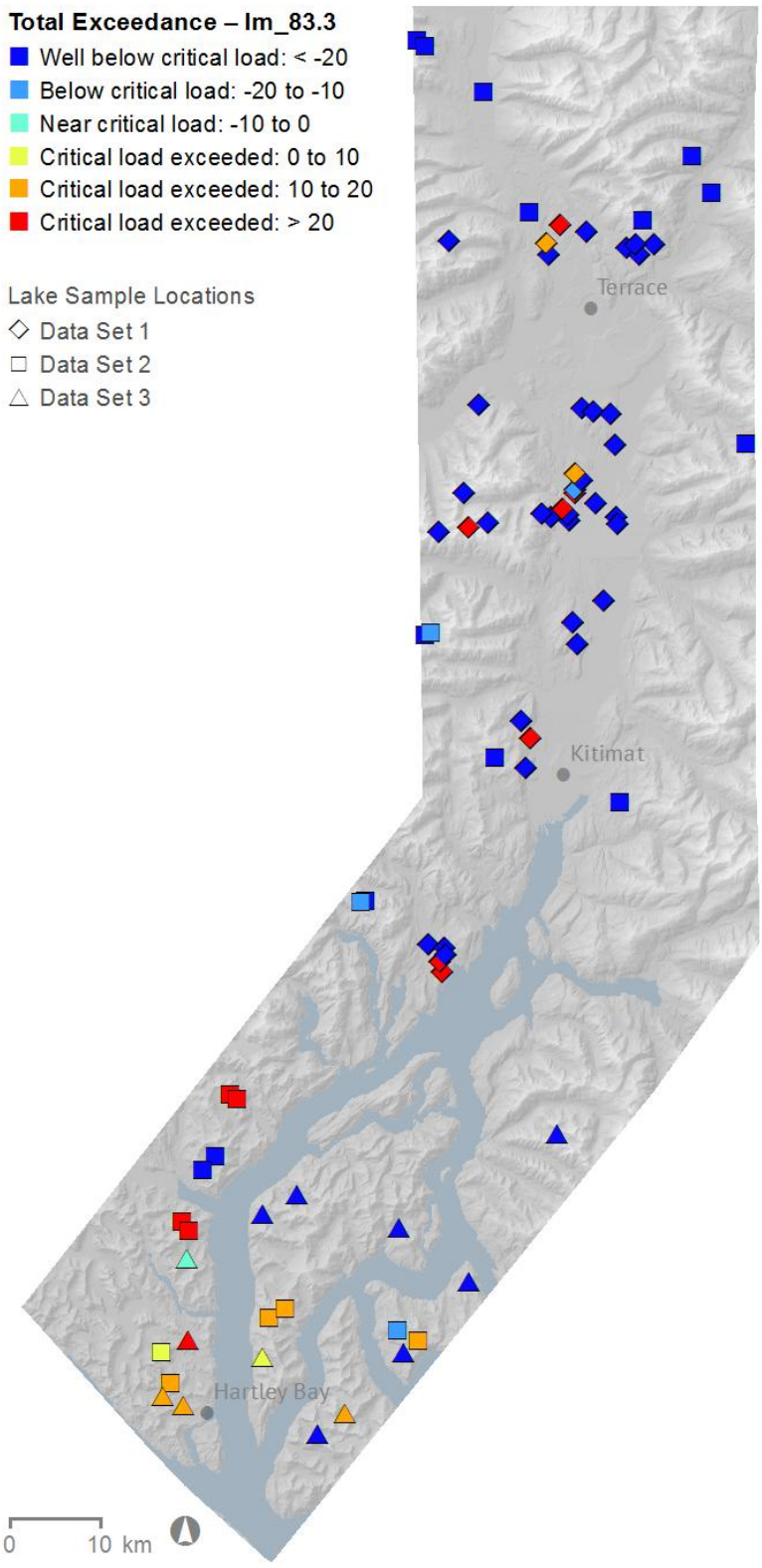

Total Exceedance – E_66.1
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km

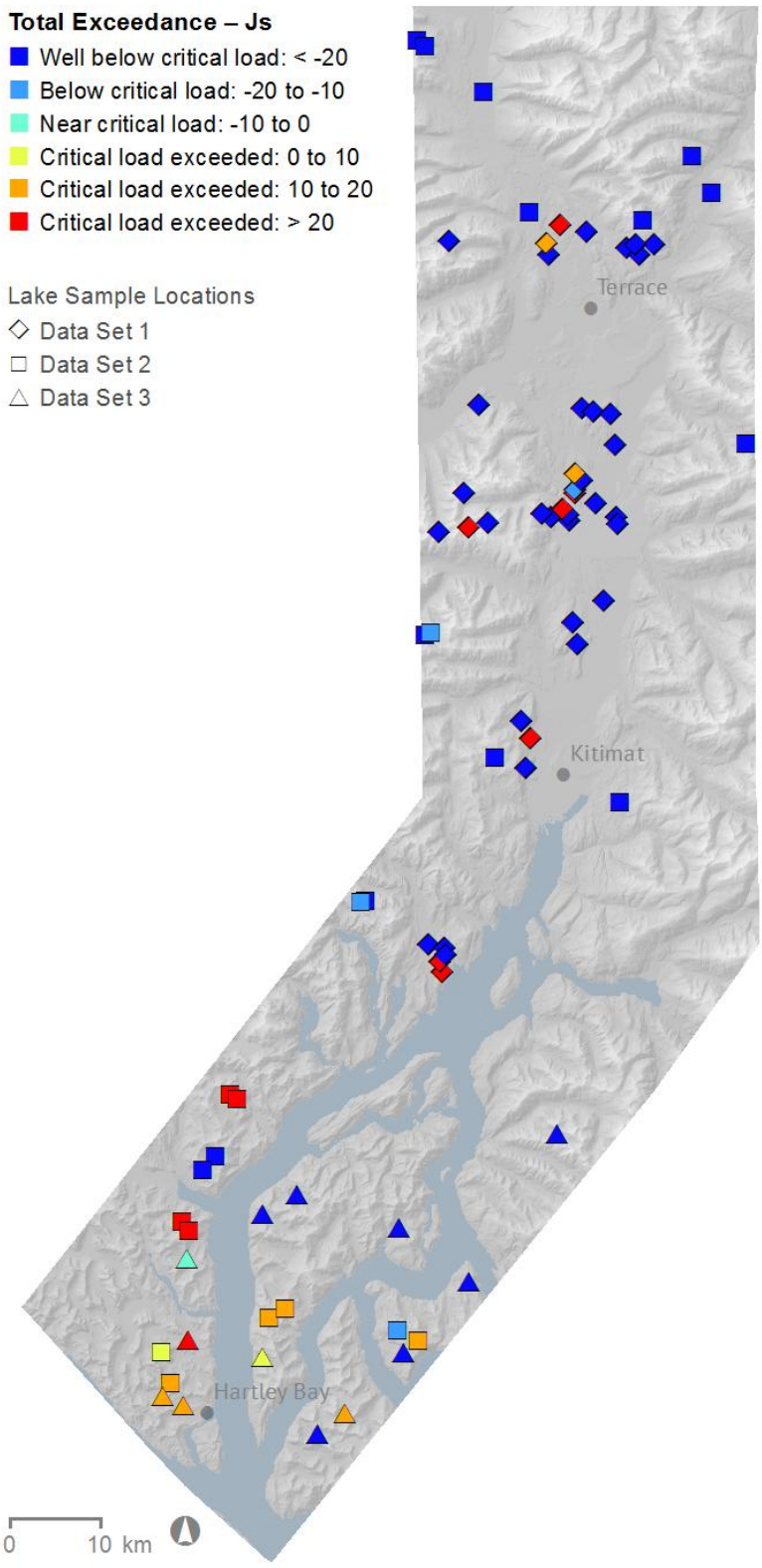

Total Exceedance – F_72.6
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km

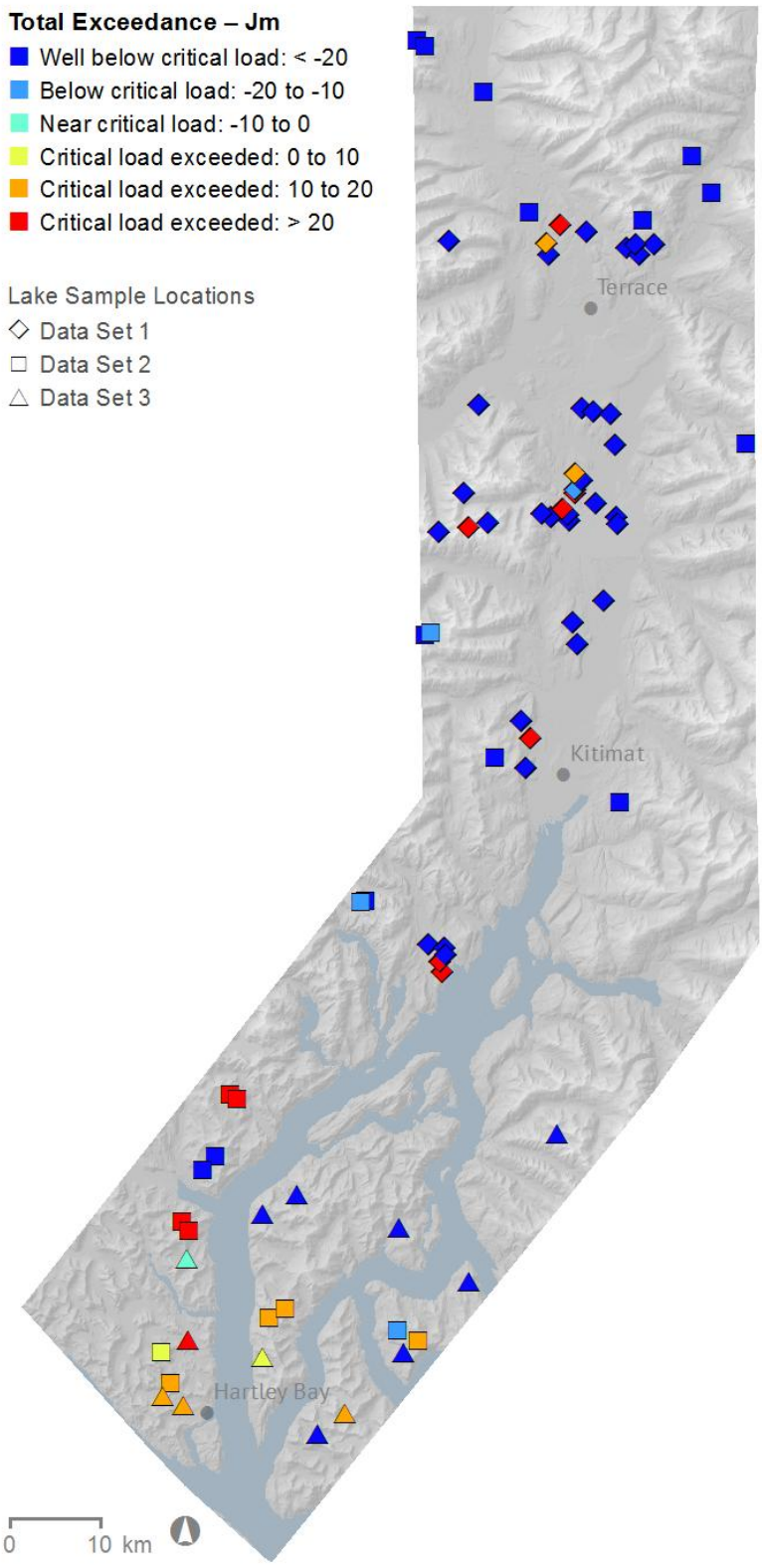

Total Exceedance – G_76.2
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km


Total Exceedance – H_82.6
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km


Total Exceedance – ls_83.3
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km


Total Exceedance – Im_83.3
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km


Total Exceedance – Js
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km


Total Exceedance – Jm
Well below critical load: < -20
Below critical load: -20 to -10
Near critical load: -10 to 0
Critical load exceeded: 0 to 10
Critical load exceeded: 10 to 20
Critical load exceeded: > 20
Lake Sample Locations
Data Set 1
Data Set 2
Data Set 3
Terrace
Kitimat
Hartley Bay
0
10 km

APPENDIX 24: SENSITIVITY ANALYSIS OF DEPOSITION YEAR

This appendix contains a sensitivity analysis comparing the results of the KMP SO_2 Technical Assessment (ESSA et al. 2013), which used average S deposition from 2006, 2008, and 2009, with the results of using just the worst deposition year (2008) as was done in the current study. For this sensitivity analysis we re-ran the SSWC model for the study area used in the KMP SO_2 Technical Assessment (ESSA et al. 2013), but applied only the 2008 levels of S deposition, and then compared the outcomes with the results from ESSA et al. (2013). All other methods were identical to those used in ESSA et al. (2013).

Table A24-1shows the differences between using the average S deposition from 2006, 2008, and 2009, versus using only S deposition from 2008. The key findings (only available for lakes in data set 1, the lakes that were analyzed in ESSA et al. 2013) are as follows:

- Using just 2008 generated predictions of S deposition that were on average 5.6 meq/m^2/yr higher (16% higher) than using the average deposition for 2006, 2008, and 2009 (bottom row of Table 0-1). Across the 41 lakes in data set 1, the percent change in deposition from using just 2008 ranged from a 10% decrease (only 4 of the 41 lakes showed a decrease) to a 36% increase.
- Pre-KMP deposition was on average 1.9 meq/m^2/yr higher (12%) using just 2008 than using the average deposition for 2006, 2008, and 2009.
- Using just 2008 on average lowered CL estimates by 1.2 meq/m^2/yr relative to using 2006, 2008, and 2009. This is due to the higher estimates of pre-KMP deposition, which lower the estimates of original, pre-industrial concentrations of sulphate and base cations.
- There were only negligible changes in estimated original, pre-industrial pH_o for 40 of the 41 lakes (≤0.05 pH units), but the estimate for LAK028 increased by 0.15 pH units.
- Using just 2008 increased the exceedance of CLs on average by 6.8 meq/m^2/yr compared to using the average deposition for 2006, 2008, and 2009, though there was a substantial increase in exceedance for three lakes just north of Kitimat: LAK027 (20.0 meq/m^2/yr); LAK028 (34.0 meq/m^2/yr); and LAK030 (50.9 meq/m^2/yr).
- As shown in the right side of Table A24-1 and in Figure A24-1, the predicted ΔpH was up to 0.26 units greater (i.e., a larger decline) using just 2008 deposition than using the average deposition for 2006, 2008, and 2009. The five lakes shown in red in Table A24-1 (lakes with a ΔpH greater than -0.3 pH units) demonstrate the largest differences in ΔpH from using just 2008 deposition rather than using the average deposition for 2006, 2008, and 2009. The five lakes with ΔpH greater than -0.3 pH units are the same in both cases.
- Further analysis indicates that the results from using just 2008 deposition for the KMP study area generate ΔpH values that are very similar to the results for Scenario D_61.8 in this study.

Table A24-2 shows examples of ΔpH_{2008} values calculated for fixed values of $\Delta pH_{avg\ of\ 2006,\ 2008,\ 2009}$ using the regression based on this sensitivity analysis (Figure A24-1). The difference between these estimates of ΔpH indicates the potential extent to which using 2008 deposition may overestimate the values of ΔpH using average deposition. We can infer from these detailed results that if we had used the average deposition for 2006, 2008, and 2009 in this study, there may have been two fewer lakes with a ΔpH greater than -0.3 pH units.

Table A24-1. Results from the sensitivity analysis of deposition year. The left-hand columns show the differences in results between using 2008 deposition and average deposition (i.e., average of 2006, 2008, 2009). The right-hand columns show actual results under the two different cases. Sdep = sulphate deposition. KMP = Kitimat Modernization Project deposition scenario. Pre-KMP = deposition levels prior to KMP upgrade. SO_{4o} = original sulphate concentration. CL(Ac) = critical load of acidity as calculated in the Steady State Water Chemistry model (SSWC). Ex(A) = exceedance of critical load, as calculated by the SSWC model. Ex(A)(%) = the percentage increase in Ex(A) (only calculated for lakes with positive exceedance). pH_o = estimated original, pre-industrial pH. pH_∞ = predicted future steady state pH. ΔpH = the predicted future change in pH under KMP deposition.

LakeID	Difference for Deposition Year 2008 vs Average Deposition Year (2006, 2008, 2009)										Absolute Values					
	KMP Sdep	KMP Sdep (%)	pre-KMP Sdep	pre-KMP Sdep (%)	SO_{4o}	CL(Ac)	Ex(A)	Ex(A) (%)	pH_o	pH_∞	Ex(A) (avg)	Ex(A) (2008)	pH_∞ (avg)	pH_∞ (2008)	Δ pH (avg)	Δ pH (2008)
LAK001	6.5	19%	1.5	10%	-2.0	-1.5	8.0		0.00	0.00	-569.0	-561.0	7.6	7.6	0.00	0.00
LAK002	6.1	18%	1.8	11%	-2.3	-0.9	7.1		0.00	-0.01	-78.4	-71.3	6.6	6.5	-0.06	-0.07
LAK003	13.6	20%	2.3	6%	-1.6	-2.3	15.9		0.00	0.00	-423.2	-407.4	7.1	7.1	0.00	0.00
LAK004	6.7	21%	1.0	7%	-0.5	-0.5	7.2		0.00	0.00	-170.8	-163.7	6.5	6.5	-0.01	-0.01
LAK005	9.1	19%	2.7	12%	-3.0	-1.5	10.6		0.01	-0.03	-66.5	-55.9	6.0	6.0	-0.10	-0.13
LAK006	7.8	18%	1.0	5%	0.0	0.0	7.8	54%	0.01	-0.26	14.2	22.0	5.3	5.0	**-0.48**	**-0.74**
LAK007	2.5	7%	-2.6	-15%	2.7	2.6	-0.1		0.00	0.00	-1353.7	-1353.8	8.0	8.0	0.00	0.00
LAK008	5.5	12%	-0.4	-2%	0.5	0.4	5.1		0.00	0.00	-1635.3	-1630.2	7.9	7.9	0.00	0.00
LAK011	6.4	22%	1.0	7%	0.0	0.0	6.4		0.00	-0.01	-70.2	-63.7	6.6	6.6	-0.04	-0.05
LAK012	7.3	18%	0.6	3%	0.0	0.0	7.3		0.00	-0.05	-37.4	-30.1	5.5	5.5	-0.13	-0.18
LAK013	4.7	14%	1.1	7%	-1.4	-1.1	5.8		0.00	0.00	-686.8	-681.0	7.4	7.4	0.00	0.00
LAK014	6.9	16%	0.8	4%	-1.0	-0.4	7.4		0.00	-0.02	-68.1	-60.7	6.4	6.4	-0.07	-0.10
LAK015	11.7	19%	-3.7	-11%	2.8	3.4	8.3		0.00	-0.01	-161.7	-153.5	6.0	5.9	-0.01	-0.02
LAK016	8.6	20%	1.6	7%	-1.8	-0.9	9.6		0.00	-0.03	-70.9	-61.4	6.2	6.2	-0.07	-0.10
LAK017	4.8	15%	-2.0	-11%	0.0	0.0	4.8		0.00	0.00	-198.2	-193.4	6.8	6.8	0.00	-0.01
LAK018	2.1	6%	-2.8	-18%	2.9	2.8	-0.7		0.00	0.00	-1438.8	-1439.5	8.1	8.1	0.00	0.00
LAK022	6.9	17%	0.3	2%	-0.4	-0.1	7.0		0.00	-0.20	-12.2	-5.2	5.5	5.3	**-0.39**	**-0.59**
LAK023	8.0	20%	1.5	7%	0.0	0.0	8.0	88%	0.01	-0.25	9.0	17.0	5.2	4.9	**-0.54**	**-0.79**
LAK024	2.1	10%	-0.5	-5%	0.5	0.5	1.6		0.00	0.00	-314.5	-312.9	7.1	7.1	0.00	0.00
LAK027	15.9	18%	4.1	7%	-2.5	-4.0	20.0		0.00	0.00	-160.4	-140.4	6.6	6.6	0.00	0.00
LAK028	23.5	24%	24.2	38%	-15.3	-10.5	34.0	66%	0.15	0.01	51.2	85.3	4.6	4.6	**-0.38**	**-0.37**

LakeID	Difference for Deposition Year 2008 vs Average Deposition Year (2006, 2008, 2009)										Absolute Values					
	KMP Sdep	KMP Sdep (%)	pre-KMP Sdep	pre-KMP Sdep (%)	SO_{4o}	CL(Ac)	Ex(A)	Ex(A) (%)	pH_o	$pH_{-\infty}$	Ex(A) (avg)	Ex(A) (2008)	$pH_{-\infty}$ (avg)	$pH_{-\infty}$ (2008)	Δ pH (avg)	Δ pH (2008)
LAK030	29.8	25%	21.1	29%	-11.9	-21.1	50.9		0.00	0.00	-677.2	-626.3	7.4	7.4	0.00	0.00
LAK032	3.8	23%	0.2	3%	-0.4	-0.2	4.0		0.00	0.00	-928.2	-924.2	7.0	7.0	0.00	0.00
LAK034	3.5	18%	0.1	1%	-0.1	0.0	3.5		0.00	-0.01	-105.9	-102.4	6.7	6.7	-0.03	-0.04
LAK035	2.5	15%	0.2	3%	-0.2	-0.1	2.6		0.00	-0.01	-74.8	-72.2	6.2	6.2	-0.05	-0.07
LAK037	3.3	17%	0.3	3%	-0.3	-0.2	3.4		0.00	-0.01	-115.3	-111.9	6.5	6.5	-0.03	-0.04
LAK038	3.4	18%	0.4	5%	-0.5	-0.3	3.7		0.00	0.00	-159.2	-155.5	6.5	6.5	-0.01	-0.01
LAK039	3.2	17%	0.3	4%	-0.3	-0.2	3.4		0.00	-0.01	-79.5	-76.1	6.3	6.3	-0.03	-0.04
LAK041	1.2	23%	0.1	4%	-0.1	0.0	1.2		0.00	-0.01	-47.5	-46.3	6.5	6.5	-0.01	-0.02
LAK042	3.6	23%	0.3	4%	0.0	0.0	3.6	1697%	0.01	-0.06	0.2	3.8	4.5	4.4	-0.20	-0.26
LAK044	3.4	21%	0.1	1%	0.0	0.0	3.4	21%	0.00	-0.12	16.7	20.1	4.9	4.7	**-0.55**	**-0.67**
LAK045	0.8	16%	0.2	9%	-0.1	-0.2	1.0		0.00	0.00	-219.7	-218.7	6.9	6.9	0.00	0.00
LAK047	2.0	24%	0.5	12%	0.0	0.0	2.0	19%	0.00	-0.01	10.2	12.2	5.9	5.9	-0.03	-0.04
LAK049	3.0	29%	0.7	12%	-0.3	-0.6	3.6		0.00	0.00	-221.7	-218.1	6.8	6.8	0.00	0.00
LAK050	1.8	25%	0.5	12%	-0.2	-0.3	2.1		0.00	0.00	-101.9	-99.8	6.5	6.5	0.00	-0.01
LAK051	4.0	36%	0.9	17%	-1.0	-0.8	4.8		0.00	0.00	-225.1	-220.3	6.7	6.7	0.00	0.00
LAK053	-0.5	-4%	3.4	57%	-1.9	-1.7	1.2		0.01	0.01	-71.7	-70.4	6.6	6.6	-0.01	0.00
LAK054	-1.4	-10%	4.0	57%	-2.5	0.0	-1.4	-10%	0.05	0.05	14.8	13.3	4.5	4.6	-0.06	-0.01
LAK055	-1.1	-9%	4.4	66%	-2.5	-2.7	1.6		0.01	0.01	-107.2	-105.6	6.1	6.2	-0.01	0.00
LAK056	-1.3	-10%	3.9	60%	-2.5	-0.7	-0.6	-5%	0.04	0.04	12.4	11.7	4.4	4.5	-0.06	-0.01
LAK057	-1.2	-9%	4.4	66%	-2.5	-4.4	3.2		0.00	0.00	-406.9	-403.7	6.6	6.6	0.00	0.00
Average	**5.6**	**16%**	**1.9**	**12%**	**-1.2**	**-1.2**	**6.8**		**0.01**	**-0.02**	**-266.6**	**-259.8**				

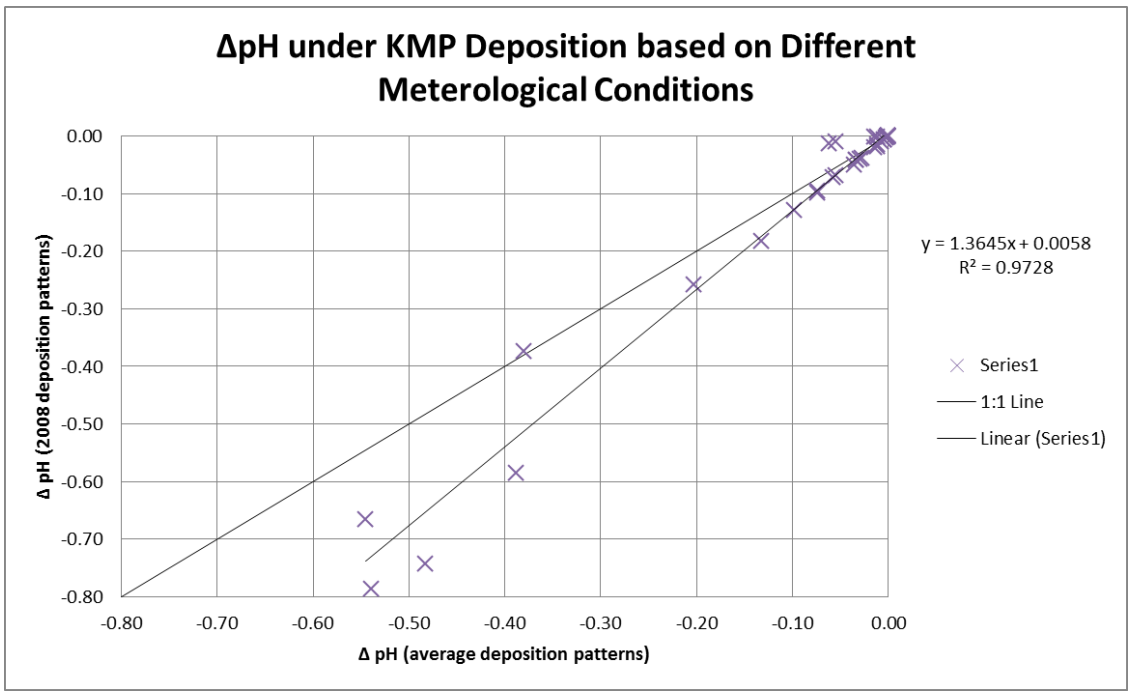


Figure A24-1. Effect on predicted ΔpH of using just the 2008 deposition year instead of the average deposition over 2006, 2008 and 2009. Top graph shows the regression line of ΔpH_{2008} vs. $\Delta pH_{\text{avg of 2006, 2008, 2009}}$.

Table A24-2. Examples of the equivalent ΔpH under 2008 deposition for defined levels of ΔpH under average deposition (i.e., 2006, 2008, 2009), as calculated using the regression shown in Figure A24-1. The difference shows the estimated extent to which using only 2008 deposition may overestimate ΔpH values (i.e., values that are more negative) as compared with using average deposition. These results are based on the sensitivity analysis of the data set 1 lakes under KMP deposition levels.

$\Delta pH_{\text{avg of 2006, 2008, 2009}}$	ΔpH_{2008}	Difference in ΔpH (2008 vs. average deposition)
-0.10	-0.14	-0.04
-0.20	-0.28	-0.08
-0.30	-0.42	-0.12
-0.40	-0.55	-0.15
-0.50	-0.69	-0.19
-0.60	-0.82	-0.22

References Cited

ESSA Technologies, J. Laurence, Limnotek, Risk Sciences International, Rio Tinto Alcan, Trent University, Trinity Consultants and University of Illinois. 2013. Sulphur Dioxide Technical Assessment Report in Support of the 2013 Application to Amend the P2-00001 Multimedia Permit for the Kitimat Modernization Project. Volume 2: Final Technical Report. Prepared for Rio Tinto Alcan, Kitimat, B.C. 450 pp.

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