Environment Fund
File 1070-20

Impact of Sour Gas Production Flare Tests on Vegetation Final Report

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03-1480-058

Acknowledgements

Constantin Visan, Andrea Morison, Richard Slocomb, Bill Bayrak and David Ross of the BC Oil and Gas Commission are gratefully acknowledged for their support and administration of this project. This project could not have been completed without the direct support for the research and access to well sites provided by various people including Catherine Lloyd, Christine Zarowny, and Rob Staniland of Talisman Energy Ltd.; Bill Strecker, Bill Clapperton and Scott Dionne of Canadian Natural Resources Ltd.; Pierre Barrett of Burlington Resources Ltd., and Norm Wiens and Rej Tetrault of Shell Canada. Dr. A. Legge, Biosphere Solutions Inc., Calgary, Alberta and Dr. J. Innes, Forest Resource Management, University of British Columbia, Vancouver, B.C. provided advice on the use and reliability of sulphur measurements, including inorganic to organic ratios in conifer foliage. Dr. Legge personally trained some of the field staff in recognition of sulphur dioxide injury and has been a source of guidance throughout our work on sulphur dioxide. Our thanks to them all.

Summary

Sour gas well flare production tests in northeastern British Columbia were evaluated over a four year period. Twenty four wells were evaluated; a total of seventeen wells with a variable percentage of H_2S in the gas were monitored prior to and after the flare tests. Injury to vegetation at sour gas well sites was caused by several factors, including sulphur dioxide. However drought, climate and mechanical injury caused by tree removal and pad creation as well as saline compounds are also important factors influencing vegetation response. The results generally show that sour gas well flare tests (with the parameters included in the eight well flare test examples discussed in this report) conducted in summer months can have small amounts of vegetation damage, especially at well pad edges. Trees on the pad edge should be managed more carefully. Dead and injured trees on the pad edge have the potential to introduce disease and fire hazard.

Winter time exposures can be considerably higher than the volumes / concentrations / duration times observed in the summer exposures and still have no visible effects. Non-visible impacts, as indicated by an elevated sulphate-sulphur to estimated organic sulphur ratios were not consistently evident except in the higher concentration / duration winter exposures. None of the well flare tests included in the 16 pre and post-flare assessments approached the severity of the flare event at d-13-G/93-I-9 observed by Legge and Jaques (2001). This implies that the ground level concentrations at all of the wells observed in this study were below an 'unacceptable level of injury'. The H_2S% is a relatively robust indicator of potential ground level concentrations. In mid-winter, when temperatures drop below 20 degrees Celsius, conifers are in a dormant state and tend not to react to sulphur dioxide exposures.

Lichens of the genus's *Peltigera, Hypogymnia* and *Bryoria* all tend to accumulate sulphur in tissue when concentrations of sulphur dioxide exceed 1 ppb (approximately). These plants have a higher accuracy for showing impacts of sour gas well flare tests than any other receptor. Lichen thalline sulphur concentrations are still below background levels in most of the sour gas field area of interest but tend to be "enhanced" around continuous sources, such as gas plants and older sour gas wells with glycol dehydrators.

The flaring guidelines are conservative and adequately protect vegetation. Flaring could be restricted to winter months to avoid injury. Summer flaring has a higher probability of causing injury because most vegetation is metabolically active. Appropriate training and knowledge to evaluate the impact of well flare tests mentioned in the guidelines is required. Future monitoring of sour gas well flare tests with higher than 5% H_2S should occur prior to site development to one month past the flare, and should take into consideration confounding factors. The attention of this monitoring should focus on plans for remediation, where necessary. The development of a monitoring protocol for sour gas well

development is highly recommended. The protocol must include some flexibility and professional judgment.

Data from this project could be useful for the design and implementation of a regional cumulative effects study that is based on real field data, as opposed to models, and would provide baseline and comparative benchmarks for assessing the impacts of gas well development in B.C.

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Background

This project is an examination of the effects of sour gas well test flaring on the vegetation resources of northeastern B.C. Between the fall of 1999 and the fall of 2003, a series of sour gas well production tests were evaluated in northeastern B.C. With sponsorship from Talisman Energy, Canadian Natural Resources Ltd, and Burlington Energy, several well sites were visited prior to and after the flare tests. Some wells were assessed repeatedly in years following the flare tests, and some wells were only evaluated once, post-flare. This paper provides a review of the vegetation and passive monitor data from these tests, as well as evaluating confounding factors, expression of injury and other issues surrounding the impacts of sour gas well flaring on the vegetation of northeastern B.C.

Scope

Sour gas well production tests may result in brief exposures of sulphur dioxide (SO_2) to the environment, which can be toxic to vegetation and may results in a change of foliar sulphur status and/or expression of characteristic injury (see right). (Examples of visible injury are also shown in Appendix 1). Modeling of exposures for most of the wells included in this document (see compendium of model documents in Appendix 1) indicated the potential for exceedances of the B.C. provincial guidelines for sulphur dioxide emissions.

There is only one unpublished paper (discussed below) describing the effects of a well flare test in northeastern B.C. where vegetation was severely injured (Legge and Jaques 2001). Most of the published literature on sulphur dioxide impacts on vegetation is based on carefully controlled experiments, often with standard plant stock, controlled growing conditions and precisely measured sulphur dioxide dosages. Field experiments are less common; they are often conducted in open-topped growth chambers and semi-controlled conditions. This project was conducted between the autumn of 2000 to the autumn of 2003 (one pre-project well test in 1999 was included) and was done in completely non-controlled environments at different times of the year, with variable gas concentrations, exposure durations, meteorological conditions, topography (and therefore dispersal), and in variable receiving environments. As often as possible, the same species of receptor vegetation were retained at each site. However, due to differing species compositions, even this was not always achievable. Therefore, this document is intended to show general trends in responses of vegetation to well flare tests in order to provide recommendations as to when, and under what circumstances, negative impacts from well flare testing are most likely to occur, and how they can best be minimized or avoided.

This project depended on the verbal communication between industrial personnel involved in the drilling or exploration of potential natural gas sources and the author of this document, and as such was held completely confidential. Most of the well tests discussed in this document were reported individually to the industrial clients in the months following the tests. The results of each of the tests are summarized in Appendix 1. Some well tests were evaluated *a posteriori*, i.e., after the flare test only, and not before. There are limitations to these data such as; long term operational impacts possibly over-riding the influence of the flare test, effects following the tests may have been missed, or the vegetation recovered in the interval between the test and the post-flare assessment. The information summaries for these casual observations are provided in Appendix 2.

This report deals primarily with response of conifers and lichens to sour gas well flaring. Use of deciduous trees, shrubs, and herbs were not included primarily because most of the preliminary tests included in this study took place in the winter months, when these plants were under snow or without leaves[1]. An equivalent number of summer flare tests were completed in 2003, following an extension on this report to obtain these data.

Engineering details and emissions characteristics are not covered in this report, although summary details are provided in Appendix 1, where they were made available. This document is not meant to be a comprehensive review of the impacts of sulphur dioxide on vegetation. For this information and discussion, other publications are highly recommended; such as Legge *et al.* (1998), and Bell and Treshow (2002). A brief discussion of the mode of action of sulphur dioxide with particular emphasis on the methods used here is discussed below.

Objectives

The purpose of this report is to document the effects of sour gas well production test flares on vegetation using changes in symptoms, foliar sulphur chemistry, and lichen chemistry from pre to post-flare test. Sulphur dioxide concentrations were estimated using passive sulphur dioxide monitors. Casual observations were also made at a number of well sites identified in the Oil and Gas

[1] Although tree bark and tree rings have been used to evaluate long-term exposures to substances including sulphur dioxide (Kuik and Wolterbeek 1994; Takala *et al*. 1991), acute exposures are more often evaluated using other techniques including lichen or vegetation chemistry and expression of symptoms.

Commission records as having high H_2S concentrations in the natural gas, and long duration well flare tests.

Methods

Sour gas well production tests may result in exposures of variable duration and concentrations of sulphur dioxide (SO_2) to vegetation. In order for a well test to be considered for pre and post-flare biomonitoring, modeling of emissions behavior indicated that exposures would likely be in exceedance of the B.C. Provincial Guidelines for sulphur dioxide emissions. Current policy is to issue permits for flaring that confine flaring episodes to periods within a set of favorable meteorological conditions accepted by the Oil and Gas Commission and the Ministry of Environment (Legge 1995). The well sites included in this document had variable durations and concentrations of sulphur dioxide, and occurred in winter or summer in mountainous terrain. These wells ranged between 4.08% and 30.7% (mean 15.06%) H_2S content in the gas. Because pre-test modeling predicted elevated levels of sulphur dioxide with the potential to cause foliar damage in the vicinity of the well, a vegetation assessment was conducted prior to and after the flare test to determine the occurrence and magnitude of injury.

Study Area

Two main sour gas fields were considered in this study, but only the Grizzly (southeast corner of Figure 1) to Sukunka drainages provided pre and post-flare data for consideration. Figure 1 shows the distribution of the well flare tests in the Grizzly to Sukunka Valleys, and Pine Plateau area of interest. The post-flare (only) assessments were completed primarily in the Blueberry area north of Fort St. John (not shown in Figure 1).

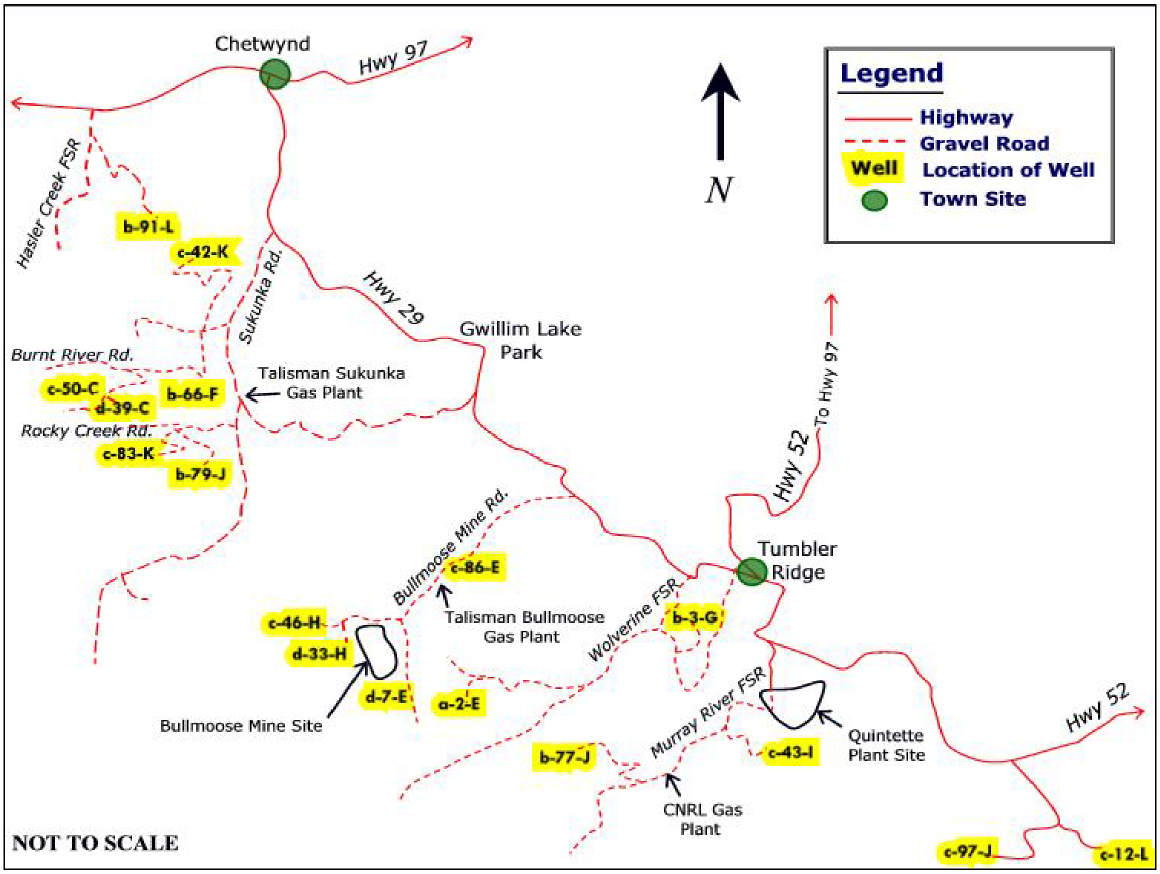

Figure 1. *Locations of sour gas well flare tests with pre- and post-flare vegetation response data, near Tumbler Ridge and Chetwynd, B.C.*

Data characteristics and completeness

A total of 24 wells were observed. Complete field data were collected for seventeen of these wells (Appendix 1). Comprehensive data for each well consisted of installed, exposed and collected passive monitors, pre and post-flare collections of lichens and conifers, symptom records and modeling data. The grounds for not including some wells in this paper are that they had incomplete data or were never flared. Some wells could not be assessed properly post-flare because of restricted access, and in one case passives were not used. Also, some locations were missing comparable species of lichens or conifers.

A range of H_2S contents, durations, sulphur dioxide concentrations and season of flare tests were covered. Eight well tests for which complete data sets exist occurred in winter (October to March) and eight in summer (April to September). The classification used for ‘winter’ versus ‘summer’ may not be the consistent with the literature, but in the area of interest, this period roughly covers the time when sites have snow-cover, or not. Actual dormancy was not estimated. It was assumed that the winter exposures took place during a relatively slow metabolic period.

Aside from the well flare data obtained, additional well flare data was supplied by R. Slocomb (2001). Data from the Oil and Gas Commission (OGC) was used to identify summer and spring flare tests with high concentrations of sulphur dioxide, as these were thought to be most susceptible to injury from sulphur dioxide. A summary of the findings from this list of wells is shown in Appendix 2. The OGC data was sorted by time of the flare test (from March to September) and by concentration of H_2S (Appendix 3). Smaller volume flares were removed from the short-list of well sites to visit.

Assessment methods

Two methods for evaluating injury to vegetation at well flare test sites were used.

1. Detailed assessments; it was possible to evaluate the condition of the vegetation prior to the well flare test and again after the well flare test. Site visits were conducted; plots were established in areas predicted to be impacted or in the direction of prevailing winds near the well site. These were re-evaluated after the flare test. In some cases, it was possible to do repeated evaluations periodically over time.

2. Selected post-flare assessments; it was not possible to know the condition of the vegetation prior to the flare. Site visits were conducted, and injury was described by staff trained in recognizing sulphur dioxide exposure symptoms.

Pre versus post-flare methods:

Overall layout

In the detailed pre-flare assessment and installation of biomonitoring plots, the pre-flare modeling documentation was reviewed, if available. The on-site drilling foreman was contacted and permission to work off lease was obtained. The site and surrounding area was observed and compared to the model isopleths.

Biomonitoring plot site selection

Prospective biomonitoring sites were selected based on maximum potential for exposure to sulphur dioxide. For the first few wells, plots were located in the areas predicted by the model to receive high exposures, but predicted injury was found to be too disjunct from the well pads at distances as far away as 3 kilometers. Once it was noted that injury patterns tended to be closer to the well pad edge, stations were established around the well pad, as well as in the areas predicted by the models. In all but the first well (c-12-L) within this study, at least one biomonitoring station was placed on the edge of the well pad.

In some cases pre-flare modeling was not available in time for the plot installation. Even if the pre-flare model was available, each site was assessed individually using both field interpretation and meteorological data. Prevailing wind direction was not always reliably shown in the earlier pre-flare modeling (*i.e. circa* 1999 to 2001); therefore, noting the wind-pruning patterns on exposed ridge-growing trees was often used to discern the direction of the prevailing wind. Prevailing wind direction and topographic characteristics, such as ridges, nearby steep hill sides, exposed promontories, etc. were thought to be likely maximum exposure areas. An average of 6 (minimum of 4) locations were established at each well. Well pad edges consistently received at least 2 monitoring stations and up to 20 biomonitoring stations were placed in areas predicted to receive maximum sulphur dioxide exposures. A typical installation is shown in Figure 2.

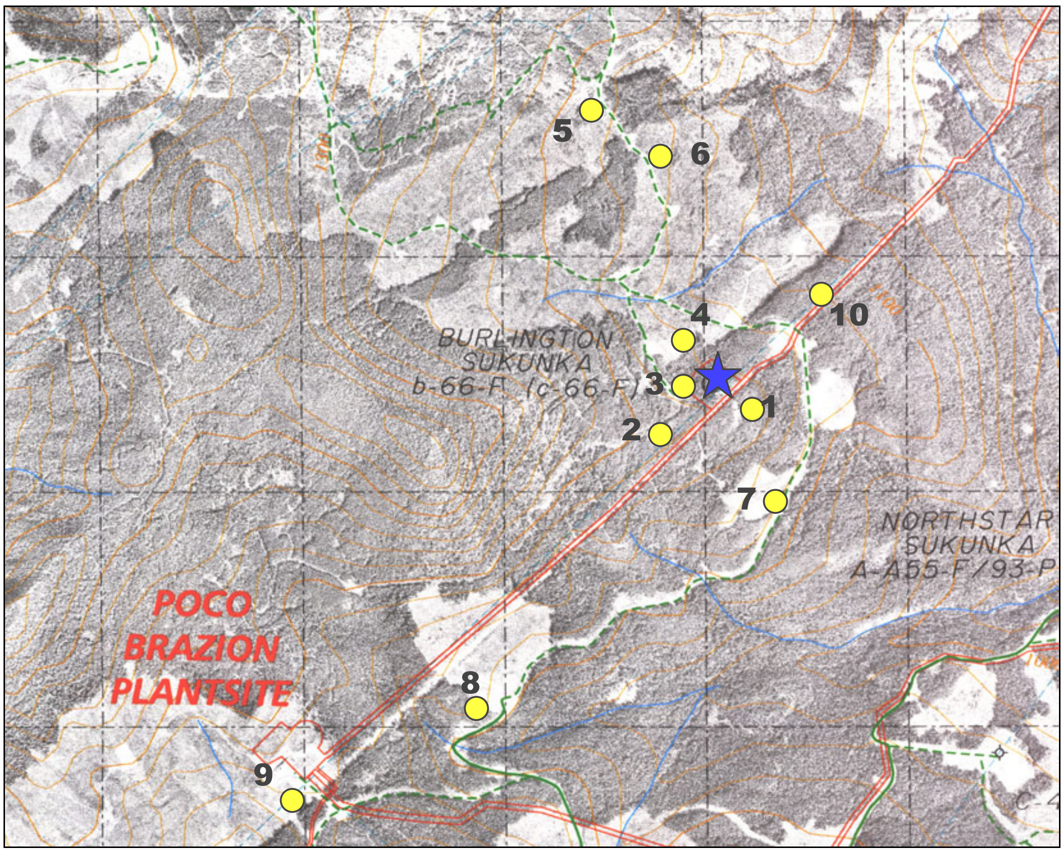

Figure 2. *Example of the layout for biomonitoring plots at a sour gas well flare test (Location is well site b-66-F/93-P-5).*

In most cases, trees on the edge of forest openings (*i.e*. edges) were used for the installation of monitors. Forest edges are known to receive up to 4 times the concentrations of both particulate and gaseous air pollutants than closed forests (Weathers *et al*. 2001). However, some closed forest sites were included based on the model predictions.

Biomonitoring plot installation: field procedures

At each well site Maxxam passive monitor rain shelters were installed in openings, usually by mounting them on a 14 to 16 inch dbh (diameter at breast height) coniferous tree stem, as high as possible. Branches adjacent to the monitor were pruned to reduce interception of emissions at the filter surface. Passive filters were installed in the rain shelter facing downward. Each well flare test received an average of two filters per rain shelter (i.e. per biomonitoring location). Three replicates of exposed mid-crown conifer foliage were collected, using pole pruners and rubber gloves, from three separate trees within the plot at each station. Sub-alpine fir (*Abies lasiocarpa*) was collected wherever it was available, followed by lodgepole pine (*Pinus contorta)* and white spruce *(Picea glauca*) if no other conifer species were present. Trees from which pre-flare collections were made were marked with flagging tape so that a comparative replicate could be collected after the flare. Tissue from sulphur sensitive lichen species were collected as they occurred in areas around each monitoring location. If sampled during the winter, only arboreal lichens were collected; primarily *Hypogymnia physodes* or if this was not available, *Bryoria sp. (*mainly *fuscescens).* Ground-dwelling lichens such as *Peltigera canina* were also sampled if not covered by snow, as they absorb sulphur in direct proportion to ambient air concentrations.

At each biomonitoring station for a given well production test, tissue and lichen collections were made, plant lists and soil samples were taken of surficial litter-fiber-humus (LFH) layers and mineral soil at a depth of 20 cm. Soils and LFH layers were archived. Photographs were taken of exposed vegetation in areas believed to be susceptible to injury (models were used to assist where they were available). As plots were being established, traverses were made around the area surrounding the well site, and a list of forest pathogens, both past and present, were noted. Conifer tissue samples were placed in plastic Ziploc© bags in the field; they were labeled and stored in coolers until arrival at the labs either in Victoria or Castlegar, B.C.

Biomonitoring plot installation: laboratory procedures

Conifers were taken from cold storage within 1 to 3 days of collection, clipped into present and past year's growth; each year's clippings were then stored in individual paper bags. Lichens were cleaned of bark, soil, rocks, etc., but not rinsed in water. They were also stored in clean paper bags. All bags were re-labeled with their field numbers, then left to air-dry at 14°C for approximately two weeks. Once dried, the tissue was coarsely ground in a stainless steel mill. Between samples, the mill was thoroughly cleaned with ethyl alcohol, rinsed with distilled water, and then dried with clean paper towel. Samples were then issued a unique identifier (chain of custody number) which subsequently followed each of the samples through the various stages of shipping and laboratory analysis. Prepared samples were sent, with a chain of custody spreadsheet (in electronic and hardcopy formats), to Pacific Soils Analysis Inc. laboratory in Richmond, B.C., for sulphur chemistry analysis. The lab was contacted and advised that the samples had been shipped and the waybill information was relayed. The original waybills were kept on file. Samples were always shipped to the lab as soon as possible in order to minimize sample degradation.

Sulphate sulphur (in conifers only) was determined using a method adapted from Johnson and Nishita (1952). A single gram aliquot of conifer tissue was boiled in dilute 0.1 N HCI for ten minutes, then a 2 ml aliquot was removed to a flask. Concentrated hydriotic, formic, and hypophosphoric acids were then added. This solution was bubbled through with nitrogen gas diffusion, followed by the trapping of sulphur nitrates with a sodium hydroxide catalyst. A bismuth nitrate yellow indicator was used to reveal a colour change, which was then read by spectrophotometer.

Total sulphur in tissue samples was determined by flame spectrophotometry in the LECO furnace. A split sample of tissue used in the sulphate determination was weighed into the crucible and incinerated. The colored flare was read as parts per million (ppm) of the dry weight of the sample.

Organic sulphur in conifers was estimated by subtracting the sulphate sulphur (SO_4-S) from the total sulphur for each split sample of foliage. Inorganic to organic sulphur ratios (Si:So) were calculated by dividing the total available sulphur by the estimated organic sulphur. In some cases both green and adjacent reddened tissue were analyzed.

Most soils were archived, as short duration flares were suspected to have a negligible effect on soils, either through soil acidification or sulphate fertilization effects. Soils were analyzed for one well site, however. This method is shown in Appendix 4.

Ambient sulphur dioxide concentrations recorded by the passive monitoring systems were calculated by Maxxam Analytics based on a comparison with a field blank, using the real-time exposure period, wind speed, and an estimate of relative humidity. Analysis involves extracting sulphur dioxide from the filter using de-ionized water and hydrogen peroxide. The extract is then analyzed for sulphate using Ion Chromatography (IC) (EPA method 300.0 *cited in* Maxxam Analytics Inc., 1997).

Post-flare procedures

Following a well flare test, clearance was obtained from well owners to re-visit the site. Any signs of injury or symptoms of exposure to sulphur dioxide were noted and replicate photographs were taken. At each monitoring station, the exposed sulphur dioxide passive filters were removed from the rain shelter, sealed in resealable bags and placed into the original protective canisters. A new pair of latex gloves was worn at each monitoring station. The rain shelter was then removed from the tree. Photographs were taken at each site. Lichens and conifers from marked trees (from the same pre-flare collection sites), preferably from the same branch were collected using the similar methods as described above. Similar methods of storage, transport, clipping, drying, grinding and analysis as for the pre-flare dataset were employed.

Analytical Methods for Pre versus Post-flare well test data:

Sulphur dioxide, especially acute exposures, usually causes visible and diagnostic injury to vegetation (Legge *et al.* 1998; Malhotra and Blauel 1980). Typical symptoms of injury were recorded and distinguished from other pathological conditions. This was achieved with the aid of several diagnostic guides (Henigman *et al*., 1999; Callan 1998; Hiratsuka *et al,* 1995; Allen *et al*, 1996; Ziller 1974; Coates *et al.,* 1990) as well as field interpretation of soils and vegetation. Atlas reference (Legge *et al.* 1998, Malhotra and Blauel 1980) photographs of tissue samples identified by Dr. Legge as having acute exposure injury to sulphur dioxide during various field trips to northeastern B.C. were also used.

Pre and post-flare symptom tables were compiled and photographs were taken, these are stored in binders and can be made available on request. The pre and post-flare conifer and lichen sulphur chemical analysis results were compiled, along with dates and durations of the flares, post-flare predicted sulphur dioxide concentrations, and Maxxam Analytics-measured concentrations. Response data was considered to be a change in total sulphur concentration in lichens from pre to post-flare, change in total sulphur, sulphate and sulphur inorganic to organic (Si:So) ratios in conifers and variation in Maxxam Analytics monitor data in relation to post-flare predicted sulphur dioxide concentrations and durations. Not all of these data analyses are shown in this document however, they are presented in Appendix 1. Bar graphs and boxplots of the data were used to examine the distribution of the response data. Tukey's boxplots. Systat™ and Sygraph™ statistical packages were used. Tukey's box-plots are a visual method of showing statistically significant differences ($p<0.05$) between data distributions from sequentially sampled populations (Tukey, 1977; Velleman and Hoaglin, 1981; Wilkinson *et al.*, 1992). Comparisons of summer *versus* winter response data were made. Analysis of variance and regression of concentration of ambient sulphur dioxide versus change in total sulphur and change in inorganic to organic sulphur ratios were completed. The symptom data for each of the seventeen wells for which complete data is available were tabularized.

Post-flare test site assessment methods

The diagnosis of injury *following* well flare tests, when little was known of the pre-flare condition was more uncertain than pre versus post-flare comparisons. Only those flare test areas with known injury (*e.g*. B.P. Amoco South Grizzly, Marten Creek) or well flare tests that had high concentrations of H_2S, spring and summer exposures, and high total gas volumes were evaluated. Discussions with other investigators (A. Legge *pers comm*. 2001), or industrial or government agency people with first-hand experience of the events in question were utilized. Well sites with no pre-flare data were visited in July and August of 2001. A traverse was made around the well site and in the direction of prevailing wind, using available meteorological data (Meyer *pers. com*. 2001). Collections were made of lichen and conifer tissue at varying distances from the well site and at the edge of the well pad, where available, and archived for later analysis, if deemed necessary.

Symptoms of past acute injury from sulphur dioxide are difficult to distinguish from other injury, particularly if the well is still flaring, or if a long time has passed since the flare event. Most of the post-flare assessments were done within 24 months of the event, or sooner. For the above reasons, however, post-flare assessments have a degree of uncertainty associated with them that may not be acceptable, depending on the environmental conditions existing at the well site. Clearing of vegetation, removal of injured trees, and subsequent drought injury or disease are all factors that tend to mask the effects of the well flare event itself. These interactions were described for each site.

Results and Discussion

The results of each of the sixteen well flare tests for which complete data sets are available are presented in Appendix 1, followed by a list of post-flare test (only) assessments in Appendix 2.

Sulphur dioxide concentrations

The range of summer and winter flare sulphur dioxide concentrations as indicated from the Maxxam passive monitors are shown in Figures 3a and 3b, below.

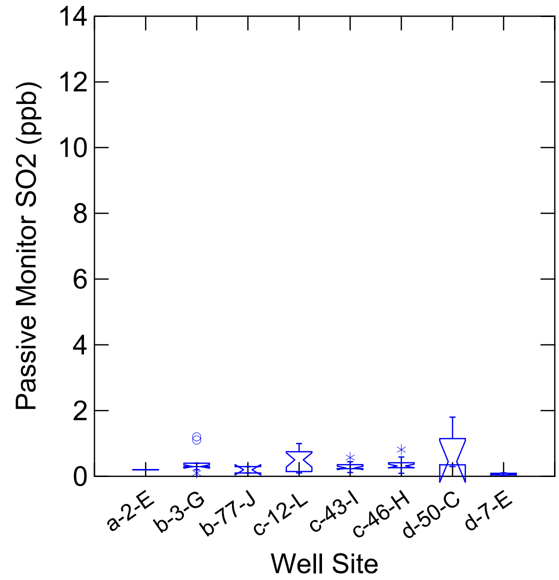

Figure 3a. *Sulphur dioxide concentrations (as measured by Maxxam passive monitors) during summer well flare tests.*

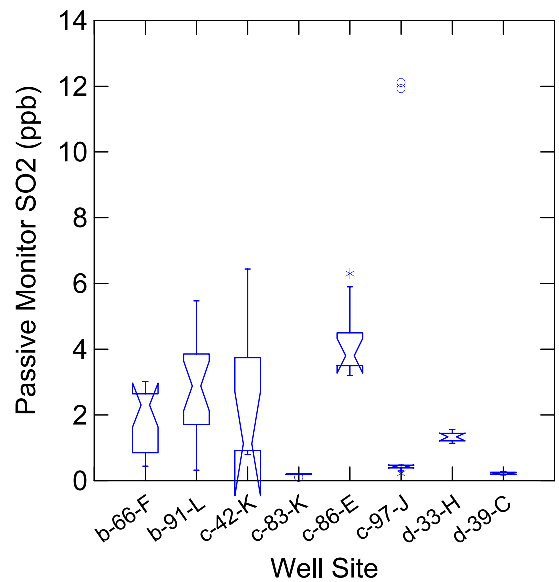

Figure 3b. *Sulphur dioxide concentrations (as measured by Maxxam passive monitors) during winter well flare tests*

Figures 3a and 3b show that site variance in sulphur dioxide is higher in winter than in summer and that concentrations in the passive monitors were generally higher in winter than in summer. Figures 3a and 3b also indicate that although the pre-flare modelling predicted all sixteen wells to potentially exceed B.C. Provincial guidelines for 1-hour, and sometimes 24-hour exposures, the passive monitors did not record particularly high concentrations. This is likely due to the fact that the passive filters are a per day average of ambient SO_2 and were subjected to non-flare conditions for the majority of their exposure periods; some of which were quite long. Monitors were set out prior to the flaring event and were decommissioned sometime after the flare depending on permission granted for site accessibility. Other variables that contributed to long exposure periods include delays in the drilling operations or flaring approval and road construction that restricted access. If concentrations had been higher, vegetation symptom expression might have been more immediate; for example, most of the response to exposures as high as 5 ppm (5,000 ppb or 13,300 µg/m^3) occurs within the first 3 hours of exposure (Dochinger and Jensen 1975). The highest concentration recorded by the passive monitors, over a very short exposure period of 11 days (c-97-J/93-I-10) was 12.11 ppb.

Figure 3c (below) shows the relationship between measured sulphur dioxide concentration recorded by the Maxxam Analytics passive monitors and the H_2S concentration of summer and winter flare tests.

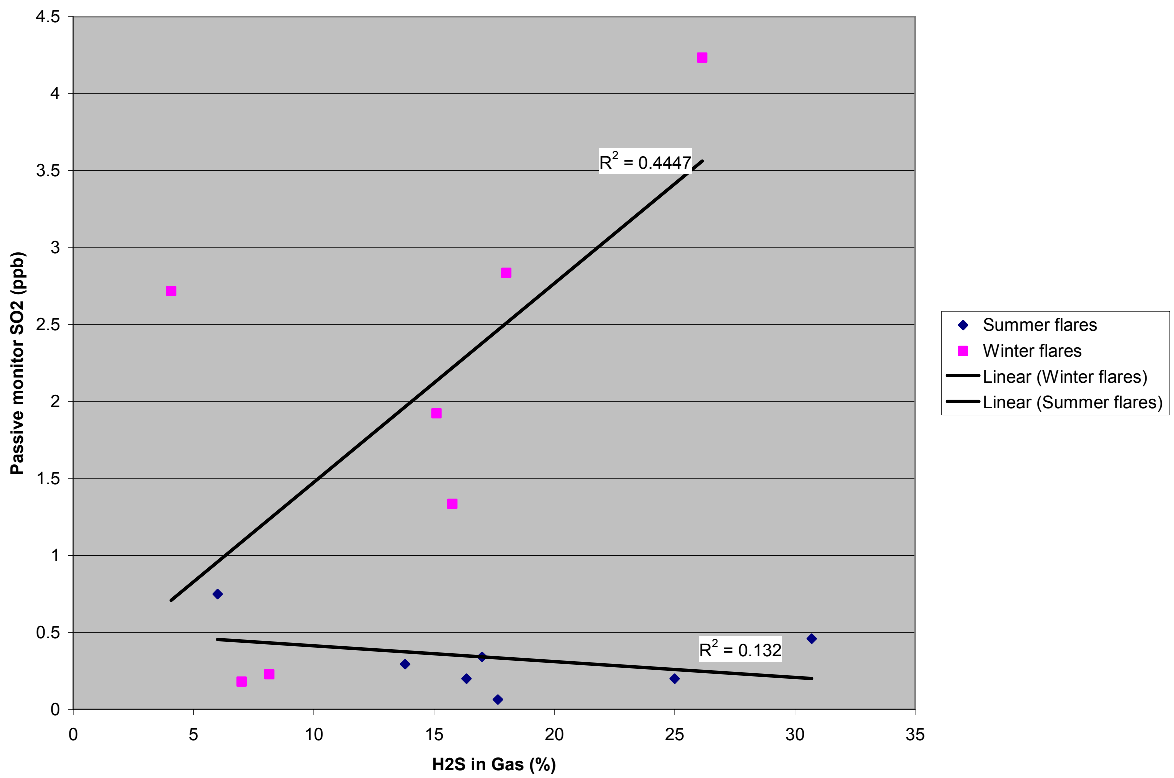

Figure 3c. Sulphur dioxide concentration measurements from the Maxxam Analytics monitors versus H_2S concentration in summer and winter flare tests.

Although based on a limited sample size, Figure 3c indicates a tentative relationship between measured H_2S (hydrogen sulphide) and the monitored sulphur dioxide concentration for each well site, during the higher concentration winter exposures, where data were available. Hydrogen sulphide concentrations in natural gas appears to be the best predictor of potential sulphur dioxide concentrations, but even with this questionable predictability there is still considerable variability in vegetation response, as seen below.

The following section shows a summary of the pre and post-flare condition of vegetation at each of the seventeen well sites and the season in which they were flared.

Changes in plant condition; pre- versus post-flare

Table 1 shows a summary of the pre and post-flare condition of vegetation at each of the well sites.

Well Site	Pre-Flare Conditions	Post-Flare Conditions
b-91-L/93-P-5	Minor mechanical damage from well pad construction. Winter flared.	No discernable response to sulphur dioxide in vegetation. Minor reddening and mechanical injury to pad edge trees reduced in severity, fine branches and red needles dropped.
c-42-K/93-P-5	Several lodgepole pines on thin soils appeared chlorotic and possibly suffering from a nutritional deficiency. Wind-pruning and loss of needles from recent years growth due to drought evident in exposed locations. Winter flared.	Minor sulphur dioxide injury to lodgepole pine noted to the northeast of the lease, in the area predicted to have received the greatest concentrations of emissions. This site was re-visited the following summer; injury has recovered over time (red needles have dropped), no new injury.
d-50-C/93-P-5	Moderate climatic injury to conifer species, minor mechanical injury and exposure of roots due to well pad construction. Summer flared.	Severe localized injury, expressed as needle reddening and mechanical injury to conifers and shrubs, on north and east edges of well pad. Symptoms not consistent with sulphur dioxide, blasting for well pad construction is suspected.
c-38-C/93-P-5	Moderate levels of mechanical injury at lease edge due to well pad construction. Fluctuating water table induced injury: wet sites adjacent to this lease have accumulated standing water, and recently killed trees are present prior to the well flare test. Winter flared.	No changes in symptoms occurred since the pre-flare assessment.
d-33-H/93-P-4	Winter injury and mechanical injury to sub-alpine fir due to well pad and road construction. Winter flared.	Tree condition showed slight improvement from pre to post-flare, no discernable response to sulphur dioxide in vegetation was noted.
c-86-E/93-P-3	The forest adjacent to this lease has been heavily impacted by emissions from the neighbouring gas plant (d-77-E/93-P-3); with recent as well as old injury. Also, sub-alpine fir displayed chlorotic needle ends possibly due to winter injury; crown thinning was evident, probably attributable to poor nutrition and competition (crowded stand). Residual and recent sulphur dioxide injury was noted on windward sides of trees at most stations. At the well pad extreme crown thinning and large pitch tubules were noted in the adjacent sub-alpine dominated forest. Winter flared.	No significant changes in symptomology, some increased defoliation. Distinguishing injury solely due to the c-86-E well flare test was difficult due to the circumstances outlined in the pre-flare description. Mountain pine beetle galleries present.

b-77-J/93-I-14	Old winter injury and minor mechanical damage at pad edge. Slight chlorosis of needles on sub-alpine fir and spruce. Summer flared.	Little change in forest pathology from pre-flare assessment. Some shrub species, however, have since been damaged by leaf foraging insects.
c-83-K/93-P-4	Minor mechanical damage and compaction of materials around tree roots due to well pad construction and selective harvesting. Minor needle reddening from climatic injury. Winter flared.	Present but slight needle reddening commensurate with sulphur dioxide injury at one location to the west of well, otherwise no significant change from pre-flare assessment.
b-79-J/93-P-4	Moderate mechanical damage and compaction of materials around roots of sub-alpine fir due to well pad construction. Moderate wind-shearing to crowns bordering well pad. Desiccation injury at dry sites. Summer flared.	Slight increase in needle reddening and wind-shearing to branches facing lease.
d-7-E/93-P-3	A large fire-killed stand of dead timber occurs to the northwest of the well, in the area predicted to receive the greatest concentrations of sulphur dioxide. Minor wind shearing and other fire history were also evident. Tree death from competition in an overgrown post-fire stand was also noted in most plots. Needle blight was observed on sub-alpine fir, estimated to be approximately 2 years old. There was evidence of flooding injury due to poor road culvert installation directly north of the well, and mechanical injury from wind fallen trees as well as soil slumping in areas north of the well in the creek channel. No pre-existing injury could be misconstrued as sulphur dioxide effects in the pre-flare assessment. Summer flared	Approximately fifteen trees displayed partially dead or dying crowns at the lease edge, these symptoms appeared to be caused by a combination of hot salt water depositional injury as well as sulphur dioxide injury associated with flaring. Acid gas exposure similar to d-13-G is also possible (Legge and Jaques, 2001)
b-66-F/93-P-5	Desiccation injury to lodgepole pine and minor mechanical injury due to well pad construction. Winter flared.	Slight injury at one location less than 1 km from the well site on the pipeline. No dramatic change of injury expression from the pre-flare assessment.
c-97-J/93-I-10	Moderate frost injury and wind shearing. Winter flared.	No clear records of injury that could be attributed to an acute exposure of sulphur dioxide were noted.
c-46-H/93-P-4	Minor mechanical injury due to well pad and road construction. Summer flared.	No injury attributable to exposure of sulphur dioxide.
a-2-E/93-P-3	Severe needle reddening confined to pad edge; cause is unknown, though well pad construction is suspected; injury is in an area effected by blasting, i.e. moderate root exposure and mechanical	Increase in needle reddening and defoliation of residual injury at pad edge, especially to eastern and northern sides. No other significant changes in forest pathology. No injury noted in outlying stands.

	damage. Minor winter injury and wind shearing. Summer flared.	
b-3-G/93P3	Minor mechanical injury due to well pad and road construction. Minor climatic injury (sunscald and frost). Shrubs have minor insect damage. Summer flared.	Slight increase in insect related damage to shrub community. Minor sulphur dioxide injury at station to the east of the well within area predicted to receive greatest ground level concentrations, recoverable with time.
c-12-L/93-I-9	Minor insect damage and root disease (possibly *Inonotus tomentosus*). Summer flared.	No indication that pre-flare conditions were exacerbated by flaring. Minor acute sulphur dioxide injury was noted approximately 125m northeast of the well along a forest edge.
c-43-I/93-I-14	Winter injury evident in all plots, appearing as bleached or reddened leaf tips on exposed needles of lodgepole pine. Approximately 70% from current year, 30% appears as older than current year. Summer flared.	No change in symptom expression following the flare-test.

Examples of most of the expressed injury at the well sites shown in Table 1 are illustrated in Appendix 1. Table 1 indicates that expressed sulphur dioxide injury to conifers is often coincident with drought and winter injury. Winter injury is described by Henigman *et al.* (1999) as "…reddish-brown discoloration of foliage…as a result of a combination of climatic conditions. The unseasonable occurrence of warm dry winds by day, followed by cold air drainage at night leads to desiccation injury. Frozen soils do not allow lost moisture to be replaced quickly enough, and affected needles discolor and eventually shed. Symptoms are often more pronounced in the upper crown and on the sides of trees facing the prevailing wind. Unopened buds are usually not harmed." This type of injury is common in the area of interest and was noted at Babcock Mountain in March of 2002, where an unseasonably warm spell was followed by a severe cold snap. Windward trees at these sites have since been noted to have green shoots emerging from persistent red foliage.

Table 1 also indicates that sulphur dioxide injury seems confined to areas close to the well pad, or exposed areas near the well pad (e.g. d-7-E/93-P-3, c-42-K/93-P-5, c-12-L/93-I-9). The earlier models used in the layout of plots had some high concentrations predicted at 2 to 4 kilometers from the well. However, injury at distances greater than 1 km was noted to be extremely rare; injury distinctly attributable to the flare test at distances greater than 1 kilometer was only noted at c-38-C/93-P-5 (aka d-39-C) and b-3-G/93-P-3. At the latter site, injury was confined to outer branches of less than 5 individual trees at approximately 1.1 km from the well, and is expected to recover over time.

For those wells that were re-visited in the summer following the well test (d-7-E/93-P-3, b-66-F/93-P-5, c-42-K/93-P-5) the occurrence of injury was not as evident six to eight months after the flare than in the period directly following the flare. This was simply due to the fact that the “evidence is gone”[2], namely reddened needles had since fallen from the trees, leaving thin, but relatively green residual tree crowns with a somewhat poor appearance. The lichens at d-7-E/93-P-3 noted to be abundant and diverse in the pre-flare assessment in June 3, 2000 were in poor physical condition in the following summer. By July 16, 2003, lichens and red foliage were absent. This could be due to exposure to wind; mechanical injury and desiccation as a result of the pad creation; and the 2000 exposure to sulphur dioxide.[3] An exception to this pattern is c-86-E/93-P-3, where any ‘recovery’ was likely overridden by exposure to the Bullmoose gas plant (d-77-E/93-P-3). As noted in Table 1 above, injury to trees around c-86-E/93-P-3 were present before the flare test and were most likely affected by the gas plant.

Other sources of injury noted in Table 1 are mechanical injury caused by heavy equipment during the creation of the well pad. During pad creation, the area is logged, cleared and crushed rock is used to create a uniform, level and raised surface. The circumference of the pad is variously treated. In some cases large rock fill extends into the forest edge. Berms are often created along the down-slope edge of the pad and upslope edges are often cut away, exposing roots (see right). Trees on the edge of the pad frequently had root damage from foreign material being dumped on the roots. These trees often experienced a change in moisture regime of either flooding or desiccation. Also, trees on the pad edge were accustomed to closed canopy conditions but as a result of pad creation were abruptly exposed. Edges are more likely to trap air pollutants (Weathers *et al.* 2001), and subsequently may show signs of injury if the concentration and duration of exposure is sufficient enough to cause harm. Some damage and death (especially of root-damaged trees) is to be expected. It is possible that that weakness caused by pad creations renders trees on the edges of well pads more susceptible to injury from sulphur dioxide injury than trees growing in more closed forest conditions.

[2] A. Legge 1995. personal communication
[3] There is a possibility that well pad edge drought could cause susceptibility to sulphur dioxide. Dessication and drought is known to increase susceptibility (Chappelka and Freer-Smith, 1995).

Changes in plant tissue chemistry; pre- versus post-flare

Changes in the foliar inorganic to organic sulphur ratios of conifers exposed to sour well flare tests are shown in Figures 4 (summer flares) and 5 (winter flares).

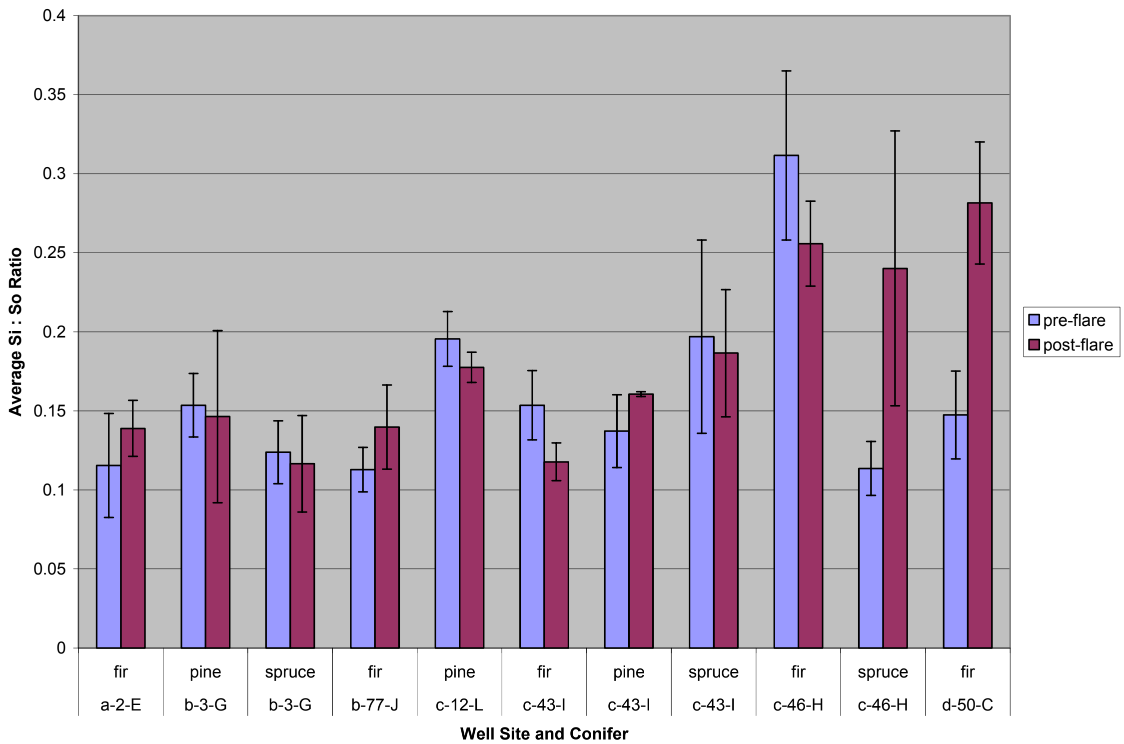

Figure 4. *Changes in average foliar inorganic to organic ratios (Si:So) in conifer foliage between pre and post well flare tests undertaken in summer (April to September). Error bars on the graphs are the standard error (STD/square root of number of samples).*

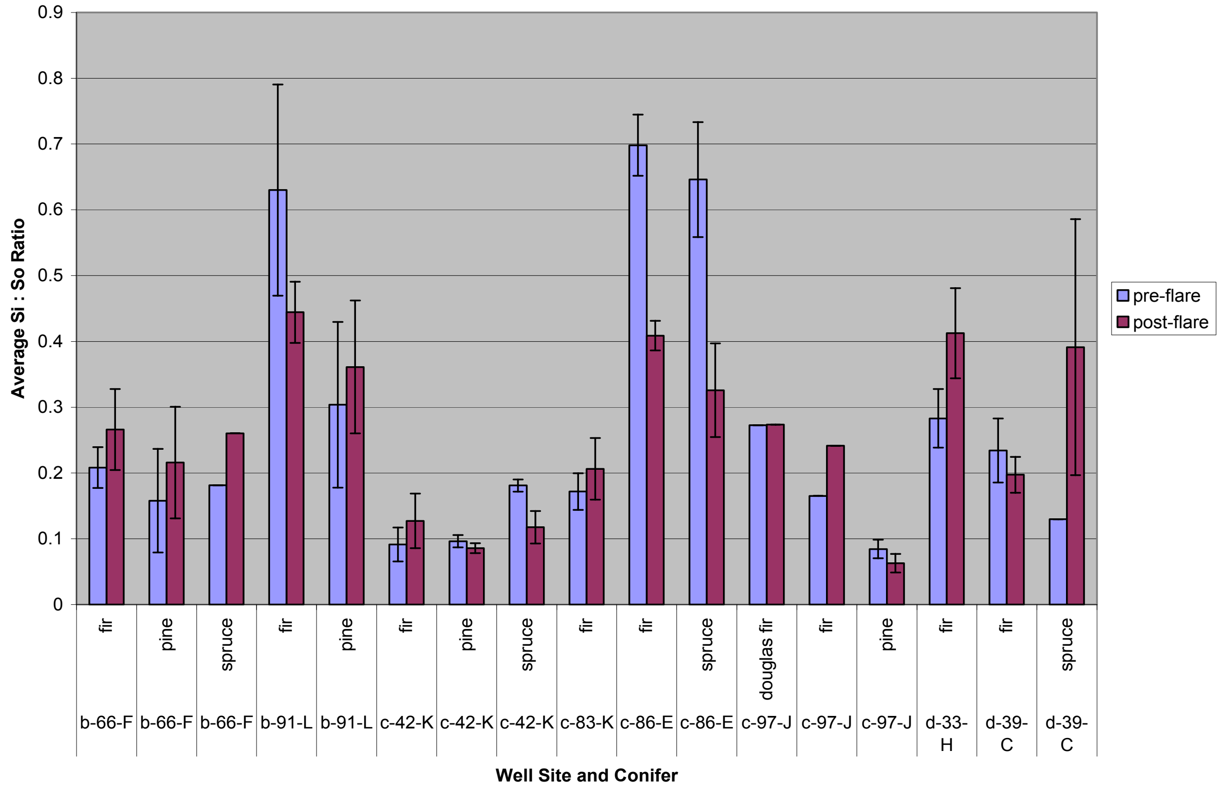

Figure 5. *Changes in average inorganic to organic ratios (Si:So) in conifer foliage between winter pre and post well flare tests. Error bars on the graphs are the standard error (STD/square root of number of samples).*

The data shown in Figures 4 and 5 represents only repeated samples from the same trees, and is sorted by species (see Appendix 1 for more details). Figure 4 indicates that there was no dramatic increase in the foliar sulphur inorganic to organic ratios (Si:So) in conifers in summer. This is likely because the sulphur dioxide durations of the flare tests in summer were not as long as in winter (see Figure 3a and 3b). Winter exposures appear to show greater variation. Figure 5 also shows no clear increase in foliar Si:So ratios, with the exception of conifers at d-39-C (c-38-C/93-P-5) (passive maximum 0.28 ppb, passive exposure time of 326 days) and b-66-F/93-P-5 (passive maximum 3.02 ppb, passive exposure time is 60 days). Although b-66-F/93-P-5 had slight injury at one location, the proximity of the Brazion Gas Plant (see Figure 2) may have influenced ratio expression at this site. Ratios increased slightly at d-39-C/93-P-5, and there was no alternative ambient source of sulphur at this site.

It is likely that the lack of dramatic change in Si:So ratios reflects natural variation in this ratio, or that conifers did not have sufficient time to react biochemically to a dramatic increase in sulphur dioxide from a sour gas well flare test. Ratios greater than 0.4 are considered an indication of incipient injury (Legge *et al.,* 1988)[4]. It may be that some of the exposures to sulphur dioxide, especially in the summer well flare tests, were too brief as well as too low in concentrations. Legge *et al*. (1988) describe the change in ratios in response to changing emissions at the continuous source West Whitecourt gas plant as follows:

> "The dynamic nature of the processes of foliar S assimilation and foliar S accumulation as a function of time is evident. The pronounced increase in foliar S accumulation from 1980 to 1982 at sample locations A_l and A_u is clearly seen as the SO_4-S/So ratio increases from 0.5 to 2.2 for A_l and from 0.4 to1.3 for A_u: µg/m^3 ".
>
> *from* Legge et al. 1988

These changes, measured in summer, were related by Legge *et al*. (1988) to stomatal resistance and photosynthetic rate, and are a result of continuous emissions from Whitecourt Gas Plant in central Alberta over several years of history. However, their objective was to "illustrate how...the data from a foliar S monitoring program can be used as an indication of the status of a pine forest ecosystem *under chronic low concentration S* air pollution" While there is evidence in the literature that Si:So ratios develop in response to sulphur dioxide emissions over time (Kaiser *et al.* 1992; Manninen *et al.* 1997; Legge *et al.* 1988) they may not be responsive enough to bioindicate the effects of a *low concentration* summer or wintertime exposure in a relatively 'pristine' area. It is worth noting that the document titled "*An Environmentally Significant Flare Event from a Sour Gas Processing Plant*" (Legge 1995) actually refers to the predictability of injury thresholds due to flaring from a *continuous* sulphur dioxide source. Predisposition or previous exposure to sulphur dioxide is known to be a factor in response of conifers to acute exposures. Legge *et al*. (1998) review the various diagnostic chemical tests that can be used to evaluate sulphur status of plants, but they also point out that "…these diagnostic tests…do not always lead to a clear-cut foliar accumulation of sulphur…the SO_2 exposed tissue does not have sufficient time and metabolic capacity to accumulate measurable amounts of sulphur before the tissue is killed". Linzon *et al*. (1979; cited in Manninen *et al*. 1997) found higher concentrations accumulated less sulphur in tissue than lower concentrations. Further, Manninen *et al*. (1997) indicate that there is not always a clear correlation between foliar total sulphur concentrations and needle damage. Figures showing the change in total sulphur, and sulphate in response to the seventeen well flare tests included in this document are shown in Appendix 1.

There is only one well documented example of serious injury caused by a well flare test at well site d-13-G/93-I-9 (Legge and Jaques, 2001) (see Appendix 2). This well flared over three periods in June and July of 2000 with differing, unspecified flare durations. The H_2S content was 32% to 35.28%, but the sulphur dioxide concentration was not known. The post-flare assessment conducted by

[4] Also referred to as 'invisible injury'

Legge and Jaques (2001) found Si:So (SO_4-S/S_o) ratios for ten samples of exposed lodgepole pine foliage to range from 0.26 in current year tissue to 0.66 in shed foliage collected from the site. They found that ratios tended to be higher in balsam poplar *(Populus balsamifera ssp. balsamifera)*, bunchberry (*Cornus canadensis)*, rose (*Rosa spp.)* and Labrador tea (*Ledum groenlandicum)* foliage. These species were not sampled during this study, as there were few, if any, literature references for them. In a comparison of retained red foliage versus green foliage from the same branches impacted by sulphur dioxide at a-2-E/93-P-3 and d-50-C/93-P-5 (see Appendix 5) we found red foliage to have slightly lower ratios than green foliage (a-2-E: 0.13 red vs. 0.15 green and d-50-C: 0.25 red vs. 0.31 green). At a non-flare test location known to have serious sulphur dioxide injury we found higher Si:So ratios in red foliage (0.62). However, the symptom expression at d-13-G/93-I-9 was dramatic, and injury was carefully documented. Sulphur dioxide, sulphuric acid, hydrochloric acid and saline aerosol (brine) were implicated at d-13-G/93-I-9 as possible causes of injury. Legge and Jaque's (2001) study determined local and regional background levels for Si:So ratios in lodgepole pine (local background ranges from 0.0465 to 0.0662, n=3; regional background ranges from 0.0226 to 0.1017; n=6). Pine samples from most of the flare tests included in this study seldom exceeded this suggested background.

Lichen sulphur concentrations by species in response to the well flare tests in summer (Figure 6) and winter (Figure 7) are shown below.

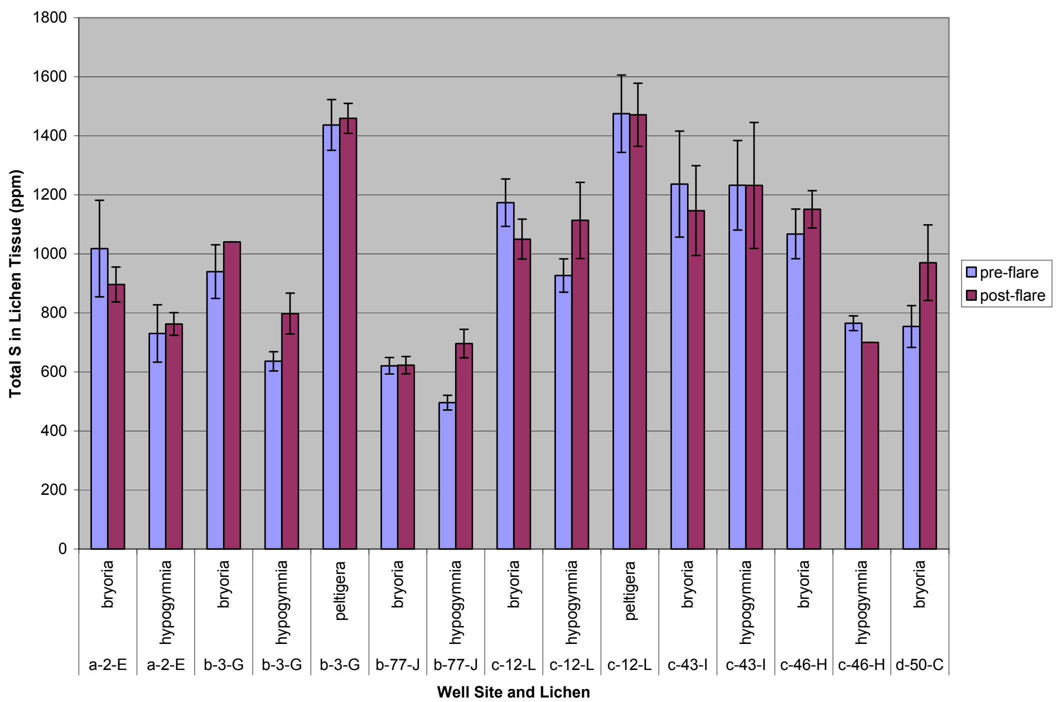

Figure 6. Change in total sulphur concentration in lichens exposed to summer (April to September) sour gas well flare tests. Error bars on the graphs are the standard error (STD/square root of number of samples).

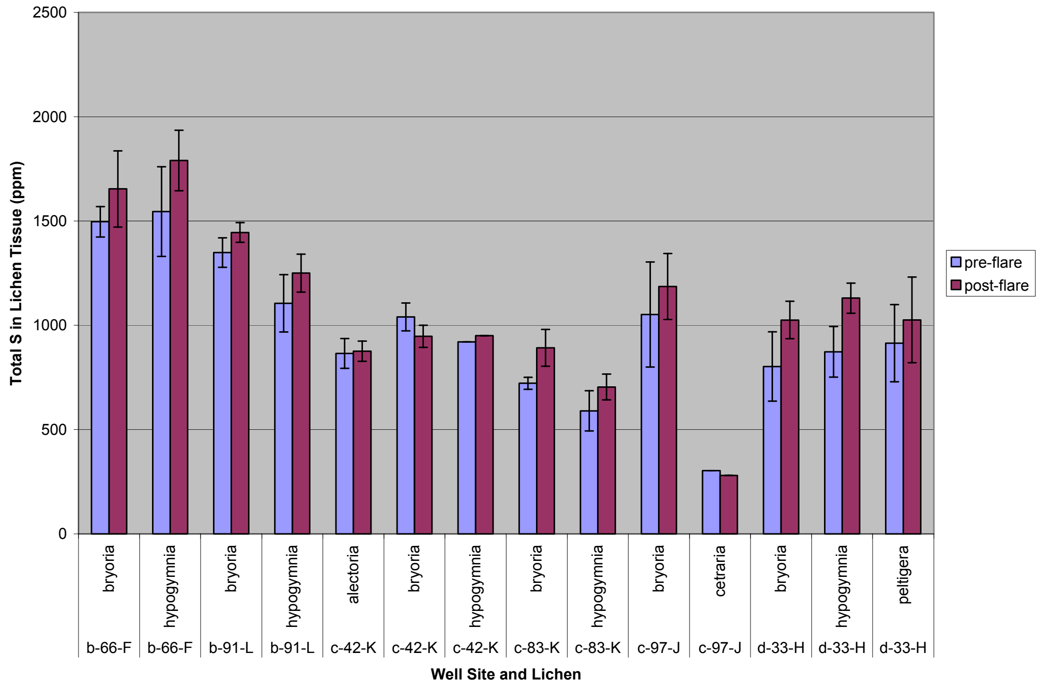

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Figure 7. Change in total sulphur concentration in lichens exposed to winter (October to March) sour gas well flare tests. Error bars on the graphs are the standard error (STD/square root of number of samples).

Figures 6 and 7 indicate a tendency for lichens to absorb sulphur during a well flare test, especially during the high concentration, longer duration winter exposures. Lichens absorb sulphur in direct proportion to exposure, and do not have the same winter resistance as conifers. The lichens prove to be useful as a general indicator of an increase in background sulphur accumulation. Ranges in concentrations of sulphur have been proposed as indicators of background, rural, enhanced and industrial concentrations of sulphur dioxide (Rhoades 1995). These concentration benchmarks may or may not apply to northeastern B.C.; however, the data collected for this report could be used to establish bench marks, and to monitor cumulative effects for sour gas well development areas in B.C. In general, lichen thalline sulphur concentrations seldom exceeded the industrial benchmark of 2000 ppm, and several collections were similar to a clean-air background of 400 ppm. At sources close to gas plants (b-66-F/93-P-5, and c-86-E/93-P-3) lichen sulphur concentrations tend to be elevated. There are several examples of both extensive programs and reviews of lichen response to air pollutants for a variety of airborne pollutants, including Volatile Organic Compounds (VOC's), brine, metals, etc. (Seaward 1993; Mulgrew and Williams 2000; Sloof 1995; Takala *et al*. 1991; Wadleigh and Blake 1999; Brutieg, 1993; Jackson *et al.* 1985; Wirth and Oberhollenzer1990; Enns 2001).

Sources of uncertainty

There are several data-gaps and sources of uncertainty in the data presented above. They are as follows;

- Duration and concentrations of the flare tests were not uniform; sample size and replication was not sufficient to allow for robust statistical analysis.
- True ground level sulphur dioxide concentrations and durations were not known and although the models were geospatially accurate given accurate meteorological data (especially from 2001 onward) the observed vegetation response did not consistently relate to the predicted short-term ground level concentrations.
- The passive monitors appeared to be poor overall indicators of these important facts, simply because they were given inconsistent exposure times, for a variety of reasons listed previously.
- Ecological variation was not just high, it was split between three or four distinct types (see Appendix 1) and therefore the reliability of comparing a sub-alpine fir response at one duration/concentration to another may be compromised by dissimilarity in climate, moisture regime, nutrient regime, seral stage development, etc.
- Variance in response was high enough that the determination of a reliable threshold value for a given field exposure or dose – response was not possible.
- No information was collected in areas completely unaffected by development *versus* post-flare impacts; all the tests that were evaluated had some degree of disturbance.
- Repeated flaring took place in some cases, and probably had an impact on passive monitor data as well as vegetation response, but the data were not sufficient to draw such conclusions.
- Some well flare sites were pre-disposed to sulphur dioxide or other emissions (e.g. b-66-F/93-P-5, c-86-E/93-P-3)
- Advancement of season of the exposure and temperatures varied during the two classes (winter, summer) of flare tests and resulted in variable absorption of sulphur
- Maxxam Analytics monitors were exposed for variable periods of time and did not reflect the actual concentrations during the exposure; the shorter the duration of exposure, the higher the concentration. Continuous monitors were available at only one site.
- Other injury tended to mask or over-ride sulphur dioxide injury, particularly winter injury (also referred to as red-belt or Chinook injury); however Legge *et al.* (1998) provides a rule-of-thumb; when sulphur dioxide is the main component of emissions-related injury, symptoms typical of sulphur dioxide will prevail.

Conclusions

Despite the lack of control and subsequent variability in response of vegetation, there are some useful indications from this study. The data presented here indicates that 'true' ground level concentrations of sulphur dioxide due to sour gas well flaring are not only difficult to determine, but effects are also very difficult to verify and attribute only to sulphur dioxide. At d-13-G/93-I-9 and d-7-E/93-P-3 other acidic and saline compounds were implicated, and several other factors influence vegetation response. Many of these appeared to be more important than sulphur dioxide. The results generally show however, that sour gas well flare tests (with the parameters included in these limited eight examples) conducted in summer months can have small amounts of vegetation damage, especially at well pad edges. Winter time exposures can be considerably higher than the volumes/concentrations/duration times observed in the summer exposures and still have no visible effects. Non-visible impacts, as indicated by an elevated Si:So with no concurrent symptom expression is more difficult to verify. Non-visible injury, such as depression of tree productivity (Legge *et al.*, 1996) is likely not a factor in short-term well flare exposures, unless they reach some kind of cumulative effects threshold.

A summary of the conclusions are as follows;

- None of the well flare tests included in the seventeen pre and post-flare assessments approached the severity of the flare event at d-13-G/93-I-9 observed by Legge and Jaques (2001). This implies that the ground level concentrations at all of the wells observed in this study were below an 'unacceptable' or non-recoverable level of injury.

- The H_2S percent is a relatively robust indicator of potential ground level sulphur dioxide concentrations, (together with meteorology, climate, etc.). At higher H_2S concentrations, (e.g. above 14%) visible sulphur dioxide injury *may* occur on trees near the pad edge, especially during spring or summer exposures.

- In mid-winter, when temperatures drop to below -20 degrees Celsius, conifers are in a dormant state and tend not to react to sulphur dioxide exposures, although it is not certain if going above a threshold concentration could still cause injury[5].

[5] Katz (1939) and Dreisinger and McGovern (1970) observed that vegetation was fairly resistant to sulphur dioxide exposure at all times during winter. For example, Katz and McCallum (1939a; cited in Legge 1995) state that an exposure of 38 hours at 5.00 ppm (13,090 $\mu g\ m^3$) caused 90% damage in Douglas fir and Yellow pine in summer, whereas the same exposure in winter caused only traces of injury to a single tree. Further, one intermittent sulphur dioxide exposure of 52,360 $\mu g\ m^3$ (20ppm) in winter to Douglas-fir had no subsequent injury. Other researchers have noted a reduced response of conifers during winter (Bortitz, 1968; MacLean *et al.* 1986).

- Injury to trees on the edge of the well pad is the most common expression of sour gas well flare test injury, and most of that is due to drought induced by pad creation and subsequent injury to the roots of edge-growing trees. This injury may be exacerbated by exposure to sulphur dioxide, and may be preventable, if trees on the pad edge were managed more carefully. Dead and half-dead trees on the pad edge have the potential to introduce disease and fire hazard.

- Lichens of the genus *Peltigera, Hypogymnia* and *Bryoria* all tend to accumulate sulphur in tissue when concentrations of sulphur dioxide exceed 1 ppb (approximately). These plants have a higher accuracy for showing impacts of sour gas well flare tests than any other receptor.

- When the above level of injury does occur, lichens on the trees at the edge of the pad tend to disappear (i.e. they do not have the same ability to recover as trees do).

- Lichen thalline sulphur concentrations are still below background levels throughout most of the sour gas fields in the area of interest, but tend to be "enhanced" around continuous sources, such as gas plants and older sour gas wells with glycol dehydrators.

Recommendations

The research in this document is not substantive enough to recommend a threshold for H_2S, although the current Oil and Gas Commission Guidelines may be too conservative[6]. The appropriate training and knowledge to evaluate the impact of well flare tests mentioned in the guidelines is required. Future monitoring of sour gas well flare tests with higher than 5% H_2S should occur from prior to well site development to one month after the flare and should take into consideration the confounding factors mentioned in Table 1 (above). The attention of this monitoring should focus on plans for remediation, where necessary. The development of a monitoring protocol for sour gas well development is highly recommended. The protocol must include some flexibility and professional judgment.

It is clear from this project that well pad construction causes some injury which often influences tree response to sour gas well production test flaring. Methods to avoid injury should be used, such as selective clearing of trees on pad edges, keeping machine blade edges to natural openings as much as possible, clearing trees to an opening at least 4 meters from berm edges or rock dumps, etc.

[6] Natural gas flaring during well testing Interim Guideline #OGC 00-01 Section 71(4).

Data from this project could be useful for the design and implementation of a Regional cumulative effects study that is based on real field data, as opposed to models, and would provide baseline and comparative benchmarks for assessing the impacts of gas well development in B.C.

Background areas (areas with no development) in the area of interest covered in this study, and in other parts of northeastern B.C. are becoming scarce. Areas such as the upper Murray River drainage are potentially useful as baseline comparisons for vegetation (and wildlife) response to gas well development.

Using data from d-13-G to model predicted concentrations known to cause injury may be a useful method to test the current threshold levels suggested in the guidelines.

References

Allen, E,A. D.J. Morrison and G.W. Wallis. 1996. Common tree diseases of British Columbia. Natural Resources Canada. Canadian Forest Service. ISBN 0-662-2480-8. Victoria, B.C. 178 pages.

Bell, J.N.B. with M. Treshow. 2002. Air pollution and plant life. Second Edition. John Wiley and Sons, Ltd. 465.

Biosphere Solutions. 2000. Preliminary evaluation and assessment of the injury to vegetation in the vicinity of the BP Canada Energy Company production test of D-13-G/93-1-9 in Northeastern British Columbia. Prepared for Ms. Jennifer Speer Environmental Coordinator/ Gas Resources. BP Canada Energy Company. 240-4th Avenue SW Calgary, Alta. 19 pages plus appendices.

Bortitz, S. 1968. Physiologicheund biochemische Beiträge zur Rauchscadenforschung. 8. Physiologische Untersuchungen über die Wirkung von SO_2 auf den Stoffweschsel von Koniferennadeln im winter. Biol. Sentralbl. 87: 489-506. Cited in: MacLean, D.C. , R.E. Schneider and L.H. Weinstein. 1986. Responses of five species of conifers to sulphur dioxide and hydrogen fluoride during winter dormancy. Environmental and Experimental Botany. 26(3) 291-296

Bruteig, I. E. 1993.The epiphytic lichen *Hypogymnia physodes* as a biomonitor of atmospheric nitrogen and sulphur deposition in Norway. Environmental Monitoring and Assessment 26:27-47.

Callan, Brenda E. 1998. Diseases of *Populus* in British Columbia: a diagnostic manual. Natural Resources Canada. Canadian Forest Service. ISBN 0-662-274/1998E. Victoria, B.C. 157 pages.

Chappelka, A. H., and P. H. Freer-Smith. 1995. Predisposition of trees by air pollutants to low temperatures and moisture stress. Environmental Pollution 87:105-117.

Coates, D., S. Haeussler and J. Mather. 1990. A guide to the response of common plants in British Columbia to management treatments. BC Forest Service and Forestry Canada. Victoria, B.C. ISSN 0835-1929:008. 154 pages.

DeKok, L.J. 1990. Sulphur metabolism in plants exposed to atmospheric sulphur. In: Rennenberg, H., C. Brunhold, L.J. DeKok and I. Stulen (eds); Sulphur Nutrition and assimilation in high plants. Regulatory , Agricultural and Environmental Aspects. Pp 125-138. SPB Academic Publishing. The Hague Netherlands.

Dochinger, L. S., and K. F. Jensen. 1975. Effects of chronic and acute exposure to sulphur dioxide on the growth of hybrid poplar cuttings. Environmental Pollution 9:219-229.

Dochinger, L.S. and C.E. Seliskar. Air pollution and chlorotic dwarf disease of eastern white pine. For Sci. 16: 46-55.

Dreisinger, B.R. 1965. Sulphur dioxide levels and the effects of the gas on vegetation near Sudbury, Ontario. Paper 65-121, presented at 58th Annual Meeting of Air Pollution Control Association, Toronto Ontario. 21 pages.

Dreisinger, B.R. and McGovern, P.C. 1970. Monitoring atmospheric sulphur dioxide and correlating its effects on crops and forests ion the Sudbury area. IN: Proceedings of the Specialty Conference Impact of Air Pollution on Vegetation, S.N. Linzon (ed). Air Pollution Control Association, April 7 - 9 1970. Park Plaza Hotel, Toronto Ontario. Published by the Air pollution Control Association, Pittsburgh, Pennsylvania. pp. 11-28.

Enns, K. 2001. Assessment of the use of lichens as biomonitoring tools in the Athabasca Oil Sands Region. For Wood Buffalo Environmental Association. http://www.wbea.org/html/land/teemreports/2001-lichens for biomonitoring.pdf

Fowler, D., J,N. Cape, J.D. Deans, I.D. Leith, M.B. Murray, R.I. Smith. L.J. Sheppard and M.H. Unsworth. 1989. Effects of acid mist on frost hardiness of red spruce seedlings. New Phytol. 113: 321-335.

Garty, J., Y. Cohen, N. Kloog, and A. Karnieli. 1997. Effects of air pollution on cell membrane integrity, spectral reflectance and metal and sulphur concentrations in lichens. Environmental Toxicology and Chemistry 16(7):1396-1402.

Henigman, John., Tim Ebata, Eric Allen, Joan Holt, and Adriane Pollard. 1999. Field guide to forest damage in British Columbia. BC Ministry of Forests and the Canadian Forest Service. Joint Publication no. 17. ISBN 0-7726-3866-7. Victoria, B.C. 348 pages.

Hermann, B. 2000. Personal communication. Sulphate sulphur or available sulphur determination methods. Vancouver B.C.

Hiratsuka, Y., D.W. Langor and P.E. Crane. 1995. A field guide to forest insects and diseases of the Prairie Provinces. Canadian Forest Service. Northwest Region. Northern Forestry Centre. ISBN 0-660-15948-1. Page 297.

Houston, D.B. and G.R. Stairs. 1970. Physiological and genetic response of Pinus strobes L. clones to sulphur dioxide and ozone exposures. Mitt. Forst Bundex – Versuchsenstalt Wein 97: 387-398. Cited in MacLean, D.C. , R.E. Schneider and L.H. Weinstein. 1986. Responses of five species of conifers to sulphur dioxide and hydrogen fluoride during winter dormancy. Environmental and Experimental Botany. 26(3) 291-296.

Jacobson, J. S., and A. C. Hill (eds.). 1970. Recognition of air pollution injury to vegetation: a pictorial atlas. Air Pollution Control Association. Pittsburgh, Pennsylvania.

Jackson, L. L., E. E. Engleman, and J. L. Peard. 1985. Determination of total sulfur in lichens and plants by combustion-infrared analysis. Environmental Science Technology 19(5):437-441.

Jäger, H.J. and L. Steubing. 1970. Fraktionierte Scwefelbestimmung in Pflanzenmaterial zur Beurteilung einer SO_2-Enwirkung. Angew. Botanik 44: 209-221 *cited in* Huttunen, S., K. Laine and H. Torvela. 1985. Seasonal sulphur contents of pine needles as indices of air pollution. Ann. Bot. Fennici 22: 343-359.

Johnson, C.M. and Nishita, H. 1952. Microestimation of Sulfur in Plant Materials, Soils, and Irrigation Waters. Analytical Chemistry. Vol 24 No 4. P736-742.

Kaiser, W., A. Dittrich, and U. Heber. 1992. Sulfate concentrations in Norway spruce needles in relation to atmospheric SO_2: a comparison of trees from various forests in Germany with trees fumigated with SO_2 in growth chambers. Tree Physiology 12. Pp. 1-13.

Katz, M. 1939. The effects of Sulphur Dioxide on vegetation. National Research Council of Canada,, Ottawa. 447 pages.

Katz, M. 1949. Sulfur Dioxide in the Atmosphere and Its Relation to Plant Life. Industrial and Engineering Chemistry. Vol.41. No. 11. p2450-2465.

Katz, M and McCallum A W 1939. Fumigation experiments in conifers in their natural habitat. Pages 218-243. In Effect of sulphur dioxide in vegetation. Publ. No. 815. National research Council of Canada Ottawa Ontario.

Ke, J., and J. M. Skelly. 1994. Relationships between symptoms expressed by Norway spruce and foliar and soil elemental status. Water, Air, and Soil Pollution 74:289-305.

Keller, Th. And H-J. Jäger. 1980. Der Einfluss bodenburtiger sulfationen auf den Schwefelgehalt SO_2 –begaster Assimilationsorgane von Waldbaumarten. Angew Botanik 54: 77-89. *cited in* Huttunen, S., K. Laine and H. Torvela. 1985. Seasonal sulphur contents of pine needles as indices of air pollution. Ann. Bot. Fennici 22: 343-359.

Klemm,R.F. 1972. Environmental effects of the operation of sulphur extraction gas plants. Report of Environ Conser. Authority, Edmonton Alberta

Kuik, P., and H. TH. Wolterbeek. 1994. Factor analysis of trace-element data from tree-bark samples in the Netherlands. Environmental Monitoring and Assessment 32:207-226.

Lawrey, J. D. 1993. Lichens as monitors of pollutant elements at permanent sites in Maryland and Virginia. The Bryologist 93(3):339-341.

Legge, A. H. 2001. Personal communication: Response to acute exposures to sulphur dioxide. Victoria, B.C.

Legge, A. H. 1995. Personal communication: Endurance of sulphur symptoms expression by coniferous tree species.

Legge, A. H. 1995. An environmentally significant flare event from a sour gas processing plant: proposed quantitative definitions. Biosphere Solutions. Calgary, AB. pp. 25.

Legge, A.H. , J.C. Bogner and S.V. Krupa. 1988. Foliar sulphur species in Pine: A new indicator of t a forest ecosystem under air pollution stress. Environmental Pollution. 55: 15-27.

Legge, A. H. , A-J Jäger and S.V. Krupa. 1998. Sulphur Dioxide. In: Recognition of air pollution injury to vegetation: a pictorial Atlas. 2nd Edition. Air and Waste Management Association. Pittsburgh, Pennsylvania. Page 3-1 to 3-42.

Legge, A. H. and D.R. Jaques. 2001. Evaluation and assessment of the injury to vegetation in the vicinity of the BP Canada Energy Company Production Test of D-13-G/93-I-9 in Northeastern British Columbia in the Summer of 2000. Biosphere Solutions. Calgary, Alberta.

Legge, A.H., M. Nosal and S.V. Krupa. 1996. Modeling the numerical relationships between chronic ambient sulphur dioxide exposures and tree growth. Can,J. For. Res. 26: 689-695.

Linzon, Samuel N. 1979. Effects of Airborne Sulfur Pollutants on Plants. From: Sulfur in the Environment: Part II, Ecological Impacts. Edited by Dr. Jerome O. Nriagu.

MacLean, D.C., R.E. Schneider and L.H. Weinstein. 1986. Responses of five species of conifers to sulphur dioxide and hydrogen fluoride during winter dormancy. Environmental and Experimental Botany. 26(3) 291-296

Malhotra, S.S. and R.A. Blauel. 1980. Diagnosis of air pollutant and natural stress symptoms on forest vegetation in Western Canada. Env. Can. Canadian Forestry Service, Northwestern Forest Research Centre, Info Rep. NOR-X-228. Edmonton, Alta.

Manninen, S., S. Huttunen, P. Rautio, and P. Peramaki. 1996. Assessing the critical level of SO_2 for Scots pine in situ. Environmental Pollution 93(1):27-38.

Manninen, Sirkku, Satu Huttunen and Paavo Peramaki. 1997. Needle fractions and S to N ratios as indices of SO_2 deposition. Water air and soil Pollution, 95: 277-298.

Materna, J., and K. Kohout. 1963. Di absorption des Schwefeldioxids durch dei Fichte. Naturwissenschaften 50: 407-408. Abstract is in Air pollut. Abstracts 2: 170 1971.

Maxxam Analytics Inc. 1997. Personal communication regarding E.P.A. method 300. Edmonton, A.B.

McLean, D. 1982. Air quality standards for fluoride to protect vegetation: Regional seasonal and other considerations. Air Pollution Control Association 32: 82-84.

Meyers, E. 2001. Personal communication. Weather data for Northeastern B.C. from MoF Forest Protection Services Stations, Victoria, B.C.

Mulgrew, Angela and Peter Williams. 2000. Biomonitoring of air quality using plants. World Health Organization Collaborating Centre for Air quality Management and Air Pollution Control. Federal Environmental Agency, Germany. Report 10. 165 pages.

Pregitzer, K., A. J. Burton, G. D. Mroz, H. O. Liechty, and N. W. MacDonald. 1992. Foliar sulfur and nitrogen along an 800-km pollution gradient. Canadian Journal of Forest Research 22(11):1761-1769.

Rhoades, F.M. 1995. Element content in lichen and bryophyte species found in Pacific Northwestern United States and Canada: Means, single values and ranges reported in literature. Mycena Consulting, Bellingham WA.

Seaward, M.R.D. 1993. Lichens and sulphur dioxide air pollution: field studies. Environmental Review 1: 73-91.

Setterstrom, C and Simmerman, P.W. 1939. Factors influencing susceptibility of pants to sulphur dioxide injury. Contributions of the Boyce Thompson Institute 10: 155-181.

Schutte, Alex. and Bob Humphries. 2000. Post flare model analysis from well test flaring at High hat C-42-K/ Prepared for talisman Energy Inc., by Levelton Engineering Ltd. File 1500-0008

Showman, R.E. 1988. Mapping air quality with lichens the North American experience. In Lichens, bryophytes and air quality. Edited by T.H. Nash III and V. Wirth. Bibl. Lichenol. 30: 67-89.

Slocomb, R. 2001. Personal Communications. Summary data. Oil and Gas Commission. Fort St. John, B.C.

Sloof, J. E. 1995. Pattern recognition in lichen for source apportionment. Atmospheric Environment 29(3):333-343.

Takala, K., H. Olkkonen, and H. R. Krouse. 1991. Sulphur isotope composition of epiphytic and terricolous lichens and pine bark in Finland. Environmental Pollution 69:337-348.

Tausz, M., L. J. De Kok, I. Stulen, and D. Grill. 1996. Physiological responses of Norway spruce trees to elevated CO2 and SO_2. J. Plant Physiol. 148:362-367.

Tomassini, F. D., K. J. Puckett, E. Nieboer, D. H. S. Richardson, and B. Grace. 1976. Determination of copper, iron, nickel, and sulphur by X-ray fluorescence in lichens from the Mackenzie Valley, Northwest Territories, and the Sudbury District, Ontario. Can. J. Bot. 54(14):1591-1603.

Tukey, J.W. 1977. Exploratory data analysis. Addison Wesley, Reading, Mass.

Velleman, P.F. and D.C. Hoaglin. 1981. Applications, basics and computing of exploratory data analysis. Duxbury Press, Boston.

Vogl, M and S. Bortitz S. 1968. Gaswechsel-physiologische Untersuchungen zur Verwendbarkeit abseschnittener Koniferenzweige unter besonderer Berucksichtigung des rauchharteschnell-testes. Biol. Zentralobl. 87: 313-324.

Wadleigh, M.A. and Blake, D.M. 1999. Tracing sources of atmospheric sulphur using epiphytic lichens. Environ. Pollut. Vol 106. P265-271.

Weathers, Kathleen, C., Mary L. Cadenasso and Stewart T.A. Pickett. 2001. Forest edges as nutrient and pollution concentrators; potential synergisms between fragmentation, forest canopies, and the atmosphere. Conservation Biology. Pages 1506-1514.

Wilkonson, L., M.Hill, J.P. Welna and G.K. Birkeneue. 1992. Statitsics: SYSTAT for Windows, Version 5 Edition. Evanston Ill. 750 pp.

Wirth, V. and H. Oberhollenzer. (eds) 1990. Lichen mapping in Europe. Stuttgart. Beitr. Naturk. Ser. A. (Biol). 456: 1-199.

World Health Organization. 1987. Air quality guidelines for Europe. WHO Regional Publications, European Series. No. 23. Regional office for Europe, Copenhagen

Ziller, Wolf, G. 1974. The tree rusts of Western Canada. Canadian Forestry Service. Department of the Environment. Publication No. 1329 Victoria, B.C. 272 pages.

APPENDIX 1. Synopsis of the main well flare tests

See attached document

APPENDIX 2. Post-flare assessments

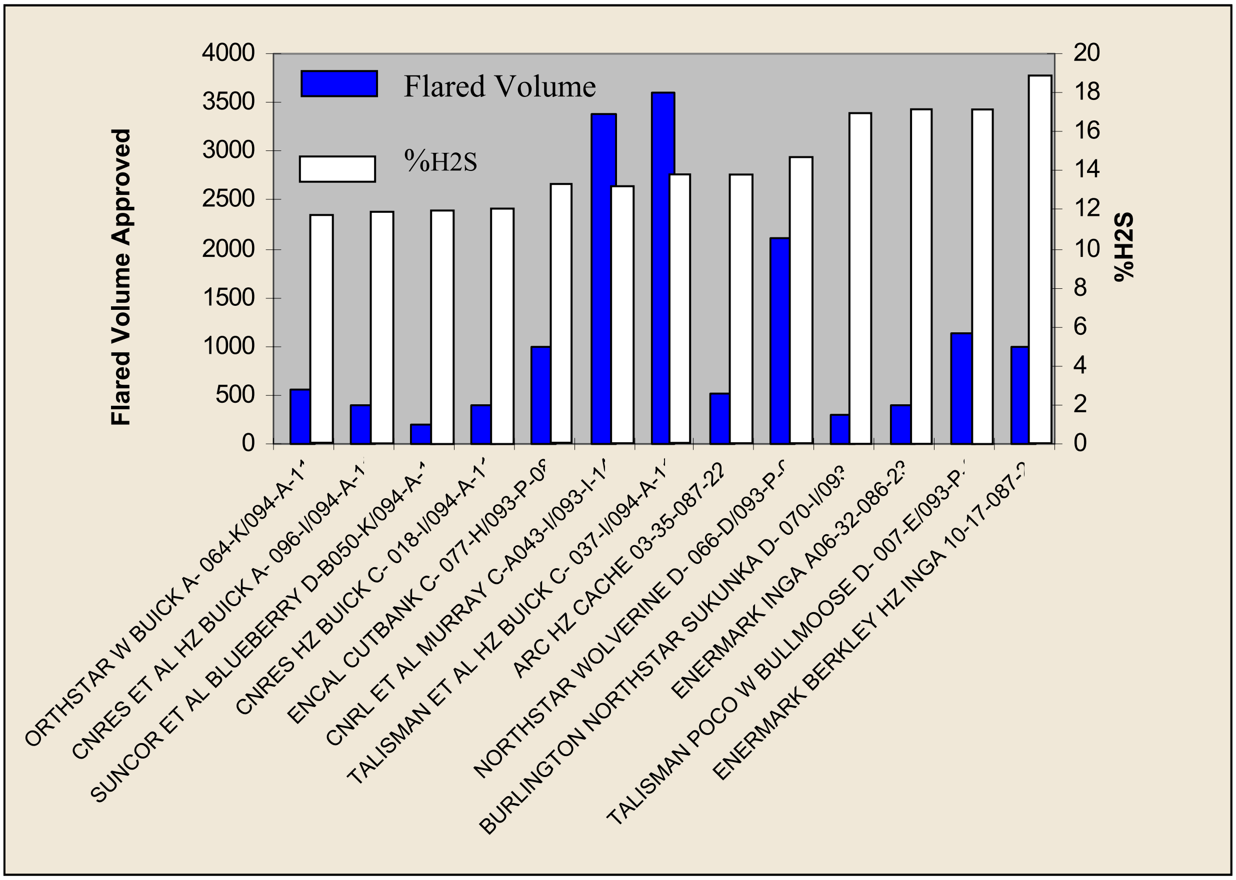
Table 2A. Project well flare test sites, their plant community type, and sensitivity ranking (based on descriptions in Legge *et al.* 1998) and the preliminary interpretation for each test flare

Well flare test site	Interpretation
a-19-H Martin Creek **Plant community** montane forest clearcut after the flare event and exposed edges, in a gentle depressional bowl; moderate to poor dispersal **Sensitivity ranking**: variable sensitivity	Post-flare event (post-fire event?) evaluation only. Traverse of previously damaged areas on foot with Government official. Sampling of older lichen tissues. Sampled in area left un-logged that was previously damaged. Sulphur concentrations in lichen tissues have probably dropped since the event; they are now at ~ 500 – 700 ppm, which is not commensurate with injury to other plants. No residual symptoms in deciduous trees. Very subtle old damage in the form of slightly thinner crowns in lodgepole pine in the residual forest. Sensitive foliose lichens are lacking in the clearcut forest near the well site, but this is common in harvested stands.
d-13-G BP Amoco South Grizzly **Plant community** mid-low elevation mesic montane forest, good to moderate dispersal **Sensitivity ranking**: moderately sensitive	Assessed after the flaring event (June of 2000). This site has been extensively studied by A. Legge (Legge and Jaques 2001) Dieback evident on most shrubs, especially alder willow and scrub birch. Labrador tea has dead terminal branch ends, but new shoots are emerging from lateral buds. Some growth is very vigorous. Recent reddening of needles of all three conifer species on the site on the southwestern edge of the pad, commensurate with the previous year. Injury extends from the edge of the pad in the direction of prevailing wind. Severity declines with distance. Lodgepole pine with some needle loss (thinning) and red tips. Small balsam fir with dead leader and new growth from lateral branches below the effected node. Bunchberry has grown back less than half it's normal size but is otherwise a-symptomatic.
d-66-D/093-P-0 Northstar Wolverine **Plant community**: lower montane wet forest and clearcut, excellent dispersal **Sensitivity ranking**: moderately to highly sensitive	Assessed after the flaring event. Flared twice in 2000 in March and September. Some evidence in shrub and herb layer of damage, with banding appearing in Labrador tea, bleaching on stiff clubmoss which may be due to drought. Planted <5 year old lodgepole pine with reddened needles, some interaction possible between drought and SO_2 Injury. Young poplars showing inter-veinal chlorosis that is most likely is due to nutritional deficiency.

Table 2A. (Continued). Project well flare test sites and continuous flares, their plant community type, and sensitivity ranking (based on descriptions in Legge *et al*. 1998) and the preliminary interpretation for each test flare

Well flare test site	Interpretation
Domcan Cache 5-33-87-22 **Plant community** low elevation boreal plains forest, clearcut regenerated to lodgepole pine on one edge, good dispersal **Sensitivity ranking**: moderately to highly sensitive	Assessed after the flaring event (May 1998). Well is capped. Understory is lush with no evidence of injury with the exception of older acute injury to two year needles of lodgepole pine in exposed areas near the well, and some casting evident in litter layer. Gall aphid and mistletoe infestations in mature stands.
c-18-I Buick Creek **Plant community**: low elevation rolling farmland, good dispersal **Sensitivity ranking**: low	Transect completed in deciduous-leading mixed forest west of the well flare test site. Has a derrick on it at present. Pathology of poplar noted adjacent to well pad. Forest ground vegetation very lush, no symptoms of sulphur dioxide injury in sensitive species, e.g. alsike clover, fire weed.
d-a-073-I/094-a-11 Talisman HZ Buick **Plant community** low elevation pasture with fragment of boreal plains deciduous forest, excellent dispersal **Sensitivity ranking**: low to moderately sensitive	Assessed after the flaring event (13 October 1999; 12 (x1000 m^3) at 14% H_2S). Deciduous trees showing signs of past injury, blackened bark and standing dead trees throughout the forested stand. Some lodgepole pines appear to have dead leaders with alternate leaders growing at mid trunk. Willow situated adjacent to grassy field showing signs of chlorosis. Appears to have been dramatically effected by the well flare test event, but need to know operational history of this well since the flare event.

APPENDIX 3. Approved well flare test volumes (From Slocomb pers. com. 2001)



A1. Short-list of high volume, high H_2S concentration spring and summer flares (data provided by R. Slocomb, Oil and Gas Commission, Fort St. John).

APPENDIX 4. Soil sample methods (archived samples)

Soil samples were air dried at temperatures not exceeding 40°C. They were then flattened with a rolling pin to break up coagulants, and sieved through a 2 mm sieve (Lavkulich, 1977). Soil pH was determined potentiometrically using a Radiometer pH meter on a 1:1 soil to distilled water slurry. Estimated electrical conductivity or salt readings were also determined on this slurry using a Radiometer Conductivity cell (Lavkulich, 1977, 1978). Total Nitrogen was determined colorimetrically using a Technicon Autoanlyser, on a semi-micro Kjeldahl digest (Lavkulich, 1977, 1978). Total Carbon was determined directly on a LECO CR 12 Carbon Analyser (Lavkulich, 1977, 1978, Mckeague, 1978). Available phosphorus was determined colormetrically using the ascorbic acid color development method on a 1:10 soil to Bray (NH4F) extract (Lavkulich, 1977, 1978, Mckeague, 1978). Available Ca, Mg, Na, and K were determined by Perkin-Elmer Atomic Absorption Spectrophotometer on a 1:5 soil to ammonium acetate extract (Mckeague, 1978). Available Cu, Zn, Fe, and Mn were determined by Perkin-Elmer Atomic Absorption Spectrophotometer on a 1:5 soil to 0.1 N HCl extract (Lavkulich, 1977, 1978, Mckeague, 1978). Available sulphate-sulphur was determined using the Hi-Bismuth Reducible method on a 1:2 soil to calcium chloride extract (Mckeague, 1978, Carter, 1993). Cation-exchange-capacity and exchangeable cations were determined by the 1N Ammonium Acetate pH=7 method (Lavkulich, 1977, 1978, Carter, 1993). Particle size was determined by the pipette method. The sand content was determined by wet sieving. The destruction of organic matter with sodium hypochlorite is the only pre-treatment used (Lavkulich, 1977, 1978, McKeague, 1978, Carter, 1993).

References

Carter, M.R. 1993. Soil sampling and methods of analysis. Canadian Society of Soil Science.

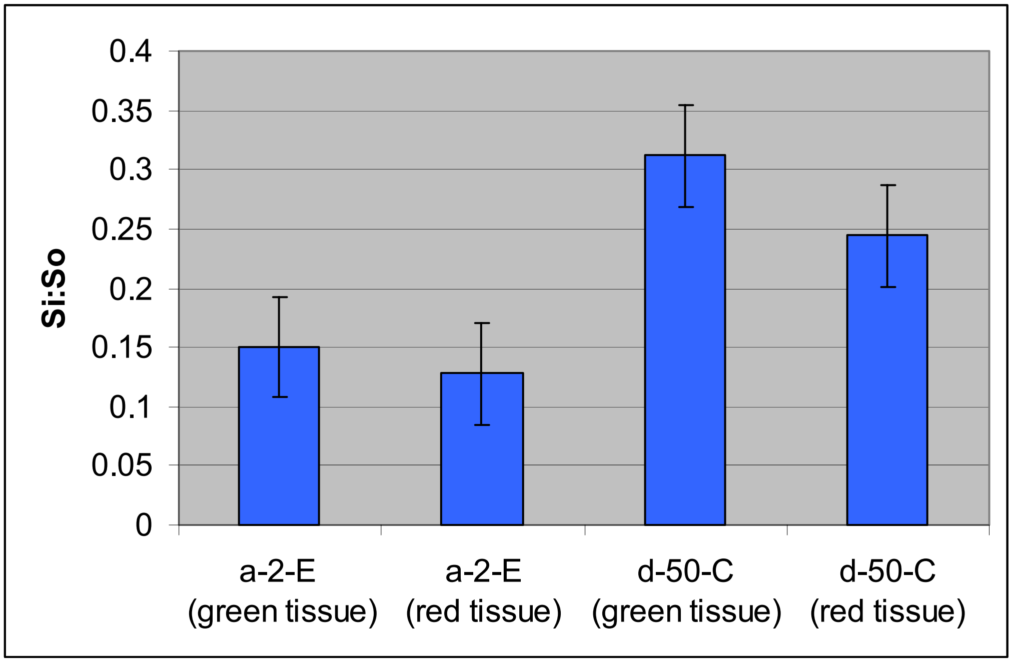
Johnson, C.M. and Nishita, H. 1952. Microestimation of sulfur in plant materials, soils, and irrigation Waters. Analytical Chemistry. Vol 24 No. 4. P736-742.

Lavkulich, L.M. 1977. Methods manual, pedology laboratory. Department of soil science, University of B.C.

Lavkulich, L.M. 1978. Methods manual, pedology laboratory. Department of soil science, University of B.C.

McKeague, J.A. 1987. Manual of soil sampling and methods of analysis.

APPENDIX 5. Summary Statistics



A2. Comparison of mean values of red and green Abies lasiocarpa Si:So ratios between well sites a-2-E/93-P-3 and d-50-C/93-P-5.

Closure

We trust the above meets your requirements. If you have any further questions, or require additional details, please contact the undersigned.

Golder Associates Ltd.

Report prepared by:	Report Reviewed by:
Katherine Enns, M.Sc., R.P.Bio Senior Environmental Scientist	Martin Rawlings, P. Eng. Senior Air Quality Engineer

Environment Fund
File: 1070-20

Impact of Sour Gas Production Flare Tests on Vegetation

Appendix 1: Well Site Summaries

Prepared for:

The Oil and Gas Commission, Fort St. John, B.C.

Prepared by:

Golder Associates Ltd.
Castlegar, B.C.

Distribution:

4 Copies	Oil and Gas Commission, Fort St. John, B.C.
2 Copies	Talisman Energy Ltd, Calgary, Alberta
2 Copies	Talisman Energy Ltd. Chetwynd, B.C.
2 Copies	Canadian Natural Resources Limited, Fort St. John, B.C.
2 Copies	Burlington Energy Canada Ltd, Fort St. John, B.C.
2 Copies	Golder Associates Ltd., Castlegar, B.C.

Golder Associates

03-1480-058

Appendix 1: Well Site Summaries

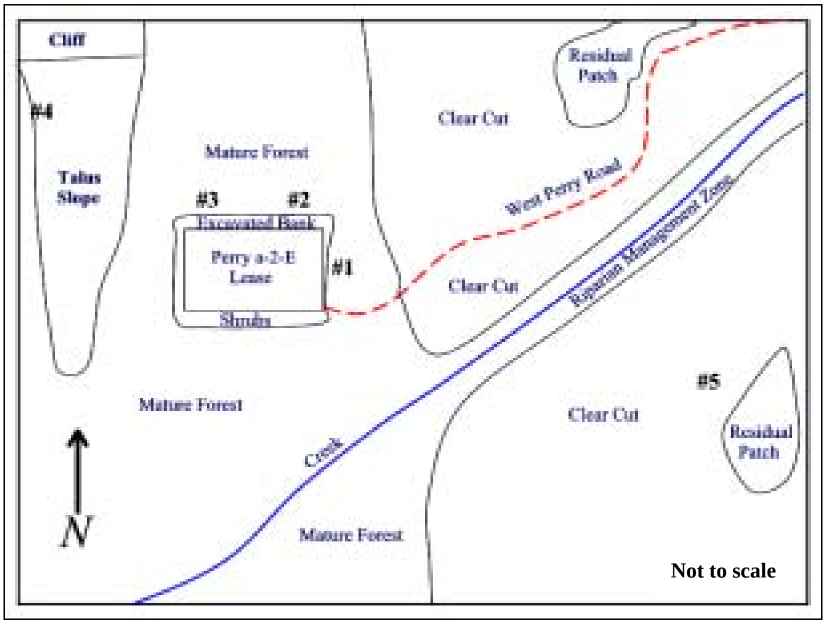
Well: a-2-E/93-P-3

General Location: Wolverine River Valley

UTM Coordinates: 602726E, 6105464N

Physiography: Sub-alpine, in steep mountainous terrain just below the tree line, at the upper end of a glaciofluvial carved trough, with a hanging valley upslope to the west of the lease (i.e. likely subjected to cold air drainage).

Biomonitoring Station Constellation:



Dates of Flare Events:

- June 11, 2003 for 6 hours
- June 15 – 16, 2003 for 24 hours

Dates of Field Work:

- May 8, 2003 (pre-flare assessment)
- June 20, 2003 (post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:

- Range: 1654 µg/m^3 – 50 760 µg/m^3 or 621.8 ppb – 19 087.2 ppb (from 4 scenarios through 6 stability classes)
- Mean value of 14 909.04 µg/m^3 or 5604.9 ppb

Actual Modeled Maximum Ground Level SO_2 Concentrations:

- June 11th 409 µg/m^3 or 154 ppb, northeast of the well
- June 15 – 16th 674 µg/m^3 or 253 ppb, northeast of the well

Maximum Measured H_2S Content: 16.35%

Meteorological Conditions:

- Predominant winds are from the southwest
- Winds speeds ranged from 2.7 to 6.9 m/s
- Temperatures ranged from ~ 0 to 15˚C

Sample Components:

- Lichens: *Bryoria sp.* (mainly *fuscescens*[1]) and *Hypogymnia sp.* (mainly *physodes*)
- Conifers: sub-alpine fir
- Passive SO_2 monitors (x = 5)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	0.1018 ppm (*Bryoria sp.)* 0.0730 ppm *(Hypogymnia sp.)*	0.0896 ppm (*Bryoria sp.)* 0.0763 ppm *(Hypogymnia sp.)*
Conifer total sulphur	942 ppm green tissue	820 ppm green tissue 872 ppm red tissue
Conifer Si:So	0.1154	0.1499 green tissue 0.1279 red tissue

Passive Monitoring Results:

Station	SO_2 (ppb)
1	0.2
2	0.2
3	0.2
4	0.2
5	damaged
Mean	**0.20**

Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

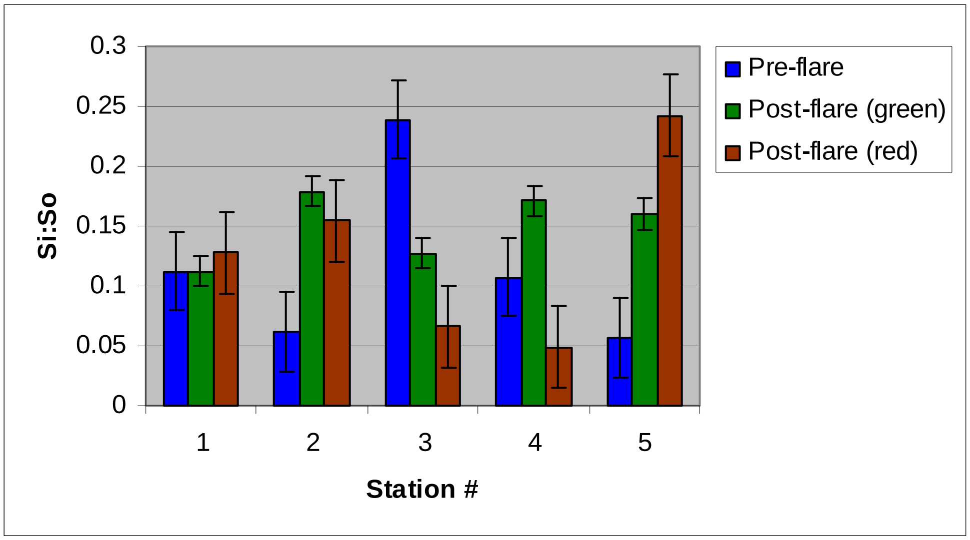
[1] Species of *Bryoria* on most sites including those described below included a somewhat variable mix of *freemontii, fuscescens, furcellata, lanestris* and *pseudofuscecens* on lower to midcanopy branches. *Bryoria fuscescens* was most common and made up most of the biomass throughout all the samples. Although sensitivity of *Bryoria* varies slightly by species, variation in sulphur uptake is not well known, especially for short term exposures, and because of the time involved in separating the species for each well site, species of *Bryoria* were composited. B. *capillaris* was also common at wetter sites.

Species Composition:
Due to snow cover species list is incomplete

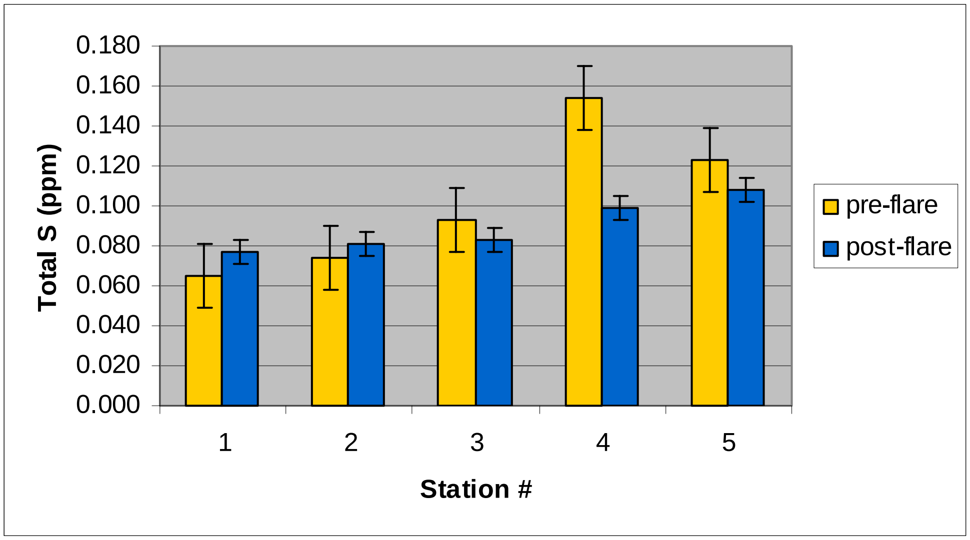
- sub-alpine fir (dominant)
- Engelmann spruce (co-dominant)
- white flowered rhododendron (dominant)
- *Platismatia glauca*
- *Usnea lapponica*
- *Bryoria fuscescens*
- *Hypogymnia physodes*
- *Hypogymnia imshaugii*

Results

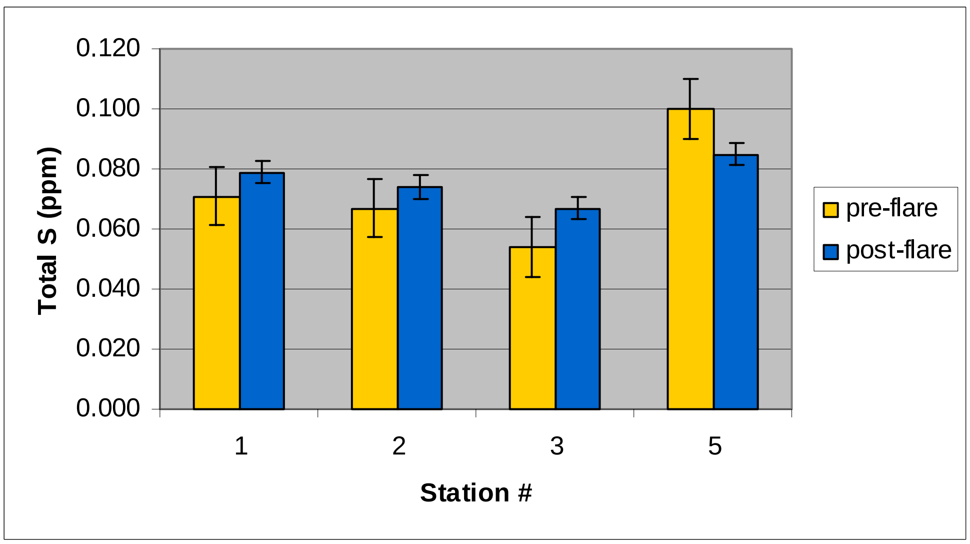
Dramatic symptoms were present on the trees before the flare test and resembled sulphur dioxide injury, although the pad creation, particularly blasting, appears to be mainly responsible. Slight cumulative injury from both sulphur dioxide and mechanical damage was noted post-flare. Mechanical injury appears to be more prevalent than emissions-related injury. Plant response (timing), tissue chemistry results and passive monitor data did not support the conclusion that the injury was solely from sulphur dioxide. During the post-flare assessment, it was noted that the injury had increased slightly and the residual damage had progressed, from red tissue on all present years of growth to dry desiccated yellow needles or defoliation. Salt brine was suspected but the sodium and chloride concentrations were low in comparison to a brine impacted site in NE B.C. Blasting for well pad construction was likely responsible for the injury at this site.



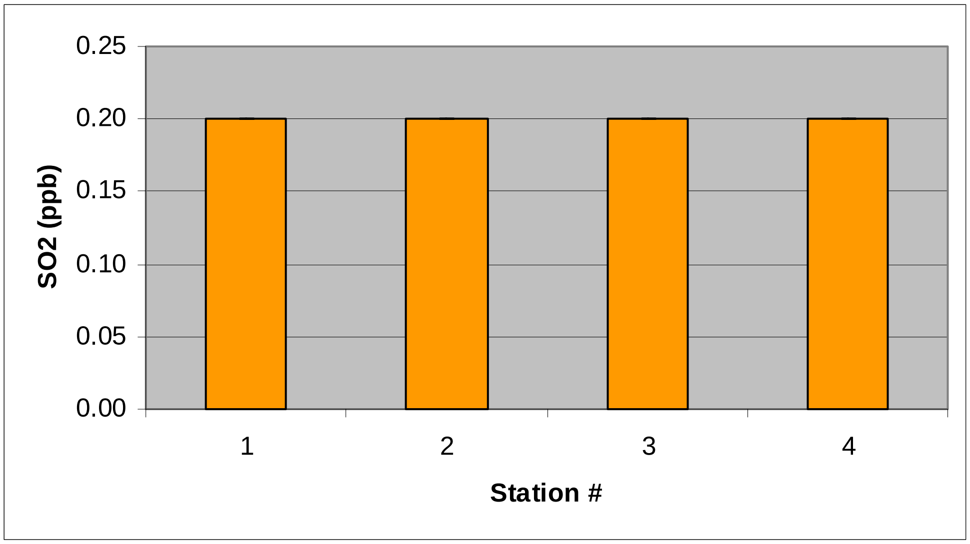
A1. Inorganic/organic sulphur ratios (Si:So) of conifer tissues collected at each of the five monitoring stations around a-2-E/93-P-3 in May (pre-flare) and June (post-flare). Post-flare (green) refers to live green sub-alpine fir tissue collected post-flare and post-flare (red) refers to red, or dead, sub-alpine fir tissue collected post-flare.



A2. Average total sulphur in Bryoria sp. collected at each of the five monitoring stations around a-2-E/93-P-3 in May (pre-flare) and June (post-flare).



A3. Average total sulphur in Hypogymnia sp. collected at each of the five monitoring stations around a-2-E/93-P-3 in May (pre-flare) and June (post-flare).



A4. Concentrations of sulphur dioxide (ppb) registered by the passive monitors located at monitoring stations around a-2-E/93-P-3. Exposure period: May 8 to June 20, 2003.

A5. Localized needle reddening at a-2-E/93-P-3, Station 1, pre-flare.

A6. Needle reddening and mechanical injury on eastern edge of a-2-E/93-P-3 lease (post-flare), facing Station 1.

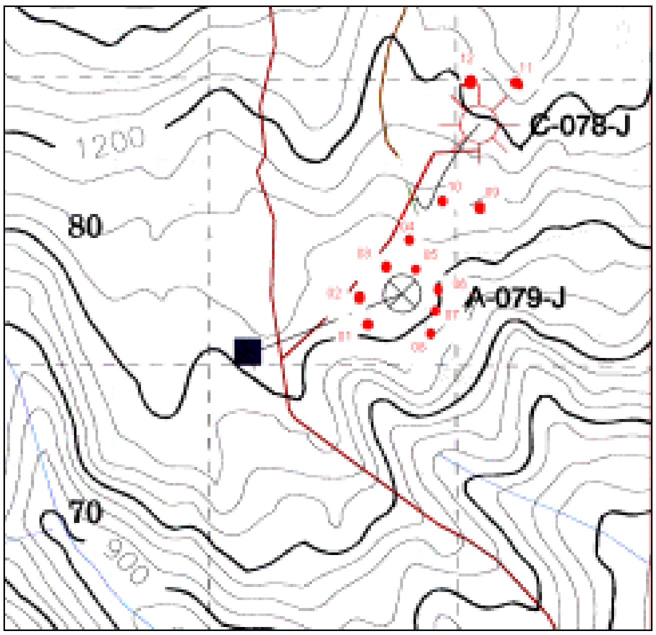
Well: b-79-J/93-P-4

General Location: Rocky Creek Rd., Sukunka River Valley

UTM Coordinates: 580432.6E, 6120378.3N

Physiography: On the edge of a gently undulating middle elevation plateau above main valley, montane to sub-alpine.

Biomonitoring Station Constellation:



Dates of Flare Events:
- April 3, 2002 for 11 hours
- April 29, 2002 for 6 hours

Dates of Field Work:
- February 8, 2002 (pre-flare assessment)
- December 14, 2002 (post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:
- Range: 610 µg/m^3 – 17 786 µg/m^3 or 229 ppb – 6686 ppb (maximum value from each of the 6 stability classes)
- Mean value of 5480 µg/m^3 or 2060.2 ppb

Actual Modeled Maximum Ground Level SO_2 Concentrations:
- April 3rd 180 µg/m^3 - 261 µg/m^3 or 68 ppb - 98 ppb, to the north-northeast and northeast of the well

- April 29th 29 µg/m^3 - 48 µg/m^3 or 11 ppb - 18 ppb, to the north-northeast and northeast of the well

Maximum Measured H_2S Content: 5.0%

Meteorological Conditions:
- Predominant winds are from the southwest
- Winds seldom exceeding 6m/s
- Temperatures ranged from ~ 5˚C to 10˚C

Sample Components:
- Lichens: *Bryoria sp.* and *Hypogymnia sp.* (mainly *physodes*)
- Conifers: Sub-alpine fir

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	1857 ppm	Not enough for post- flare collections.
Conifer total sulphur	960 ppm	876 ppm
Conifer Si:So	0.187	0.125

Passive Monitoring Results:
Passive monitors were not used in the assessment of this well

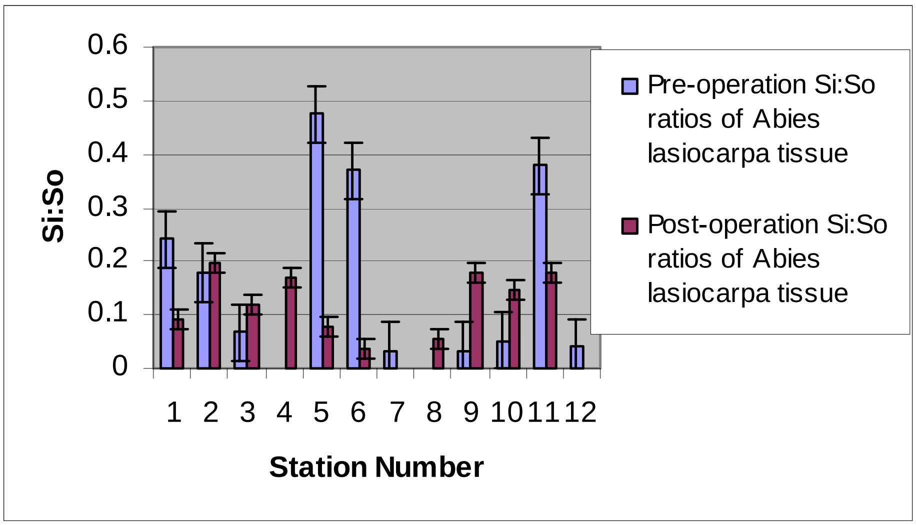
Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

Species Composition:
Species list is incomplete due to snow cover

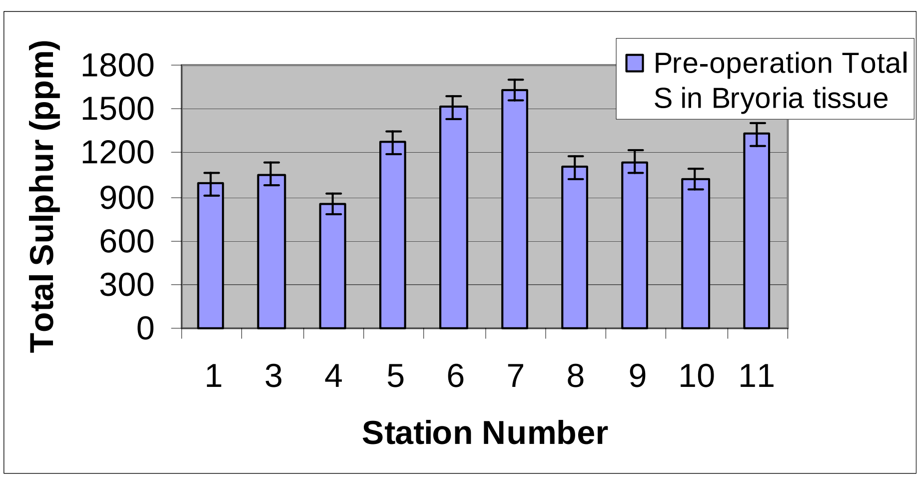
- sub-alpine fir (dominant)
- lodgepole pine (dominant)
- Douglas-fir (co-dominant)
- Engelmann spruce (co-dominant)
- bunchberry
- twinflower
- *Hypogymnia physodes*
- *Bryoria sp. (fuscescens) (See footnote above)*

Results

Injury to foliage of coniferous trees was evident before the well flare test. Mechanical injury from the well pad creation was evident. The roots of edge-growing trees were exposed and the foliar injury resembled that of drought. The results of the conifer tissue analysis from the twelve monitoring plots indicate that no changes occurred in the foliar Si:So or total sulphur concentrations in the vegetation as a result of the well flare test at b-79-J/93-P-4. There was a distinct decline in foliar Si:So from the time the foliage was collected from marked trees before the flare to the time after the flare. An old well site, now abandoned occurred to the north and may have had an impact on the pre-flare Si:So for Stations 5, 6 and 11. Lichen communities were nearly absent at most stations, and were not in sufficient quantity to allow for analysis. They were therefore not collected for post-flare tissue analysis. No monitors were used on this site as it was unknown when the post-assessment would occur and delays were expected to exceed the exposure time limits of the passive filters.



A7. Inorganic/organic sulphur ratios of sub-alpine fir tissues collected at each of the twelve monitoring stations around b-79-J/93-P-4 in February (pre-flare) and December (post-flare).



A8. Average total sulphur in lichen tissues collected at each of the twelve monitoring stations around b-79-J/93-P-4 in February (pre-flare).

A9. Crowns protected by snow loads in the forest northeast of the b-79-J/93-P-4 lease, in the area predicted by the modeling to receive high concentrations of emissions.

A10. Wind shearing, desiccation injury, and mechanical injury to lower canopy of lodgepole pine at well pad edge, pre-flare.

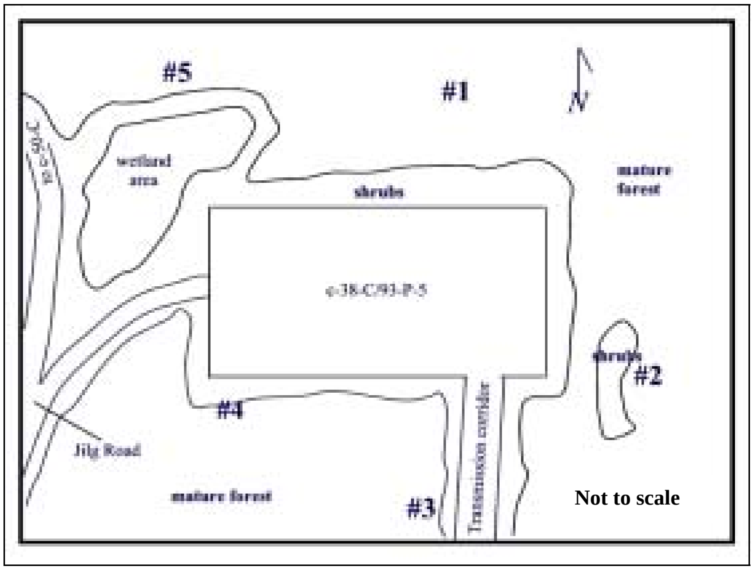
Well: c-38-C (d-39-C)/93-P-5

General Location: Lower Burnt River Rd.

UTM Coordinates: 572977E, 6126400N

Physiography: Sub-alpine hygric forest on low ridge above undulating plateau, wetlands nearby.

Biomonitoring Station Constellation:



Dates of Flare Events:

- October 31 – November 5, 2001 (intermittent flaring for a total of 18 hours)
- November 15 –19, 2001 (intermittent flaring for a total of 94 hours)

Dates of Field Work:

- September 20, 2001 (pre-flare assessment)
- August 12, 2002 (post-flare assessment)
- August 22, 2003 (secondary post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:

- Range: 216.2 µg/m^3 – 10157.1 µg/m^3 or 81.3 ppb – 3818.5 ppb (from the maximum value from each of the 6 stability classes)
- Mean value of 3141.2 µg/m^3 or 1180.9 ppb

Actual Modeled Maximum Ground Level SO_2 Concentration:

- 310 µg/m^3 or 116.5 ppb, 12 km north of the well site

Maximum Measured H_2S Content: 8.15%

Flared Volumes:

- A total volume of 417.0 e^3m^3 sour gas was flared during the October 31 - November 5, 2001 event
- A total volume of 3153.2 e^3m^3sour gas was flared during August 12, 2002 event

Meteorological Conditions:

- Predominant winds from the south and southeast during both flare events
- The flared volumes had the potential of causing foliar injury; additionally climatic condition (i.e. rain) during the flaring events may have contributed to elevated levels of injury.
- Temperatures ranged from ~ -4˚C to 10˚C.

Sample Components:

- Lichens: *Bryoria sp.*, *Hypogymnia sp.* (mainly *physodes*), and *Peltigera sp.*
- Conifers: sub-alpine fir and Engelmann spruce
- Passive SO_2 monitors (x = 5)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	Archived	889 ppm
Conifer total sulphur	928 ppm	898 ppm
Conifer Si:So	0.213	0.246

Passive Monitoring Results:

Station	SO_2 (ppb)
1a	0.28
1b	0.25
2a	0.19
2b	0.18
3a	0.22
3b	0.27
4a	0.23
4b	0.21
5a	n/a
5b	n/a
Mean	**0.24**

Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

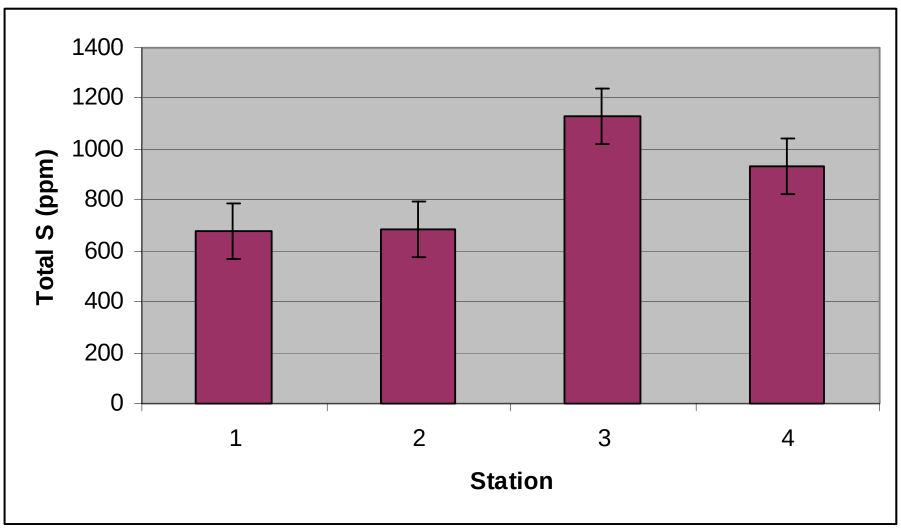
Species Composition:

- Engelmann spruce (dominant)
- sub-alpine fir (co-dominant)
- five-leaved bramble
- willow sp.
- white-flowered rhododendron
- crowberry
- pink mountain heather
- dwarf blueberry
- black huckleberry
- one-sided wintergreen
- Sitka valerian
- arrow-leaved groundsel
- common horsetail
- hawkweed sp.
- pearly everlasting
- fireweed
- small-flowered woodrush
- Indian hellebore
- beaked sedge
- Queen’s cup
- hair bentgrass
- *Hypogymnia physodes*
- *Bryoria sp.(fuscescens and capillaris)*
- *Peltigera membranacea*
- *Peltigera canina*
- *Dicranum fuscescens*
- *Cladina mitis*
- *Cladonia gracilis*
- *Cladonia chlorophaea*

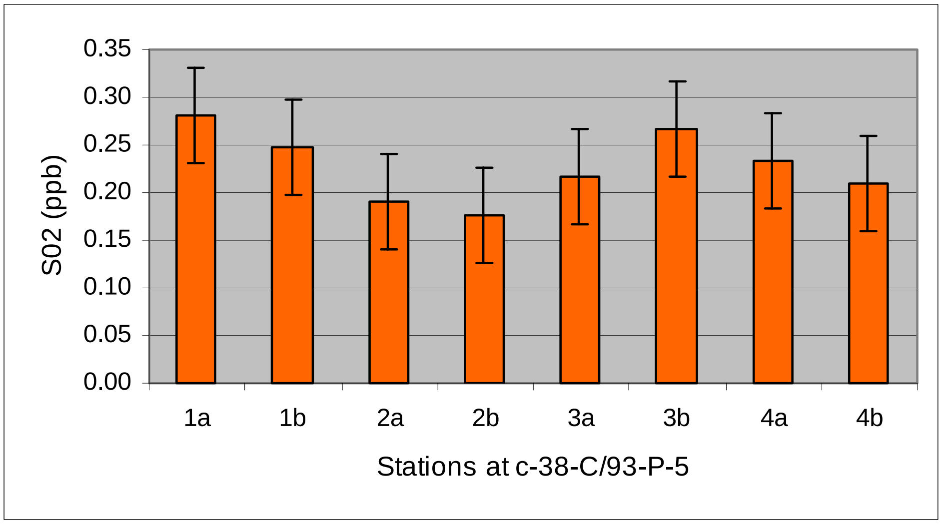
Results

The coniferous foliar Si:So values increased slightly between the pre-flare assessment and the post-flare assessment, although a considerable delay occurred between the flare events and the post-flare assessment. Slight reddening of the tips of sub-alpine fir needles was noted following the flare. There was some fall coloration in the rhododendron present before the flare. The discoloration of the coniferous tissue could have been due to both previous drought and/or winter injury. No visible change in the under-story vegetation occurred. There are no results at Station 5 as it was inaccessible during the early part of the field season following the flare test due to road construction at a neighboring well (d-50-C). The passive monitors show low sulphur dioxide concentrations due to an exceedingly lengthy exposure period.

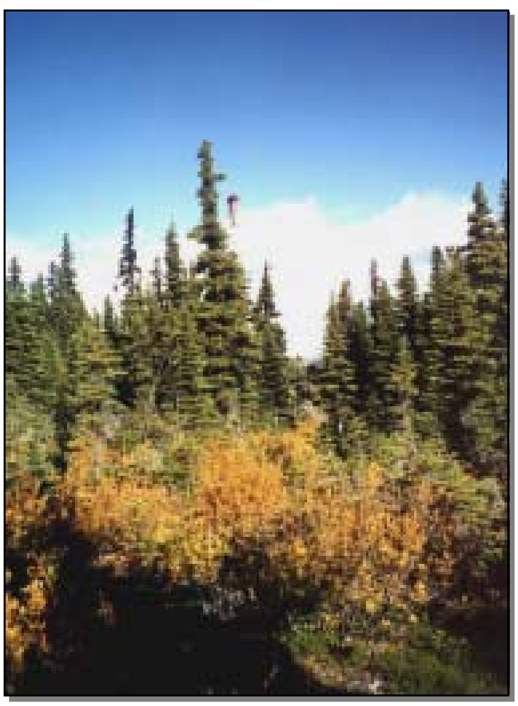
A11. Average inorganic/organic sulphur ratios of conifer tissues collected at each of the four monitoring stations around c-38-C/93-P-5 in September (pre-flare) and August (post-flare). Note: Station 5 was inaccessible during the post-flare assessment.

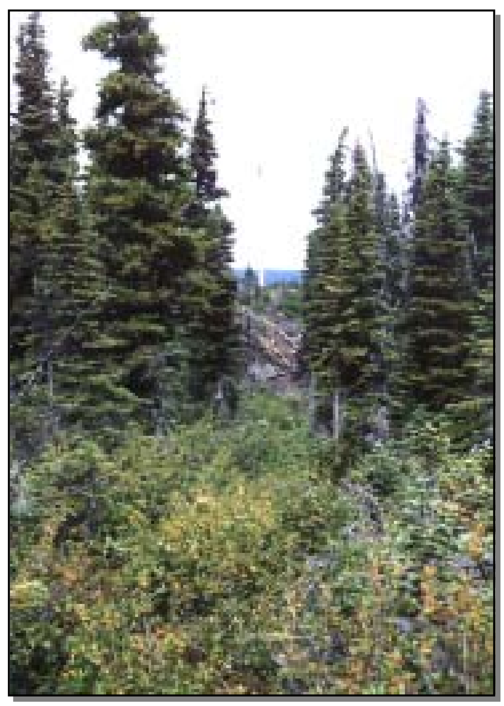


A12. Average total sulphur in lichen tissues collected at each of the four monitoring stations around c-38-C/93-P-5 in August (post-flare). Note: Station 5 was inaccessible during the post-flare assessment.



A13. Concentrations of sulphur dioxide (ppb) registered by the passive monitors located at the monitoring stations around c-38-C/93-P-5. Two samplers per station. Exposure period: September 20, 2001 to August 12, 2002. Note: Station 5 was inaccessible during the post-flare assessment; therefore no data is shown from this station.





A14 (left). Pre-flare vegetation condition at c-38-C/93-P-5, Station 2. The colour of the shrub community is caused by fall coloration.

A15 (right). Post-flare vegetation condition at c-38-C/93-P5, Station 2.

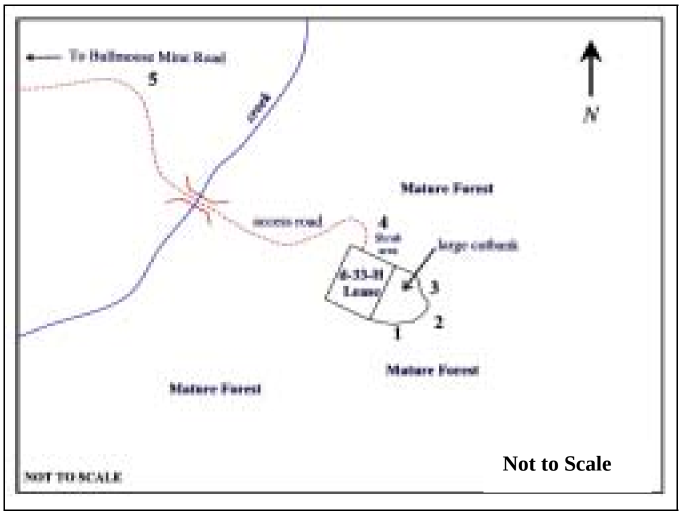
Well: c-23-H (d-33-H)/93-P-4

General Location: Bullmoose River

UTM Coordinates: 593710E, 6108200N

Physiography: Upper montane and riparian forest on a north-facing ridge

Biomonitoring Station Constellation:



Dates of Flare Events:
- December 4 – 5, 2001 for 19 hours
- December 5 –10, 2001 for 110 hours

Dates of Field Work:
- September 22, 2001 (pre-flare assessment)
- August 12, 2002 (post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:
- Range: 1539 µg/m^3 – 55614 µg/m^3 or 578.6 ppb – 20907.5 (from the maximum value from each of the 6 stability classes)
- Mean value of 17395.5 µg/m^3 or 6539.7 ppb

Actual Modeled Maximum Ground Level SO_2 Concentration:
- 43849 µg/m^3 or 16,485 ppb, to the east of the well on December 5

Maximum Measured H_2S Content: 15.76%

Meteorological Conditions:

- Predominant winds were from the South
- Wind speeds measured during the flare test ranged from 0.7 – 12.7 m/s
- Temperatures ranged from -12˚C to 2˚C during the December flare events

Sample Components:

- Lichens: *Bryoria sp.*, *Hypogymnia sp.* (mainly *physodes*) and *Peltigera sp.* (mainly *aphthosa*)
- Conifers: Sub-alpine fir
- Passive SO_2 monitors (x = 5)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	No pre-flare collections	1112 ppm
Conifer total sulphur	1147 ppm	1183 ppm
Conifer Si:So	0.278	0.412

Passive Monitoring Results:

Station	SO_2 (ppb)
1a	1.33
1b	1.32
2a	1.14
2b	1.20
3a	1.44
3b	1.36
4a	1.44
4b	1.56
5a	1.21
Mean	**1.33**

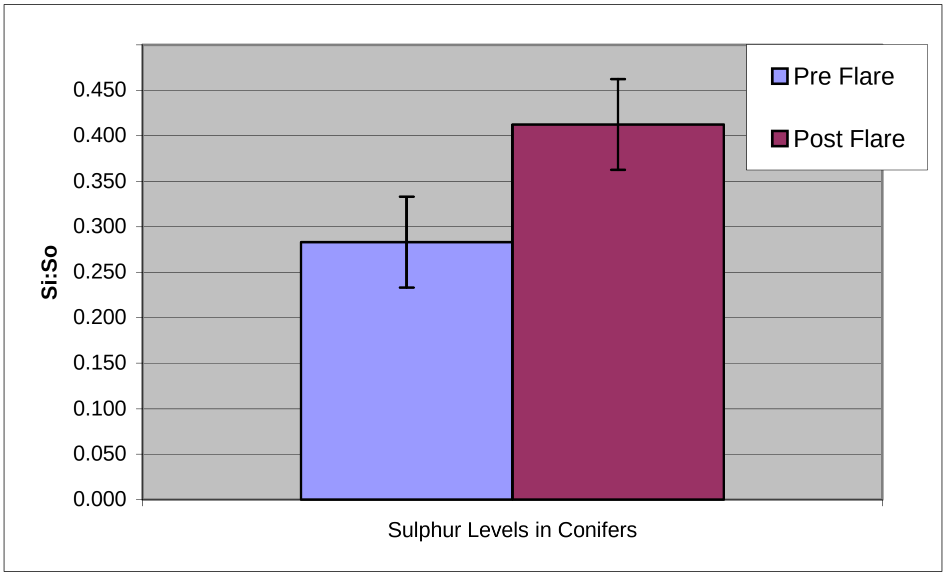
Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

Species Composition:

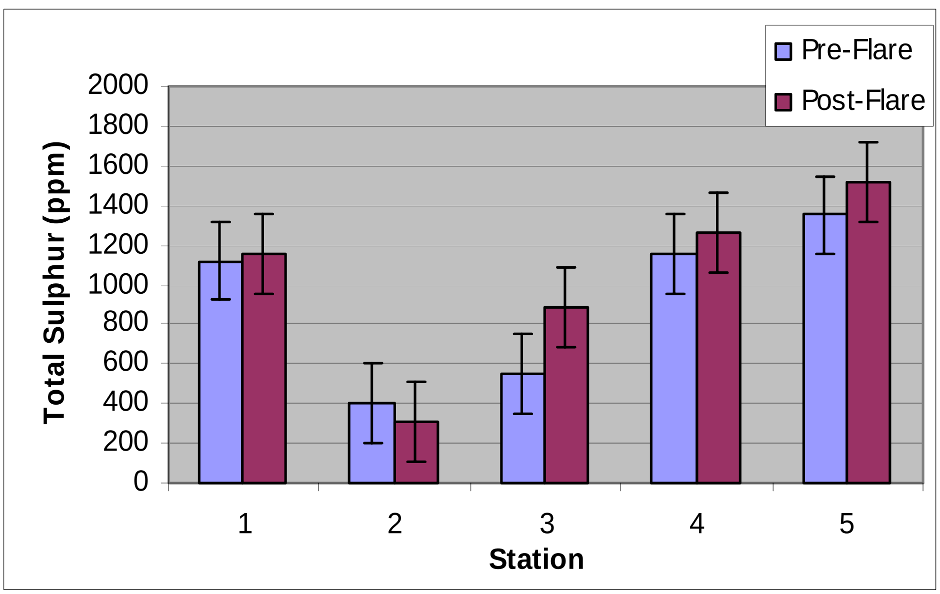
- Engelmann spruce
- sub-alpine fir
- white-flowered rhododendron
- bunchberry
- five-leaved bramble
- black gooseberry
- black huckleberry
- Sitka mountain-ash
- green wintergreen
- pink wintergreen
- twinflower
- Sitka valerian
- arctic lupine
- western meadowrue
- willowherb sp.
- clasping twisted stalk
- oak fern
- *Peltigera aphthosa*
- *Peltigera venosa*
- *Bryoria sp.*
- *Hypogymnia physodes*

Results

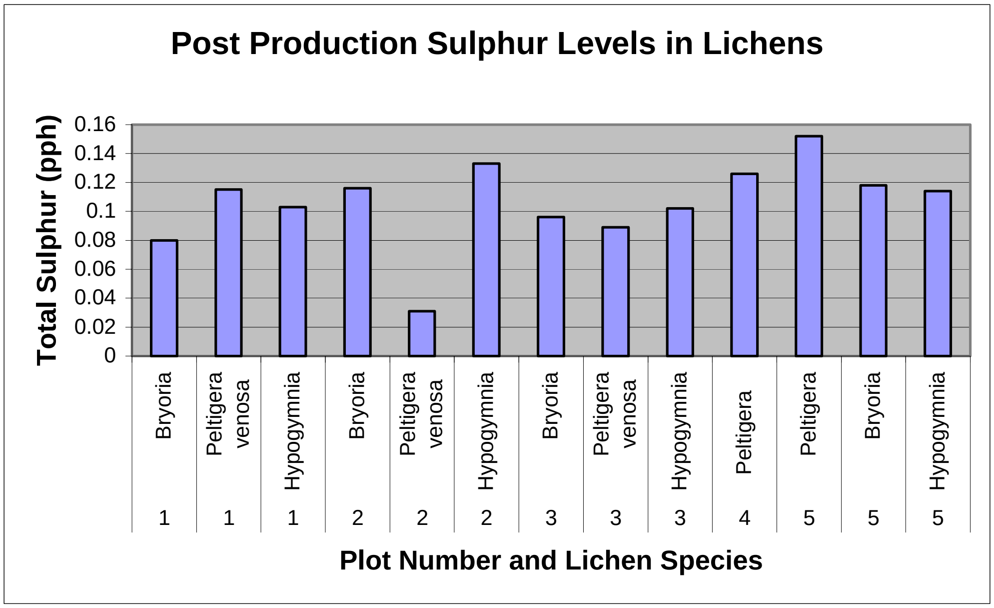
The sulphur chemistry analysis of the lichen samples taken after the flare test indicated a slight increase in total sulphur concentrations post-flare in areas down wind of the well. Sulphur inorganic to organic ratios in conifers were also slightly elevated in these areas. Very slight sulphur dioxide injury to sub-alpine fir was noted in the northeastern plot (Station 5). No visible injury was evident above the well site. A slight improvement in the condition of the under-story plants (such as black current, mountain ash, alder, and thimbleberry) was noted. This vegetation was under snow during the flare but was observed during the pre- and post-assessment. This improvement was likely due to relief from drought effects from the previous growing season.



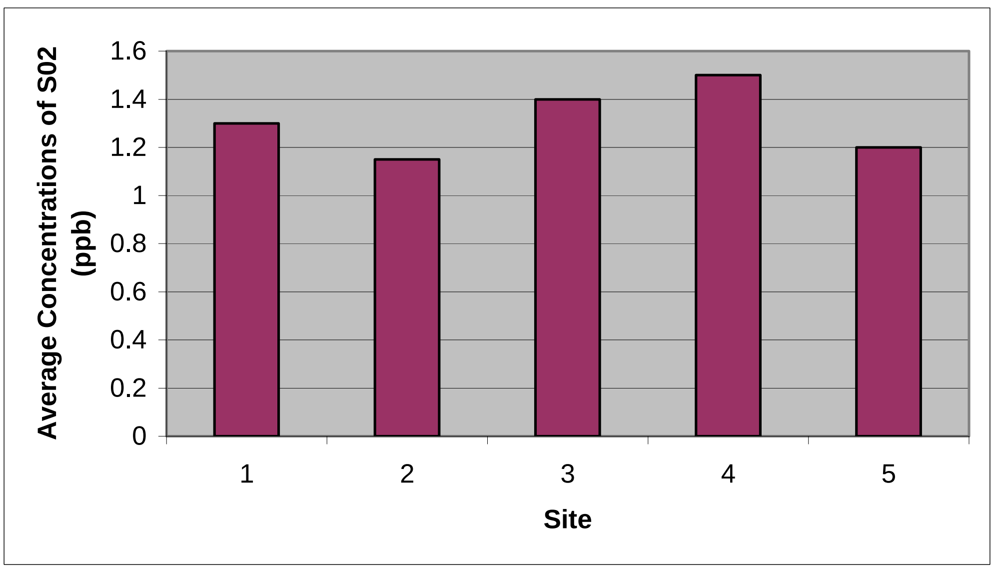
A16. Average compiled inorganic/organic sulphur ratios from sub-alpine fir tissues collected at each of the five monitoring stations around c-23-H (d-33-H)/93-P-4 in September (pre-flare) and August (post-flare).



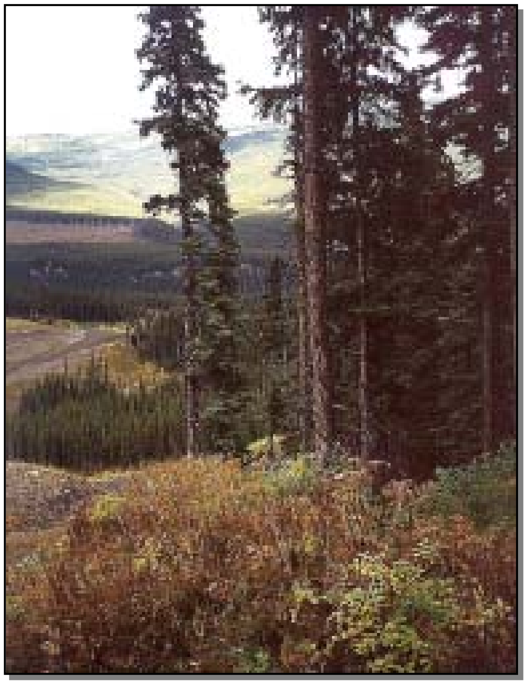
A17. Average total sulphur in Peltigera sp. collected at each of the five monitoring stations around c-23-H (d-33-H)/93-P-4 in September (pre-flare) and August (post-flare).



A18. Average total sulphur in lichen tissues collected at each of the five monitoring stations around c-23-H (d-33-H)/93-P-4 in August (post-flare).



A19. Concentrations of sulphur dioxide (ppb) registered by the passive monitors located at the five monitoring stations around c-23-H (d-33-H)/93-P-4. Exposure period: September 22, 2001 to August 12, 2002.



A20. Pre-flare vegetation condition on east edge of c-23-H (d-33-H)/93-P-4 lease.

A21. Post-flare vegetation condition on east edge of c-23-H (d-33-H)/93-P-4 lease

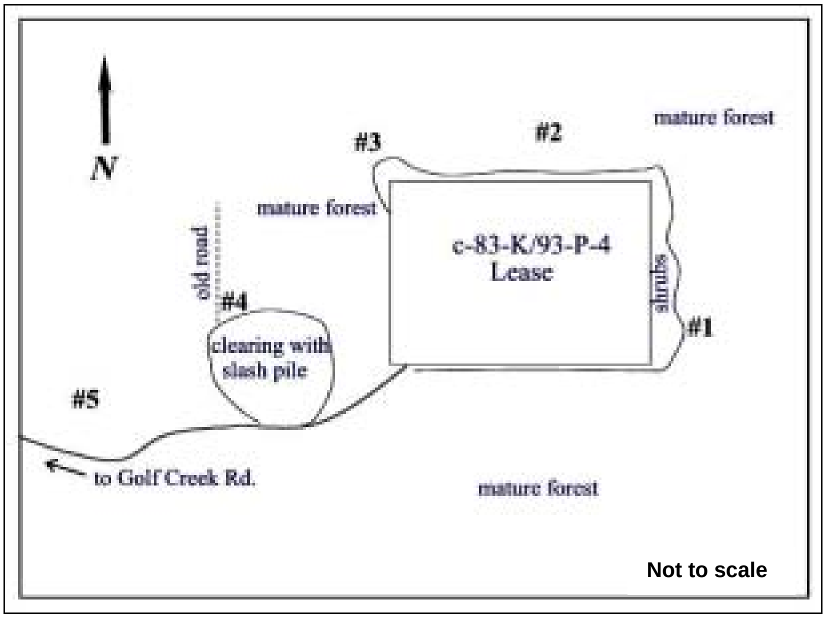
Well: c-83-K/93-P-4

General Location: Rocky Creek, near Sukunka River

UTM Coordinates: 577294E, 6121795N

Physiography: Upper montane to sub-alpine sub-ridge on the edge of the Pine Plateau.

Biomonitoring Station Constellation:



Date of Flare Event:

- December 11 -13, 2002 for 51 hours

Dates of Field Work:

- August 12, 2002 (pre-flare assessment)
- December 15, 2002 (post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:

- Range: 737 µg/m^3 - 11298 µg/m^3 or 277 ppb – 4247 ppb (from the maximum value from each of the 6 stability classes)
- Mean value of 3391 µg/m^3 or 1274.8 ppb

Actual Modeled Maximum Ground Level SO_2 Concentration:

- 140 µg/m^3 or 53 ppb, approximately 11.5 km north-northeast of the well

Maximum Measured H_2S Content: 7.0%

Meteorological Conditions:

- Predominant winds are from the South
- Wind speeds ranged from 2.0 to 7.0 m/s
- Temperatures ranged from -4˚C to 6˚C during the flare event

Sample Components:

- Lichens: *Bryoria sp.* and *Hypogymnia sp.* (mainly *physodes*)
- Conifers: Sub-alpine fir
- Passive SO_2 monitors (x = 5)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	656 ppm	940 ppm
Conifer total sulphur	1080 ppm	940 ppm
Conifer Si:So (mean)	0.215	0.200

Passive Monitoring Results:

Station	SO_2 (ppb)
1	0.20
2	0.20
3	0.20
4	0.20
5	0.10
Mean	**0.18**

Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

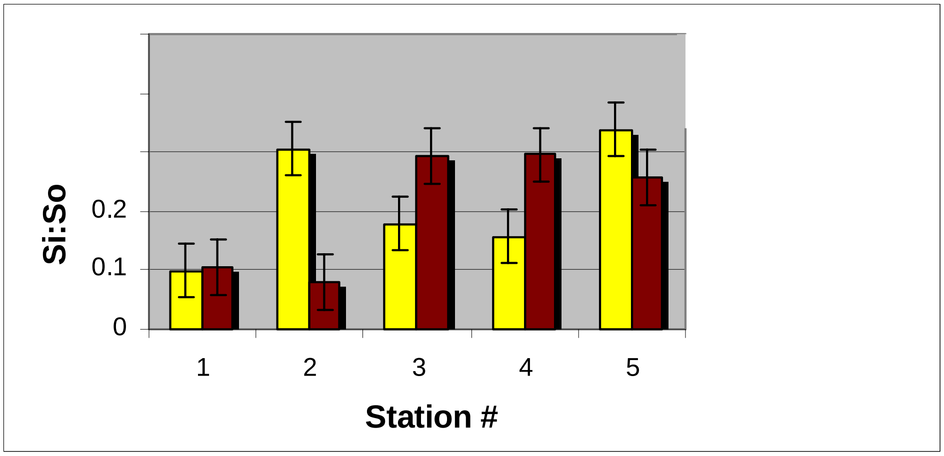
Species Composition:

- sub-alpine fir (dominant)
- Engelmann spruce (co-dominant)
- pink mountain-heather
- crowberry
- white flowered-rhododendron
- black huckleberry
- five-leaved bramble
- queens’ cup
- oak fern
- indian hellebore
- common horsetail
- mountain arnica
- western meadowrue
- one-sided wintergreen
- violet sp.
- fireweed
- willowherb sp.
- Cow-parsnip
- kneeling angelica
- stiff clubmoss
- red-stemmed feathermoss

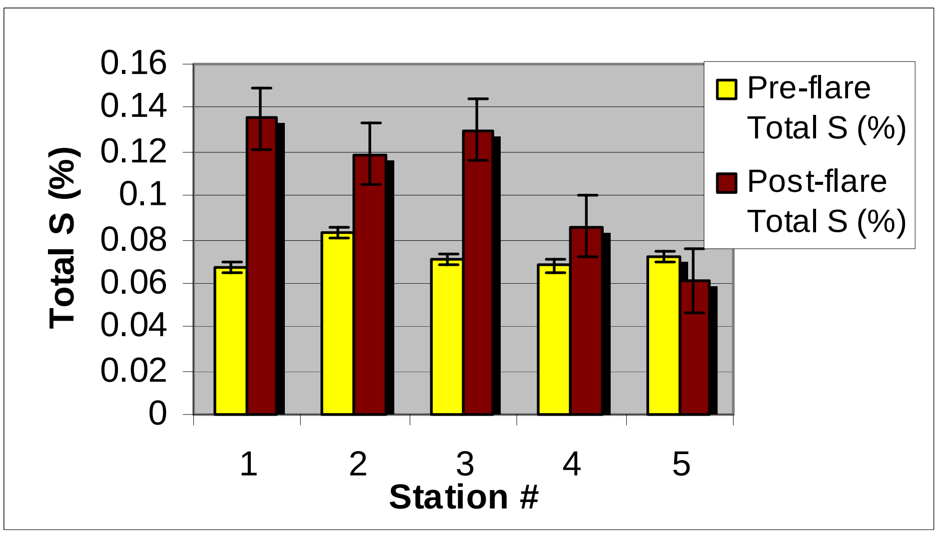
- *Hypogymnia physodes*
- *Bryoria sp.*
- *Alectoria sarmentosa*
- *Parmeliopsis ambigua*
- *Parmeliopsis hyperopta*
- *Parmelia sulcata*
- *Cladonia pyxidata*
- *Cladonia sp.*
- *Cladina mitis*

Results

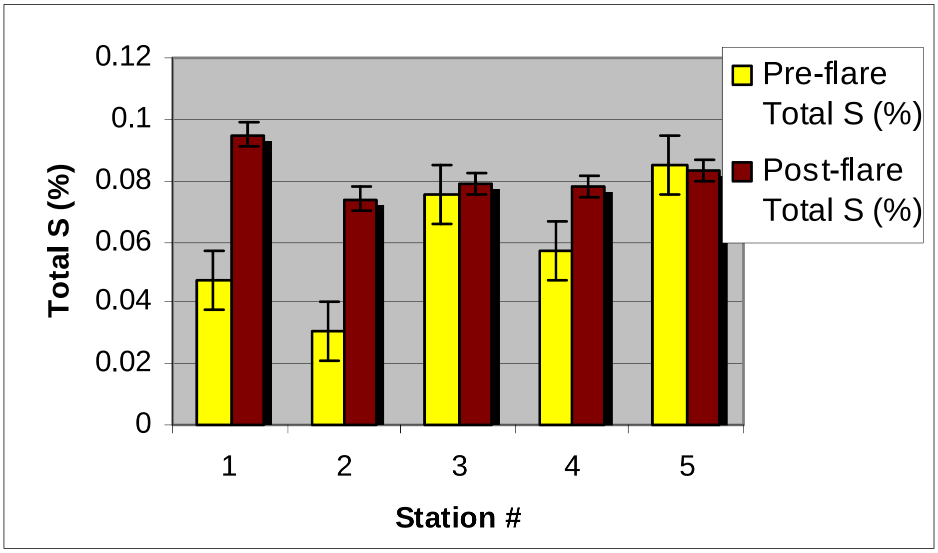
There was visible injury to the trees at this site, but it could not be singly attributed to sulphur dioxide. Symptoms of drought, winter burn and physical injury from machines were seen on the trees on the edge of the well pad prior to the flare test. Reddening in conifer foliage increased slightly between the time of the pre-flare assessment to the time of the post-flare assessment. The pad creation may have pre-disposed trees at this site to sulphur dioxide injury. Sulphur in lichens increased from pre to post-flare, especially close to the well. Sulphur inorganic to organic ratios in the conifers increased at stations to the northeast and east of the well, respectively.



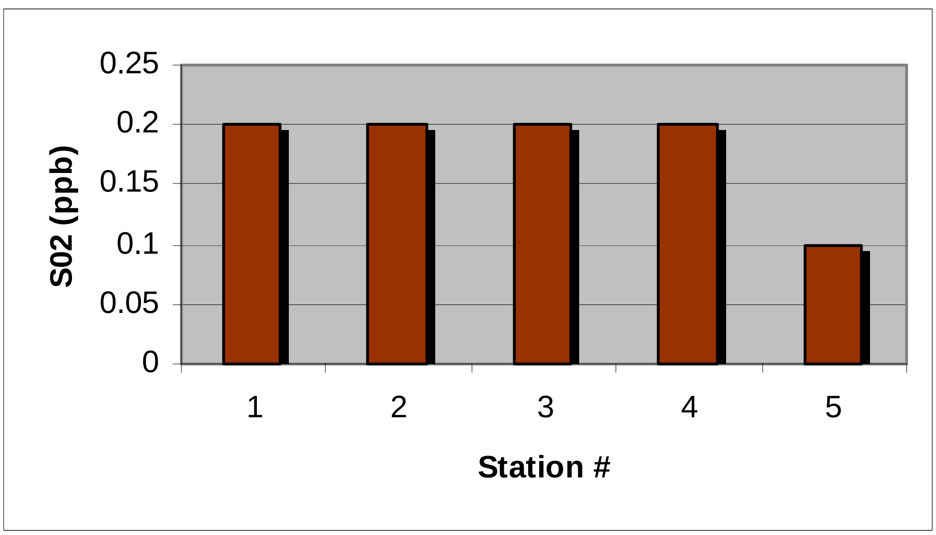
A22. Average inorganic/organic sulphur ratios of sub-alpine fir tissues collected at each of the five monitoring stations around c-83-K/93-P-4 in August (pre-flare) and December (post-flare).



A23. Average total sulphur in Bryoria sp. collected at each of the five monitoring stations around c-83-K/93-P-4 in September (pre-flare) and August (post-flare).

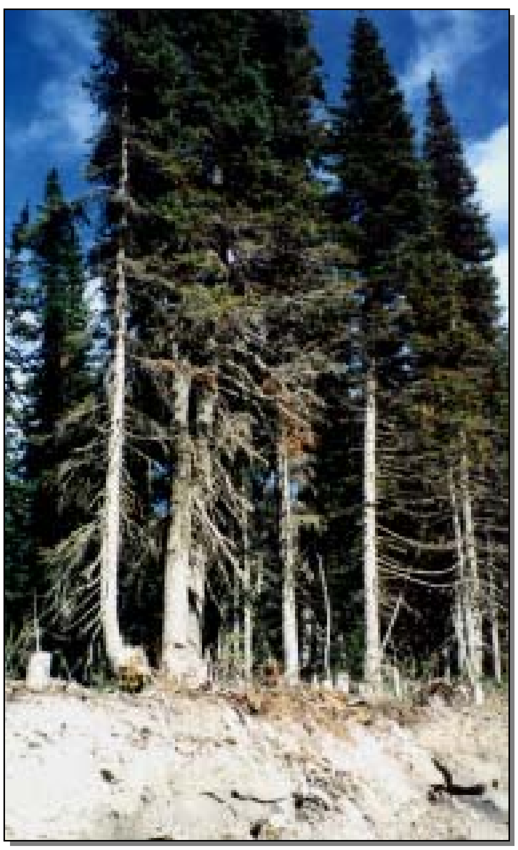


A24. Average total sulphur in Hypogymnia physodes collected at each of the five monitoring stations around c-83-K/93-P-4 in September (pre-flare) and August (post-flare).



A25. Concentrations of sulphur dioxide (ppb) registered by the passive monitors at the monitoring stations around c-83-K/93-P-4. Exposure period: August 12 to December 15, 2002.

A26. Winter injury at c-83-K/93-P-4 Station 1, on exposed sub-alpine fir bordering well pad prior to flaring in August 2002.



A27. Mechanical injury to lower limbs of sub-alpine fir at the c-83-K/93-P-4 well pad edge, also, some wind shearing is evident in the crowns, pre-flare, August 2002. Note the roots protruding from the excavated edge of the well pad.

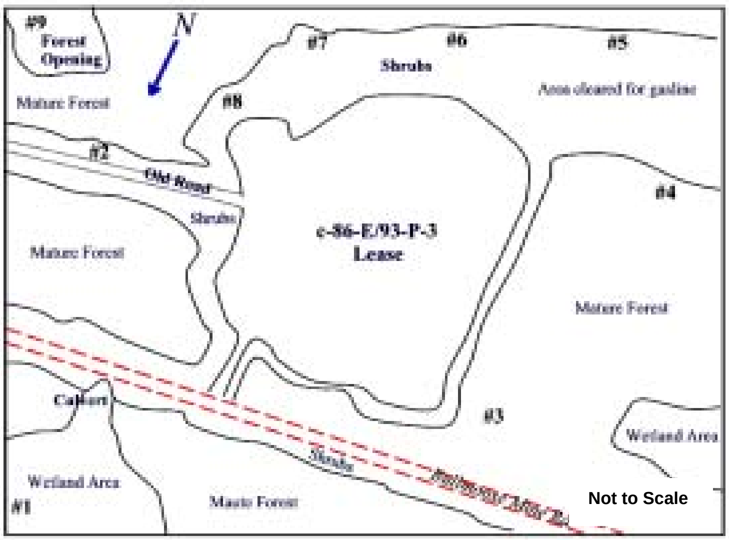
Well: c-86-E/93-P-3

General Location: Bullmoose River

UTM Coordinates: 699045E, 6113132N

Physiography: Windward lower slope of a wide, serpentine river valley bottom

Biomonitoring Station Constellation:



Date of Flare Event:

- January 29 - 30, 2003 for a total of 8 hours

Dates of Field Work:

- December 13, 2002 (pre-assessment)
- May 8, 2003 (post-flare assessment)
- June 13, 2003 (secondary post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:

- Range: 2432 µg/m^3 – 118 149 µg/m^3 or 914 ppb – 44 417 ppb (from 6 stability classes through 4 scenarios)
- Mean value of 32 932.25 µg/m^3 or 12 380.55 ppb

Actual Modeled Maximum Ground Level SO_2 Concentrations:

- January 29th 1242 µg/m^3 or 467 ppb, to the north of the well
- January 30th 1424 µg/m^3 or 535 ppb, to the north of the well

Maximum Measured H_2S Content: 26.15%

Meteorological Conditions:
- Predominant winds are from the South
- Wind speeds ranged from 1.2 to 4.6 m/s
- Temperature ranged from -1˚C to 3˚C during flare event

Sample Components:
- Lichens: not enough arboreal lichens to sample
- Conifers: Sub-alpine fir and Engelmann spruce
- Passive SO_2 monitors (x = 9)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	No tissue available for analysis	No tissue available for analysis
Conifer total sulphur	1695 ppm	1488 ppm
Conifer Si:So	0.672	0.390

Passive Monitoring Results:

Station	SO_2 (ppb)
1	5.90
2	4.10
3	6.30
4	3.20
5	3.80
6	3.30
7	3.50
8	4.50
9	3.50
Mean	**4.23**

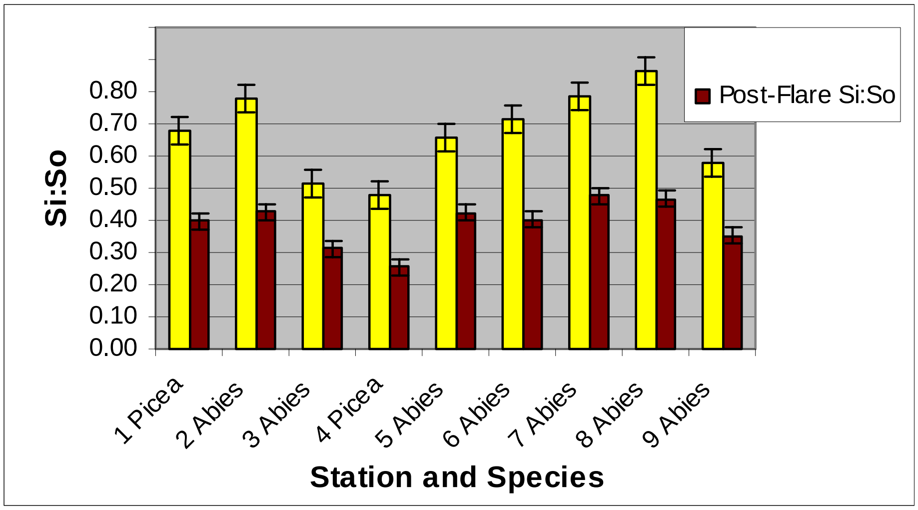
Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

Species Composition:
List is incomplete due to snow cover

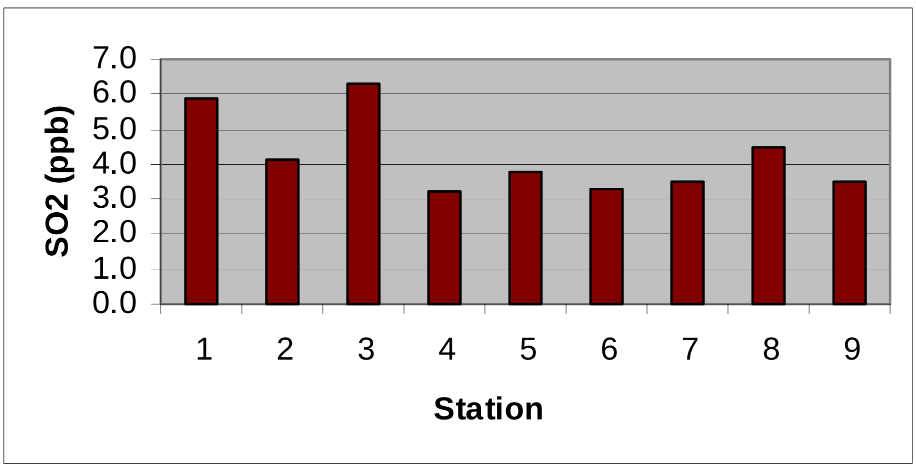
- Engelmann spruce (dominant)
- sub-alpine fir (co-dominant)
- trembling aspen
- balsam poplar
- green alder
- baldhip rose
- white-flowered rhododendron
- crowberry
- twinflower
- five-leaved bramble
- bunchberry
- thimbleberry
- cow parsnip
- pink wintergreen
- grouseberry
- *Cladonia spp.*
- *Parmelia sulcata*
- *Parmeliopsis ambigua*
- *Parmeliopsis hyperopta*

Results

This well site had extensive injury noted during the pre-flare assessment. Most of the injury ranged in age from recent (< 1 year) to several years old. The older and recent injury is likely due to the neighboring Bullmoose Gas Plant (d-77-E/93-P-3). A path of injury extends from the plant, across the well site and down the valley for a distance of approximately 1 .5 km, becoming sporadic and confined to single trees and shrubs at the margins of the area of injury. The only species of lichens present are known to be relatively resistant to sulphur dioxide. Lichens present had twisting and bleaching symptoms, typical of chronic exposure to sulphur dioxide. In all cases the foliar Si:So declined in tissue between the pre and post-flare assessment, possibly due to metabolic uptake of sulphate during the breaking of dormancy in April. Small amounts of injury were attributable to the c-86-E/93-P-3 well flare test, as this injury has effected the most recent year's growth.



A28. Average inorganic/organic sulphur ratios of conifer tissues collected at each of the nine monitoring stations around c-86-E/93-P-3 in December (pre-flare) and May (post-flare).



A29. Concentrations of sulphur dioxide (ppb) registered by the passive monitors at the nine monitoring stations around c-86-E/93-P-3. Exposure period: December 13, 2002 to May 8, 2003.

A30. Post-flare minor acute sulphur dioxide injury at Station 1 to current year's growth, this injury is likely due to the flaring episodes at c-86-E/93-P-3. Note it occurs on the more sensitive second year needles.

A31. Station 3 pre-flare, showing severe, variable-aged injury to sub-alpine fir at c-86-E lease edge.

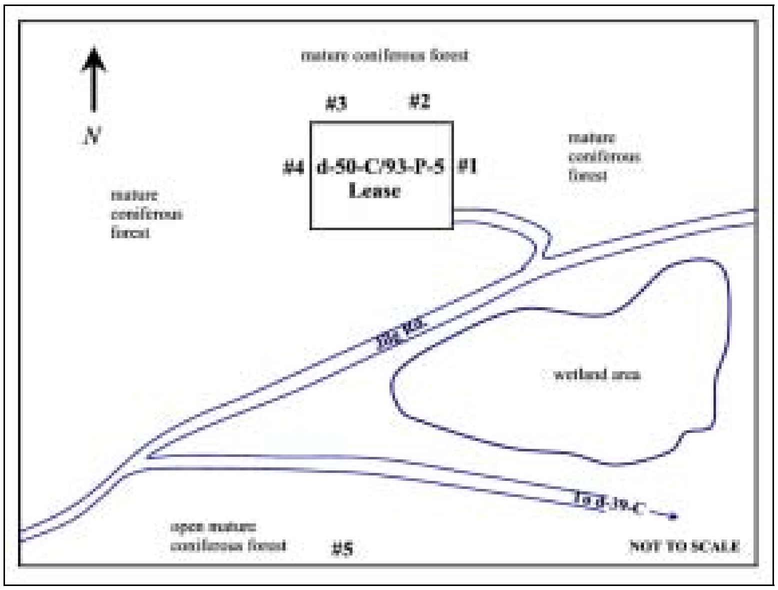
Well: d-50-C/93-P-5

General Location: Lower Burnt River Road

UTM Coordinates: 571829E, 6127610N

Physiography: Edge of sub-ridge on undulating plateau in mid sub-alpine

Biomonitoring Station Constellation:



Dates of Flare Events:

- September 9, 2003 for a total of 10 hours
- September 11 – 13, 2003 for a total of 54 hours

Dates of Field Work:

- December 14, 2002 (pre-flare assessment)
- September 20, 2003 (post-flare assessment)

Predicted Maximum Ground Level 1-hour SO_2 Concentrations:

- Range: 302 µg/m^3 - 7612 µg/m^3 or 113.5 ppb – 2861.7 ppb (from maximum values from each of the six stability classes)
- Mean value of 2480.8 µg/m^3 or 932.6 ppb

Actual Modeled Maximum Ground Level SO_2 Concentration:

- 357 µg/m^3 or 134 ppb, to the north of the well

Maximum Measured H_2S Content: 6.00%

Meteorological Conditions:
- Winds are predominately from the west-northwest
- Winds speeds ranged from 3.2 to 12.0 m/s
- Temperatures ranged from 3˚C to 11˚C during the flare events

Sample Components:
- Lichens: *Bryoria sp.*
- Conifers: Sub-alpine fir
- Passive SO_2 monitors (x = 5)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	754 ppm	970 ppm
Conifer total sulphur	842 ppm (green tissue)	1042 ppm (green tissue) 910 ppm (red tissue)
Conifer Si:So	0.147 (green tissue)	0.311 (green tissue) 0.244 (red tissue)

Passive Monitoring Results:

Station	SO_2 (ppb)
1	1.80
2	damaged
3	0.50
4	0.40
5	0.30
Mean	**0.75**

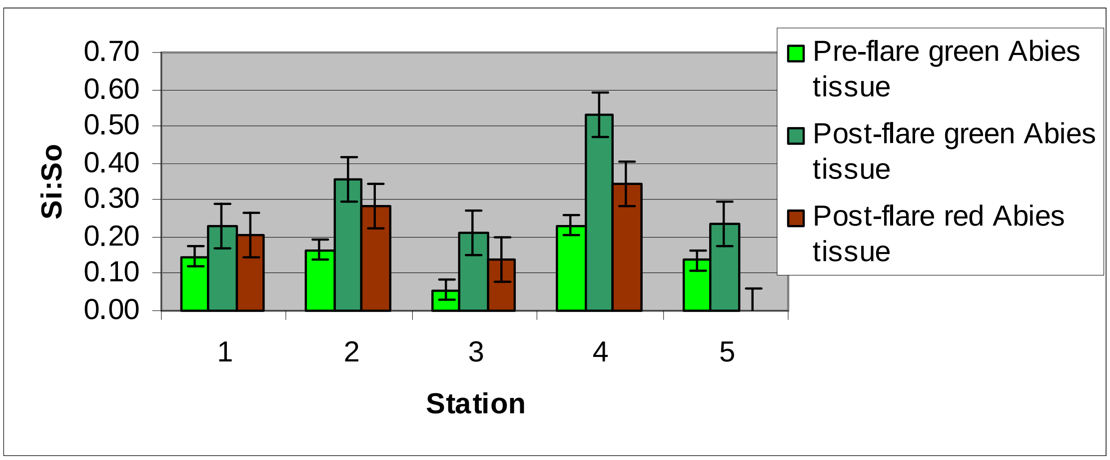
Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

Species Composition:
List is incomplete due to snow cover

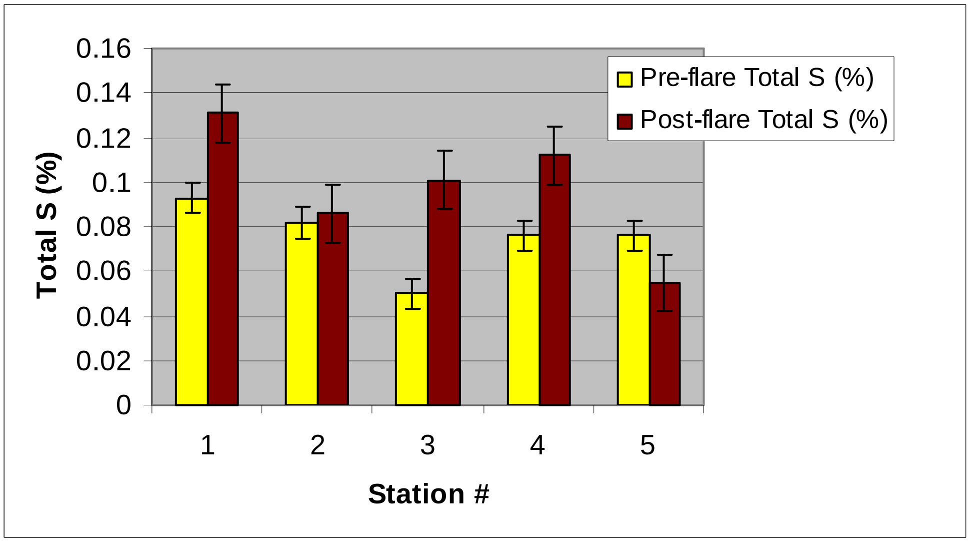
- sub-alpine fir (dominant)
- lodgepole pine (co-dominant)
- black spruce (co-dominant)
- white-flowered rhododendron
- pink mountain-heather
- crowberry
- *Hypogymnia physodes*
- *Hypogymnia imshaugii*
- *Parmeliopsis hyperopta*
- *Parmeliopsis ambigua*
- *Alectoria sarmentosa*
- *Bryoria sp.*

Results

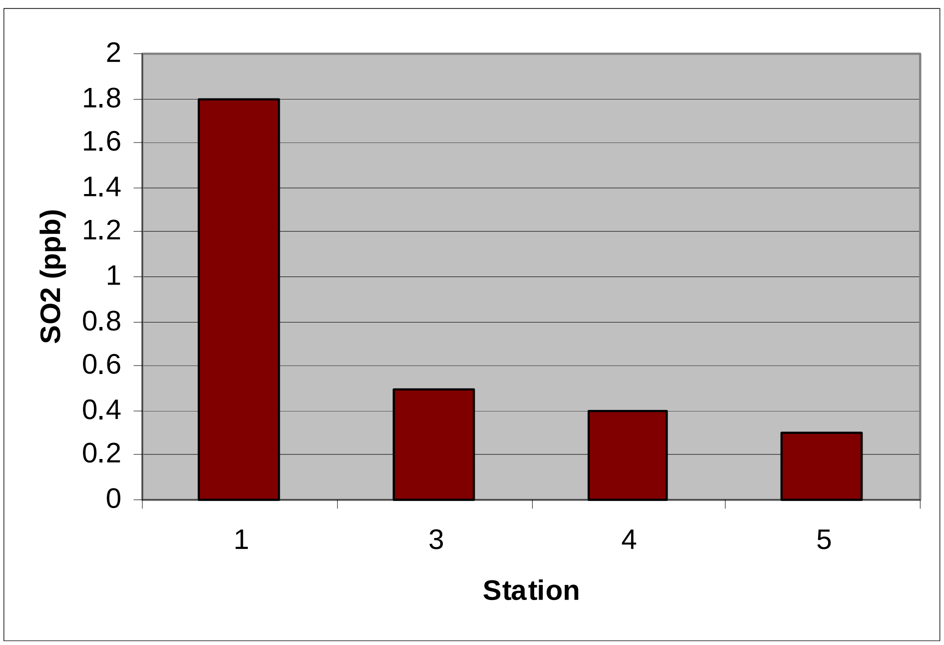
This flare test was delayed following the initial pre-flare assessment. As in other well flare tests, the maximum injury at this well site has occurred in the area directly adjacent to the lease and in the direction of the prevailing winds. Injury was present before the flare-test, however. Some of the injury appears to be influenced by rock blasting on the well pad edge. Slight new injury to rhododendron was noted after the well flare test. Sulphur dioxide exposures were highest on the pad edge in the direction of prevailing wind during the flare test. Injury to trees was noted to have increased from the pre-flare assessment to the post-flare assessment. The lichen tissues showed an increase in total sulphur following the flare test. The injury at this well may be due to a combination of acute exposure to sulphur dioxide and physical injury from blasting, i.e. predisposition to injury.



A32. Average inorganic/organic sulphur ratios of conifer tissues collected at each of the five monitoring stations around d-50-C/93-P-5 in December (pre-flare) and September (post-flare).



A33. Average total sulphur in lichen tissues collected at each of the five monitoring stations around d-50-C/93-P-5 in December (pre-flare) and September (post-flare).



A34. Concentrations of sulphur dioxide (ppb) registered by the passive monitors at the five monitoring stations around d-50-C/93-P-5. Exposure period: December 14, 2002 to September 20, 2003. Note: filter from Station 2 was damaged; therefore no results are available at this station.

A35. Injury noted during pre-flare assessment at d-50-C/93-P-5 Station 1, to sub-alpine fir. Photo taken during post-flare assessment.

A36. Injury to sub-alpine fir noted in pre-flare assessment, between Stations 1 and 2 at d-50-C/93-P-5. Photo taken during post-flare assessment.

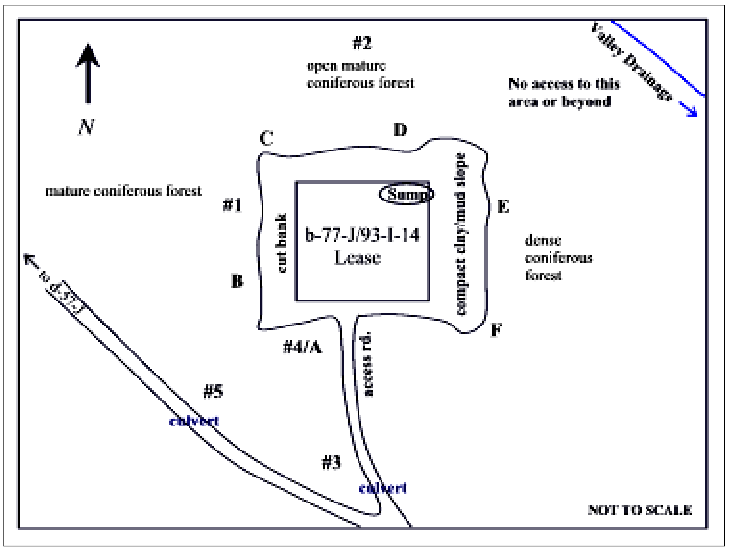
Well: b-77-J/93-I-14

General Location: Murray River

UTM Coordinates: 614484E, 6093313N

Physiography: Flank of the mountain range west of the Murray River in montane to sub-alpine forest

Biomonitoring Station Constellation:



Date of Flare Event:

- August 23, 2003 for a total of 2 hours

Dates of Field Work:

- June 20, 2003 (pre-flare assessment)
- September 18, 2003 (post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:

- Range: 1512 µg/m^3 – 44 183 µg/m^3 or 568.4 ppb – 16 610 ppb (from 6 stability classes through 4 scenarios), west and northwest of well
- Mean value of 11 703.46 µg/m^3 or 4399.8 ppb

Actual Modeled Maximum Ground Level SO_2 Concentrations:

- 389 µg/m^3 or 146 ppb at 13:00 on August 23, northeast of the well
- 275 µg/m^3 or 103 ppb at 14:00 on August 23, northeast of the well

Maximum Measured H_2S Content: 25.0%

Meteorological Conditions:

- Winds are predominately from the west-southwest and south-southwest
- Winds speeds ranged from 2.2 to 2.9 m/s
- Temperature ranged from 7.2˚C to 7.4˚C during the flare

Sample Components:

- Lichens: *Bryoria sp.* and *Hypogymnia sp.*
- Conifers: Sub-alpine fir
- Passive SO_2 monitors (x = 5)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	496 ppm *(Hypogymnia sp.)* 621 ppm *(Bryoria sp.)*	700 ppm *(Hypogymnia sp.)* 623 ppm *(Bryoria sp.)*
Conifer total sulphur	798 ppm	847 ppm
Conifer Si:So	0.1098	0.1397

Passive Monitoring Results:

Station	SO_2 (ppb)
1	0.30
2	0.30
3	0.10
4	damaged
5	0.10
Mean	**0.20**

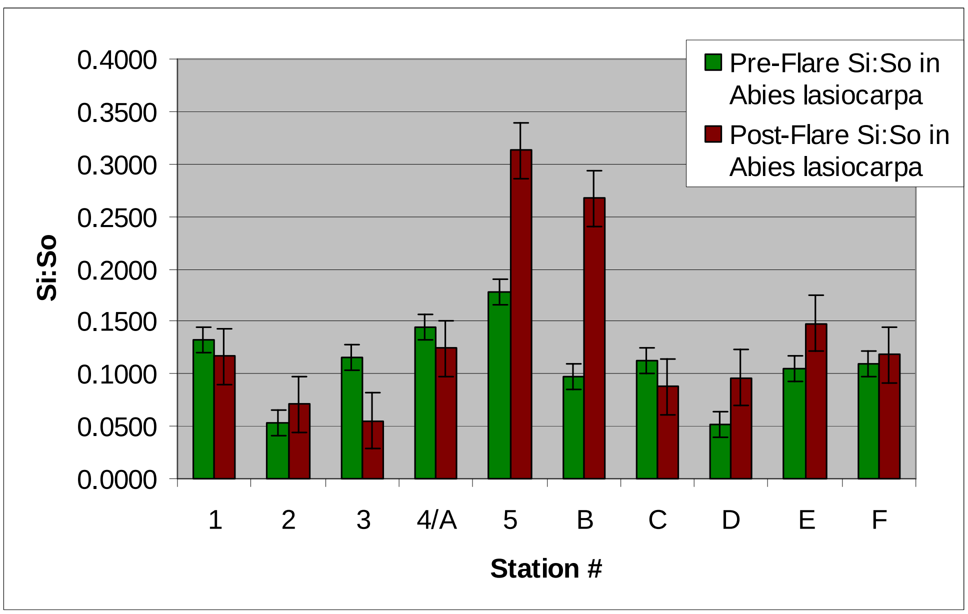
Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

Species Composition:

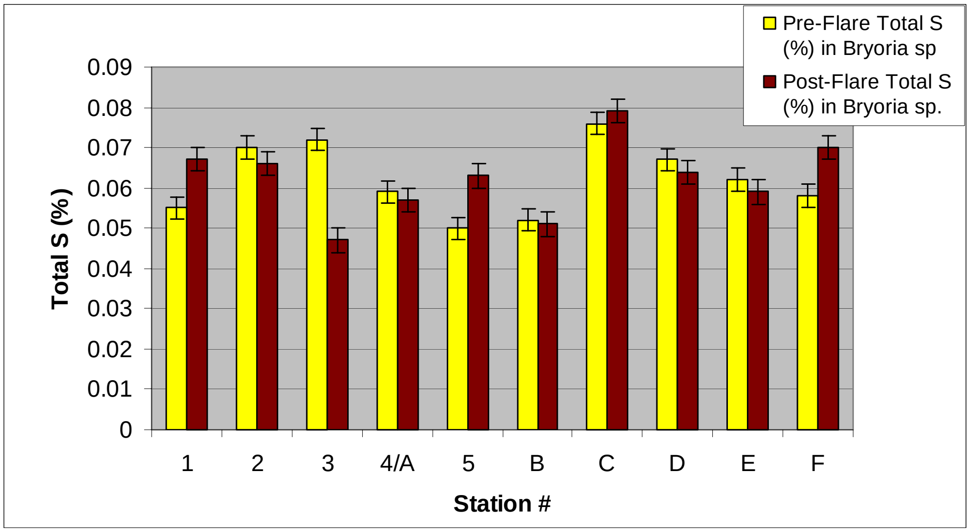
- Engelmann spruce
- black spruce
- sub-alpine fir
- lodgepole pine
- Sitka alder
- bunchberry
- Douglas maple
- white-flowered rhododendron
- black huckleberry
- black gooseberry
- clasping twisted stalk
- common horsetail
- western meadowrue
- thimbleberry
- pink mountain-heather
- false Solomon's-seal
- Indian hellebore
- wintergreen sp.
- *Bryoria sp.*
- *Hypogymnia physodes*
- *Usnea lapponica*
- *Parmelia sulcata*
- *Peltigera sp.*
- *Cetraria spp*

Results

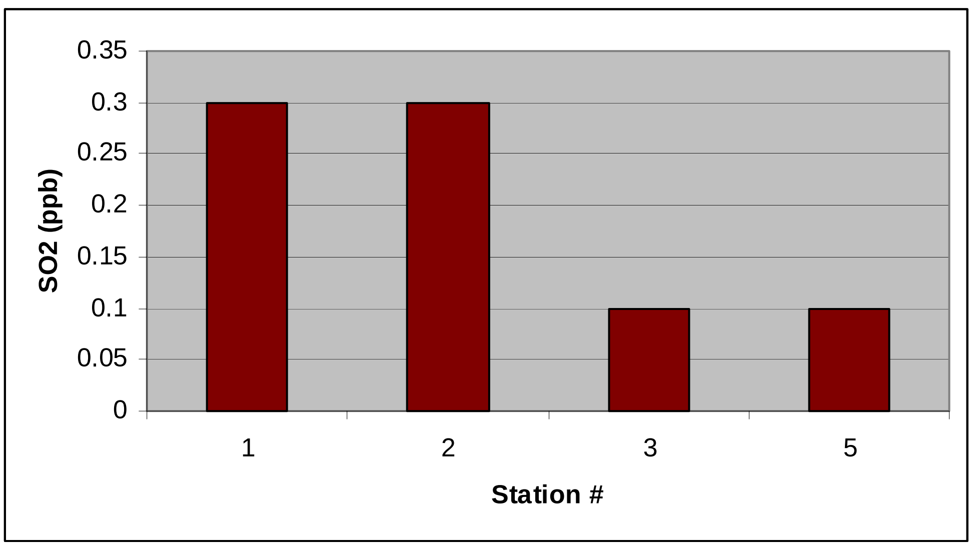
Some residual red-belt injury (i.e. warm Chinook winds followed by a cold-snap; i.e. climatic injury) from the winter prior to the flare tests was noted in both the pre-flare assessment and again following the flare test. The brightness of the red coloration in the foliage had faded in the period between the first assessment and the post-flare assessment. Trees on this ridge have shown 'red belt' injury on at least three other periods during the spring within the last ten years. After the flare, recent minor sulphur dioxide injury to sub-alpine fir was noted in the higher elevation windward plots and was combined with apparent climate injury. Other forest pathogens were evident on weakened trees (see photo A41 below).



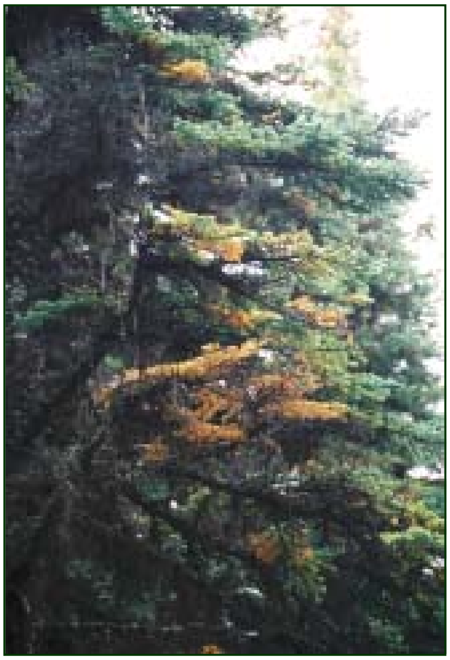
A37. Average inorganic/organic sulphur ratios of conifer tissues collected at each of the ten monitoring stations around b-77-J/93-I-14 in June (pre-flare) and September (post-flare). Stations B, C, D, E and F are tissue collection sites only.



A38. Average total sulphur in lichen tissues collected at each of the ten monitoring stations around b-77-J/93-I-14 in June (pre-flare) and September (post-flare). Stations B, C, D, E and F are tissue collection sites only.



A39. Concentrations of sulphur dioxide (ppb) registered by the passive monitors located at the five monitoring stations around b-77-J/93-I-14. Exposure period: June 20 to September 18, 2003. Note: filter from Station 4 was damaged and therefore no data is available.



A40 (left). Mixed injury (winter and SO_2) to sub-alpine fir at b-77-J/93-I-14, Station 3 pre-flare. Photo taken June 20, 2003.

A41 (right). Winter injury at b-77-J/93-I-14, Station 2, post-flare. Photo taken Sept. 18, 2003. Note the expression of mixed and repeated injury including the possibility of a root rot pathogen is evident on this tree.

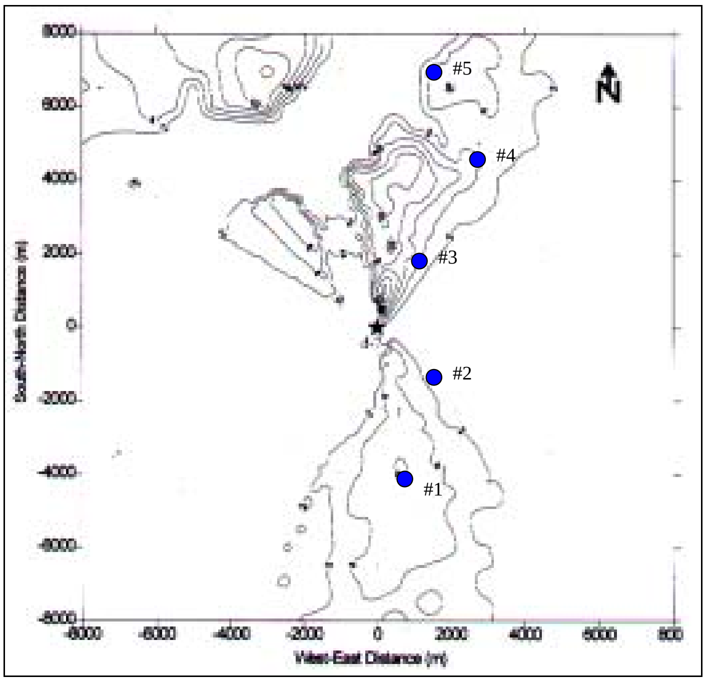
Well: d-7-E/93-P-3

General Location: Bullmoose River

UTM Coordinates: not available but position is:
Latitude 55˚5’23.96 N, Longitude 121˚27’10.59 W

Physiography: Valley bottom location, on undulating well-drained fluvial and glaciofluvial materials in a steep-sided glacially carved trough at middle to low elevation.

Biomonitoring Station Constellation:



Date of Flare Event:
- June 22 to June 23, 2000 for a total of 25 hours.

Dates of Field Work:
- June 3, 2000 (pre-flare assessment)
- September 2, 2000 (post-flare assessment)
- July 17, 2003 (secondary post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:
- Range: 1754 µg/m^3 to 53 138 µg/m^3 or 659.4 ppb to 19 976.7 ppb (from maximum values at elevations below and above the stack height), to the northeast (567 meters) and north-northwest (1.3 km).

Actual Modeled Ground Level SO_2 Concentrations:

- Range: 21 104 µg/m^3 to 27 761 µg/m^3 or 7934 ppb to10 437 ppb (from 3 highest modeled concentrations), 1.3 km southwest of the well, and maximum number of hours in exceedance of the A and B BC Air Quality Objective to the northwest of the well (3 to 9 km).
- Mean value of 23 810.7 µg/m^3 or 8951.4 ppb

Maximum Measured H_2S Content: 17.65%

Meteorological Conditions:

- Winds are predominately from the southeast
- Winds speed ranged from 1 - 2m/s
- Temperatures ranged from ~ 5˚C to 10˚C during the flare event

Sample Components:

- Lichens: *Peltigera aphthosa* and *Hypogymnia physodes*
- Conifers: sub-alpine fir
- Passive SO_2 monitors (x = 5)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	1287 ppm	1307 ppm
Conifer total sulphur	1055 ppm	1025 ppm
Conifer Si:So	0.26	0.28

Passive Monitoring Results:

Station	SO_2 (ppb)
clear cut 1	0.09
clear cut 2	0.11
clear cut 3	0.09
gasline 1	0.03
gasline 2	0.03
gasline 3	0.03
uphill forest 1	0.09
uphill forest 2	0.10
uphill forest 3	0.10
well site 1	0.05
well site 2	0.04
well site 3	0.06
doo7e-1 a	0.05
doo7e-1 b	0.06
doo7e-1 c	0.05
Mean	**0.98**

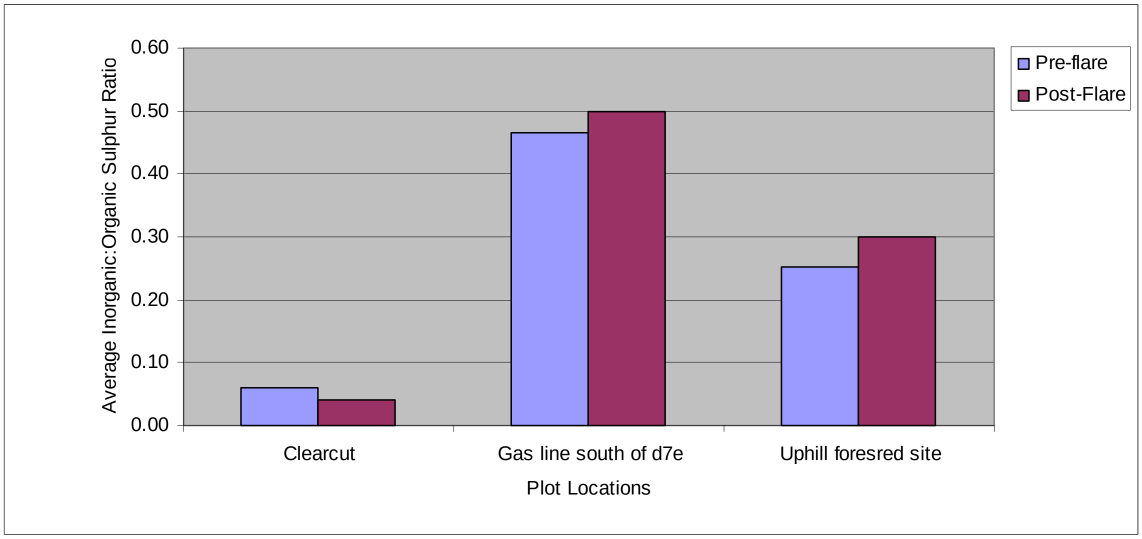
Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

Species Composition:

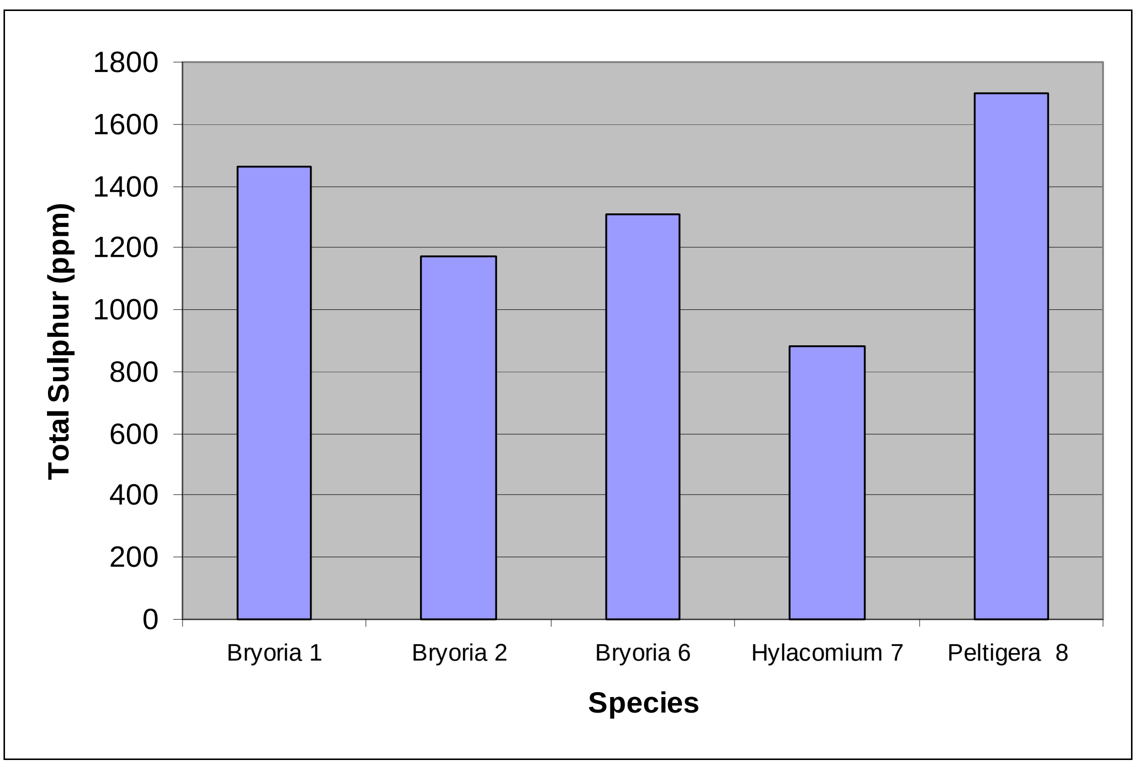
- lodgepole pine
- white spruce
- sub-alpine fir
- Douglas maple
- Sitka alder
- prickly rose
- white-flowered rhododendron
- black huckleberry
- black gooseberry
- clasping twisted stalk
- thimbleberry
- false Solomon's-seal
- one-sided wintergreen
- wintergreen sp.
- *Lobaria sp.*
- *Peltigera aphthosa*
- *Peltigera canina*
- *Bryoria sp.*
- *Hypogymnia physodes*
- *Cavernosa lapponica*
- *Parmelia sulcata*
- *Peltigera sp.*
- *Cetraria spp*

Results

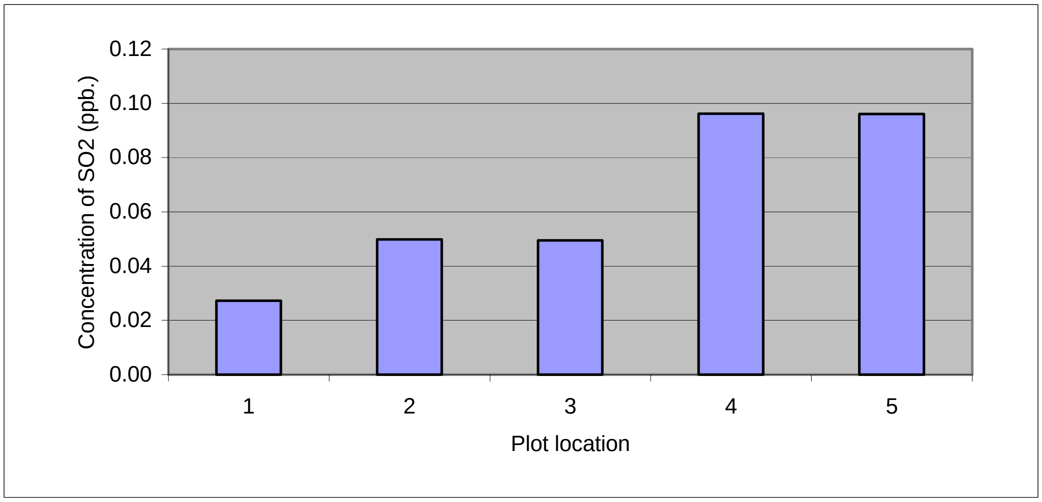
Prior to this well flare test, there some expression of injury in the conifers due to the creation of the well pad. Most of this injury was present on the trees down-slope of the pad edge, to the north of the pad. This was most likely due to the weight of the berm on the rooting area. However, following the flare test, obvious sulphur dioxide injury was noted on trees at the edge of the pad to the north of the well, also. The injury ranged from mild to severe. The severe injury on the pad edge covered the midsections of the crowns in windward positions, facing the well pad. Lodgepole pine trees were severely impacted. Some had primer red foliage with no banding patterns, others had reddened needle tips with yellow banding at the mid-sections of the needles, and green proximal leaf portions on previous years foliage. This is characteristic of a short-term acute exposure to sulphur dioxide. On these trees, some of the current foliage remained green. Further into the stand north of the well, the injury was confined to the upper portions of the crowns. In the first 15 meters into the forest from the pad edge, injury was noted on prickly rose (*Rosa acicularis)* and thimbleberry *(Rubus parviflorus).* This consisted of brownish marginal and interveinal bifacial necrosis on exposed upper leaves. Olive green to pale yellow chlorosis with brown margins was common on exposed *Peltigera aphthosa* and *Peltigera canina.* The pre-flare model for this well had predicted the maximum injury to occur several hundred meters to the northeast. All of the areas predicted to receive injury were located on the mountain side above the well; monitors were installed in these areas. The passive monitors showed a very low exposure to sulphur dioxide in the cutblock to the northwest of the well site and the rest were below background levels. Further, the post-flare modeling indicated an area to the northwest of the well had been impacted. This area was assessed during the post-flare visit. There were no visible signs of injury in this area. Visible injury was only observed at the well pad edge. Some of the injury at the well pad edge appeared to be similar to salt injury. Elevated salt, possibly from brine contaminated produced water was found in lichen, moss and foliar tissue at the well pad edge. This declined with distance into the stand, and was noted to decline in concentration in tissue over time (three separate tissue collections were made). Subsequent visits to this well test indicated trees had started to recover from injury, that is they were greener than in the previous assessments, and most of the reddened foliage had fallen to the ground.



A48. Average inorganic/organic sulphur ratios of sub-alpine fir tissues collected at each monitoring station (where available) around d-7-E/93-P-3 in June (pre-flare) and September (post-flare).



A49. Average total sulphur in lichen tissues collected from each monitoring station (where available) around d-7-E/93-P-3 in July 2003 (secondary post-flare).



A50. Concentrations of sulphur dioxide (ppb) registered by the passive monitors located at five monitoring stations around d-7-E/93-P-3. Exposure period: June 3 to September 20, 2000.

A51. Pre-flare condition of pine and sub-alpine fir on north edge of d-7-E/93-P-3 lease. Photo taken June 3, 2000.

A52. Sulphur dioxide injury to the same stand of tress shown above in Figure A51 at d-7-E/93-P3. Photo taken September 2, 2000, post-flare.

A53 (right). Residual injury recovering (mainly just stripped branches with no foliage) at the same stand shown above (Figures A51 and A52), on the north edge of the d-7-E/93-P-3 lease. Photo taken July 17, 2003, during secondary post-flare visit.

A54 (left). Recovering from injury: sub-alpine fir along north edge of lease at d-7-E/93-P-3. Photo taken July 17, 2003.

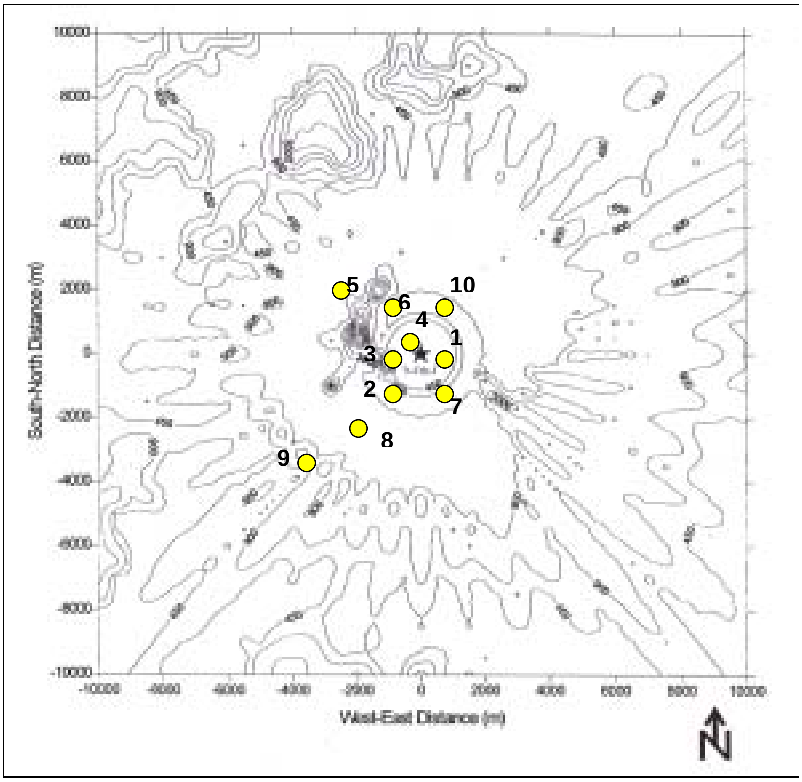
Well: b-66-F/93-P-5

General Location: Brazion Creek, High Hat Mountain

UTM Coordinates: 574456.6E, 6138290.0N

Physiography: montane, on gently sloping plateau above main valley

Biomonitoring Station Constellation:



Date of Flare Event:

- January 30, 2001 for 8.5 hours

Dates of Field Work:

- December 14, 2000 (pre-flare assessment)
- February 12, 2001 (post-flare assessment)

Predicted Maximum Canopy Level 1-Hour SO_2 Concentrations:

- Range: 9372 µg/m^3 – 10 089 µg/m^3 or 3523.3 ppb- 3792.9 ppb (from maximum values generated by models using Sukunka Valley meteorology and screening meteorology), both occur at approximately 2.1 km west-northwest of the well

Actual Modeled Maximum Ground Level SO_2 Concentrations:

- 445 µg/m^3 or 167 ppb was predicted by ISCST3 during the 1st hour of flaring
- 441 µg/m^3 or 166 ppb was predicted by ISCST3 during the 6th hour of flaring
- All of the rest of the maximum hourly predictions ranged from 50 µg/m^3 - 180 µg/m^3 or 19 ppb - 68 ppb
- Highest ground level concentration occurred northeast of the well

Maximum Measured H_2S Content: 15.1%

Meteorological Conditions:

- Winds are predominately from the west-southwest
- Winds speeds ranged from 4.2 to 8.5 m/s
- Temperatures ranged from -4.3˚C to -6.2˚C during the flare

Sample Components:

- Lichens: *Bryoria sp.* and *Hypogymnia physodes*
- Conifers: sub-alpine fir, lodgepole pine, and Engelmann spruce
- Passive SO_2 monitors (x = 10)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	1506 ppm	1687.75 ppm
Conifer total sulphur	950 ppm	Not available
Conifer Si:So	0.191	0.250

Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

Passive Monitoring Results:

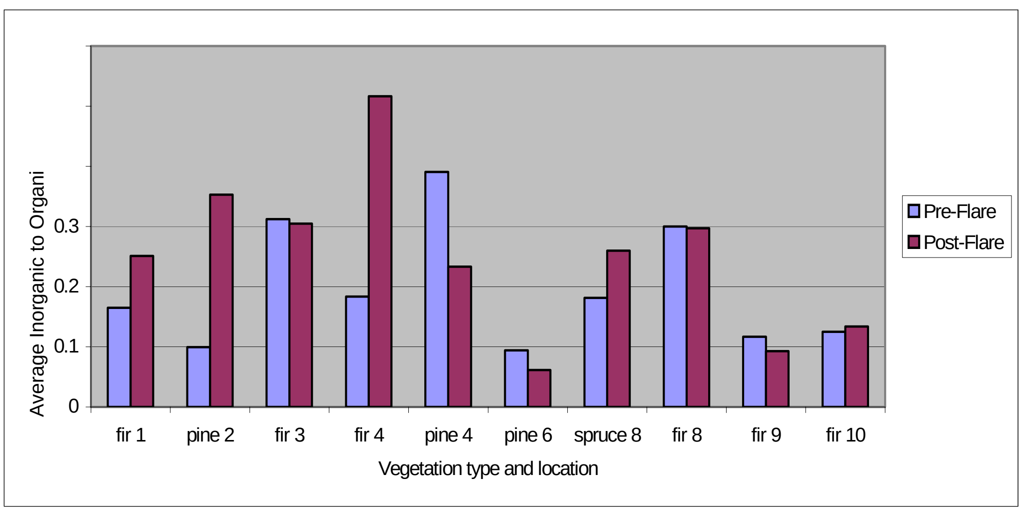
Station	SO_2 (ppb)
1a	2.36
1b	2.34
2a	2.64
2b	2.57
3a	2.27
3b	2.65
4a	2.02
4b	2.14
5a	0.44
5b	0.47
6a	0.74
6b	0.75
7a	n/a
7b	n/a
8a	3.02
8b	2.64
9a	0.85
9b	0.89
10a	2.91
10b	2.90
Mean	**1.92**

Species Composition:
Species list is incomplete due to snow cover

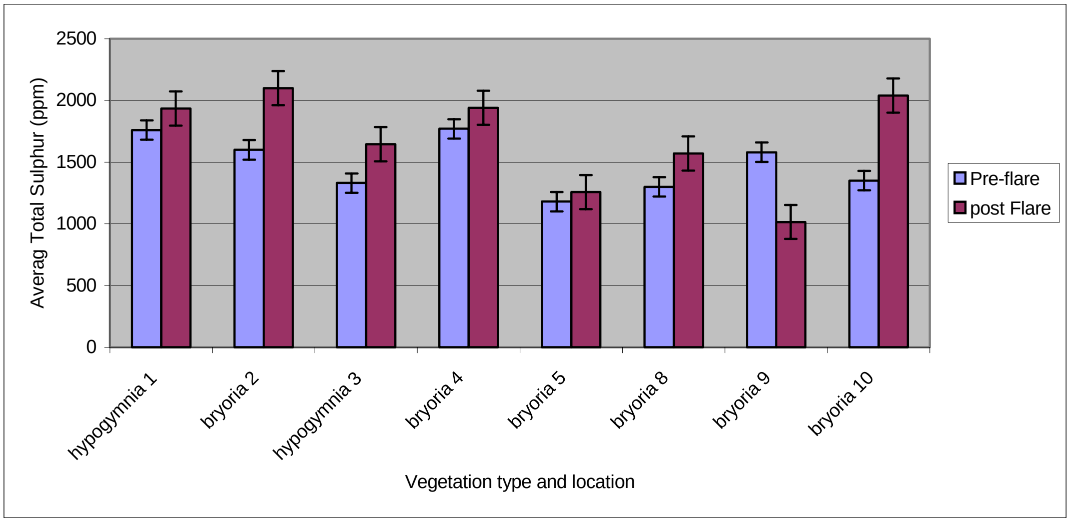
- sub-alpine fir
- lodgepole pine
- Engelmann spruce
- soopolallie
- white-flowered rhododendron
- Sitka alder
- balsam popular
- black current
- *Bryoria sp.*
- *Hypogymnia physodes*
- *Platismatia glauca*

Results

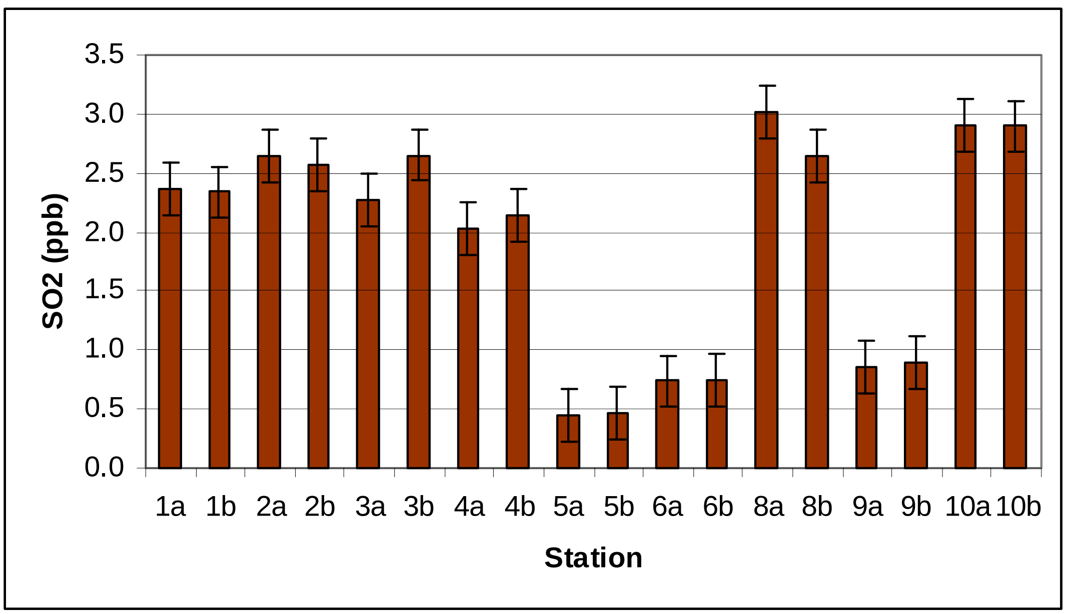
Sulphur dioxide concentrations at b-66-F/93-P-5 increased slightly from background levels to a mean of 1.9 ppb (measured by the passive monitors) during the well flare test. However, the Brazion gas plant may have influenced these results. Two very sensitive conifer species, sub-alpine fir and lodgepole pine, showed an increase in Si:So ratios after the flare, especially at sites adjacent to the well pad. The Maxxam passive monitors confirmed that the locations predicted by the model to receive maximum concentrations did receive some sulphur dioxide. However, the predicted concentrations were not observed and this was not entirely due to the length of exposure time of three months, which is an allowable time for exposure for these monitors. Trees on the pipeline edge to the north of the well pad did show very minor sulphur dioxide injury during the post-flare assessment. Most of the injury present around the well was due to mechanical damage from well pad construction. It is likely that winter dormancy protected vegetation at this site from any effects from the sour well production test flare.



A55. Average inorganic/organic sulphur ratios of conifer tissues collected at each of the ten monitoring stations (where available) around b-66-F/93-P-5 in December 2000 (pre-flare) and February 2001 (post-flare).



A56. Average total sulphur in lichens collected at each of the ten monitoring stations (where available) around b-66-F/93-P-5 in December 2000 (pre-flare) and February 2001 (post-flare).



A57. Concentrations of sulphur dioxide (ppb) registered by the passive monitors at ten monitoring stations (two samplers per station) around b-66-F/93-P-5. Exposure period: December 14, 2000 to February 12, 2001. Note: Station 7 filters/results are missing.

A58. Snow cover on lodgepole pine at b-66-F/93-P-5.

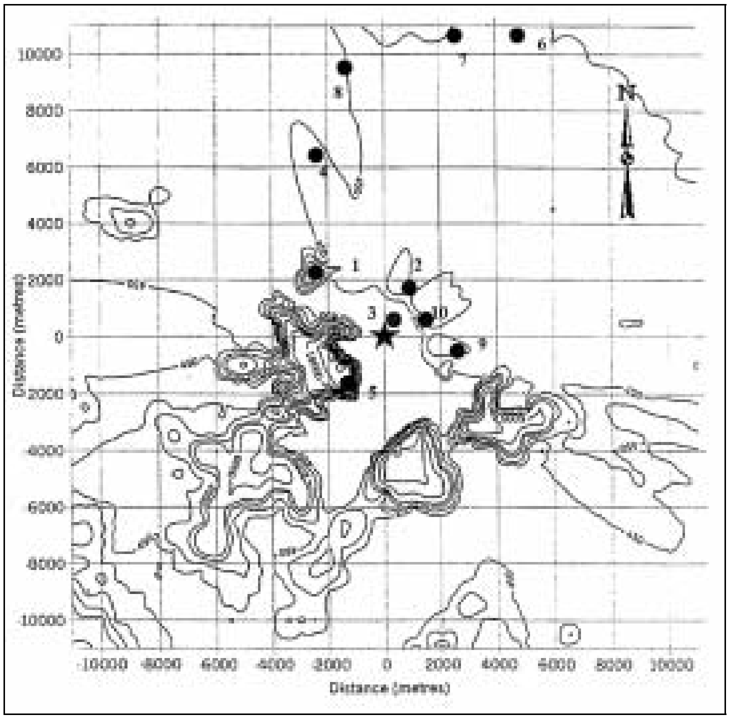
Well: b-91-L/93-P-5

General Location: Upper Pine plateau near the Pine River Gas Plant

UTM Coordinates: not available but the location is:
Latitude 55˚29'40"N, Longitude 121˚53'0"W

Physiography: Edge of a gently undulating montane plateau above a main river valley.

Biomonitoring Station Constellation:



Dates of Flare Events:
- October 18, 2000 for 8 hours
- November 14 -17, 2000 for 75 hours

Dates of Field Work:
- October 11, 2000 (pre-flare assessment)
- December 17, 2000 (post-flare assessment)

Predicted Maximum Canopy Level 1-Hour SO_2 Concentrations:
- Range: 23 736 µg/m^3 – 25 292 µg/m^3 or 8923.3 ppb – 9508.3 ppb (from the maximum values of 4 scenarios in stability class 6, only)
- Mean value is 24 357.2 µg/m^3 or 9156.84 ppb
- Maximum concentration predicted to occur 1.9 km southwest of the well

Actual Modeled Maximum Ground Level SO_2 Concentrations:

- October flare range: 516 µg/m^3 – 598 µg/m^3 or 194 ppb – 224.8 ppb (from 3 highest 1-hour concentrations predicted by the models), ~7.4 km to the east-northeast
- October flare mean: 564 µg/m^3 or 212.0 ppb
- November flare range: 6690 µg/m^3 – 9103 µg/m^3 or 2515.0 ppb – 3422.2 ppb (from 3 highest 1-hour concentrations predicted by the models), ~1.9 km to the west-southwest of the well
- November flare mean: 7589 µg/m^3 or 2830.5 ppb

Maximum Measured H_2S Content: 17.94%

Meteorological Conditions:

- For October winds were 243.2 degrees, air temperature was 2.1 ˚C
- For November winds were 79.0 degrees, air temperature was -4.0 ˚C
- Southwest winds are predominant at this well

Sample Components:

- Lichens: *Bryoria* sp. and *Hypogymnia* sp. (mainly *physodes)*
- Conifers: sub-alpine fir and lodgepole pine
- Passive SO_2 monitors (x = 10)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	1227 ppm	1348 ppm
Conifer total sulphur	not available	not available
Conifer Si:So	0.50	0.41

Passive Monitoring Results:

Station	SO_2 (ppb)
1a	1.97
1b	2.02
2a	0.32
2b	4.62
3a	5.42
3b	5.47
4a	2.91
4b	3.14
5a	1.24
5b	1.10
6a	2.86
6b	3.16
7a	3.61
7b	3.60
8a	1.59
8b	1.47
9a	1.84
9b	2.00
10a	4.28
10b	4.10
Mean	**2.8**

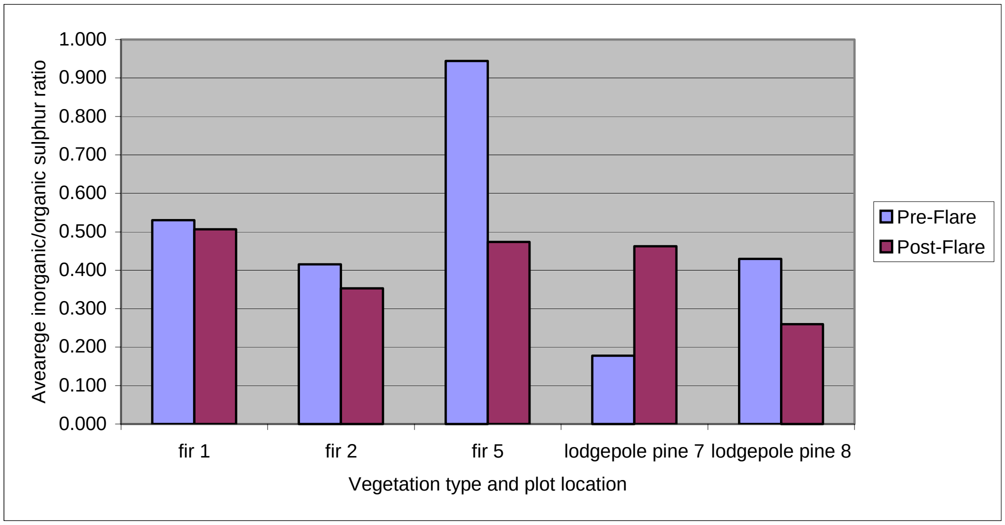
Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

Species Composition:
Species list is incomplete due to snow cover.

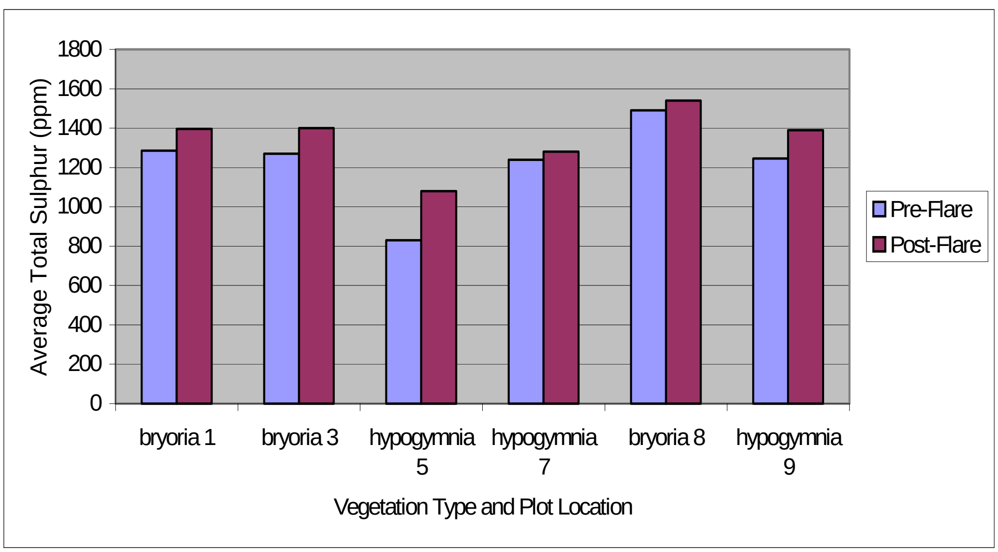
- lodgepole pine
- sub-alpine fir
- Engelmann spruce
- soopolallie
- white-flowered rhododendron
- sitka alder
- trembling aspen
- black current
- *Isothecium spiculiferum*
- *Bryoria sp.*
- *Hypogymnia physodes*
- *Platismatia glauca*

Results

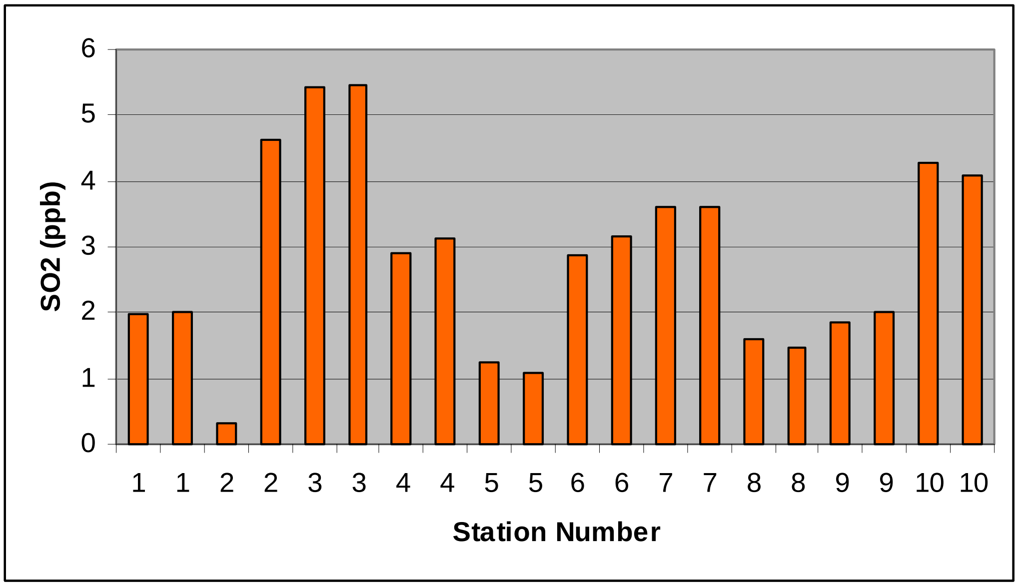
Sulphur dioxide at b-91-L/93-P-5 was detected in the monitors, with one of the higher average concentrations of the well flare tests assessed in this project. The sub-alpine fir and lodgepole pine, two very sensitive species of conifers, were exposed and did not respond with visible injury. However, a small stand of mechanically damaged subalpine fir trees on the northwest corner of the well in a depression area beside a pipeline was noted to have both physical and foliar sulphur dioxide injury (i.e. red tips and yellow banding on needles of two years age). Due to the temperature at the time of the post-flare assessment (-52°C) it was difficult to see the crowns of the trees. Although the reddening of needle tips was noted in three individual trees, in mid and lower crowns, it is possible additional trees could have responded to sulphur dioxide from the flare test. A visit to this well site in the following summer showed some residual injury (Figure A62). Trees at further distances from the well site showed no symptoms commensurate with sulphur dioxide injury and no change in foliar sulphur status. Sulphur content in sensitive lichen species increased (Figure A60).



A59. Average inorganic/organic sulphur ratios of conifer tissues collected at each of the ten monitoring stations (where available) around b-91-L/93-P-5 in October (pre-flare) and December (post-flare).



A60. Average total sulphur in lichens (ppm) collected at each of the ten monitoring stations (where available) around b-91-L/93-P-5 in October (pre-flare) and December (post-flare).



A61. Concentrations of sulphur dioxide (ppb) registered by the passive monitors located at ten monitoring stations around b-91-L/93-P-5, two samplers per station. Exposure period: October 11 to December 17 (67 days).

A62. Post-flare injury on sub-alpine fir located to the northwest of the b-91-L/93-P-5 lease.

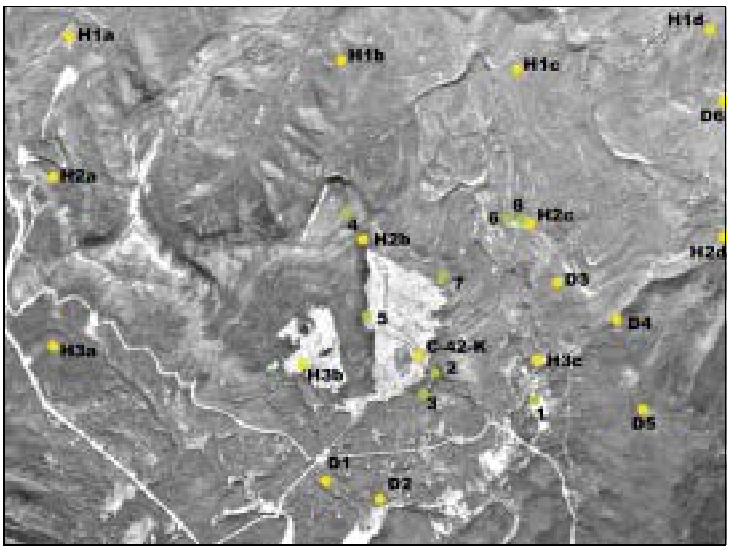
Well: c-42-K/93-P-5

General Location: High Hat Mountain, above Sukunka River Valley

UTM Coordinates: 577300E, 6145650N

Physiography: Gentle sloping upper elevation plateau and steep sub-ridge beneath the prominent main ridges of High Hat Mountain

Biomonitoring Station Constellation:



Date of Flare Event:
- January 15 – 23, 2000, actual flare period is not available

Dates of Field Work:
- January 3, 2000 (pre-flare assessment)
- February 3, 2000 (post-flare assessment)
- December 2000 (secondary post-flare assessment)
- July 2001 (third post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:
- Dispersion Analysis was not available.

Actual Modeled Ground Level SO_2 Concentrations:
- Range: 630 µg/m^3 – 17 213 µg/m^3 or 236.8 ppb – 6471.1 ppb (from maximum value estimated by ISCST3 and RTDM models), occurred north of the well

Maximum Measured H_2S Content: 18.1%

Meteorological Conditions:

- Winds are predominately from the southwest
- Maximum hourly wind speed was 7.15 m/s
- Temperatures ranged from -15 ˚C to -28˚C

Sample Components:

- Lichens: *Alectoria sp., Bryoria sp., and Hypogymnia sp. (mainly physodes)*
- Conifers: lodgepole pine and sub-alpine fir
- Passive SO_2 monitors (x = 8)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	999 ppm	921 ppm
Conifer total sulphur	878 ppm	876 ppm
Conifer Si:So	0.10	0.10
Passive SO_2 Filters	N/A	2.35 ppb

Passive Monitoring Results:

Station	SO_2 (ppb)
1	1.17
2	0.88
3	0.79
4	0.94
5	1.08
6	6.44
7	1.24
8	6.25
Mean	**2.35**

Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

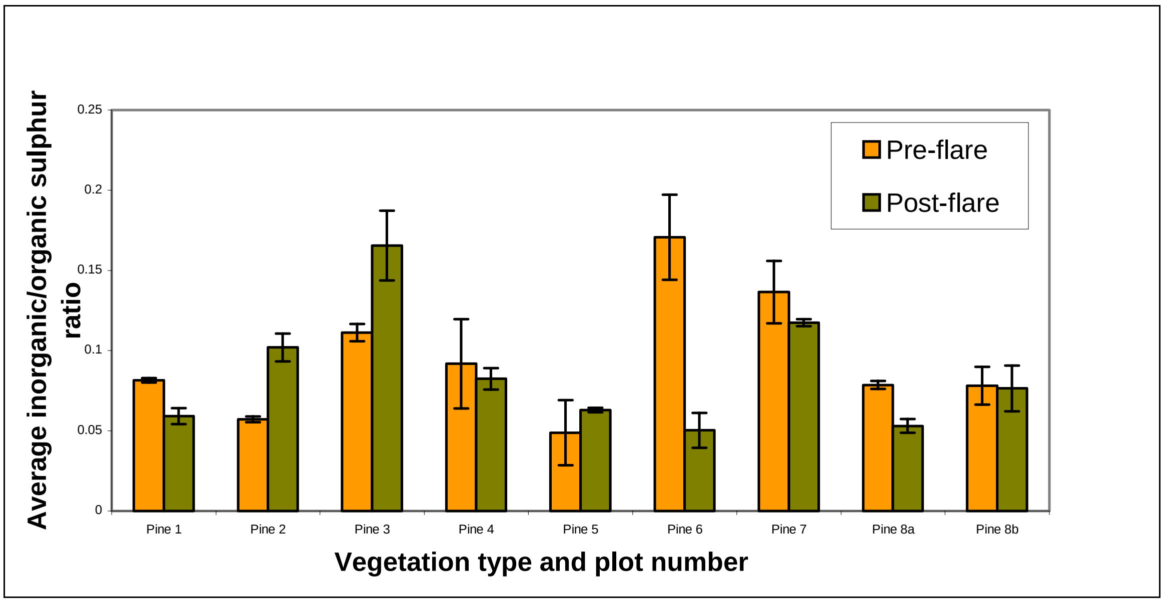
Species Composition:
Partial species list only

- lodgepole pine
- sub-alpine fir
- Engelmann spruce
- white spruce

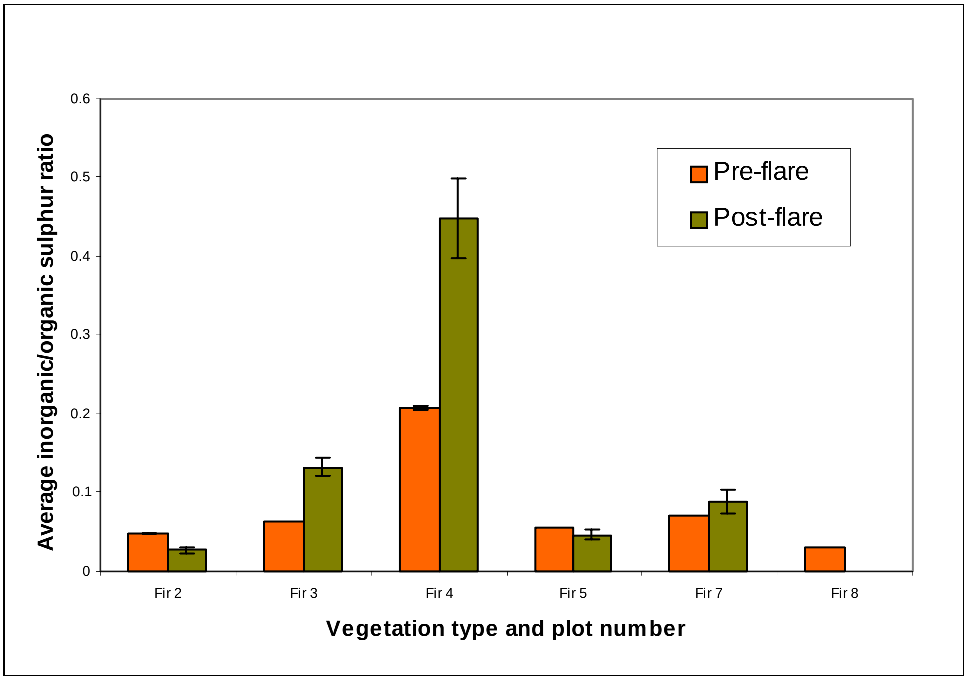
- *Alectoria sp.*
- *Bryoria sp.*
- *Hypogymnia physodes*

Results

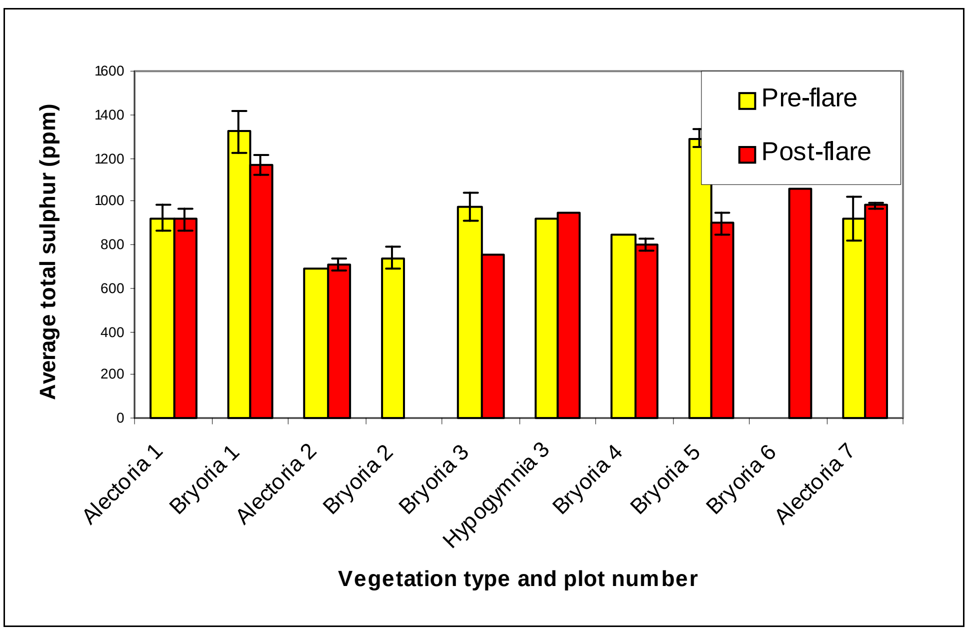
Sulphur dioxide concentrations in the monitors were highest to the northwest of the well site on an exposed sub-alpine ridge, where impacts were predicted to occur. Injury attributed to sulphur dioxide in this area consisted only of slight needle tip chlorosis on one tree. Most of the injury was confined to the well pad edge and was not noticed until the July 2001 secondary post-flare field assessment. This is because most of the investigation in the first post-flare assessment concentrated in areas predicted by the model to receive injury (i.e. *beta* error). It is possible that effects from pad construction increased the sensitivity of the trees along the lease edge to sulphur dioxide exposure. A transect extending into the stand determined that total sulphur content in lichens declined within 15 meters of the edge of the lease. Si:So ratios in conifers appear not to have responded to the well flare test.



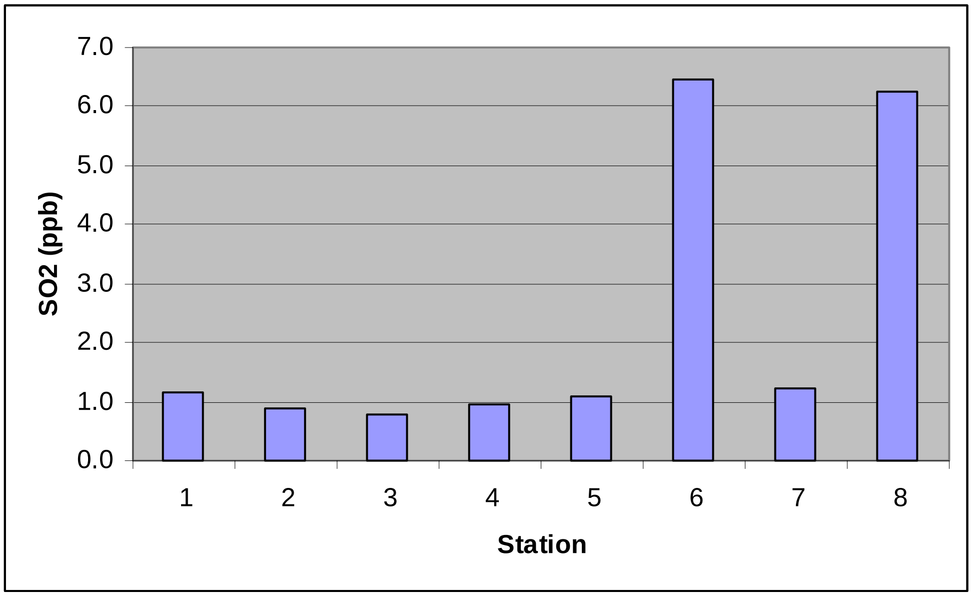
A64. Average inorganic/organic sulphur ratios of lodgepole pine tissues collected at each of the eight monitoring stations around c-42-K/93-P-5 in January (pre-flare) and February (post-flare).



A65. Average inorganic/organic sulphur ratios of sub-alpine fir tissue collected (where available) at each of the eight monitoring stations around c-42-K/93-P5 in January (pre-flare) and February (post-flare).



A66. Average total sulphur in lichens (ppm) collected at each of the eight monitoring stations (where available) around c-42-K/93-P-5 in January (pre-flare) and February (post-flare).



A67. Concentrations of sulphur dioxide (ppb) registered by the passive monitors located at eight monitoring stations around c-42-K/93-P-5. Exposure period: January 3 to February 3, 2000.

A68. Minor sulphur dioxide injury to outward-facing crowns of conifers on the well pad edge at c-42-K/93-P-5. Photo taken post-flare, July 2001.

A69. Eastern edge of c-42-/93-P-5K lease edge, post-flare, July 2001.

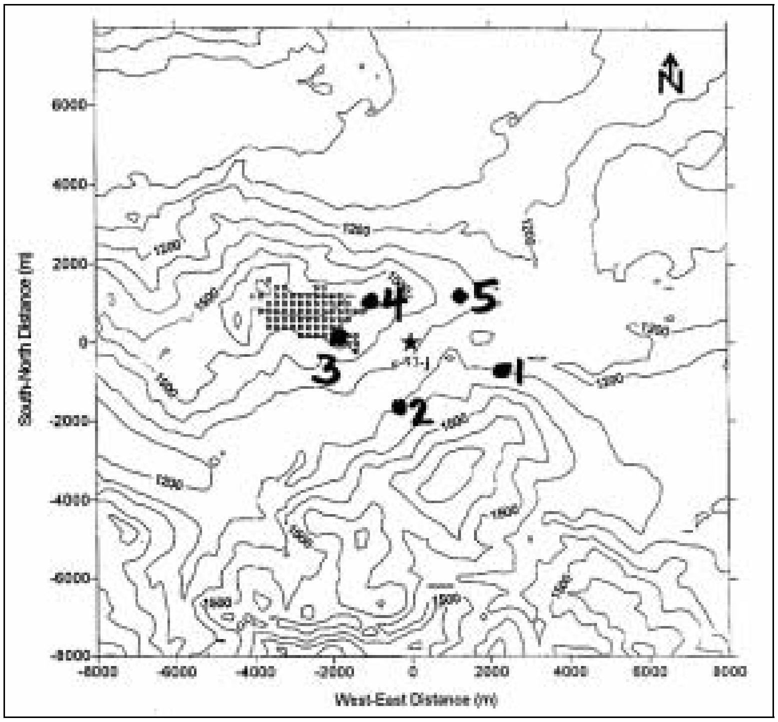
Well: c-97-J/93-I-10

General Location: Grizzly Valley

UTM Coordinates: not available but located at:
Latitude 54˚44'44. 85"N Longitude 120˚42'32. 23"E

Physiography: Large undulating plateau

Biomonitoring Station Constellation:



Date of Flare Event:

- March 18 – 23, 2000 for a total of 122 hours

Dates of Field Work:

- March 14, 2000 (pre-flare assessment)
- March 25, 2000 (post-flare assessment)

Predicted Maximum Ground Level 1-hour SO_2 Concentration:

- Dispersion Analysis not available

Actual Modeled Maximum Ground Level SO_2 Concentrations:

- Range: 2474 µg/m^3 - 3048 µg/m^3 or 930 ppb – 1146 ppb (from the 3 highest values estimated by the models), ~1.6km northwest of the well
- Mean value of 2759 µg/m^3 or 1037.2 ppb

Maximum Measured H_2S Content: 4.08%

Meteorological Conditions:

- Winds were primarily from the southwest
- Strong winds from the east-southeast occurred on the morning of March 21, reaching speeds in excess of 22.2 m/s
- Light southwesterly winds were observed for the final 37 hours of the flare
- Temperatures ranged from ~ 4˚C to -5˚C during the flare period

Sample Components:

- Lichens: *Bryoria fuscescens, Cetraria sp., and Hypogymnia physodes*
- Conifers: lodgepole pine, white spruce, and Douglas-fir
- Passive SO_2 monitors (x = 5)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	802.2 ppm	959.2 ppm
Conifer total sulphur	878 ppm	876 ppm
Conifer Si:So	0.129	0.128

Passive Monitoring Results:

Station	SO_2 (ppb)
1a	0.30
1b	0.22
2a	0.42
2b	0.39
3a	0.48
3b	0.45
4a	0.40
4b	0.48
5a	11.92
5b	12.11
Mean	**2.7**

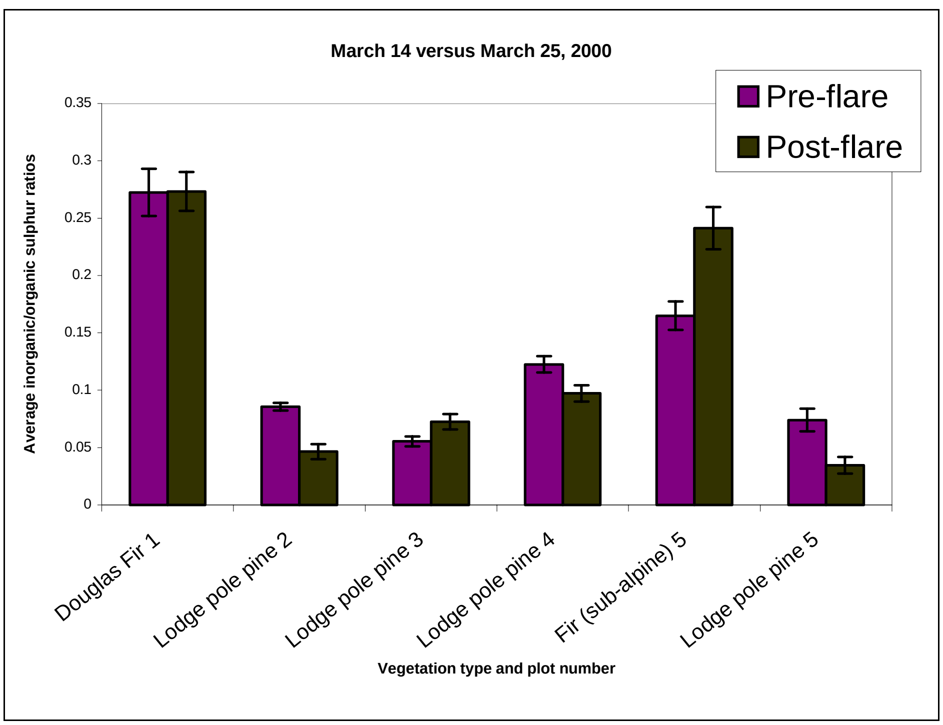
Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

Species Composition:
Species list is incomplete due to snow cover

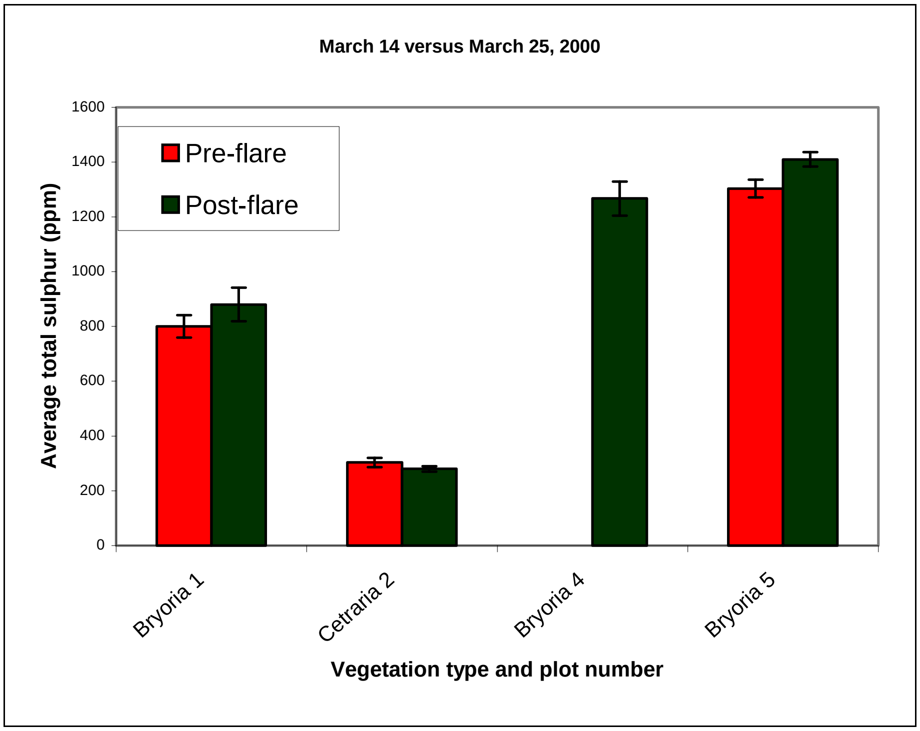
- Engelmann spruce
- lodgepole pine
- sub-alpine fir
- white-flowered rhododendron
- Sitka alder
- trembling aspen
- black current
- *Bryoria sp.*
- *Hypogymnia physodes*
- *Platismatia glauca*

Results

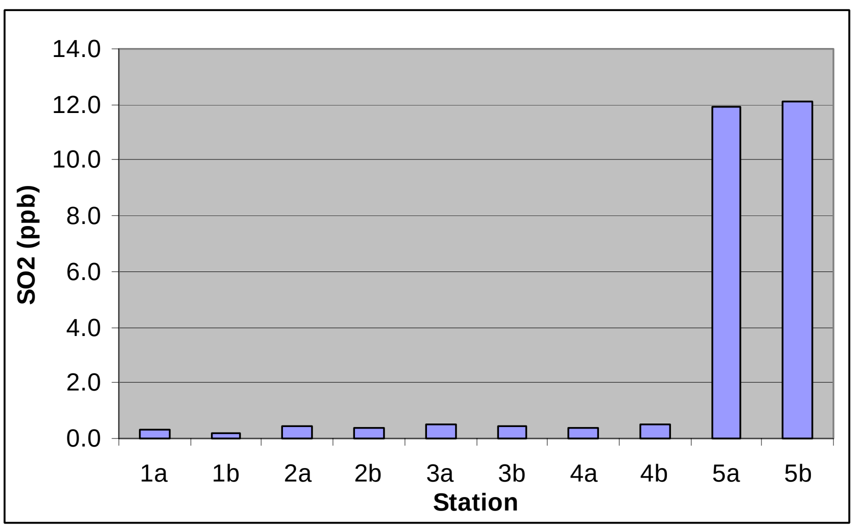
Sulphur dioxide emissions from the flare test at c-97-J/93-I-10 resulted in a slight increase in Si:So ratios in sub-alpine fir at the station directly east of the well, in the direction of the prevailing wind. Slight sulphur dioxide injury was noted in lodgepole pine in combination with winter injury at this location. Passive monitoring results confirmed sulphur dioxide exposures to the east-northeast of the well; Station 5 was the only monitor which registered an elevated concentration of sulphur dioxide. Based on post-flare modeling, the concentrations predicted to occur were very high, however. The monitors placed in the predicted high concentration areas did not record levels higher than 1 ppb (background). As the exposure period of the monitors was relatively short (11 days), the diluting effect of prolonged exposures was not at issue.



A70. Average inorganic/organic sulphur ratios of conifer tissues collected at each of the five monitoring stations around c-97-J/93-I-10 on March 14 (pre-flare) and March 25, 2000 (post-flare).



A71. Average total sulphur in lichen tissues (ppm) collected at each of the five monitoring stations (where available) around c-97-J/93-I-10 on March 14 (pre-flare) and March 25, 2000 (post-flare).



A72. Concentrations of sulphur dioxide registered by the passive monitors at five monitoring stations around c-97-J/93-I-10, two samplers per station. Exposure period: March 14 to March 25, 2000.

No photos are available of this well site.

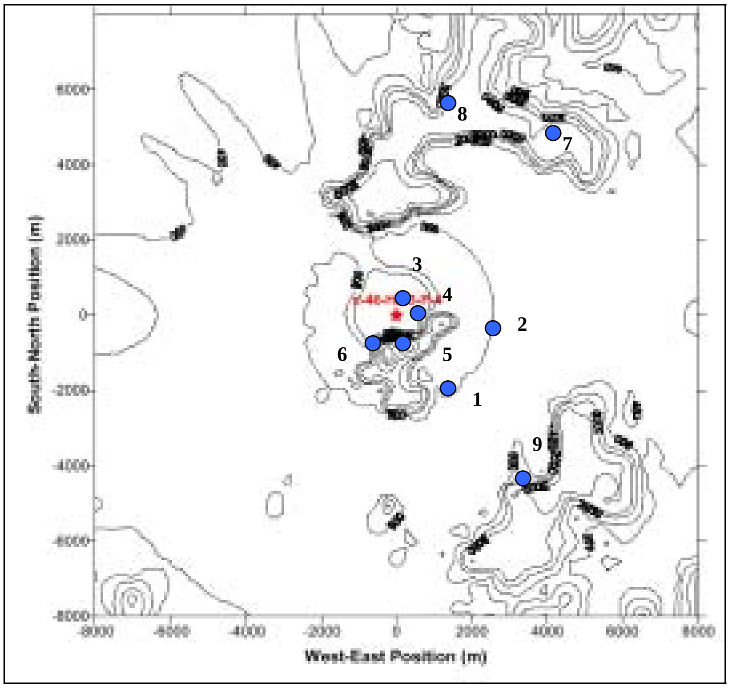
Well: c-46-H/93-P-4

General Location: Bullmoose Valley

UTM Coordinates: 590903E, 6109051N

Physiography: sub-alpine, steep mostly northwest facing mountainside, alpine tundra occurs within 200m of the well.

Biomonitoring Station Locations:



Date of Flare Event:

- May 2001, actual periods are not available

Dates of Field Work:

- May 28, 2001 (pre-flare assessment)
- June 12, 2001 (post-flare assessment)

Predicted Maximum Ground Level 1-hour SO_2 Concentrations:

- Range: 675.3 µg/m^3 – 27 403 µg/m^3 or 253.9 ppb – 10 301.9 ppb (from 6 stability classes through 2 scenarios)
- Mean value of 7810.6 µg/m^3 or 2936.3 ppb

Actual Modeled Maximum Ground Level SO_2 Concentrations:

- Modeled numbers are not available as this site was monitored with a real-time continuous monitor which failed to detect sulphur dioxide above 1 ppb.

Maximum Measured H_2S Content: 17% (from pre-flare dispersion analysis)

Meteorological Conditions:
Actual meteorological conditions during the flare event are not available

- Winds are predominately from the southwest (Modeling Dispersion Analysis)
- Winds speeds are not available
- Ambient temperature ranges are not available

Sample Components:

- Lichens: *Bryoria sp.* and *Hypogymnia sp. (*mainly *physodes)*
- Conifers: sub-alpine fir and spruce
- Passive SO_2 monitors (x = 9)
- Due to the conditions of the flare and the duration, tissue and ambient analysis was completed at five of the nine monitoring stations, the remaining four were archived.

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	1007 ppm	1110 ppm
Conifer total sulphur	865 ppm	982.6 ppm
Conifer Si:So	0.262	0.253

Passive Monitoring Results:

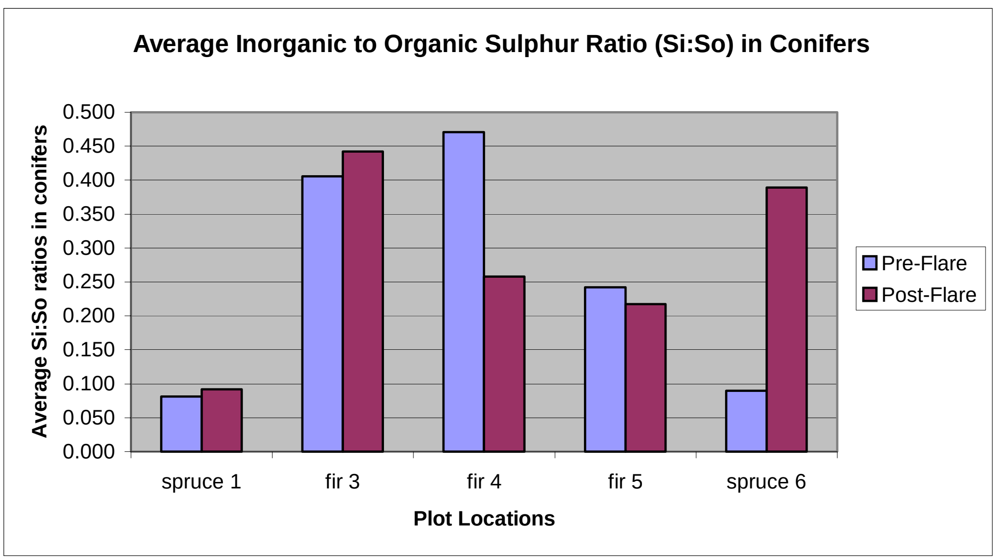
Station	SO_2 (ppb)
1a	0.15
1b	0.09
2a	0.21
2b	0.26
3a	0.30
3b	0.45
4a	0.46
4b	0.34
5a	0.31
5b	0.33
6a	0.16
6b	0.28
7a	0.35
7b	0.36
8a	0.41
8b	0.59
9a	0.29
9b	0.81
Mean	**0.34**

Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)

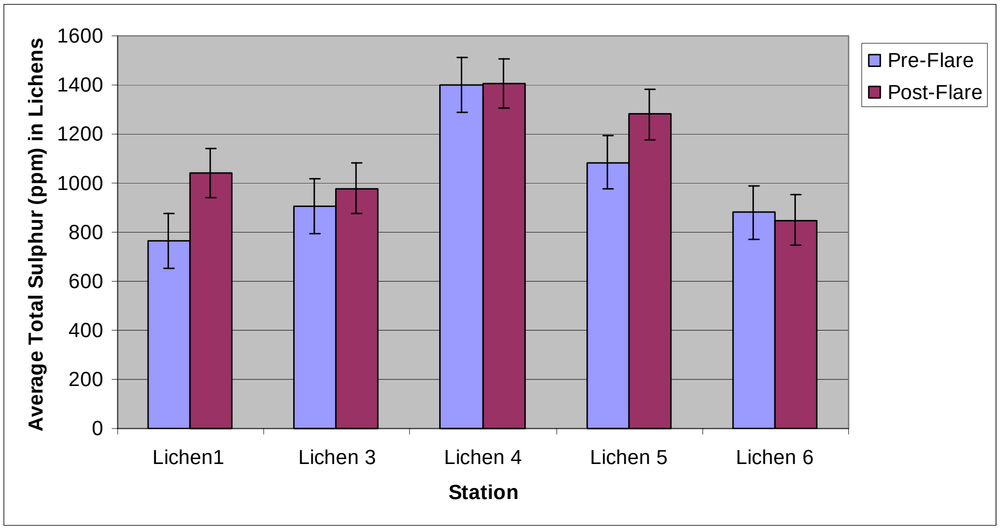
Species Composition:
No species list available

Results

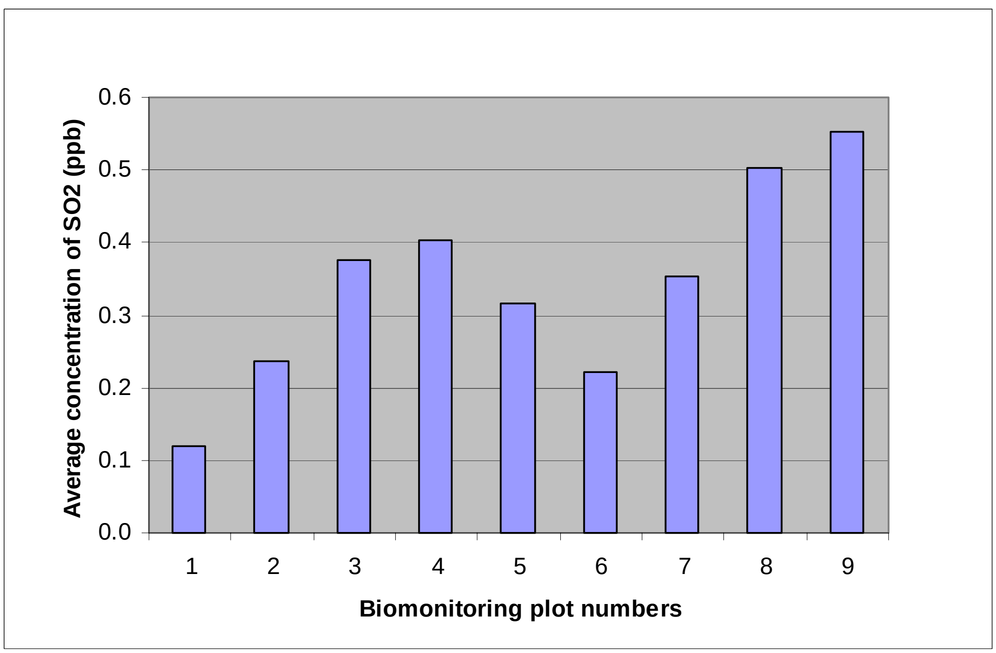
Despite the high concentration of sulphur dioxide predicted for this well flare test, c-46-H/93-P-4 produced only small quantities due to a low volume flare. Both the real-time continuous monitor and the adjacent Maxxam Analytics monitors showed < 1 ppb. This site, as well as b-3-G/93-P-3 (below), are the only well flare tests which employed both continuous and passive monitors. Both show agreement between the two monitor types. The passives detected lower concentrations than the continuous monitors; most of them were situated in areas predicted to receive high emissions from the modeling. The higher values occurred close to the well site, near were the continuous monitor was located. The vegetation did not responded to this well flare test. No injury was detected and no increase in the sulphur status of lichen and conifer tissues occurred.



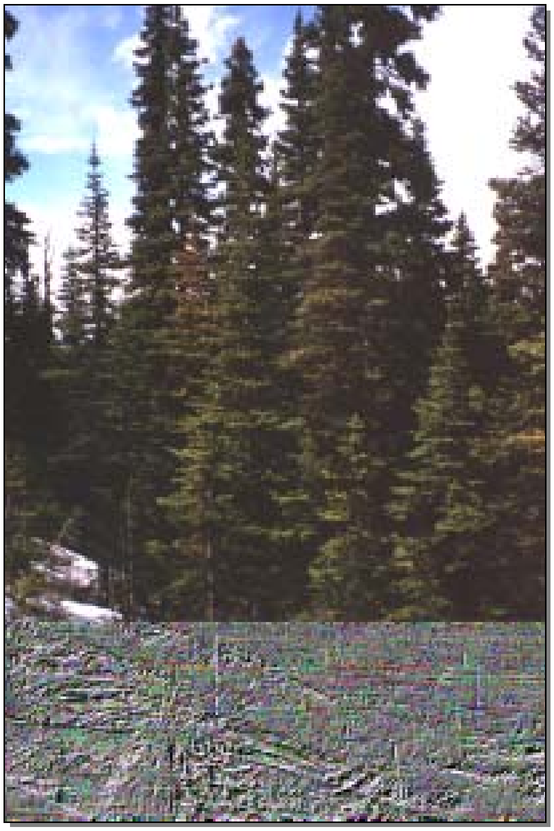
A73. Average inorganic/organic sulphur ratios of conifer tissues collected at each of the monitoring stations (where available) around c-46-H/93-P4 in May (pre-flare) and June (post-flare).



A74. Average total sulphur in lichen tissue (ppm) collected at each of the monitoring stations (where available) around c-46-H/93-P-4 in May (pre-flare) and June (post-flare). Note these data are an example of non-flare event related fluctuations in sulphur concentrations.



A75. Concentrations of sulphur dioxide (ppb) registered by the passive monitors located at nine monitoring stations around c-46-H/93-P4. Exposure period: May 28 to June 12, 2001.



A76. Pre-flare vegetation condition between Stations 3 and 4 on the lower slope, adjacent and north-northeast edge of the c-46-H/93-P-4 well pad.

A77. Post-flare vegetation condition at Station 4, adjacent to the c-46-H/93-P-4 well pad, on the lower slope.

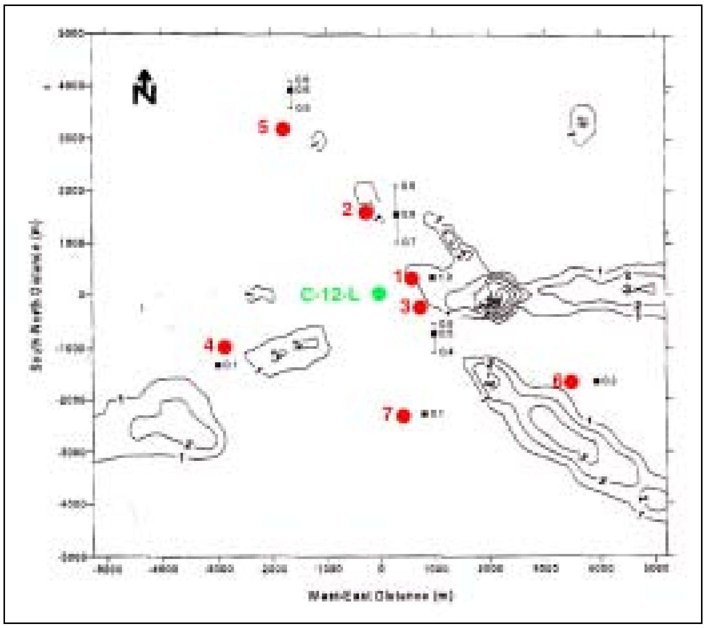
Well: c-12-L/93-I-9

General Location: Ojay: Grizzly Valley

UTM Coordinates: not available but located on the South Grizzly Road near the Alberta boarder south of Red Deer Creek.

Physiography: in a small north-south trending valley in rolling foothills, on the edge of the Alberta plain.

Biomonitoring Station Constellation:



Date of Flare Event:

- September 21 – 30,1999 for a total of 208.5 hours
- The flaring was continuous except for between 08:00 to 16:30 on September 23, when flows were reduced to zero.

Dates of Field Work:

- August 24 – 28, 1999 (pre-flare assessment)
- October 17 – 18, 1999 (post-flare assessment)
- October 28, 1999 (second post-flare assessment)
- July 15, 2003 (third post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:

- Dispersion Analysis is not available.

Actual Modeled Maximum Ground Level SO_2 Concentrations:

- Post-Flare Analysis is not available.

Meteorological Conditions:

Details not presented due to unavailability of Post-Flare Analysis.

- Winds predominately from the southeast

Sample Components:

- Lichens: *Peltigera aphthosa, Bryoria sp., and Hypogymnia sp.*
- Conifers: lodgepole pine
- Passive SO_2 monitors: (x = 7)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	1179.5 ppm	1190ppm
Conifer total sulphur	1230.95 ppm	947.62 ppm
Conifer Si:So	0.20	0.18

Passive Monitoring Results:

Station	SO_2 (ppb)
1a	1.00
1b	1.00
1c	1.00
2a	0.70
2b	0.90
2c	0.80
3a	0.40
3b	0.50
3c	0.50
4a	0.10
4b	0.10
4c	0.10
5a	0.60
5b	0.50
5c	0.60
6a	0.20
6b	0.20
7a	0.10
7b	0.10
Mean	**0.495**

Vegetation Type:

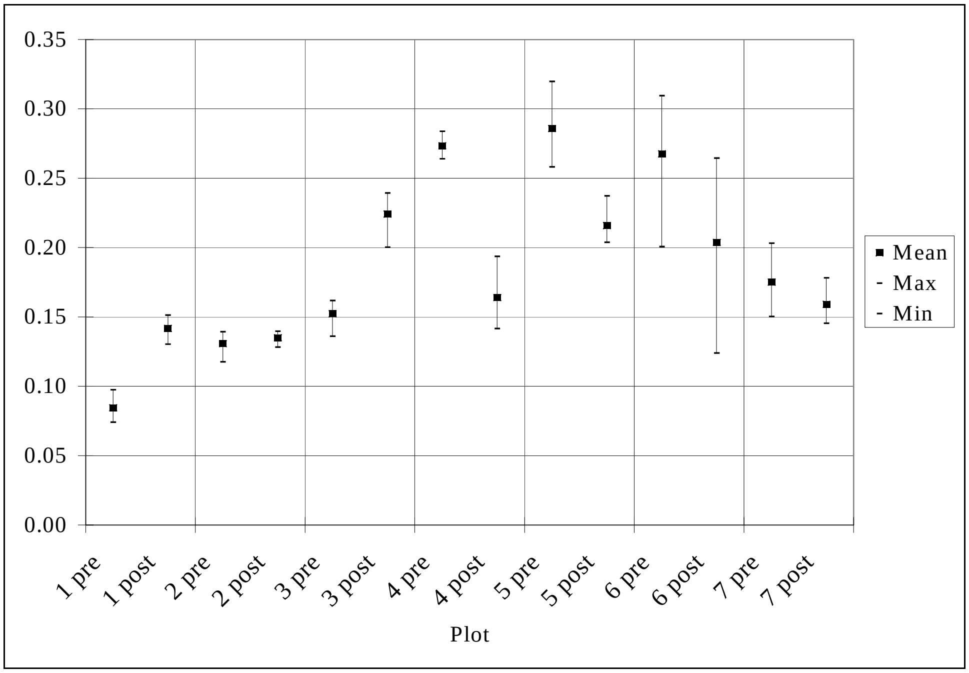
Late seral stage Boreal White Spruce and Black Spruce (BWBS)

Species Composition:

- Lodgepole pine
- Douglas-fir
- Paper birch
- Sitka alder
- Bunchberry
- Douglas maple
- Soopolallie
- Prickly rose
- Clasping twisted stalk
- Richardson's geranium
- Pine grass
- False Solomon's seal
- Princes pine
- Winter green sp.
- *Cetraria canadensis*
- *Hylacomnium splendens*
- *Pleurozium schreberi*
- *Bryroria sp.*
- *Platismatia glauca*
- *Hypogymnia physodes*
- *Parmelia sulcata*
- *Peltigera canina*
- *Peltigera membranaceae*
- *Peltigera aphthosa*

Results

The isopleths of the model indicated that injury would be 1.5 km from c-12-L/93-I-9, along the eastern slope of the hillside. No injury or dramatic changes in sulphur status were noted in any of these locations. Visible injury appeared on a single juvenile subalpine fir tree on the edge of the pad on the berm upslope and to the east of the well. This tree showed slight reddening to the windward side of the crown following the well flare test. The areas to the east of the well showed a slight increase in Si:So ratios. This site was visited again in 2003; the tree with the red foliage had recovered with very little needle loss.



A78. Average inorganic/organic sulphur ratios of lodgepole pine collected at each of the seven monitoring stations around c-12-L/93-I-9 in August (pre-flare) and October (post-flare).

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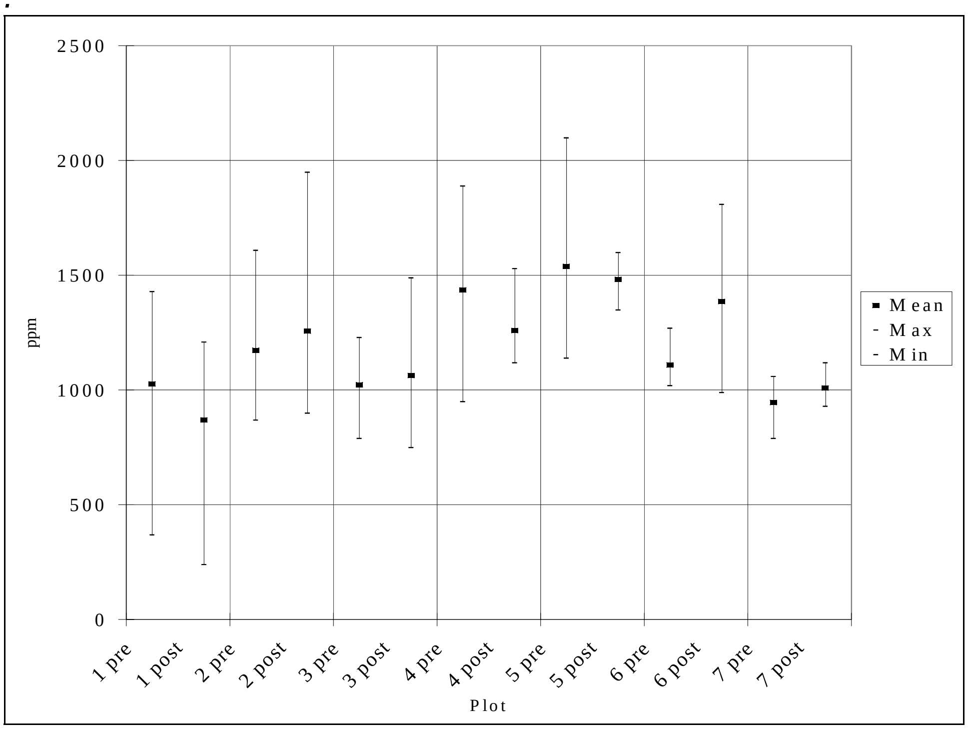
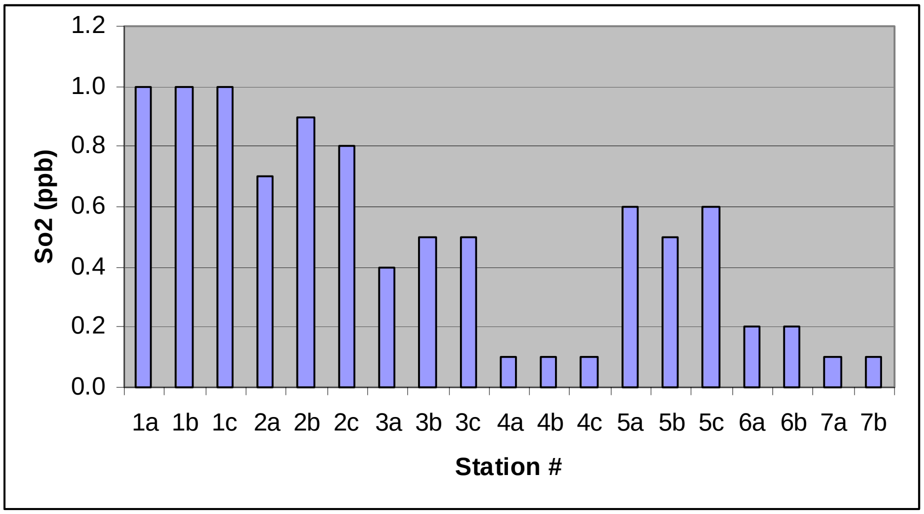


A79. Average total sulphur in lichens (ppm) collected at each of the seven monitoring stations around c-12-L/93-I-9 in August (pre-flare) and October (post-flare).



A80. Concentrations of sulphur dioxide (ppb) registered by the passive monitors (3 samplers per station) located at seven monitoring stations around c-12-L/93-I-9. Exposure period: August 24 to October 18, 1999.

There are no photos are available for c-12-L/93-I-9.

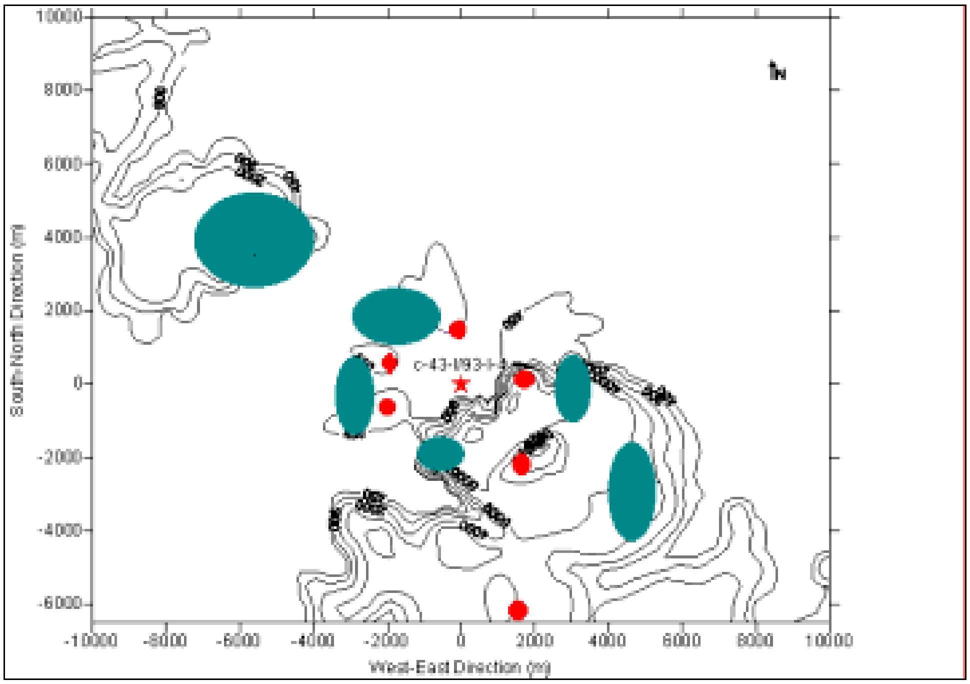
Well: c-43-I/93-I-14

General Location: Murray River

UTM Coordinates: 625974E 6097585N

Physiography: lower montane valley side

Biomonitoring Station Constellation:



Note: red dots are monitoring stations.

Date of Flare Event:

- June 7, 2001 for 7 hours

Dates of Field Work:

- May 10, 2001 (pre-flare assessment)
- June 13, 2001 (post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:

- Range: 610 µg/m^3 – 24 805 µg/m^3 or 229.3 ppb – 9325.2 ppb (from 2 scenarios through 6 stability classes)
- Mean 7803.5 µg/m^3 or 2933.65 ppb

Actual Modeled Maximum Ground Level SO_2 Concentrations:

- 854 µg/m^3 or 321.1 ppb (in stability class 2), occurred east-northeast of the well

Maximum Measured H_2S Content: 11.0%

Meteorological Conditions:

- Wind speeds were ~4.3 m/s, predominantly from the southwest

Sample Components:

- Lichens: *Hypogymnia sp. and Bryoria sp.*
- Conifers: sub-alpine fir, spruce, and lodgepole pine
- Passive SO_2 monitors (x = 7)

Vegetation Response:

Mean values of:	Pre-Flare	Post-Flare
Lichen total sulphur	1198 ppm	1203 ppm
Conifer total sulphur	859.58 ppm	797.89 ppm
Conifer Si:So	0.154	0.144

Passive Monitoring Results:

Station	SO_2 (ppb)
1a	0.37
1b	0.35
2a	0.57
2b	0.44
3a	0.25
3b	0.24
4a	0.26
4b	0.24
5a	0.12
5b	0.23
6a	0.13
7a	0.32
7b	0.30
Mean	**0.294**

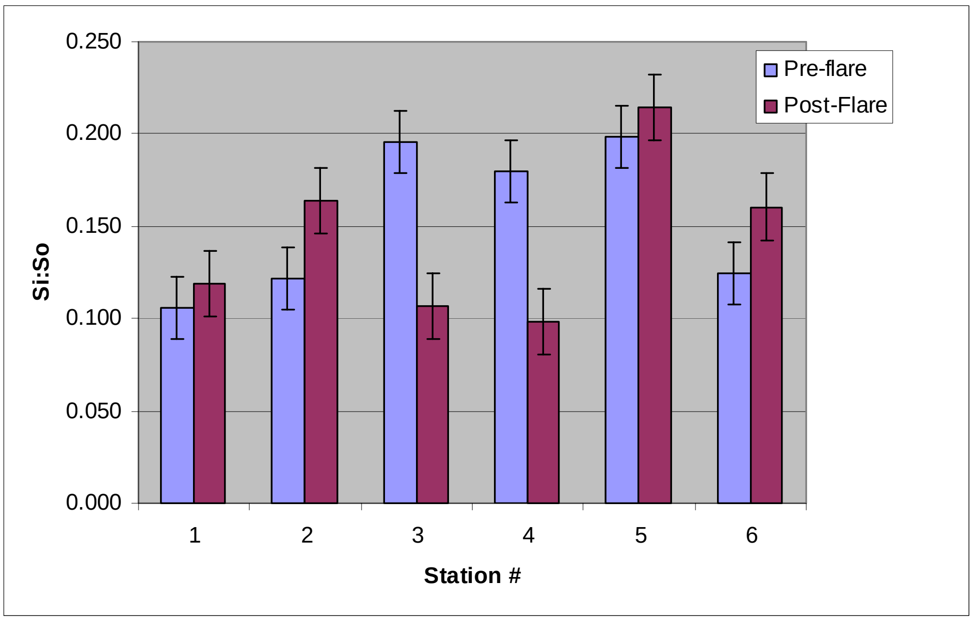
Vegetation Type:
Engelmann Spruce – Sub-alpine Fir (ESSF)
Past fire history, broadleaf deciduous (trembling aspen and paper birch) seral stage

Species Composition:

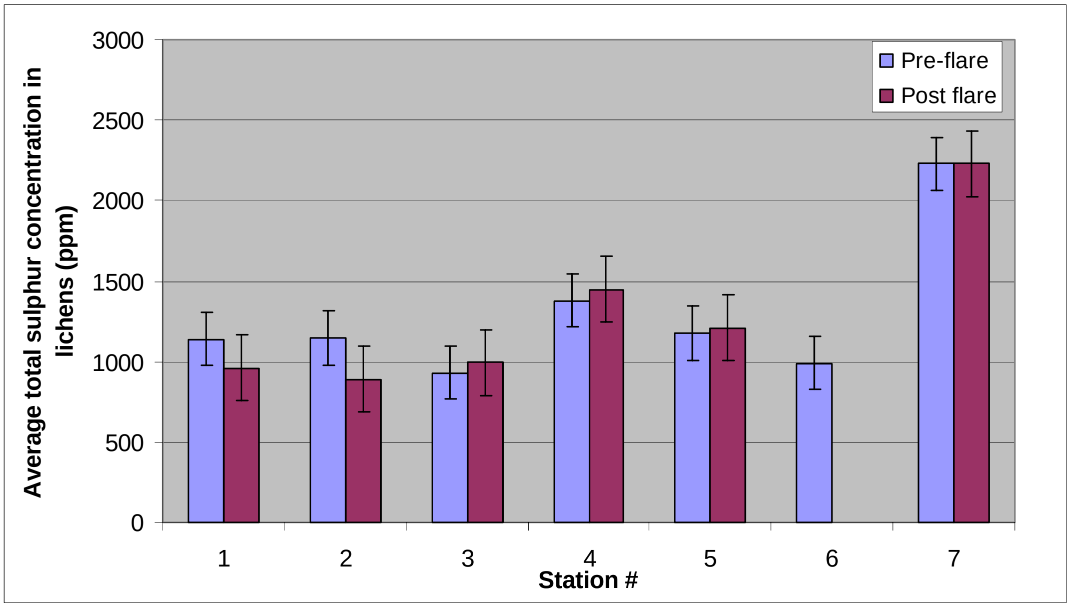
- trembling aspen
- sub-alpine fir
- lodgepole pine
- Douglas-fir
- paper birch
- Sitka alder
- prickly rose
- soopolallie
- false Solomon's seal
- *Parmelia sulcata*
- *Bryoria sp.*
- *Peltigera canina*
- *Peltigera membranaceae*
- *Peltigera aphthosa*

Results

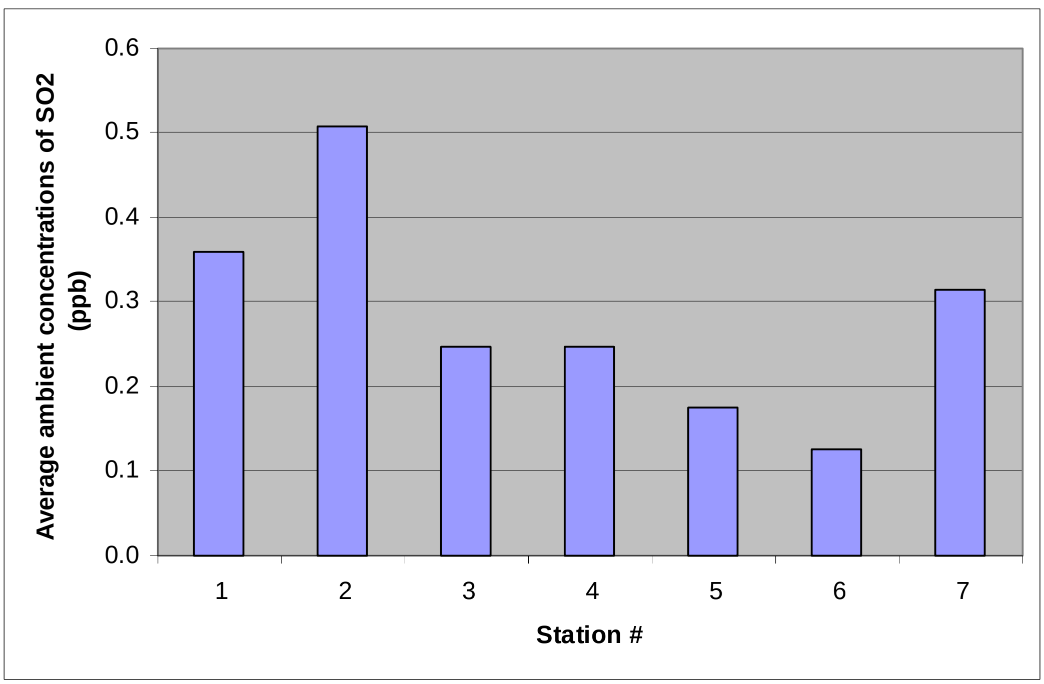
Mechanical injury was present on lodgepole pine at the edge of the lease prior to the well flare test. This was likely a combination of drought, root exposure, and winter injury. Following the flare-test there was little change in the Si:So ratios of the conifers. There was also very little change in the sulphur content of the lichen samples, although one station was exposed to emissions from another, older well site with a glycol dehydrator, and were therefore relatively high (>2000 ppm). The deciduous forest showed no observable impacts to exposed foliage from sulphur dioxide, but little is known about the timing, concentrations and duration of this flare test.



A81. Average inorganic/organic sulphur ratios of conifer tissues collected at each of the seven monitoring stations (where available) around c-43-I/93-I-14 in May (pre-flare) and June (post-flare).



A82. Average total sulphur in lichen tissues (ppm) collected at each of the seven monitoring stations (where available) around c-43-I/93-I-14 in May (pre-flare) and June (post-flare).



A83. Concentrations of sulphur dioxide (ppb) registered by the passive monitors located at seven monitoring stations around c-43-I/93-I-14. Exposure period: May 10 to June 13, 2001.

A84 (left). c-43-I/93-I-14 lease and forest stand edge, as viewed from Station 4, pre-flare May 10, 2001.

A85 (right). Vegetation condition at c-43-I/93-I-14, Station 6, pre-flare, May 10, 2001.

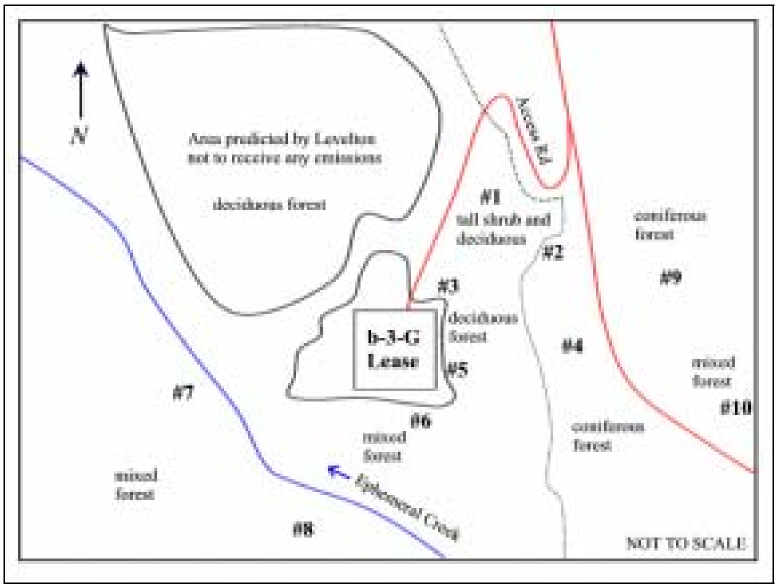
Well: b-3-G/93-P-3

General Location: Wolverine River Valley

UTM Coordinates: 617525.9E, 6105752.7N

Physiography: Undulating plateau above main valley, montane to sub-alpine

Biomonitoring Station Constellation:



Dates of Flare Events:

- July 20 - 30, 2003 for 39 hours
- August 18 - 22, 2003 for 24 hours

Dates of Field Work:

- July 3, 2003 (pre-flare assessment)
- September 19, 2003 (post-flare assessment)

Predicted Maximum Ground Level 1-Hour SO_2 Concentrations:

- Range: 2360 µg/m^3 - 48 540 µg/m^3 or 887.2 ppb - 18 248.1 ppb (from 5 scenarios through 6 stability classes)
- Mean value of 33 738 µg/m^3 or 12 684 ppb

Actual Modeled Maximum Ground Level SO_2 Concentrations:

- 1271 µg/m^3 or 478 ppb (July flare), east of well site
- Range: 454 µg/m^3 -1378 µg/m^3 or 171ppb - 518 ppb (August flare) (based on exceedances of the B.C. Level A Air Quality Objective [450µg/m^3] through 6 stability classes) , northeast of well site
- Mean value of 754.75 µg/m^3 or 284 ppb (August flaring period)

Measured H_2S Content:

- 15.0 to 30.7% (July flare)
- 11.0 to 20.5% (August flare)

Meteorological Conditions:

- For the July flare wind speeds ranged from 0.2 to 3.3m/s, predominately from the west
- For the August flare wind speeds ranged from 0.3 to 3.1 m/s and winds were predominately from the west-southwest

Sample Components:

- Lichens: *Hypogymnia physodes* and *Peltigera sp.*
- Conifers: spruce, and lodgepole pine
- Passive SO_2 monitors (x = 10)

Vegetation Response:

Mean value of:	Pre-Flare	Post-Flare
Lichen total sulphur	1436.7 ppm (*Peltigera sp.*) 636 ppm (*Hypogymnia physodes*)	1458.8 ppm (*Peltigera sp.*) 798 ppm (*Hypogymnia physodes*)
Conifer total sulphur	887 ppm	856 ppm
Conifer Si:So	0.1639	0.1404

Passive Monitoring Results:

Station	SO_2 (ppb)
1	0.30
2	0.30
3	0.30
4	0.30
5	0.40
6	1.10
7	0.10
8	0.20
9	0.40
10	1.20
Mean	**0.46**

Vegetation Type:

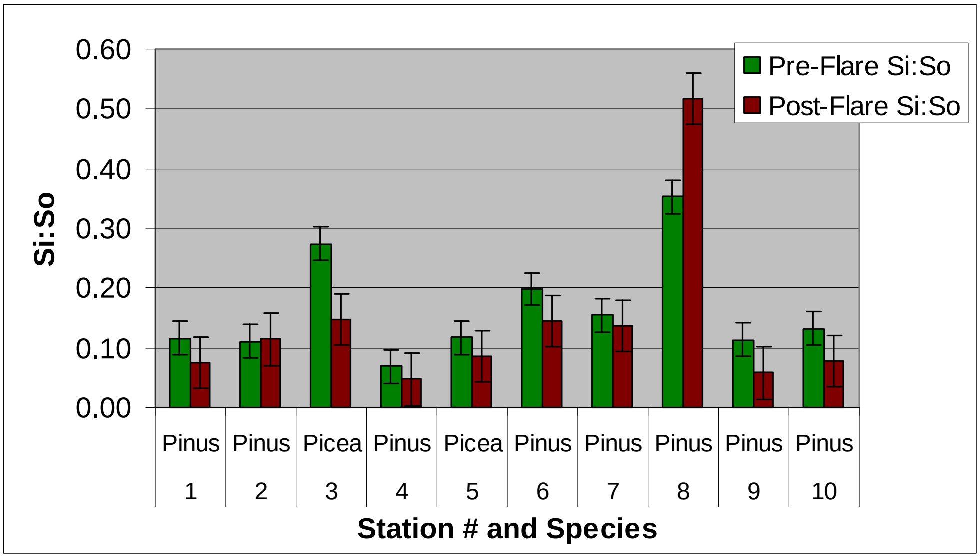
Engelmann Spruce – Sub-alpine Fir (ESSF)
Past fire history, broadleaf deciduous (trembling aspen) seral stage

Species Composition:

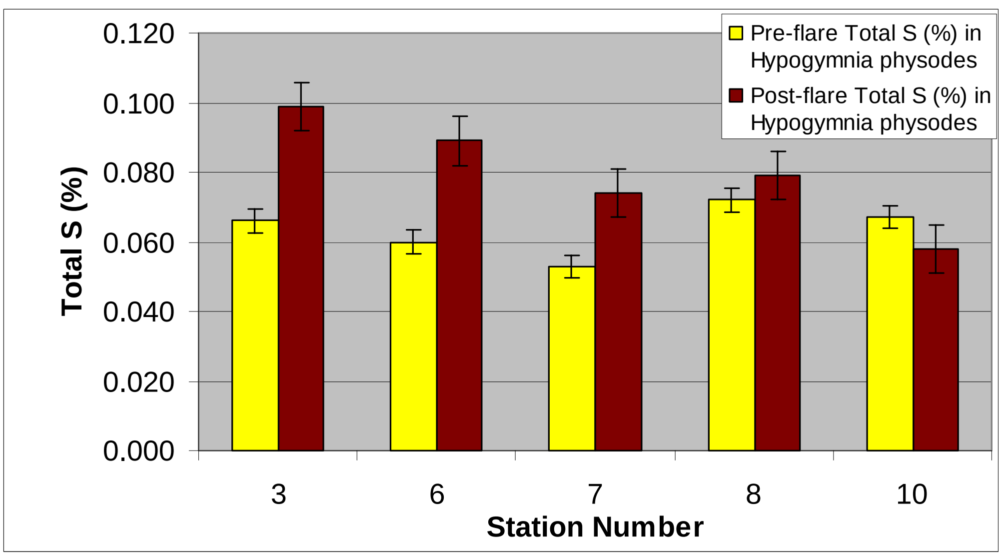
- trembling aspen (dominant)
- lodgepole pine (co-dominant)
- sub-alpine fir (understory)
- Engelmann spruce
- soopolallie
- Sitka alder
- high-bush cranberry
- birch-leaved Spirea
- prickly rose
- chokecherry
- saskatoon
- common juniper
- kinnikinnick
- willow sp.
- black gooseberry
- twinflower
- bunchberry
- prince's pine
- mountain sweet-cicely
- creamy peavine
- american vetch
- fireweed
- tall bluebell
- wild strawberry
- wild sarsaparilla
- hawkweed sp.
- heart-leaved arnica
- paintbrush sp.
- oak fern
- cow-parsnip
- sweet-scented bedstraw
- one-sided wintergreen
- common horsetail
- violet sp.
- red-stemmed feathermoss
- *Bryoria fuscescens*
- *Hypogymnia physodes*
- *Hypogymnia imshaugii*
- *Platismatia glauca*
- *Peltigera membrancea*
- *Peltigera sp.*
- *Dicranum fuscescens*
- *Cladina mitis*
- *Cladonia gracilis*
- *Cladonia chlorophaea*
- *Campylium stellatum*

Results

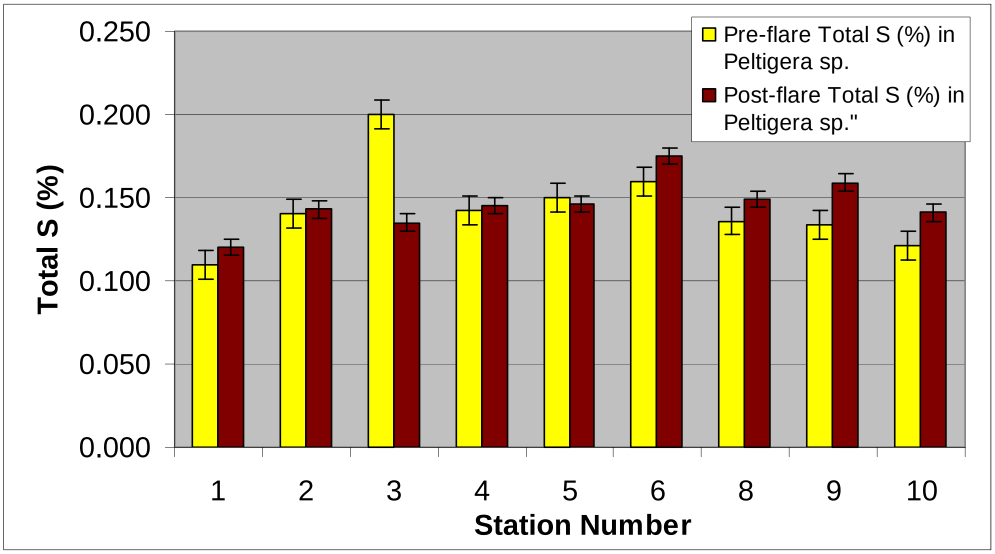
Based on previous work on gas well production tests, maximum injury usually occurs in the area directly adjacent to the lease, in the direction of prevailing winds. However, at this site slight injury and slightly higher records of sulphur dioxide were noted at approximately 1.1 km from the well in the direction of prevailing winds. This is likely due to the steepness of the terrain directly adjacent to the well and the direction of prevailing winds. Overall forest pathology showed little change from pre to post-flare. The injury was confined to exposed foliage of three trees, and is thought to be recoverable. The injury, shown in Figures A90 and A91, occurred in the area predicted to receive the greatest ground levels sulphur dioxide concentrations by the modeling; this conclusion is supported by the passive monitoring data as well as sulphur chemistry analysis of conifer and lichen tissue.



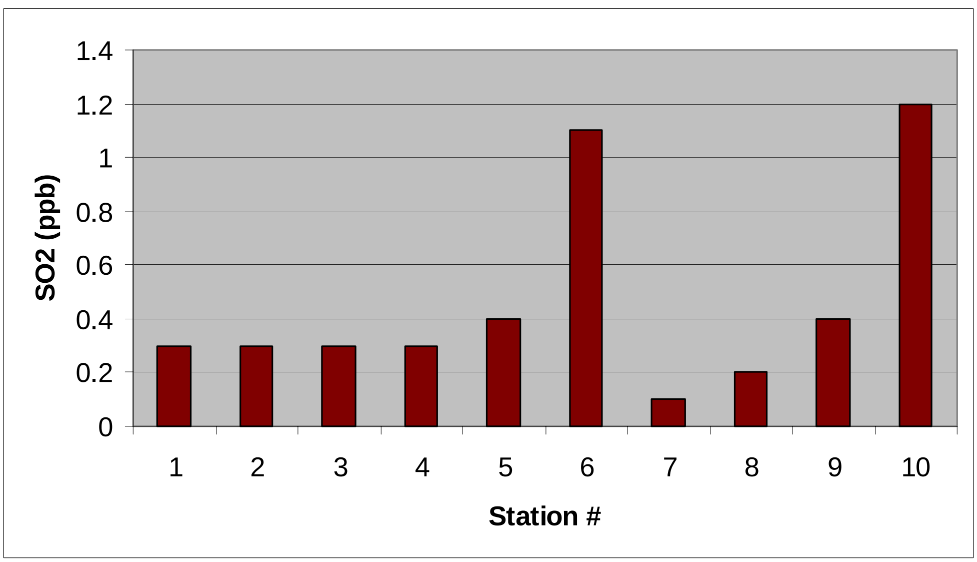
A86. Average inorganic/organic sulphur ratios for conifer tissues collected at each of the ten monitoring stations around b-3-G/93-P-3 in July (pre-flare) and September (post-flare).



A87. Average total sulphur in Hypogymnia physodes collected at each of the ten monitoring stations (where available) around b-3-G/93-P-3 in July (pre-flare) and September (post-flare).



A88. Average total sulphur in Peltigera species collected at each of the ten monitoring stations (where available) around b-3-G/93-P-3 in July (pre-flare) and September (post-flare).



A89. Concentrations of sulphur dioxide (ppb) registered by the passive monitors located at ten monitoring stations around b-3-G/93-P-3. Exposure period: July 3 to September 19, 2003.

A90-91. Minor tip burn possibly from sulphur dioxide on lodgepole pine at b-3-G/93-P-3, Station 10.

A92. Eastern edge of b-3-G lease facing Station 5, note a few aspen in the foreground have minor mechanical injury to their lower stems.

Closure

We trust the above meets your requirements. If you have any further questions, or require additional details, please contact the undersigned.

Golder Associates Ltd.

Report prepared by:

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