Sulphur Dioxide Technical Assessment Report
in Support of the 2013 Application to Amend the P2-00001 Multimedia Permit

Kitimat Modernization Project

Volume 1: Executive Summary
Final Report

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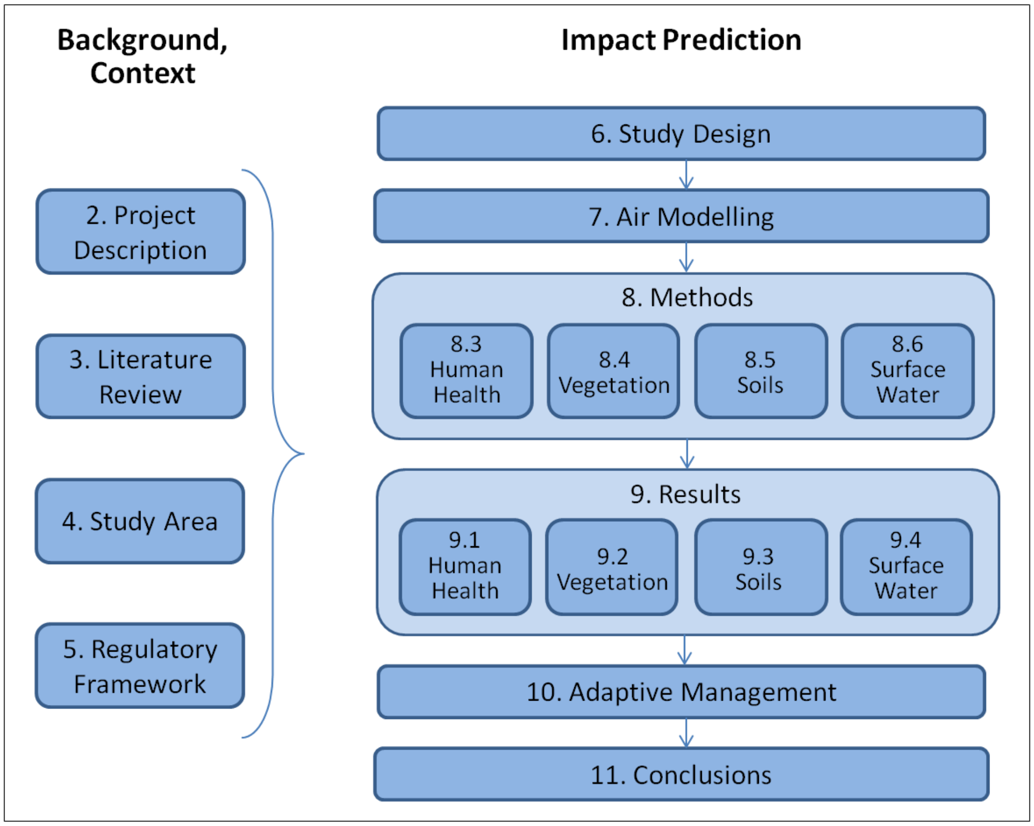
1 Introduction

This executive summary presents the key findings from the SO_2 Technical Assessment Report for the Kitimat Modernization Project SO_2 Permit Amendment. The following diagram represents the main sections of the summary, and has been included here to help readers understand its structure and flow.

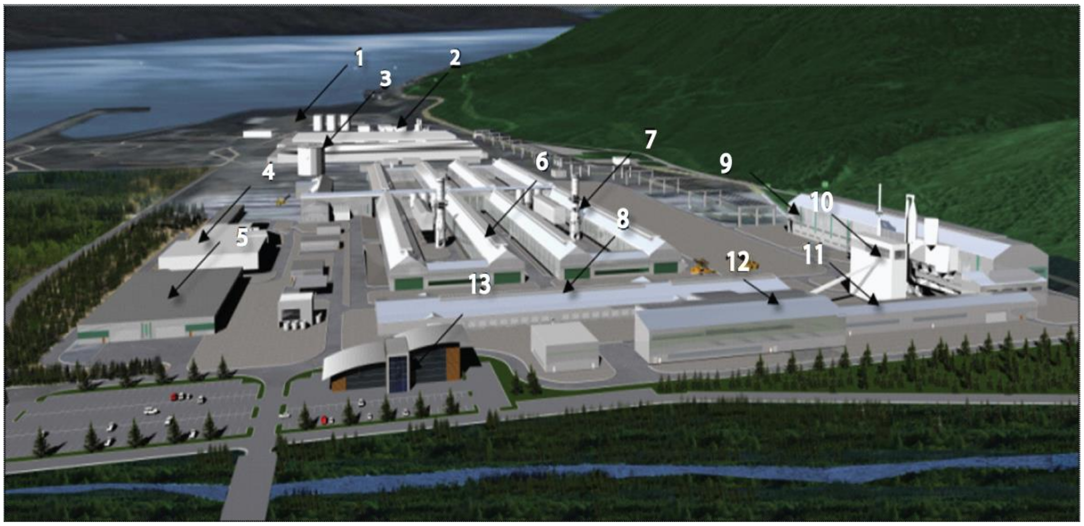


Rio Tinto Alcan (RTA) is modernizing the Kitimat Aluminum Smelter with state of the art AP-4X pre-bake smelting technology through the replacement of the existing 60 year old vertical stud Söderburg (VSS) technology. The new aluminum smelting technology is more efficient, producing more aluminum per kilowatt hour of electricity than the smelting technology in current use. As a result, the Kitimat Smelter will increase both the production of aluminum and the consumption of petroleum coke, the primary source of sulphur emissions. The purpose of this permit amendment application is to add the new SO_2 emission sources associated with a modern pre-bake aluminum smelting process to RTA's P2-00001 Multimedia Waste Discharge Permit, as well as to increase the permitted limit on SO_2 emissions from the current 27 tonnes per day (t/d) to a new limit of 42 t/d.

The scope of this technical assessment focuses solely on total SO_2 emissions from the modernized Kitimat Aluminum Smelter and their associated impacts on human health and the environment. Other emissions that are typical of the aluminum smelting process, such as hydrogen fluoride emissions and particulates, are not within the scope of this technical assessment report.

2 Project Description

The scope of the Kitimat Modernization Project (KMP) is to replace the old VSS smelting technology with a modern pre-bake AP-40 smelter. The project will be constructed over the footprint of the north end of the smelter (potlines 7 and 8 area) and will increase Kitimat's aluminum production to 420,600 tonnes per year (t/yr) from the current name plate capacity of 282,000 t/yr. KMP is an important project for Rio Tinto Alcan that will deliver both financial and environmental returns. The change in technology will deliver efficiencies in aluminum production (reduced raw materials consumption intensity) and improved emission controls. To support the AP-40 smelting technology, KMP will install a number of services such as for carbon anode production and a cast house to freeze the expanded metal production. Figure 1 shows a rendition of the completed modernization project with various components of the new smelter facility.



1: Kitimat Port Facilities
2: Carbon South
3: Alumina Silo
4: Existing Casthouse B
5: New Casthouse C
6: Potroom
7: GTC
8: Pallet Storage
9: Anode Baking Furnace
10: Bath Treatment Plant
11: Anode Storage
12: Rodding Shop
13: Main Office

Figure 1: 3D Schematic of Project Layout

A key aspect of KMP is the environmental benefits that arise from modernizing the aluminum smelting process in Kitimat. The existing VSS smelting process is an open process that fugitively releases fluorides, polycyclic aromatic hydrocarbons (PAHs), particulates and SO_2. Modernizing the smelter with new state of the art AP-40 smelting technology will reduce the smelter's environmental footprint by capturing and filtering exhaust process gases better (Figure 2). PAH emissions will be reduced by over 90% with the pre-bake process, where anodes are baked in an anode baking furnace before being using in the smelting process. Sulphur dioxide emissions will be the only emissions to increase, and that is due to the increased consumption of petroleum coke and ongoing challenges with the quality of coke that is available on the market. Sulphur dioxide emissions are projected to range from 33 t/d to 42 t/d.

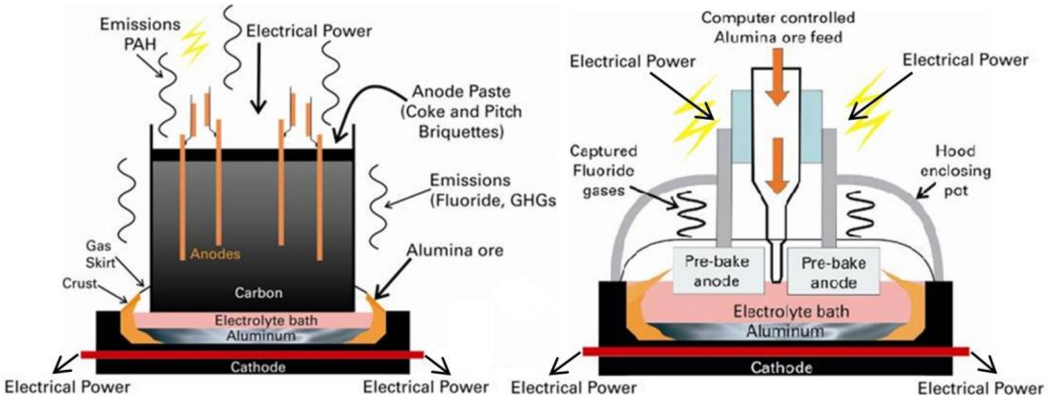


Figure 2: Difference between VSS and Pre-bake Smelting

Petroleum coke is a key strategic raw material for the primary aluminum industry and is used as the carbon source for the anodes in the electrolysis process. Strong market forces within the coke market limit the availability of suitable grades of coke for producing anodes. To meet the shortfall of anode grade coke, the aluminum industry has been forced to use a wider variety of coke quality that has higher levels of impurities (metals and sulphur).

Petroleum coke is a waste product from the petroleum refinery industry – a residual product after the volatile fuels and oils have been distilled from crude oil. Refineries produce hydrocarbon products through a distillation process. The residual fuel oil is feed stock for the coking process that produces the end coke waste product. It is important to note that the coking process is not intended to produce coke, but is a process to extract the last remaining light fuels from the residual oil. Coke produced from the refinery without going through a calcination process is referred to as green coke.

Green coke contains impurities of volatiles, moisture, metals (nickel and vanadium), ash and sulphur. To remove volatiles, moisture and some of the sulphur, green coke is calcined in a rotary kiln to 1,200 to 1,400^{o}C. This process drives off volatile hydrocarbons and moisture, and increases both the electrical conductivity and physical strength of the coke.

The primary aluminum industry uses anode grade coke which is a limited segment of petroleum coke production. Physical properties of anode grade coke limit the coke to either a needle or sponge form that is produced from a delayed coking process. Chemically, the anode grade coke needs to have low concentrations of metal (vanadium, nickel and iron) and sulphur impurities. Coke that does not meet the criteria for anode use can affect the calcination process, smelting process and ultimately the final quality of the aluminum metal produced.

The segment of coke on the global market that meets the requirements for anode production is small. There is strong competition within the aluminum industry, and from other industries such as steel and energy, for access to the anode grade coke. Further complicating and limiting the supply of anode grade coke are the economics of the refinery industry to maximize its profitability. This affects the coke through increased levels of contaminants (metals and sulphur) or by not producing coke in favour of selling the residual heavy oil from the distillation process as a high sulphur heavy fuel oil. Currently, there is a shortfall of anode grade coke that is expected to be an ongoing challenge for the aluminum industry, driving up the price of suitable anode grade coke and forcing the industry to use non-traditional coke that is often of marginal quality for producing aluminum.

Low sulphur coke that is desirable for use in the aluminum industry is also limited in availability. Sulphur content has been steadily increasing in the coke due to declines in sweet (low sulphur) crude oils and increased efforts by the refinery industry to extract more hydrocarbons in the coking process. Trends in the growth of coke production do not support any significant growth in sustainably available low sulphur cokes.

Procurement and coke management practices have had to change and adapt to the new market conditions. Sourcing strategies have had to extend further afield than the traditional North American coke market, and to multiple refineries and coke calciners to obtain supplies of coke with different quality ranges that are blended into an acceptable range for anode use. As coke is a waste product that does not contribute significantly to a refinery’s bottom line, there is little incentive or ability for the aluminum industry to influence the coke quality available for making aluminum.

KMP will require approximately 200,000 tonnes of coke per year. The project will utilize the full capacity of the existing calciner (approximately 80,000 t/yr) and the remainder will be procured as calcined coke imported to Kitimat. As sulphur contents in green and calcined coke are trending upwards, there is an expectation that KMP will be using cokes with sulphur levels averaging 2.9% sulphur, but that could go as high as 3.8%. KMP will use blending as a method of combining multiple cokes to produce an average coke blend that meets quality requirements for anode production.

KMP will have three primary sources of SO_2 emissions: the coke calciner (20%), anode baking furnace (5%), and the potrooms (75%). Plant wide emissions from these combined sources are calculated based on the mass fraction of sulphur in green coke, calcined coke, and pitch consumed in the carbon life cycle.

3 Sulphur Dioxide Literature Review

One of the first things done for the technical assessment study was to develop what is called a source-pathway-receptor model that illustrates how sulphur dioxide (SO_2) releases affect people and the environment (Figure 3). The “source” is where the SO_2 comes from. The “pathway” is the route it takes to its destination. The “receptor” is the destination. This model was then used to organize a review of the scientific literature to better understand the processes behind each pathway in the diagram.

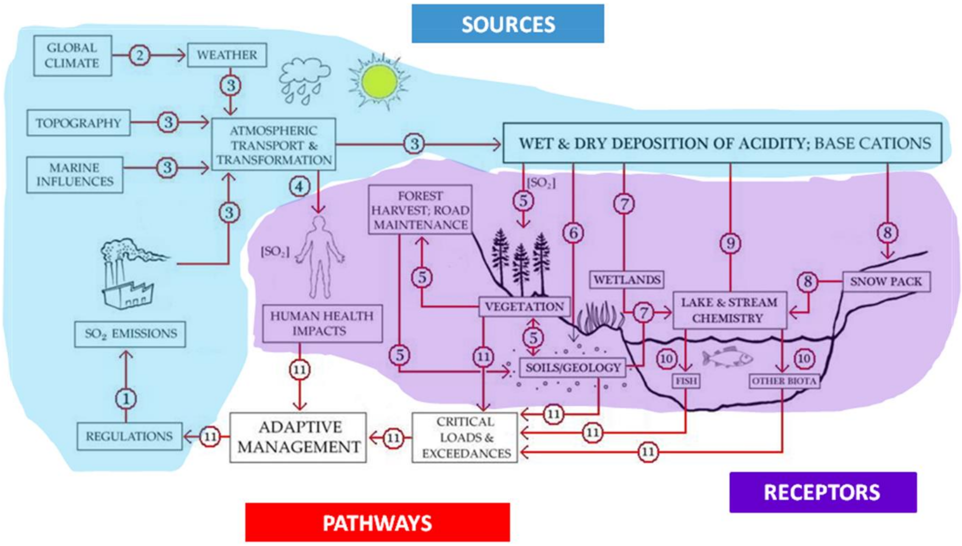


Figure 3: Source-Pathway-Receptor model of SO_2 emissions in the environment

SO_2 in the air gets transformed into sulphuric acid and then falls to the earth where it can affect people, plants, animals, streams, and lakes. This process is called “acidic deposition”. Acidic deposition doesn’t always cause harm, because sometimes the water or soil can neutralize the effect. The largest amount of acid that can be deposited without having a harmful effect is called the “critical load”. Different receptors have different critical loads, depending on their sensitivity.

SO_2 is a very stable chemical compound that can occur as a gas, liquid, or solid. It is colourless and has a strong, irritating odour. It is also easily dissolved in water, which is an important part of the process that changes SO_2 into sulphuric acid (H_2SO_4) to form acid rain. Conversion of SO_2 into H_2SO_4 can happen in the air, in raindrops, and on the surface of soot particles. All three pathways involve water. The speed of the conversion is affected by light conditions, humidity, and temperature.

Over the past 100 years, many parts of the world have become more acidic because of air pollution from energy and food production. These acids then move through air, soil, vegetation, and surface waters, potentially setting off a number of harmful effects. SO_2 in the environment affects human health (Link 4 in Figure 3), vegetation (Link 5), soils (Link 6), wetlands (Link 7), lake and stream chemistry (Link 9), and animals (Link 10).

When people inhale SO_2, its reaction products can stimulate receptors in the lungs and initiate a reflexive contraction (constriction) of smooth muscles in the bronchi. Activation of these receptors can also cause cough, rapid shallow breathing, and potentially affect the cardiovascular system causing changes in pulse rate and blood pressure. Data from literature reviewed by the Scientific Advisory Committee of the U.S. EPA in 2008, and findings from more recent studies, consistently demonstrate a link between short-term exposure to SO_2 and respiratory disease. The evidence is sufficient to establish a cause-effect relationship. Scientific literature suggests that SO_2 does not induce respiratory diseases in healthy people but rather exacerbates existing chronic respiratory diseases. Individuals with pre-existing respiratory diseases, in particular with asthma, are susceptible to the effects of SO_2. SO_2 causes a decrease in lung function accompanied by respiratory symptoms in exercising asthmatics. Physical exercise increases lung ventilation and SO_2 uptake. There is suggestive, but not sufficient and consistent, evidence of a link between short term exposure to SO_2 and mortality. The U.S. EPA has 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. There is insufficient evidence for a cause-effect link between short-term SO_2 exposure and non-respiratory disease, or between long-term SO_2 exposure and any health outcome. Information on populations potentially vulnerable to the effects of SO_2 (e.g., individuals with low socio-economic status) is limited.

Sulphur is an essential nutrient for plants, but SO_2 in the air becomes toxic to plants if levels get too high or they are exposed for too long. SO_2 can directly affect the growth of plants such as food crops and trees, and it can cause physical damage to plant leaf surfaces. Plants can also be directly and indirectly affected by acidic deposition resulting from SO_2 in the air. Direct effects include loss of mineral nutrients from leaves and branches, a reduced ability to withstand cold winter temperatures, and visible damage to leaf surfaces. Indirect effects come about when acid gets deposited on the soil and destroys the mineral nutrients (e.g., calcium) stored there, making them less available for plant growth and reducing the soil's ability to buffer future acid inputs. As soils become more acidic, they also lose their ability to buffer acid inputs to the waters that filter through them, resulting in the acidification of lakes and streams.

Wetlands are often naturally slightly acidic. Under some conditions, though, weak wetland acids can act as buffers. A chemical process in the wetland replaces the strong acids from acidic deposition with weak acids, resulting in little to no change in overall acidity until the weak acids are all used up. Wetlands can also act as "acid banks", by storing acids in bottom sediments. During dry spells, chemical processes convert the stored acid into a form that is readily washed out into the catchment with the next rainstorm.

The effect of acidic deposition on lake and stream water varies depending on the geology and physical characteristics of the watershed. Impacts are most likely to occur in regions of acid-sensitive terrain where there are elevated rates of acidic deposition. The more sensitive the terrain (i.e., thinner soils, and lower buffering capacity) the less deposition it will take for acidity to rise to damaging levels. As lakes and streams become more acidic, their ability to neutralize further acid input declines, and they become even more vulnerable to acidification.

Water chemistry in streams and lakes is vitally important to aquatic biota. A pH of less than 6.0 produces conditions that are damaging for many species. Damage occurs directly in response to acidity (e.g., impaired reproduction, increased mortality), and indirectly in response to changes in the food web. An extensive review of the literature indicated that sea-going steelhead (or resident rainbow trout) are among the most acid-sensitive salmonids studied, and are affected by pH values of 5.5 or less. In some places, acidification of surface waters has resulted in decreased survival, size, and abundance of fish, and in the loss of fish and other aquatic biota from lakes and streams. For amphibians, sensitivity to acidification varies widely by species, with mortality typically beginning to occur at about pH 5.0. Terrestrial wildlife, particularly species that prey on aquatic invertebrates, can be indirectly affected by acidification through declining availability of prey.

Terrestrial wildlife, particularly species that prey on fish or aquatic invertebrates, can be indirectly affected by acidification through declining abundance and accessibility of prey. The implications for aquatic and riparian birds include impacts to migration and staging, energy acquisition (protein, nutrients), egg production, and brood rearing. Birds of the forest canopy may also suffer indirect effects from acidification. Large scale losses of the tree canopy could lead to a decreased abundance of birds that rely on the canopy for food and shelter. Evidence for direct impacts of SO_2 on terrestrial animal species comes largely from experimental studies on small mammals and domestic livestock. For small mammals, even short exposures at low levels (<2,600 $\mu g/m^3$) triggered respiratory distress, but did not result in permanent damage to the respiratory system. Studies of SO_2 exposure on terrestrial wildlife are rare and inconclusive.

4 Environment and Communities of the Study Area

This technical assessment study is being carried out in the Kitimat Valley of northwestern British Columbia. The Kitimat Valley is a wide area of low and generally simple terrain, flanked on either side by rugged mountains. The Valley stretches from tidewater at the town of Kitimat in the south to beyond the city of Terrace, approximately 60 km to the north. The Rio Tinto Alcan aluminum smelter is located at the southern end of the valley.

Air quality in Kitimat and Terrace is tracked by the National Air Pollution Surveillance Network, the B.C. Ministry of Environment, and Rio Tinto Alcan. Data from the mid- to late 2000s indicates that air quality in both communities is quite good. Levels of particulate matter, nitrogen dioxide, sulphur dioxide, and ground-level ozone were all less than the limits set by the province. Rio Tinto Alcan also monitors rain chemistry in Kitimat. The pH of normal rain ranges from 5.0 to 6.5. Between 2001 and 2006, the pH of rainwater averaged 4.46 to 4.92 at a monitoring station near the aluminum smelter, which is low enough to qualify it as acid rain. Given how close the monitoring station is to the smelter, however, it is very likely that this result is not representative of the entire study area.

Within the technical assessment study area, 41 lakes and 14 streams were selected for sampling (20 stream sites were sampled as 6 streams were sampled in two locations). The largest of the lakes is Lakelse Lake, located 40 km north of the town of Kitimat. Lakelse Lake is very important to local communities and First Nations because it supports a thriving commercial and recreational fishery. Water quality in the lake is considered to be good, but development around the lake may be putting water quality at risk. The streams selected for sampling are also of high public importance because they are used for fishing, water-based recreation, and/or as a household water supply.

The Kitimat Valley is underlain mainly by intrusive igneous rock. The major rock types consist mainly of Paleozoic to early Tertiary granitic rocks and Proterozoic to Paleozoic high-grade metamorphic rocks. The most abundant granitic rocks are quartz diorite and granodiorite. The dominant soils are Ferro-Humic and Humo-Ferric Podzols that have formed on colluvium, glaciofluvial and glaciomarine parent materials. The residue from prolonged physical and chemical weathering provides a coarse textured, acid parent material.

The acid sensitivity of the soil landscape is largely dependant on the chemical properties of the soil parent material, with the rate of mineral chemical weathering being the most important factor. Within the study region, spatial information on soil and soil parent material is limited, therefore acid sensitivity was evaluated using bedrock geology. The study area comprises 13 bedrock types, ranging in acid sensitivity. The majority of the study area was classified as moderately acid sensitive.

Vegetation in the Kitimat Valley ranges from coastal and valley-bottom wetlands, to floodplain shrubs and deciduous forest, and thick coniferous forests with understories that include blueberries and dense mosses, to subalpine shrublands. High elevations are mostly rock, snow and ice. Communities in the region have a long history of involvement with the forest sector, and forestry continues to be important to local economies.

The marine and freshwater environments of the Valley are rich with fish and other aquatic animals. Salmon and trout are a large part of the recreational, First Nation, and commercial fishery in the Douglas Channel and Kitimat Arm. Other commercially important fish species include halibut, cod, turbot, skate, sole, starry flounder, shiner perch, prawns, and shrimp. Marine mammals occur in the Douglas Channel and Kitimat Arm mainly during the summer, and include whales, porpoises, seals, the northern sea lion, and the Pacific striped dolphin. Bird life in the marine environment is predominated by seabirds and waterfowl. Many species occur in great numbers during spring migration when they come to feed on spawning runs of herring.

The freshwater environment supports many of the same fish species as the marine environment, including coho, pink, chum, sockeye, and Chinook salmon. Coastal cutthroat trout, steelhead/rainbow trout, bull trout, Dolly Varden char, mountain whitefish, and eulachon are also present in many streams. Little is known about the plants and animals that live in the lakes of the study area, with the exception of Lakelse Lake due to its commercial and recreational importance. The Lakelse system supports about 35% of the total Skeena River commercial fishery catch for all species. Rainbow/steelhead trout, coho, and cutthroat trout support major sport fisheries.

The forests, shrublands, and wetlands of the Kitimat Valley offer a wide range of habitats for a host of terrestrial wildlife species. Large mammals include deer, moose, wolf, coyote, black bear, and grizzly bear. Additionally, a number of small mammal species (voles, mice, squirrels) and various fur-bearers, including marten, weasel, and beaver, are also present. Over 200 bird species occur in the Kitimat Valley, including both resident (year-round) and migratory species.

Forestry has been and continues to be a main activity in the Kitimat Valley, which contains parts of the Kalum and Pacific Timber Supply Areas as well as parts of Tree Farm Licenses 1 and 41. The rocky mountainous terrain limits agriculture, with most of the agricultural activity in and around Terrace. Economic activity in the Valley also includes industrial manufacturing.

The technical assessment area includes eight protected areas, comprising 2,718 hectares, and land managed for outdoor recreation and wildlife. Outdoor recreation activities include hiking, camping, fishing, hunting, four-wheeling, cross country skiing, and snowmobiling. Wildlife and wildlife habitat is managed within the Kalum Land and Resource Management Plan, and includes the use of Special Resource Management Zones.

People of the Haisla Nation have inhabited the Kitimat Valley for over 8,000 years. The Haisla’s main community today is Kitamaat Village, located across the Douglas Channel from the Kitimat Aluminum Smelter. Traditional activities on the land include fishing, hunting, trapping and harvesting plants for food and medicine. Cultural heritage areas, which may include archeological sites, structural features, heritage landscape features, and traditional use sites, also exist on the land.

Two Bands of the Tsimshian First Nation claim home to the Terrace area. The Kitselas Band primarily claims territory to the east and south of Terrace (east Skeena and Lakelse), while the Kitsumkalum Band is primarily resident to the west and north of Terrace along the Kalum and Skeena Rivers.

Other communities within the technical assessment study area are Terrace and Kitimat. Kitimat is a town of nearly 9,000 inhabitants located near the southern end of the Kitimat Valley. It was created in the 1950s after the Provincial Government of British Columbia invited Alcan to develop hydroelectric facilities and an aluminum smelter in the area.

To this day, Rio Tinto Alcan is the single largest employer in Kitimat with approximately 1,500 employees. Other important contributions to the local economy come from public administration, recreation, accommodation and food services, construction, professional services, and health care. The City of Terrace is located 63 km north of Kitimat on the Skeena River, and is home to approximately 11,500 people. Terrace is a regional retail and service hub for northwestern British Columbia. It has also historically been a major forestry centre, opening its first sawmill in 1908. The largest employers in Terrace today are in the public sector, and Rio Tinto Alcan is the largest private sector employer with 350 permanent employees. Efforts to diversify the economy include investments in tourism, recreation, mining, transmission line construction, education and skills training.

5 Regulatory Framework

Under the British Columbia Environmental Management Act, industrial waste discharges are regulated under permit. RTA B.C. Operations Kitimat Aluminum Smelter has a Pollution Prevention (P2) Multimedia Permit, P2-00001, which authorizes the discharge of air emissions, effluent and refuse from the Kitimat smelter. RTA's discharge permit is unique in being the only P2 Multimedia Permit in effect in British Columbia. Section 4.2 of the Permit allows for plant-wide SO_2 emissions of 27 t/d from the electrolysis potrooms (fugitive roof emissions and dry scrubbers) and coke calciner. This section needs to be amended to increase SO_2 emissions to 42 t/d, remove emission sources from the old smelting process, and add the new AP-40 pre-bake smelting processes that emit SO_2. The requested SO_2 emission limit amendment to the P2-00001 Multimedia Permit is considered to be a significant amendment under the Public Notification Regulation of the Environmental Management Act and requires a public consultation process.

The process for completing a significant permit amendment varies depending on the complexity of the permit application. Small amendments can be completed within three months, while complex permit applications, such as for this application to increase SO_2 emissions, can take up to two years to complete the scientific studies on the various lines of evidence as well as completing the consultation process. As the permit could not be completed before KMP received notice to proceed from Rio Tinto Alcan's board of directors, a memorandum of understanding (MoU) was drawn up between RTA and the B.C. Ministry of Environment. The MoU laid out the process for completing the permit amendment using logical and systematic adaptive management principles for developing the permit. Key elements of the program for adaptive management include:

- completing science-based emissions modelling;
- developing and implementing a science-based biophysical and ambient air monitoring program to measure ambient SO_2 concentrations and impacts;
- regulating the SO_2 emissions from the Kitimat Modernization Project until the end of 2018 according to the policy entitled "Pollution Control Objectives for the Mining, Smelting and Related Industries of British Columbia, 1979 (Reprinted in 1989)", in its existing form on the effective date of this MoU; and
- developing and implementing SO_2 mitigation strategies if the emissions modelling and monitoring show potential adverse impacts related to SO_2.

Under the MoU, guidelines for ambient air quality established under B.C.'s Provincial Pollution Control Objectives (PCOs) will be used to assess and regulate SO_2 emissions from KMP. The PCOs are specific to the Province's mining and metals sector and provide ambient air quality objectives for SO_2 emissions resulting from end-of-pipe mining and smelting activities. The PCOs set a range of acceptable ambient SO_2 concentrations, with application of the lower range targeted to protect sensitive receptors.

At the Federal level, there are Canada-wide air quality guidelines established by the Canadian Council of Ministers of the Environment. These guidelines will be replaced with a Canadian ambient air quality system (CAAQS) that will be established under the Canadian Environmental Protection Act. The CAAQS will establish regional airsheds and a framework for air zone management. Additionally, the Comprehensive Air Monitoring System will set industrial emission requirements that set a base level performance for major industries, including the aluminum sector. The SO_2 baseline industry emission requirements (BLIER) for the aluminum sector will involve a qualitative SO_2 BLIER for electrolysis, anode baking, and coke calcinations for existing and new facilities. The qualitative SO_2 BLIER includes data collection and reporting to allow for the assessment of emission control and prevention, and will come into effect in 2013. Additionally, a working group of experts will be formed to develop a pollution prevention (P2) action plan.

6 Study Design

Five studies were conducted for this assessment. The first study focused on the air pathway in the source-pathway-receptor model, as this is the pathway that leads to both direct effects and indirect effects of SO_2 emissions on the receptors. This study produced two important predictions: (1) atmospheric concentrations of SO_2; and (2) S deposition. Predictions of SO_2 concentrations were important inputs to studies of human health impacts and direct impacts on vegetation. Predictions of SO_4 deposition were used to assess indirect impacts on vegetation via soils, potential changes in soils, and the potential responses of lakes and streams.

The remaining four studies focused on the receptors: human health, vegetation, soils, and water and aquatic biota. The receptor studies followed two different approaches: the studies of human health and vegetation used the frequency and magnitude of exceedances of SO_2 concentration *thresholds* to predict impacts, while studies of soils and surface water used exceedances of *critical loads* of acidity to predict impacts on these receptors.

Figure 4 illustrates how each of these studies fits in the source-pathway-receptor model, and Figure 5 summarizes the high-level similarities and differences in the general study approaches. Potential impacts on wildlife were investigated through a literature search (see Section 3.5.5, Volume 2 of the SO_2 Technical Assessment Report) but not formally studied as part of our assessment because empirical evidence for direct impacts of SO_2 on wildlife is scarce and inconclusive.

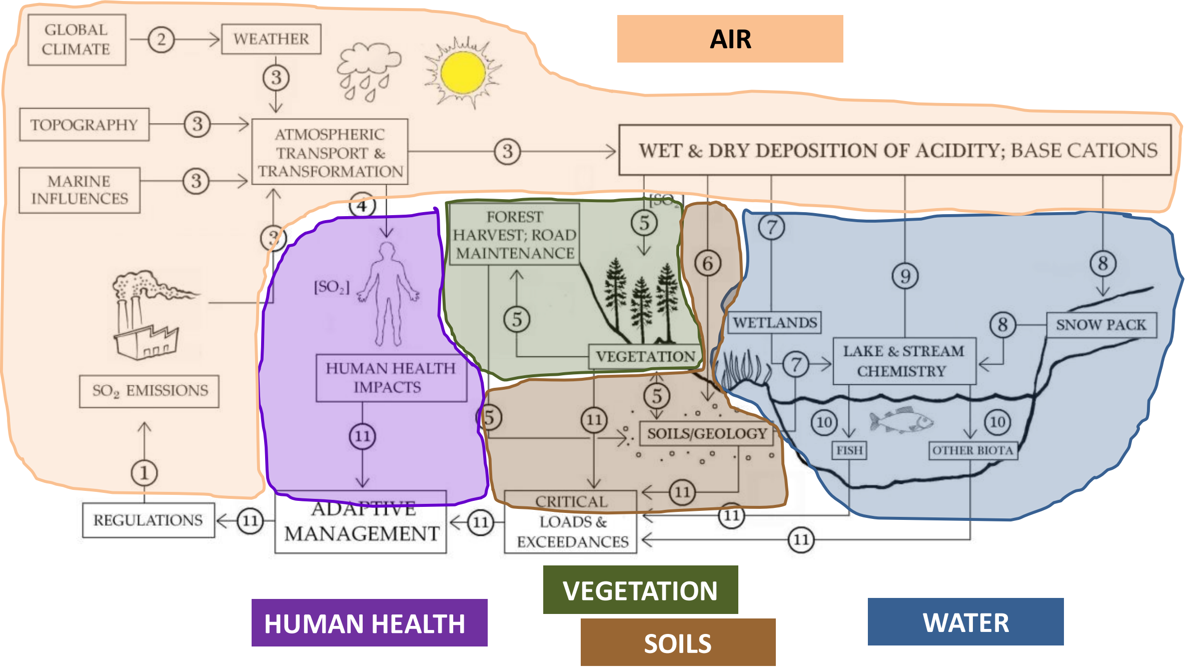


Figure 4: Study design overlaid on the source-pathway-receptor model

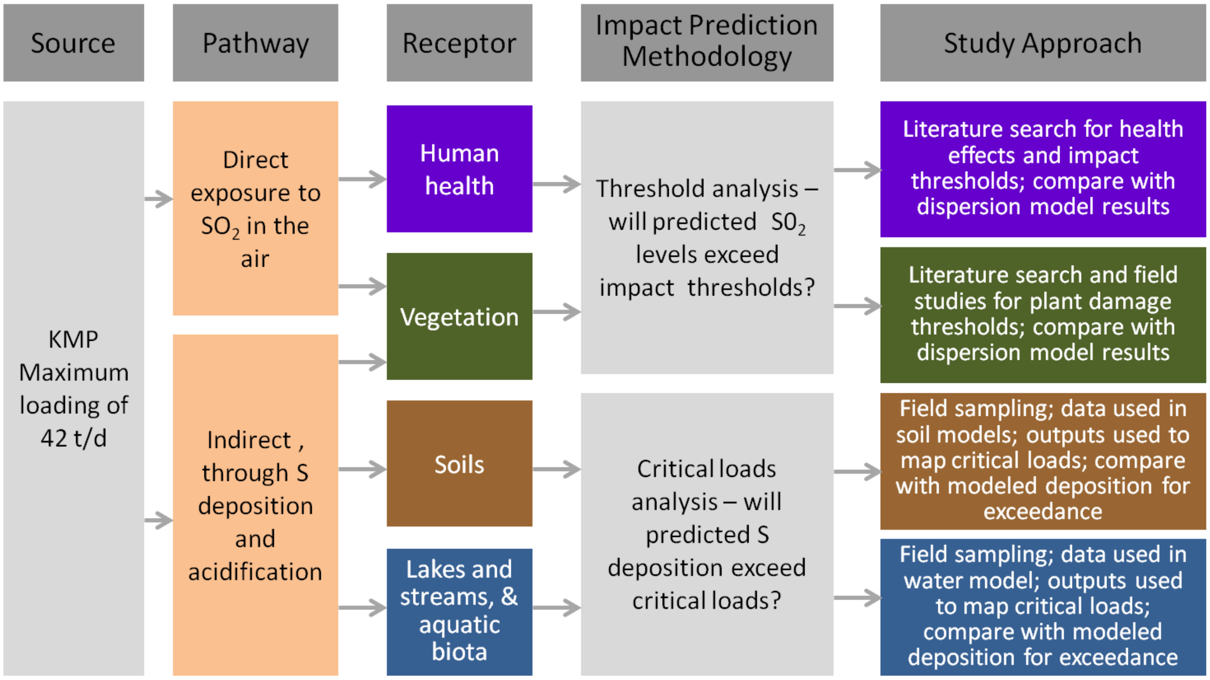


Figure 5: High-level study approaches for the receptors

7 Ambient Air Quality Monitoring and Air Dispersion Modelling

Ambient air quality in the Kitimat Valley is monitored by a comprehensive network providing information on the spatial and temporal changes in atmospheric SO_2. The overall network provides information on SO_2 across a wide area in the Kitimat Valley (Figure 6), which is used to evaluate the modelled distribution of SO_2 in the region.

The network incorporates weekly passive diffusive samplers (PDS) for SO_2, and continuous (hourly) monitoring of SO_2 and other air pollutants. Four of the stations continuously measure SO_2 by UV fluorescence, which is integral to assess the potential health and vegetation impacts of KMP. The PDS network was established to monitor weekly air concentration of SO_2 during snow-free periods, supplementing the continuous monitors.

Annual average atmospheric SO_2 in the Kitimat region generally meets the air quality objectives of B.C.'s Ministry of Environment, which has been established at an annual average SO_2 concentration of 25 $\mu g/m^3$ SO_2 (approximately 9.4 parts per billion (ppb)). Sulphur dioxide in the PDS network ranged from 0-9 ppb during the period June to September 2012 based on 18 weekly exposure periods. The higher concentrations generally follow the modelled plume pattern, with the highest concentrations at the KMP station, localized to the vicinity of the facility (Figure 6). In general, concentrations of SO_2 in the ambient air show a time trend consistent with monthly emissions from the RTA facility.

Precipitation (rain and snow) chemistry is measured at one station with an additional station proposed to begin operations in 2013 at Lakelse Lake. Wet deposition monitoring has been carried out since July 2000 at Haul Road; the station was upgraded with new equipment in September 2012 and incorporated into the National Atmospheric Deposition Program (NADP). As of November 2012, available data from the NADP station compared well with historic data. An overall decreasing trend in wet sulphate (SO_4^{2-}) ion and ambient SO_2 is apparent during the period 2009 to 2011, consistent with decreasing emissions of SO_2 from the smelter facility. Further, observed total (wet and dry) deposition estimates of sulphur at the Haul Road station show reasonable agreement with modelled estimates.

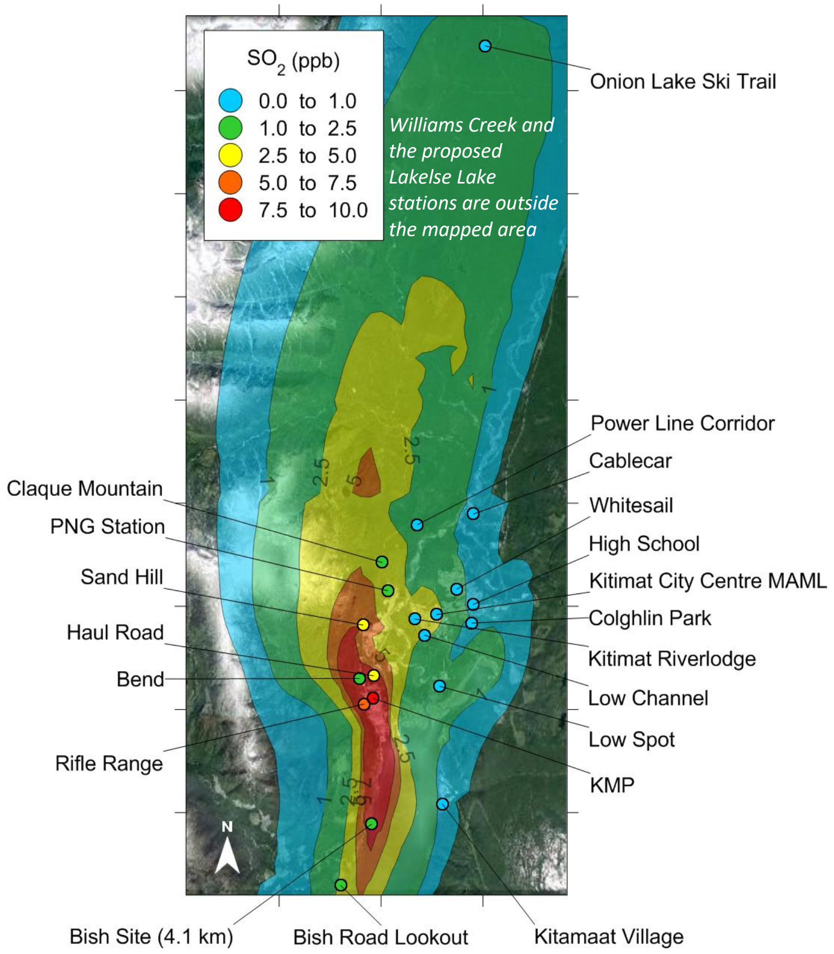


Figure 6: Location of passive diffusive monitoring sites in the Kitimat Valley, British Columbia, and median ambient SO$_2$ concentrations during June to October 2012 compared with modelled pre-KMP annual average air concentrations

7.1 Description of emission scenarios

Trinity Consultants conducted air dispersion modelling, using a model called CALPUFF, in order to estimate sulphur dioxide (SO$_2$) air concentrations and total sulphur deposition due to the Kitimat Smelter for the Kitimat Modernization Project (KMP). Trinity modelled two emission scenarios:

1. **Post-KMP Scenario:** using SO$_2$ emission rates at the requested permit level for the Kitimat Modernization Project; and
2. **Pre-KMP Scenario:** using actual annual average SO$_2$ emission levels.

The purpose of the post-KMP scenario is to estimate impacts from KMP SO$_2$ emissions *before* the project takes place. The post-KMP SO$_2$ emission rates are based on the maximum expected production (420,600 tonnes of aluminum per year) and the maximum expected SO$_2$ emissions level (36.4 kg SO$_2$ per tonne of aluminum).

The pre-KMP modelling analysis serves a twofold purpose:

1. First, the pre-KMP modelling results provide a baseline against which the post-KMP predicted concentrations can be compared.
2. Second, the pre-KMP SO_2 modelling results are compared to the SO_2 monitoring data available for the same meteorological years. This comparison provides understanding of the level of conservatism of the CALPUFF model.

7.2 SO_2 from source to atmosphere

Trinity applied the CALPUFF modelling system to model the transport and transformation of SO_2 emissions from the Kitimat Smelter sources to atmosphere. The following sections summarize the methods used for and the results of this CALPUFF modelling analysis.

Methods

The CALPUFF dispersion modelling analysis follows the modelling protocol developed for the project in cooperation with the B.C. Ministry of Environment (MOE).[1]

The technical challenges of applying the CALPUFF model were addressed through several years of discussions with MOE, beginning in 2007. The major outcomes of the process included:

1. Establishing an accepted CALPUFF modelling protocol for modelling conducted for a previous design of KMP.
2. Making several improvements from the first protocol, including:
    - use of three years of meteorological data (2006, 2008 and 2009), rather than only one (2006);[2]
    - use of refined terrain and coastline options; and
    - use of the latest version of CALPUFF.
3. Completing a robust quality assurance review with MOE of the key control parameters.
4. Completing sensitivity studies for background ozone concentrations and the use of 5th generation mesoscale model meteorological data (MM5 data) to determine the effect of these parameters on the CALPUFF model output (see Appendix 7.6-2 in Volume 3 of the SO_2 Technical Assessment Report).
5. Establishing an improved CALPUFF modelling protocol based on the outcomes of the discussions and studies discussed above.

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[1] Trinity Consultants submitted a final modelling protocol on September 4, 2012 for approval by the B.C. Ministry of Environment (MOE). The Ministry accepted and agreed to the proposed approach, with consideration of sensitivity study results presented on November 1, 2012.

[2] Trinity and MOE selected years 2008 and 2009 because these years are the most recent, readily available years of complete and representative data. Year 2006 was used because 2006 data had been obtained for the previous CALPUFF analysis.

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. This worst case air quality estimate assumes continuous emissions during all meteorological conditions over three years, with the intent of capturing worst case meteorological conditions for comparison to standards or thresholds. This conservative comparison ensures that the actual project impacts will be overestimated, giving a conservative estimate of impacts to human health and the environment. Typical levels of conservatism range from 50 percent over-prediction, up to over-predicting by four times.

SO_2 Ambient Concentration Modelling Results

Trinity compared the pre-KMP modelling results to the SO_2 monitoring data available for the modelled years (2006, 2008, and 2009) at the three SO_2 monitoring stations in Kitimat. The comparison showed that the CALPUFF model results were roughly double compared to the actual concentrations measured at the monitoring stations. The average model result is 227% of the measured SO_2 concentration, averaged over the three years, three SO_2 monitoring sites, and four averaging periods (see Appendix 7.6-3 in Volume 3 of the SO_2 Technical Assessment Report). The results of the study provide a level of confidence that the CALPUFF model is not under-predicting, because the station, averaging period, and yearly average CALPUFF estimates were all greater than the monitoring data measurements. Additionally, the study provides a check that the model is estimating within expectations:

- the 227% over estimate is well within the range of expectations of 150% to 400%; and
- the comparison of modelled concentrations to monitored concentrations does not vary substantially from site to site, year to year, or averaging period to averaging period.

The results summarized above affirm that the CALPUFF model performs well and meets the needs for the other studies included in the SO_2 technical assessment study.

Figure 7, Figure 8, Figure 9 and Figure 10 present a comparison of the pre-KMP and post-KMP air modelling results. Each figure shows the modelled results compared to the ambient air Pollution Control Objectives (PCOs) established by B.C. MOE for the mining, smelting, and related industries. Figure 7 and Figure 8 compare to the maximum range of the 1-hour SO_2 Objective of 900 micrograms per metre cubed ($\mu g/m^3$), and Figure 9 and Figure 10 compare to the minimum range of the 1-hour Objective (450 $\mu g/m^3$). Appendix 7.6-4 and 7.6-5 in Volume 3 of the SO_2 Technical Assessment Report provide additional exceedance plots, concentration contour plots, and summary tables for each year comparing modelled SO_2 concentrations to other objectives and air quality standards.

Comparisons to the PCOs do not provide conclusions related to impacts on the environment or human health. Sections 9.1 through 9.4 describe how the SO_2 air concentration results predicted by the air dispersion modelling analysis impact human health and vegetation, and how the sulphur deposition results impact soils and water.

There are no established objectives in British Columbia or Canada for sulphur deposition. Therefore, the sulphur deposition results are not compared to a set of deposition thresholds. Rather, Sections 9.3 and 9.4 discuss soil and water impacts, respectively. Both sections apply the total sulphur deposition modelling results in order to define the soil and water study areas, and to compare predicted deposition levels to critical loads.

Figure 11 and Figure 12 show pre-KMP and post-KMP deposition levels (respectively), based on climate years 2006, 2008 and 2009. The post-KMP zone of predicted impact, defined as 10 kilograms per hectare per year (kg/ha/yr) of SO_4 deposition, shows impacts extending north approximately 60 km (including portions of Terrace) and south approximately 15 km (short of extending to Jesse Lake). The soil and water sampling study areas considered the entire modelled zone of impact and included some potentially sensitive areas beyond the zone of impact.

Discussion

The comparison of the modelled SO_2 concentrations to the established PCOs provides a first indication of how KMP will affect SO_2 concentrations. However, these comparisons do not provide conclusions related to impacts on the environment or human health. Sections 9.1 and 9.2 describe how the predicted SO_2 air concentrations impact vegetation and human health, respectively. Sections 9.3 and 9.4 describe how the predicted sulphur deposition results impact soils and water (which in turn can affect vegetation and animal life).

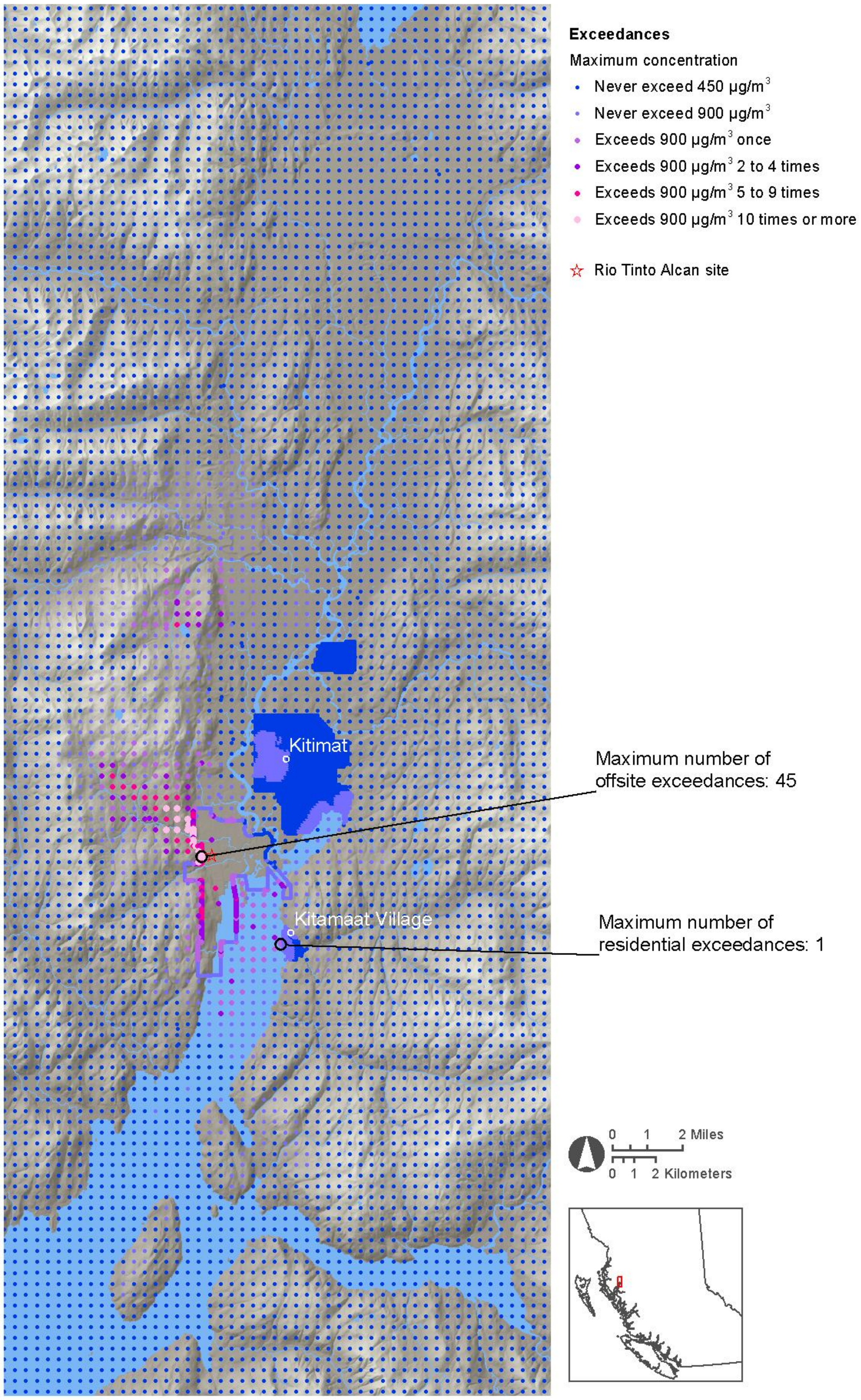

Figure 7: Maximum number of exceedances per year over 900 µg/m^3, 1-hour averaging period, pre-KMP SO_2 emissions

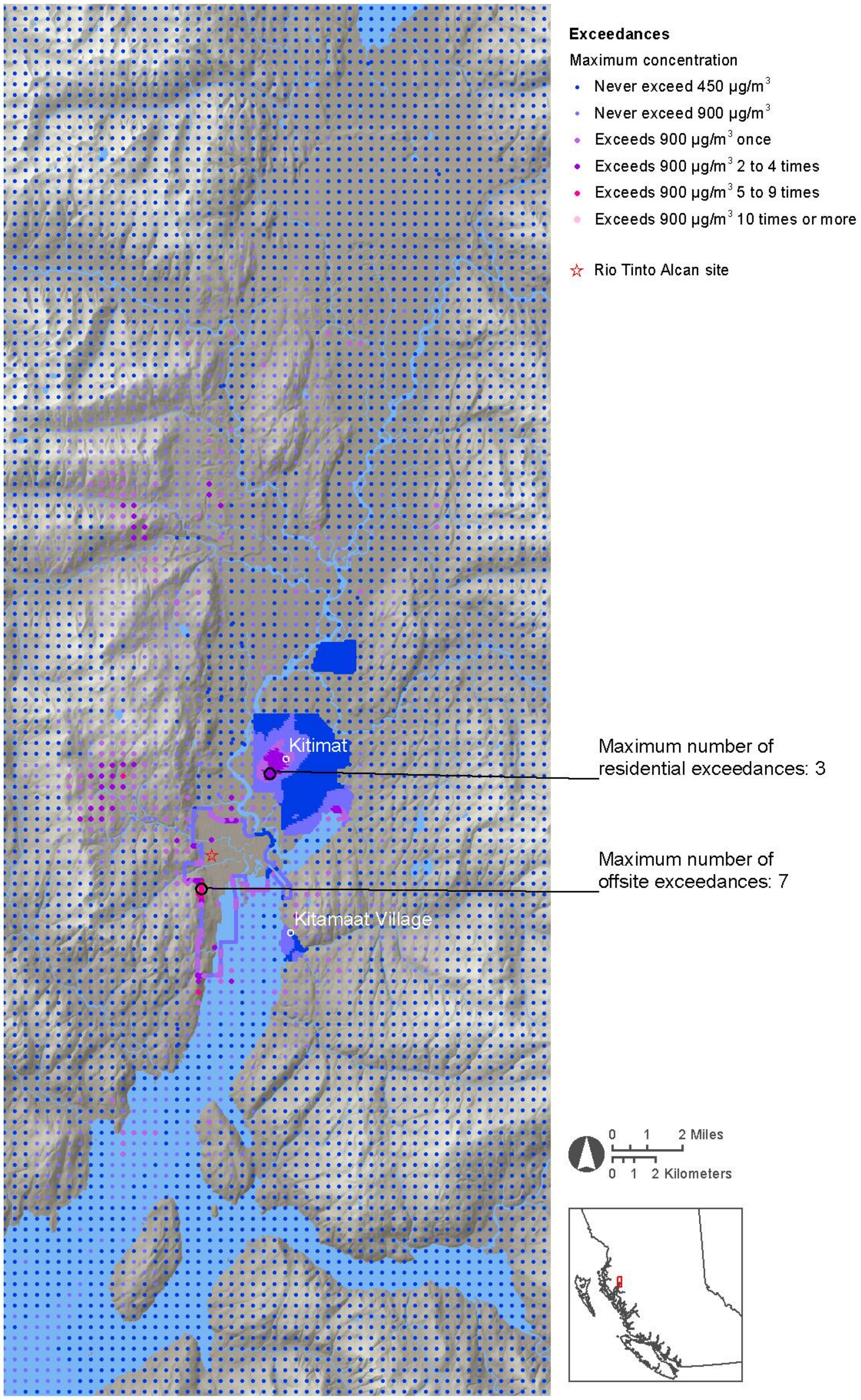

Figure 8: Maximum number of exceedances per year over 900 µg/m^3, 1-hour averaging period, post-KMP SO_2 emissions

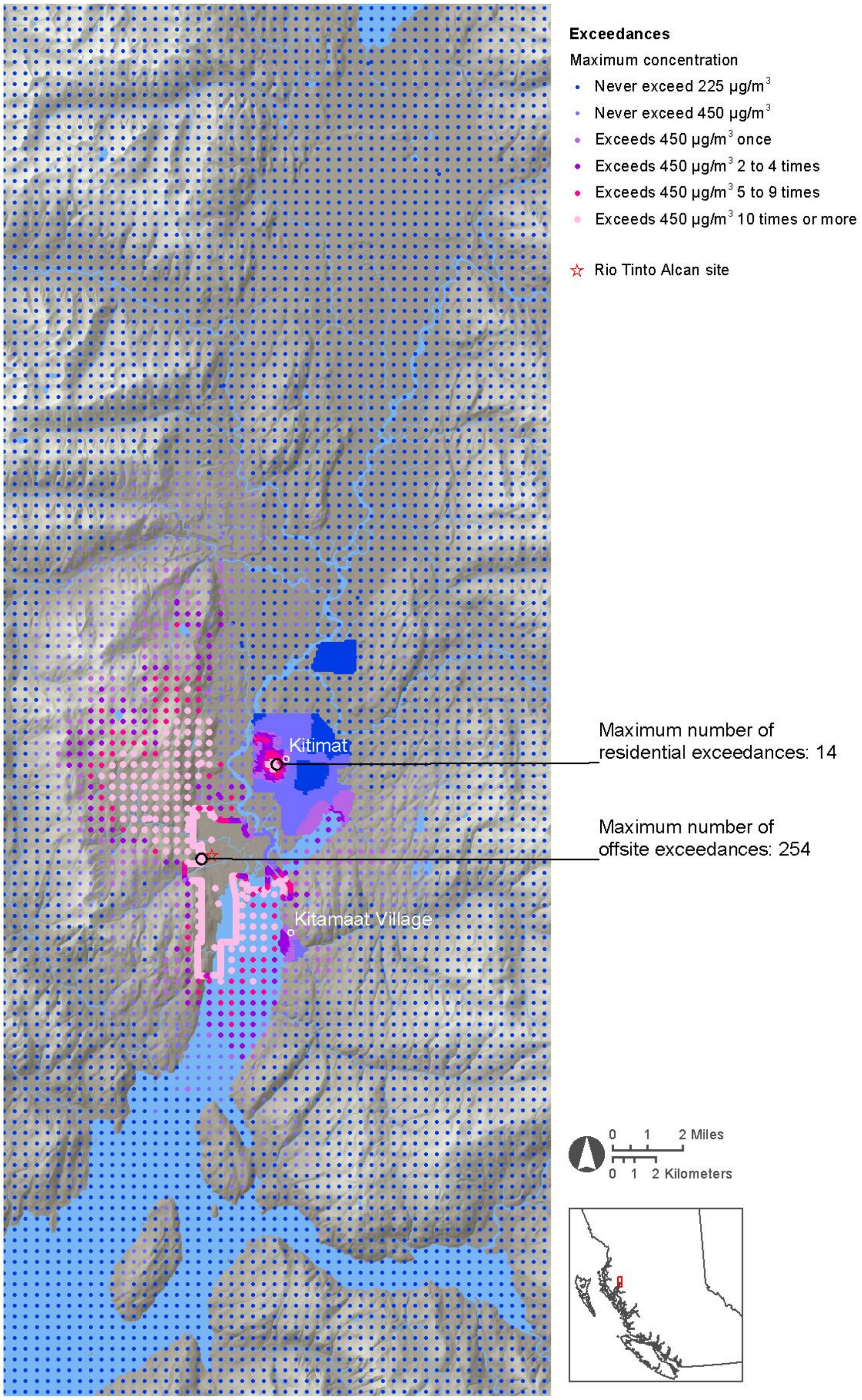

Figure 9: Maximum number of exceedances per year over 450 µg/m^3, 1-hour averaging period, pre-KMP SO_2 emissions

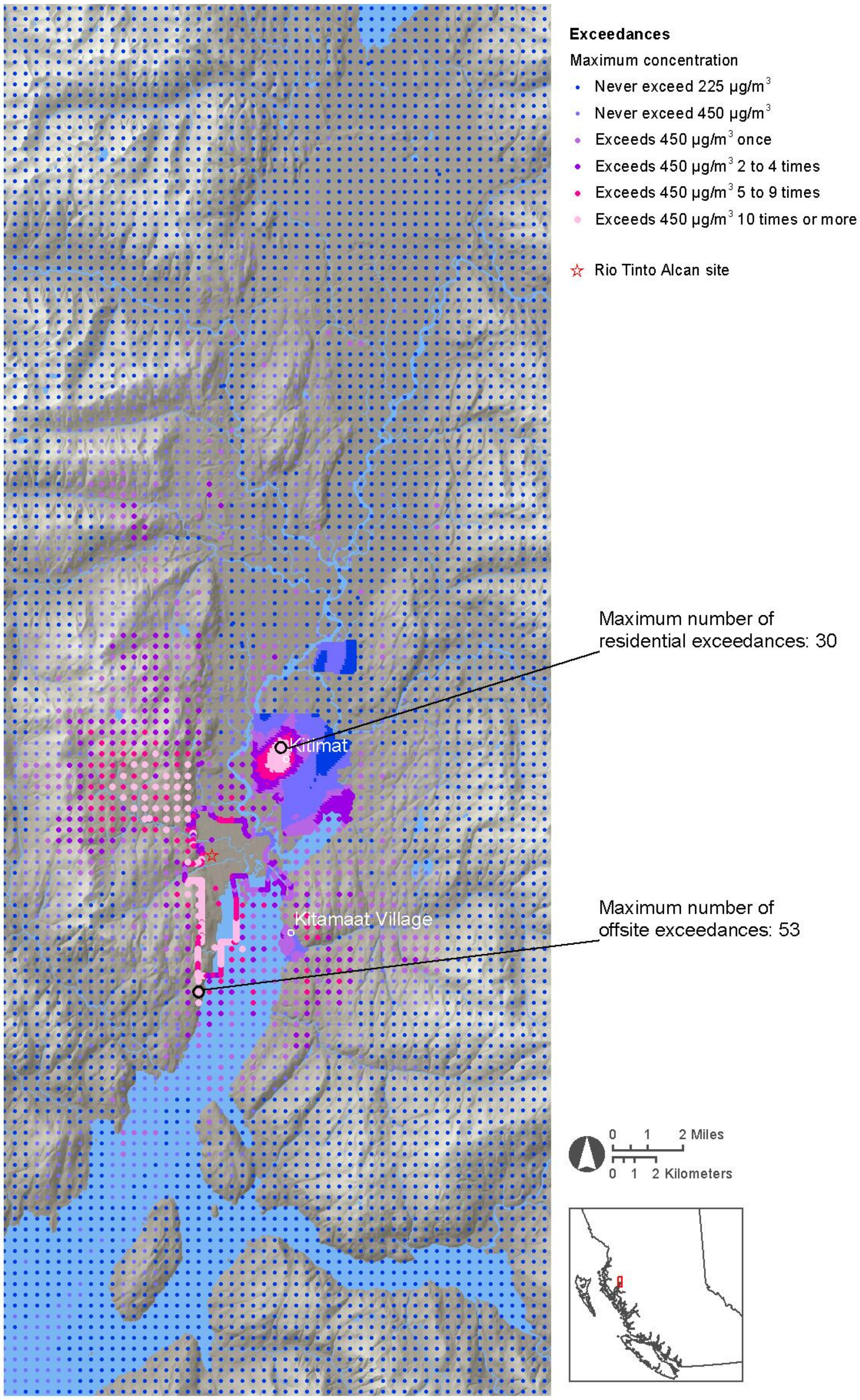

Figure 10: Maximum number of exceedances per year over 450 µg/m^3, 1-hour averaging period, post-KMP SO_2 emissions

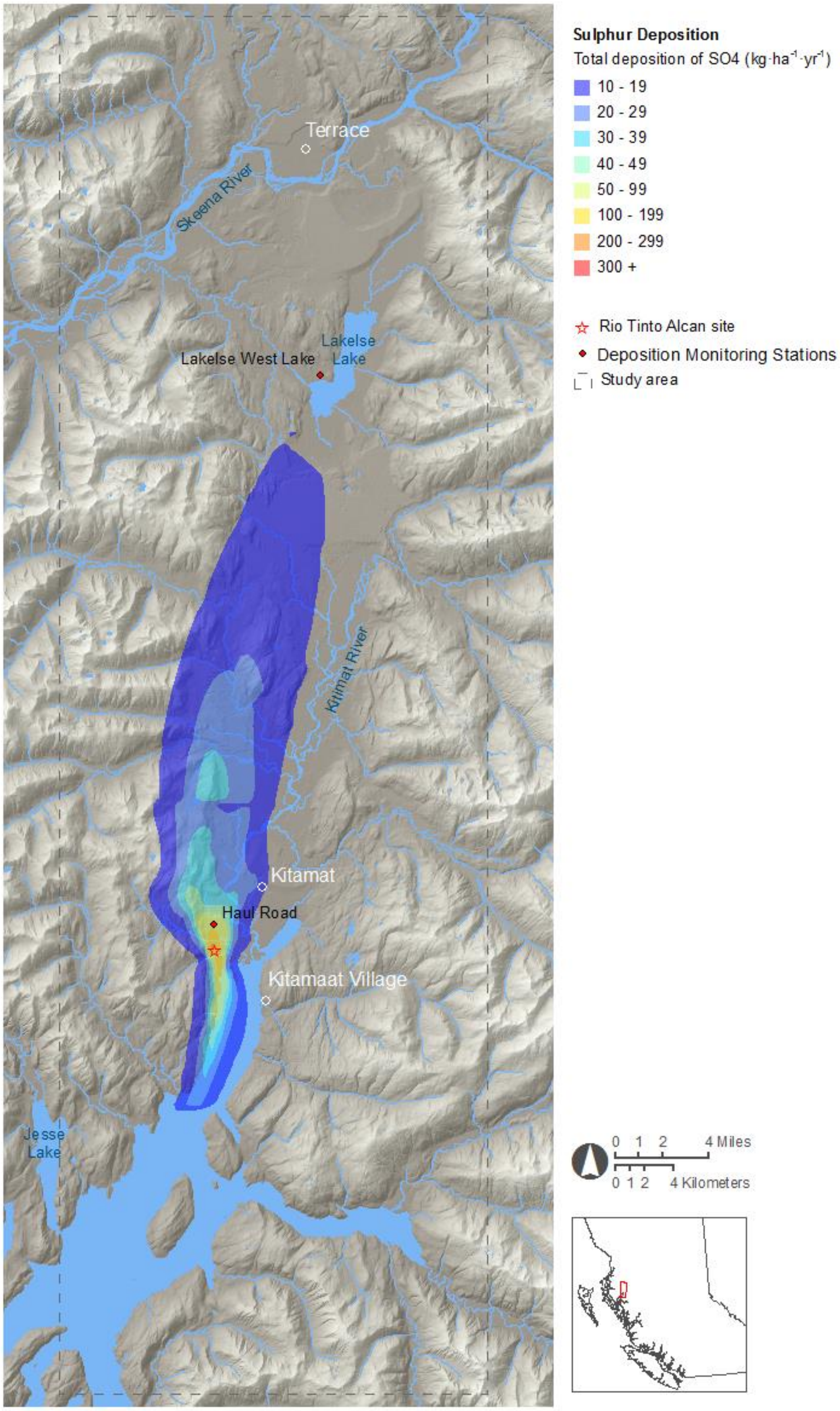

Figure 11: Pre-KMP total deposition of SO_4 (kg/ha/yr)

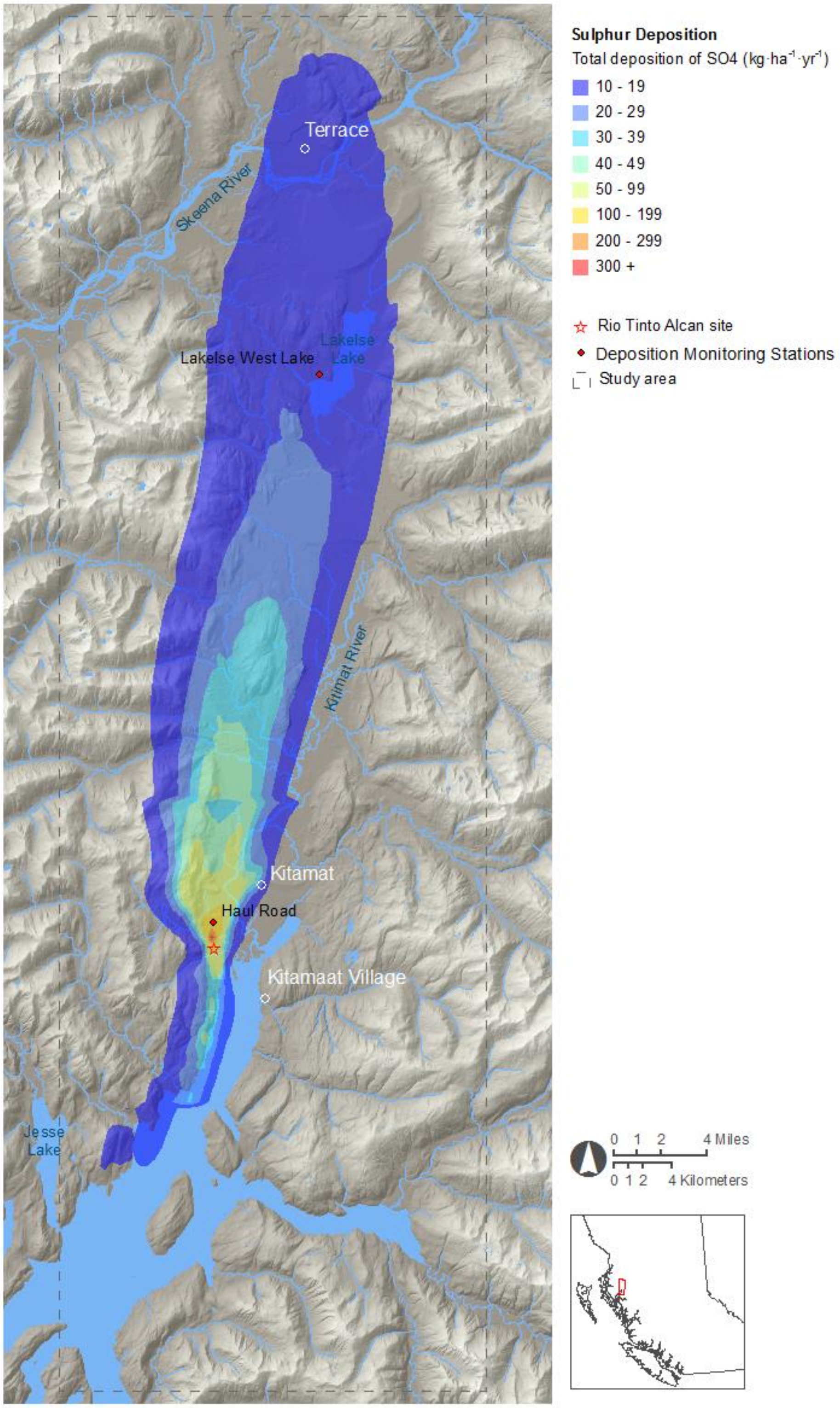

Figure 12: Post-KMP total deposition of SO_4 (kg/ha/yr)

8 Methods of Assessing Impacts on Receptors

8.1 Risk Assessment Framework used to evaluate impacts

A structured and transparent risk assessment framework is used to present the technical assessment conclusions. The framework has two dimensions: the probability or likelihood of an impact, and the consequence of such an impact. Applying the framework could lead to one of four possible impact categories ranging from low (green) or moderate (yellow) to high (orange) or critical (red), depending on the degree of likelihood and consequence.

Low	No impact or acceptable impact; routine monitoring
Moderate	Acceptable impact but in need of closer scrutiny; moderate monitoring
High	Unacceptable impact; contingency / response action; intensive monitoring
Critical	Extremely unacceptable impact; critical response action; very intensive monitoring

8.2 Adaptive management

Uncertainties are inherent in any prediction of impacts. Despite the rigorous assessments described in the upcoming sections of this executive summary, some critical uncertainties remain regarding the impact predictions. The critical uncertainties from the technical assessment are very explicitly identified for each receptor included in the study. An adaptive management plan will be used to resolve these uncertainties, and is being been designed based on the results of the technical assessment.

8.3 Human health study methods

The links between SO_2 and health outcomes have been extensively studied in the scientific literature. The only relationship for which there is considered to be sufficient evidence to conclude that a cause-effect link exists is the one between short-term exposures and increases in respiratory symptoms.

When inhaled at sufficiently high levels, SO_2 can irritate the airways causing a reflexive response in tissues surrounding the airways which restricts airflow. The concentration that might cause this response in someone depends on whether they have existing chronic respiratory disease and on their level of physical activity. For people with existing chronic respiratory diseases, response to SO_2 is more pronounced and occurs at much lower concentrations (e.g., below 500 $\mu g/m^3$), particularly when they are physically active (and therefore breathing heavily). It is important to note that SO_2 does not cause the respiratory disease. Rather, it increases the likelihood of symptoms in people who already have the underlying chronic disease. People with normal respiratory function will not respond to inhalation of SO_2 unless the concentrations are much higher (e.g., above 2,500 $\mu g/m^3$). Because post-KMP conditions are not expected to reach these higher concentrations, this assessment focuses only on people with existing chronic respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD). Approximately 12%

of Kitimat area residents are expected to have one of these diseases, similar to the percentages seen from provincial and national data.

Restricted airway responses will vary in severity and can cause a sense of “tightness” in the chest, coughing and rapid shallow breathing, and can potentially affect the cardiovascular system causing changes in pulse rate and blood pressure. The effects are short-term and reversible. They can also be caused by other irritants such as allergens, exercise, and cold air. Symptoms can be relieved by reducing activity levels, moving indoors (where SO_2 levels are expected to be lower), and by using the same medication that people with chronic respiratory diseases use in response to these symptoms when caused by other irritants.

The health risk assessment was conducted by Risk Sciences International Inc. (RSI), and employed an exposure-response relationship derived by the Environmental Protection Agency of the United States, and published in 2009. This relationship predicts the increase in the frequency with which people with existing respiratory diseases will experience restricted airway symptoms at different levels of short-term exposure to SO_2.

The expected levels and patterns of exposure of people in the Kitimat area are based on a predictive model of SO_2 concentrations post-KMP. These predictions were provided by Trinity Consultants. The predictions are in the form of estimates of hourly average SO_2 concentrations at a large number of residential and commercial locations, and simulated over the course of three years.

Exposures were calculated for four areas within Kitimat: (1) the Service Centre (business area, north of Rio Tinto Alcan operations); (2) Lower Kitimat (the residential area south of Haisla Road); (3) Upper Kitimat (the residential area north of Haisla Road); and (4) Kitamaat Village. Exposures that occur indoors are calculated separately from exposures that occur outdoors, since indoor exposures are expected to be at reduced concentrations.

Due to the nature of the concentration-response relationship, the health risk is driven by the whole distribution of SO_2 exposures and not driven by the exceedance of any particular threshold. The distribution of exposures is highly skewed, with a considerable fraction (more than 90%) of 1-hour averaged residential exposures predicted to be below 10 $\mu g/m^3$. Also, a great majority (more than 99%) of 1-hour averaged residential exposures are predicted to be below 100 $\mu g/m^3$.

To estimate the number of health outcomes, RSI developed a baseline exposure scenario which includes the frequency and location of physical exercise. In this scenario, RSI generated an estimate of between 150 and 200 restricted airway responses per year due to SO_2 exposure across the population of susceptible Kitimat area residents. Under the assumption that people with restricted airway diseases experience symptoms once per week on average, the baseline rate for these symptoms would be approximately 60,000 per year.

This estimate increases or decreases in direct response to changes in assumptions regarding the number of susceptible individuals who are physically active, and the frequency of their physical activity. It also increases or decreases in response to changes in assumptions regarding the proportion of exercise that occurs outdoors. The estimate is generally considered conservative (more likely to overestimate than to underestimate risk) due to the nature of the dose-response relationship assumed, the high levels of outdoor physical activity assumed when compared to the Canadian public in general, and other simplifying assumptions that may lead to overestimation of risk.

The predicted restricted airway responses will cause short-term, reversible symptoms that are similar to the symptoms that can be caused by exercise alone, or other airway irritants such as allergens and very cold air. People with normal respiratory function are not expected to experience symptoms due to SO_2 at the concentration levels predicted.

8.4 Vegetation study methods

A Vegetation and Monitoring Inspection Program in the vicinity of the Rio Tinto Alcan smelter at Kitimat has been in effect for more than 40 years. Needles of western hemlock are collected annually and analyzed for concentrations of fluoride (F) and, since 1997, sulphur. Sulphur is an essential element for plant growth and occurs in concentrations of 0.1% or more under background conditions. Background can be quite variable, depending on soil conditions and plant species. Analysis of the results of 14 years of vegetation collection and analysis shows that sulphur concentrations at most sampling sites in the Kitimat Valley are at or near background concentrations of between 0.08 and 0.12%. At some sites near the smelter, or in the major growing season dispersion pattern, concentrations of up to 0.24% sulphur in needles have been measured. While these concentrations are higher than reported background concentrations, they are within the concentrations reported to be normal in the scientific literature.

A qualified professional plant scientist visits the area biennially to assess the health and condition of vegetation. The inspection focuses on injury due to pollutants, but also documents plant diseases, insect infestations, and other environmental stresses, such as drought and nutrient deficiency. Over the history of the program, symptoms associated with SO_2 injury to vegetation have been noted on rare occasions. When noted, they have not been wide-spread or severe.

To address the potential changes in direct effects of SO_2 that might be associated with KMP, results of dispersion modelling were analyzed with particular focus on vegetation. Thresholds of concern—concentrations and durations of exposures that have been reported to cause injury to sensitive vegetation or those set by government regulation to protect vegetation—were used to assess potential risk.

8.5 Soils study methods

The acidification of soils owing to increased emissions of sulphur dioxide (SO_2) has been identified as an area of concern in the source-receptor-pathway model (see Section 3 above). The acidification of soils is caused by increased deposition of sulphuric acid that over time will reduce the buffering capacity of soils through the loss of essential base cations (Bc) such as calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+) from the plant rooting zone. Furthermore, as soils acidify, the concentration of metals such as aluminum (Al) in soil solution increases to levels potentially toxic to vegetation (i.e., phytotoxic levels). Consequently it is generally accepted that the ratio of Bc to Al in soil solution is the best predictor of adverse biological effects caused by soil acidification. This should not be confused with the potential phytotoxic effects of atmosphere SO_2 that can directly damage vegetation.

It is well recognized that soil acidification can take decades or even centuries to occur. Therefore a widely used method to assess the potential for soil acidification is the calculation of a critical load. A critical load is the maximum amount of sulphur (S) deposition that a soil can receive without acidifying to a potentially damaging level. Models used to calculate critical loads assume steady state and do not predict *when* acidification will occur, but are suited to risk assessment to identify potential areas of concern. The critical load is primarily determined by the soil base cation weathering rate (release of base cations from minerals to the available soil pool). In this study the critical load of acidity for mineral forest soils was estimated and compared with modelled post-KMP predicted acidic deposition to identify areas that will potentially acidify to unacceptable levels.

Regional critical loads were derived from site specific soil observations (51 pits), randomly sampled across the study domain stratified by bedrock geology. The estimated soil base cation weathering rate was significantly lower for alpine and till soils compared with other surficial materials. Regional weathering rates were derived for each of the dominant bedrock geology types (based on 4-6 soil samples per bedrock category). Critical loads were then estimated for every forested grid cell (0.5 km × 0.5 km) in the study domain (69% of the study area or 1991 km^2) consistent with the resolution of modelled acidic deposition. The approach incorporated soil base cation weathering, base cation harvesting removals (based on annual allowable cut) and an acceptable level of acid leaching (based on a base cation to Al ratio of 1.0) that would not damage trees. Base cation deposition was not included due to the lack of data, and therefore critical load estimates are conservative.

Soils in the region are dominated by silicate minerals, are generally acidic and have a moderate sensitivity to acidic deposition. The areas with the lowest weathering rates, and hence the lowest critical loads, are generally located to the south of Kitamaat Village (the south-east portion of the study area) and at higher elevations south-west of Terrace.

8.6 Surface water study methods (lakes and streams)

As discussed in Section 3 (above), the effects of acidic deposition on lakes and streams depend on both the geology and physical characteristics of the watershed, and the level of acidic deposition. We focused our water sampling on areas predicted to receive more than 10 kg/ha/yr of total sulphate deposition under KMP, since studies elsewhere in North America have shown that lakes receiving less than this amount of deposition have few or no acidic lakes. To be precautionary, we also sampled lakes in areas which receive less than 10 kg/ha/yr of sulphate deposition, but in areas with the most acid-sensitive types of bedrock. We focused our study on 41 lakes, and also sampled 20 sites in streams considered to be of high public importance (see fold-out map at the back of this volume).

Water chemistry in streams and lakes is vitally important to aquatic biota. A pH of less than 6.0 produces conditions that are damaging for many species, and pH 6.0 is the threshold used in the Canada-wide Acid Rain Strategy, as well as in many other acidification studies. Our analysis involved 4 steps:

1. assessing how many lakes and streams are currently below pH 6, and the likely reasons for their low pH;
2. determining the critical load of deposition that each watershed could receive while maintaining a surface water pH greater than 6.0, or if its pH were already less than 6.0, to not acidify further;
3. examining how many lakes and streams would receive a level of sulphate deposition in excess of their critical load once KMP was fully implemented; and
4. predicting how much change in pH could be expected with KMP, and estimating the original, pre-industrial pH of each lake.

9 Assessment Results

9.1 Human health study results

The predicted levels of SO_2 in the Kitimat area are well below the B.C. Ministry of Environment Provincial Pollution Control Objectives (PCOs), with the exception of less than 100 hours per year (i.e., less than 1% of the time). It is important to note that these PCOs do not correspond to thresholds for health effects. The predicted numbers of exceedances of PCOs are not predictive of the number of predicted respiratory responses. The full distribution of SO_2 exposures must be taken into account to predict health risk.

Under a conservative baseline scenario, SO_2 exposures post-KMP could cause between 150-200 restricted airway responses per year among physically active susceptible individuals with existing asthma and/or chronic obstructive pulmonary disease. When exploring various alternate assumptions associated with patterns of exercise frequency and location, the number of predicted airway responses falls within a range from 50 to 500.

Restricted airway responses are reversible, common among susceptible individuals, and can be caused by exposures other than SO_2 (allergens, cold temperatures, physical exercise). Reducing the level of physical activity, relocating indoors (where SO_2 levels should be lower) and through use of medication either before exercise or after symptoms are detected would be the recommended treatment.

Overall, the health risk is categorized as moderate (**yellow**). This determination is based on the combination of a relatively small increase (less than 1%) in the number of restricted airway events (a reversible health outcome) among the population of residents with existing restricted airway diseases.

9.2 Vegetation study results

Results show that the U.S. EPA National Secondary Air Quality Standard will not be exceeded post-KMP and that there are only a few hours per growing season at a small number of sites when Canadian National Ambient Air Quality Guidelines and Objectives will be exceeded.

The results of the Critical Load analysis for soils indicate that the risk of indirect effects on vegetation through sulphate deposition to soils is low (**green**).

Analysis of modelling for pre-KMP conditions show that there are many more hours at or above the thresholds of concern than are projected to occur after KMP.

Based on an analysis of the scientific literature, the results of the monitoring program, and the projected exposures, impacts on vegetation from exposure to emissions of SO_2 in the vicinity of KMP is expected to be low (**green**). The major uncertainty associated with this projection is the accuracy of the dispersion modelling. If actual ground level concentrations occur that match a higher level of likelihood in the risk assessment matrix for vegetation, then more substantial effects might be anticipated. However, given the years of monitoring program results, and the current exposure conditions (likely greater than expected under KMP), it will still be unlikely that measureable and wide-spread direct effects on vegetation will be observed.

9.3 Soils study results

Under the post-KMP deposition scenario there is only a small area (0.25 to 0.41 km^2 on land mostly owned by RTA) that is predicted to receive sulphur deposition in excess of the critical load. This area is immediately adjacent to the smelter facility and receives the greatest modelled sulphur deposition (Figure 13). The level of exceedance in this area is very high, and it is considered highly likely that soils will acidify beyond an acceptable level there. Under the Risk Assessment Framework, the risk of unacceptable soil acidification is moderate (**yellow**). Critical load estimates show a high probability of exceedance close to the RTA facility, but this represents less than 0.1% of the study area and is restricted to two of the bedrock categories.

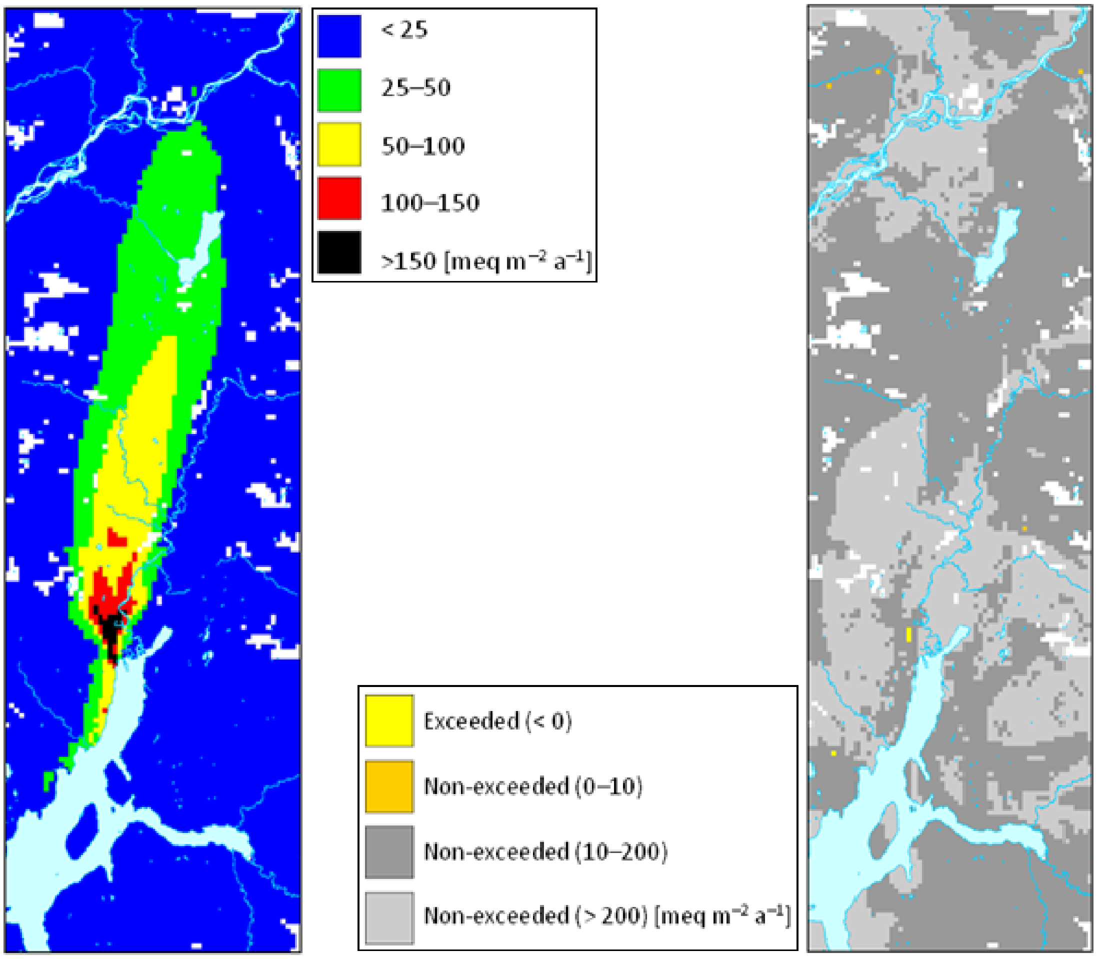

Figure 13: Modelled sulphur deposition post-KMP (left) and exceedance of maximum critical load of sulphur (right)

9.4 Surface water study results (lakes and streams)

Currently, all 20 stream sites and 30 of the 41 lakes (including Lakelse Lake) have a pH greater than 6.0. Of the 11 lakes with a current pH of less than 6, four lakes were naturally acidified due to organic acids, five show possible smelter influence in addition to natural organic acidification, one lake just north of Kitimat shows strong evidence of smelter effects, and one lake is a very acid-sensitive alpine lake with no dominant cause of acidification (pH 5.96).

With the exception of a few acid-sensitive lakes, most lakes in the Kitimat Valley (and all sampled streams) are very insensitive to acidification. When KMP is fully implemented:

- all 20 stream sites and 32 lakes (making up 99% of the sampled lake area, and including Lakelse Lake) are **very unlikely** to exceed their critical load (blue dots in Figure 14);
- one lake is **unlikely** to exceed its critical load (green dot);
- two lakes would be **likely** to exceed their critical load (orange dots); and
- six lakes are **almost certain** to exceed their critical load (purple and red dots).

Altogether there are 10 lakes of concern: 8 lakes with predicted critical load exceedance (5 of which are predicted to show a pH decline greater than 0.1 pH unit, and 3 of which are predicted to show less than a 0.1 pH unit decline); and 2 lakes which are predicted to show a pH decline greater than 0.1 pH unit but to not exceed their critical load. The overlap in these different classes of lakes is illustrated Figure 15.

The eight lakes with predicted exceedance of their critical loads make up 8.3% of the number of lakes, and 1% of the area of lakes in the study area. Seven of these 8 lakes are dominated or influenced by organic acids, which naturally acidified them prior to the additional acidifying effect of industrial emissions. Six of these 8 lakes are estimated to have had an original, pre-industrial pH less than 6.0, and the other 2 lakes were estimated to have had original pH levels of 6.0 and 6.02.

All 20 sampled stream sites, and 34 of the 41 lakes (including Lakelse Lake) are predicted to have no significant change in pH with KMP (less than 0.1 pH units; data points along the 1:1 line in Figure 16). Seven lakes (five of which are expected to exceed their critical load) were predicted to have future pH declines greater than 0.1 pH units due to KMP (ranging from 0.13 to 0.54 pH units), which are moderate pH declines that could potentially have biological effects (Figure 16). Figure 15 shows the overlap in the various attributes of acid-sensitive lakes (current pH, historical pH, exceedance of critical load, future pH change greater than 0.1 pH units).

Six of the seven lakes with predicted pH change of greater than 0.1 pH units are estimated to have originally had a pre-industrial pH less than 6 due to organic acids. Analyses of deposition scenarios completed by Environment Canada for southeastern Canada have excluded lakes with an original, pre-industrial pH less than 6. Excluding Kitimat Valley lakes with an original, pre-industrial pH less than 6 reduces the number of lakes with exceedance of their critical load from eight (8.3% of lakes in the study region) to two (2.2% of lakes). This is below the objective of 5% of lakes with a pH less than 6 set in the Canada-wide Acid Rain Strategy.

Based on our analysis of both natural and KMP sources of acidification, we conclude that:

- The impact of KMP on surface waters in the study area is moderate (**yellow**) – acceptable but in need of closer scrutiny, with moderate levels of monitoring to assess if mitigation actions such as liming or reduced emissions of SO_2 are required.
- There are likely to be no significant regional impacts on lakes or streams of high public importance, on fish production, on wildlife which depend on aquatic biota, or on human uses of water.

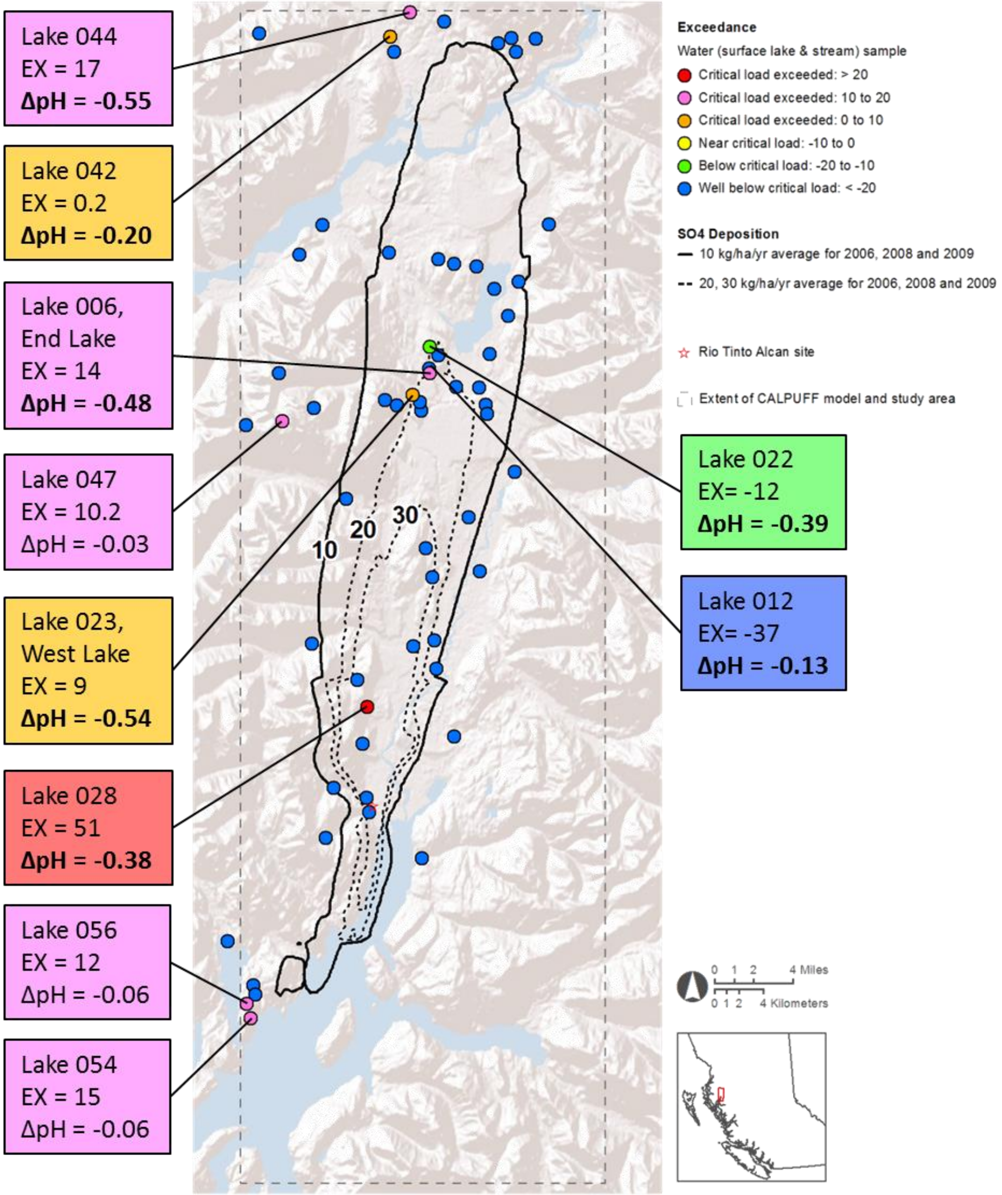

Figure 14: Spatial distribution of the 10 sampled lakes of concern: 8 with predicted critical load exceedances (EX greater than 0), and 7 with predicted pH changes greater than 0.1 pH unit (bolded). EX = exceedance; see Figure 15 for overlap in lake attributes

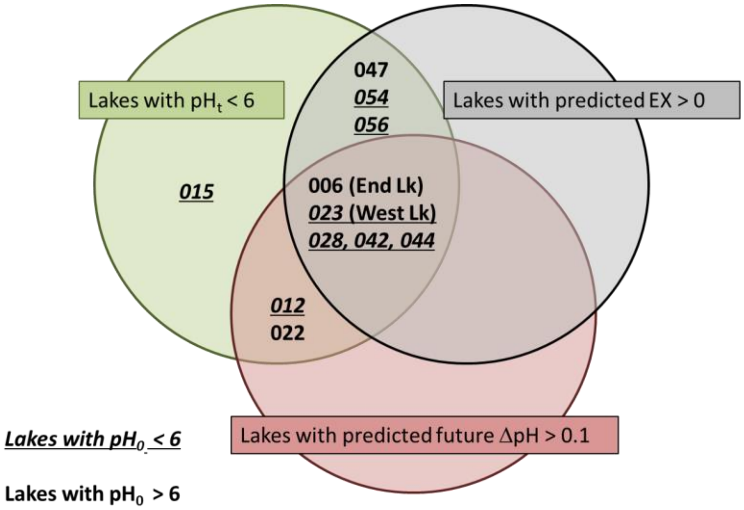

Figure 15: Overlap in the attributes of the 11 lakes with current pH less than 6, 10 of which are considered to be lakes of concern (i.e., those with either predicted exceedance or future change in pH greater than 0.1 pH units) (see fold-out map at the back of this volume for lake locations)

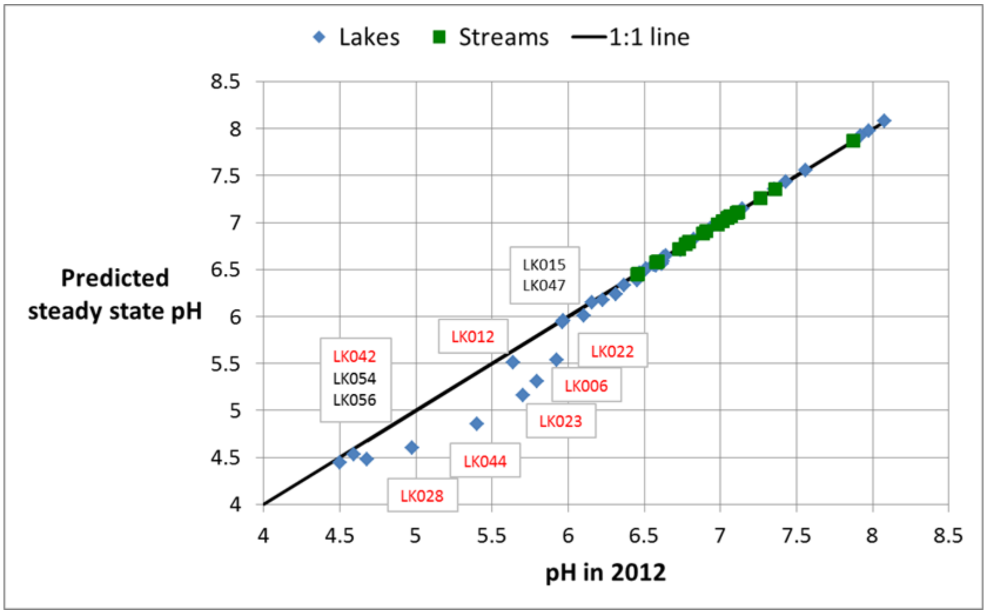

Figure 16: Predicted steady state pH (y-axis) versus pH in 2012 (x-axis) for the 10 vulnerable lakes with either predicted exceedance of their critical load, or a predicted pH change greater than 0.1 pH units (see fold-out map at the back of this volume for lake locations)

Lakes and streams along the 1:1 line are predicted to have no or negligible changes in pH. Lakes with a predicted pH change of greater than 0.1 unit are shown with red labels. Lakes with black labels were predicted to exceed their critical load but are predicted to change by less than 0.1 pH units.

10 Adaptive Management

ESSA has developed an adaptive management plan for addressing the critical uncertainties that emerged from the technical assessment. The framework for this plan is summarized in Figure 17. Section 10 in Volume 2 of the Technical Assessment Report clearly identifies these uncertainties, and also identifies alternative hypotheses for each uncertainty, steps that need to be taken to learn which hypothesis is supported by actual outcomes under KMP, and management responses should these outcomes be unacceptable according to the assessment framework. The goal of the adaptive management plan is to keep KMP SO_2 emissions below a level that would cause unacceptable impacts on water and aquatic biota, vegetation and human health.

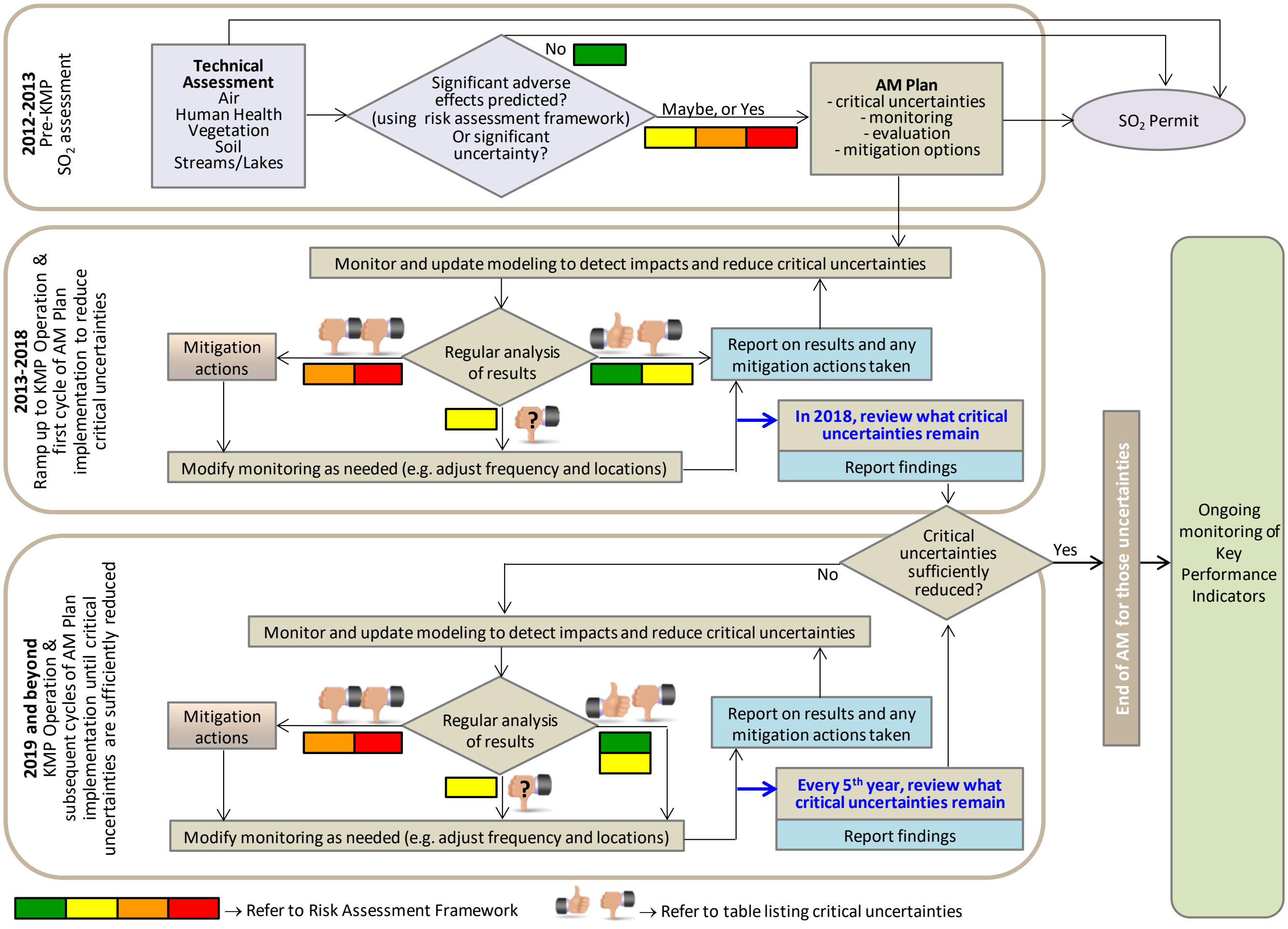

Figure 17: Adaptive Management Framework for KMP

11 Conclusions

We conclude that people with either asthma or chronic obstructive pulmonary disease (about 12% of the population) are likely to be *infrequently* affected by *medium* consequence, reversible events post-KMP. The remainder of the population (88%) in the study area is expected to be *unaffected* by increased SO_2 emissions under KMP. The increase in specific airway resistance may or may not be detectable by the susceptible individual. Given the mildness of the predicted health outcomes, the characterization of the consequence as medium could be considered somewhat conservative. The increase in the number of restricted airway events due to SO_2 among this population is expected to be less than 1%. Exposure to SO_2 causing restricted airway responses will result in a continuum of potential health consequences ranging from very mild to serious (e.g., emergency room visits); however, increasingly severe health outcomes are also increasingly infrequent. The overall health impact is characterized as **moderate**, an acceptable impact but in need of closer scrutiny with moderate monitoring.

The two critical uncertainties in the human health assessment are:

1. the predicted levels and spatial and temporal patterns of SO_2 concentrations that will occur in the post-KMP situation (also important for vegetation, soil and water assessments); and
2. the relationship between the peak exposures and the hourly average exposures.

We conclude that effects of KMP on vegetation are very unlikely and would be of minor consequence. Within the risk assessment framework, we consider the impact to be **low**. The major uncertainty associated with our vegetation conclusions is the accuracy of the dispersion modelling. If actual ground level concentrations of SO_2 are higher than predicted, then more substantial effects might be anticipated. Dispersion model predictions will be compared to observations during the adaptive management phase. However, given the past years of vegetation monitoring program results, and the fact that exposures under KMP are expected to be less than current pre-KMP conditions, it will still be unlikely that measureable and wide-spread direct effects on vegetation will occur.

The following four critical uncertainties will be addressed in the adaptive management plan:

1. Validation of the dispersion model – are we looking in the right place?
2. How healthy is vegetation in sites with predicted exceedance of critical loads of soil and/or lakes and streams south of Lakelse Lake?
3. Are plants of public importance showing symptoms in areas with highest exceedances of soil critical loads?
4. Do plants at Kitimat that have unknown sensitivity to SO_2 and associated pollutants (acidic deposition) fall within the range of variation in the literature?

Under the risk assessment framework we conclude that the risk of impact on soils is **moderate**, an acceptable impact but in need of closer scrutiny with moderate monitoring. There are three critical uncertainties to be addressed through the adaptive management plan:

1. Are estimates of average weathering rates by bedrock type valid for vulnerable areas (e.g., where lakes have low base cations and predicted exceedance)?

2. What is the current buffering capacity (base cation pool) of soils in exceeded areas, and when would this base cation reservoir be used up?
3. What are the base cation deposition values in the study region?

We conclude that the impact of KMP on surface waters in the study area is **moderate**. There are likely to be no significant regional impacts on lakes or streams of high public importance, on fish production, on wildlife which depend on aquatic biota, or on human uses of water. We identify four critical uncertainties:

1. How do uncertainties in deposition and surface water models affect the predicted extent and magnitude of critical load exceedance post- KMP?
2. How many of the 7 to 10 potentially vulnerable lakes to be included in the adaptive management plan actually acidify, and to what extent?
3. What is the current status of the fish community in the potentially vulnerable lakes that can be safely accessed for fish sampling?
4. If some of the potentially vulnerable lakes that can be safely sampled for fish show an acidifying trend, then do these lakes also show changes in their fish communities?

Overall, based on the results for vegetation (predicting a **low** impact) and the results for health, soils, and water assessments (each predicting a **moderate** impact), our overall conclusion is that KMP will have a **moderate** impact (i.e., acceptable but in need of closer scrutiny with moderate monitoring).