Nutrient Levels in the Atmosphere of the Elk Creek Watershed Chilliwack, BC, (1999-2000)



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Nutrient Levels in the Atmosphere of the Elk Creek Watershed, Chilliwack, B.C. (1999-2000)

EXECUTIVE SUMMARY

The Elk Creek watershed encompasses 28 km² of agricultural, urban and mountainous terrain, located near Chilliwack, British Columbia, in the eastern portion of the Fraser Valley. Due to agricultural and urban activities, the area is impacted by agricultural and storm water runoff and streambank erosion. Episodes of poor visibility also affect this area and much of the Fraser Valley. These episodes have been linked to secondary particulate formation, which is enhanced at certain times of the year due to increased concentrations of primary precursors coupled with appropriate meteorological conditions. Such precursors include ammonia, sulphate and nitrate as well as biogenic organic compounds emitted by vegetation. In addition to poor visibility, these compounds have been implicated in human health and ecosystem impacts. Ecosystem impacts are varied and occur as a result of direct deposition to land and water surfaces resulting in negative effects on plants, sensitive receiving waters and materials.

The objective of the present study was to evaluate the atmospheric concentrations and deposition rates of the following nutrients in the Elk Creek watershed: ammonia, nitrate, nitrite, sulphate and total phosphate. Such knowledge will aid in determining the role of atmospheric nutrients in the formation of fine particulates as well as assessing the risk due to atmospheric deposition of these compounds to aquatic and terrestrial ecosystems within the area.

Nutrients were measured in air and precipitation samples from May 1999 to May 2000 from a sampling platform located at the eastern end of Chilliwack Airport. A filter pack denuder was used for obtaining weekly integrated air samples for gaseous and particulate forms of sulphate, nitrate, nitrite and ammonia. A high volume sampler was used for obtaining weekly time integrated samples of total phosphate and total particulate matter. Rainfall samples were collected biweekly with a MIC precipitation sampler. Nutrients in precipitation were reported as the sum of both dissolved and particulate fractions. Meteorological measurements were taken concurrently using a meteorological tower installed at the site.

Concentrations were calculated for air and precipitation samples and data were plotted to examine seasonal patterns and co-occurrence of species. Spearman correlation tests were used to measure strengths of correlation for co-occurring species. Phase partitioning of species was examined for nutrients occurring in both gaseous and particulate forms. Dry and wet deposition rates were calculated for each species and estimates of total deposition were made for the area encompassed by the Elk Creek watershed. Concentrations and deposition rates were compared, where possible, with values reported throughout North America and Europe.

Sulphate, nitrate, nitrite and total phosphate concentrations in air and precipitation samples exhibited a similar seasonal distribution, with maximum concentrations occurring between May and September, coinciding with warmer temperatures, relatively dry periods and an increase in total particulate matter. Ammonia in air samples had a unique time series pattern with peak levels coinciding with the timing of most extensive manure application to crop fields in the spring and early fall. Peak total phosphate concentrations in air samples closely followed seasonal oscillations of total particulate matter. Phase partitioning calculations indicated that ammonia and nitrite were found primarily in the gas phase, while nitrate was found primarily in the particle phase. Sulphate was found to partition relatively equally between the two phases, except during periods of heavy precipitation when it was found primarily in the gas phase. Generally, particle phase species tended to predominate during the drier summer months and gas phase species during the wetter fall and winter months, reflecting decreased secondary particle formation and increased rain washout.

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Molar ratios indicated an excess of ammonium over sulphate and nitrate in the particulate fraction. Both ammonium sulphate and ammonium nitrate complexes are likely present, however the latter is expected to be dominant during the late fall and winter due to sulphate limitation at that time. Both complexes are optically active components of fine particulates involved in light scattering and visibility impairment. The presence of a significant amount of excess ammonium suggests the presence of other complexes such as ammonium chloride.

Mean sulphate and nitrate concentrations in air samples from Chilliwack were similar to background levels measured at Mt. Rainier, but lower than those in Seattle, Washington. In contrast, ammonia gas concentrations were double the values reported for background areas in North Carolina but similar to those reported in Phoenix, Arizona and urban Chongju, Korea. These levels, however, were 2-5 times lower than those reported for agricultural areas of the Netherlands. Ammonium ion levels in air were similar to those reported for southern Ontario and many of the eastern states of the U.S.A.

As with air samples, nitrate, nitrite, ammonium and total phosphate in precipitation samples exhibited peak concentrations during the warmest and driest months (May-September). Nitrate concentrations in precipitation were similar to those reported for the western United States but one order of magnitude lower than those measured at the Saturna Island CAPMoN station and in some of the north eastern United States. Ammonium ion concentrations in rainwater were similar to those reported for a number of agricultural Central Plain American states. The pH level of rainwater was more alkaline than that of natural rainwater, reflecting the buffering effect of ammonia.

Downward fluxes of NOy (nitrate + nitrite) and ammonia were dominated by wet deposition, while total phosphate deposition was relatively evenly divided between the dry and wet forms. Wet NOy deposition was similar to that reported for the western United States but one order of magnitude lower than in the eastern United States. Total NHx (ammonia +ammonium) deposition was in the same range as that estimated for continental north-western Europe. Total wet nitrogen deposition exceeded levels designed to protect the most acid sensitive ecosystems in the Colorado Rockies. This is significant in view of the fact that acid sensitive ecosystems are also found in the Fraser Valley and surrounding highlands. Dry deposition of total phosphate was above background levels but similar to those found in central Canada. In terms of magnitude of total deposition (dry and wet), nutrient fluxes followed a descending order: NHx> SO₄> NOy> PO₄.

Nutrient concentrations were compared to federal and provincial air and water quality guidelines, criteria and objectives, where available. None of the nutrients measured in air sampled exceeded federal or provincial air quality guidelines or objectives. Three precipitation samples exceeded the British Columbia Ministry of Water, Land and Air Protection nitrite criterion for the protection of aquatic life in freshwater, although the primary source of nitrite to freshwater is likely to be land based.

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SOMMAIRE

Le bassin du ruisseau Elk couvre 28 km² de terres agricoles, urbaines et montagneuses, situées près de Chilliwack, en Colombie-Britannique, dans la partie orientale de la vallée du Fraser. Du fait des activités agricoles et urbaines, la région subit les effets du ruissellement agricole et de celui des eaux pluviales, et il y a érosion des rives du cours d'eau. Dans cette région et dans une grande partie de la vallée du Fraser, on note également des épisodes de visibilité médiocre. Ces épisodes ont été associés à la formation de particules secondaires, qui est plus forte pendant certaines périodes de l'année en raison des concentrations plus élevées de précurseurs primaires combinées à des conditions météo appropriées. Parmi ces précurseurs, il y a l'ammoniac, le sulfate et le nitrate ainsi que des composés organiques biosynthétiques, émis par la végétation. En plus d'être à l'origine d'une visibilité médiocre, ces composés ont été associés à des impacts sur la santé humaine et l'écosystème. Les impacts sur l'écosystème sont variables et sont le résultat du dépôt direct sur l'eau et le sol, entraînant des effets négatifs sur les végétaux, les eaux en aval et les matériaux sensibles.

L'objectif de la présente étude était d'évaluer les concentrations atmosphériques et le taux de dépôt des nutriments suivants dans le bassin hydrographique du ruisseau Elk : ammoniac, nitrate, nitrite, sulfate et phosphate total. Ces données aideront à déterminer le rôle des nutriments atmosphériques dans la formation de fines particules et à évaluer le risque que le dépôt atmosphérique de ces composés représente pour les écosystèmes aquatiques et terrestres de la région.

De mai 1999 à mai 2000, on a analysé les nutriments dans des échantillons d'air et de précipitations provenant d'une plate-forme d'échantillonnage située à l'extrémité orientale de l'aéroport de Chilliwack. Un dénudeur-filtre a servi à obtenir des échantillons d'air composés hebdomadairement pour les formes gazeuses et particulaires de sulfate, nitrate, nitrite et ammoniac. Un échantillonneur de grands volumes a servir à prélever les échantillons composés hebdomadaires de phosphate total et de particules totales. Des échantillons de pluies ont été prélevés bihebdomadairement à l'aide d'un échantillonneur de précipitations MIC. Les nutriments dans les précipitations sont exprimés sous forme de la somme des fractions aussi bien dissoutes que particulaires. On a parallèlement enregistré les données météo grâce à une tour installée sur le site.

Les concentrations ont été calculées pour les échantillons d'air et de précipitations et on a représenté graphiquement les résultats obtenus afin d'examiner les variations saisonnières et la cooccurrence d'espèces. Les tests de corrélation de Spearman ont servi à mesurer la force de la corrélation pour la coocurrence d'espèces. Le partage des espèces en phases a été examiné pour les nutriments présents aussi bien sous forme gazeuse que sous forme particulaire. Les taux de dépôts sec et humide ont été calculés pour chaque espèce, et on a procédé à des estimations du dépôt total pour toute la superficie du bassin du ruisseau Elk. Les concentrations et les taux de dépôt ont été comparés, lorsque c'était possible, à des valeurs obtenues à travers toute l'Amérique du Nord et en Europe.

Les concentrations de sulfate, de nitrate, de nitrite et de phosphate total dans les échantillons d'air et de précipitations présentaient une distribution saisonnière similaire, avec des maximums entre mai et septembre, coïncidant avec des températures plus élevées, des périodes relativement sèches et une augmentation des particules totales. L'ammoniac dans les échantillons d'air présentait une distribution chronologique particulière, dont les concentrations pics coïncidaient avec les périodes d'application les plus actives de fumier sur les champs cultivés, au printemps et au début de l'automne. Les concentrations maximales de phosphate total dans les échantillons d'air suivaient de très près les oscillations saisonnières des concentrations de particules totales. Les calculs pour le partage entre phases ont montré que l'ammoniac et le nitrite se retrouvaient principalement dans la phase gazeuse, alors que le nitrate

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était surtout présent dans la phase particulaire. Il y avait partage à peu près égal du sulfate entre les deux phases, excepté durant les périodes de fortes précipitations, où il se retrouvait surtout dans la phase gazeuse. De façon générale, les espèces de la phase particulaire prédominaient surtout pendant les mois plus secs de l'été, et les espèces de la phase gazeuse durant les mois d'automne et d'hiver plus humides, ce qui reflète une formation moindre de particules secondaires et un entraînement plus important par les pluies.

Dans la fraction particulaire, les rapports molaires indiquaient un excès d'ammonium par rapport au sulfate et au nitrite. Il y a probablement présence de complexes et de sulfate d'ammonium et de nitrate d'ammonium; cependant, le dernier devrait être dominant à la fin de l'automne et en hiver du fait de la quantité limitée de sulfate pendant cette période. Ces composés sont tous deux des constituants optiquement actifs de fines particules responsables de diffusion de la lumière et d'une visibilité réduite. La présence d'une quantité significative d'excès d'ammonium laisse supposer la présence d'autres complexes, comme le chlorure d'ammonium.

Les concentrations moyennes de sulfate et de nitrate dans les échantillons d'air de Chilliwack étaient comparables aux concentrations naturelles mesurées au mont Rainier, mais inférieures à celles de Seattle (Washington). Par contre, les concentrations d'ammoniac gazeux étaient le double de celles signalées pour des régions « naturelles » de la Caroline du Nord, mais comparables à celles constatées à Phoenix (Arizona) et dans la zone urbaine de Chongju, en Corée. Il faut, cependant, noter que ces concentrations étaient de 2 à 5 fois inférieures à celles mesurées dans des régions agricoles des Pays-Bas. Les concentrations d'ion ammonium dans l'air étaient comparables à celles mesurées dans le sud de l'Ontario et dans de nombreux États de l'est des États-Unis.

Comme dans le cas des échantillons d'air, le nitrate, le nitrite, l'ammonium et le phosphate total des échantillons de précipitations présentaient des pics de concentration pendant les mois les plus chauds et les plus secs (mai-septembre). Les concentrations de nitrate dans les précipitations étaient comparables à celles mesurées dans l'ouest des États-Unis, mais dix fois moins élevées que celles obtenues à la station CAPMoN de l'île Saturna et dans certaines régions du nord-est des États-Unis. Les concentrations d'ion ammonium dans les eaux de pluie étaient comparables à celles mesurées dans un certain nombre d'États américains de la plaine centrale agricole. Le pH des eaux de pluie était plus alcalin que celui d'eaux de pluie « naturelles », ce qui reflète l'effet tampon de l'ammoniac.

Les flux descendants de NOy (nitrate + nitrite) et d'ammoniac étaient dominés par le dépôt humide, alors que le dépôt de phosphate total était assez uniformément divisé entre les formes sèche et humide. Le dépôt humide de NOy était comparable à celui observé dans l'ouest des États-Unis, mais dix fois inférieur à celui noté dans l'est. Le dépôt de NHx total (ammoniac + ammonium) se situait dans la même plage que celle obtenue dans le nord-ouest de l'Europe continentale. Le dépôt humide d'azote total était supérieur aux concentrations choisies pour protéger les écosystèmes des montagnes Rocheuses du Colorado les plus sensibles aux acides. Cela est significatif si on considère que l'on trouve également des écosystèmes sensibles aux acides dans la vallée du Fraser et dans les hautes terres voisines. Le dépôt sec de phosphate total se situait au-dessus des concentrations naturelles, mais était comparable à celui constaté dans le centre du Canada. Pour ce qui est du dépôt total (sec et humide), les flux de nutriments se rangeaient par ordre décroissant, comme suit : NHx > SO₄ > NOy > PO₄.

On a procédé à une étude comparative des concentrations de nutriments avec les lignes directrices, critères et objectifs pour la qualité de l'air et de l'eau des gouvernements fédéral et provinciaux. Aucun des nutriments mesurés dans les échantillons d'air ne dépassaient les valeurs seuils des lignes directrices ou des objectifs des gouvernements fédéral ou provinciaux pour la qualité de l'air. Trois échantillons de précipitations dépassaient les critères pour la protection de la vie aquatique en eaux douces contre le nitrite, du ministère de la Protection des

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eaux, des terres et de l'atmosphère de la Colombie-Britannique, et ce en dépit du fait que la principale source de nitrite dans les eaux douces est probablement terrestre.

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INTRODUCTION

Nutrients are elements or compounds that are essential for the growth and survival of organisms. The supply of nutrients within an ecosystem has a substantial influence on both the abundance of plant and animal life and types of species that can inhabit the ecosystem. In this report compounds containing sulphur, nitrogen and phosphorus will be collectively referred to as nutrients.

The Elk Creek watershed is located in the Fraser Valley, east of Chilliwack, British Columbia, with its headwaters on Elk Mountain, Mount Thurston and the Eastern Hillsides. It encompasses about 28 km² of agricultural, urban and mountainous terrain (Rood and Hamilton, 1995). Its watercourses flow north and drain into the Fraser River at Hope Slough. The headwaters of Elk Creek include old growth coniferous forest up to and exceeding 250 years of age. The watershed provides important spawning and rearing habitat for Coho and Chum salmon and Cutthroat trout. Important wildlife species include the Pacific giant salamander, mountain beaver and Keen's long-eared bat (Litke, 1997).

The Fraser River floodplain portion of the Elk Creek watershed is largely agricultural in nature, while the hillside areas in the middle part of the watershed have limited residential development with some recreational, agricultural and forestry land use. Agricultural activity in the flood plain of the watershed consists of dairy production, field crops, greenhouses and improved pasture lands. The density of all livestock is estimated at 2.46 animal units (AU) per hectare. Manure is applied to 58% of the total agricultural land area, commercial fertilizer to 58%, herbicides to 29% and insecticides to 12% (Statistics Canada, 1992).

There have been significant impacts to the Elk Creek watershed as a result of excessive nutrient additions from agricultural practices and urban development. The Fraser River flood plain has been cleared of most of its natural vegetation, and the creeks have been channelized to support agricultural development. Agricultural runoff, storm water runoff and stream bank erosion have impacted water quality and threatened fish habitat in the watershed (Litke, 1997).

Atmospheric impacts are also apparent, with the most obvious being the presence of strong odors from the widespread practice of manure application to agricultural fields. This practice, which serves the dual purpose of soil fertilization and manure disposal is employed throughout the year and is most intense from February to October. The reduction in manure application during the rainiest period of the year (November - January) follows recommendations stated in the Manure Management Guidelines set out by the Ministry of Water, Land and Air Protection. Consequently, the most extensive periods of manure application to grasslands occur during the fall and spring periods, as farmers seek to empty their storage tanks. In addition, manure is applied to grassland during the summer months an average of 4-5 times, immediately after each cut of forage (Environment Canada, 1998). As a result of these manure application practices, nitrogen additions to agricultural soils are high relative to the other regions in Canada (Van Vliet *et al.*, 1997). In the Fraser Valley, 32% of swine producers apply manure at rates greater than 500 kg N ha⁻¹, while 140,000 tonnes of poultry manure are applied annually (Paul, 1998).

The intensive application of manure to crop fields is believed to contribute significant amounts of gaseous ammonia to the Fraser Valley airshed. Ammonia, together with nitrate and sulphate, has been shown to be an important component of fine atmospheric particles which, due to their small size (<2.5 um), are believed to be linked to episodes of poor visibility in the Fraser Valley (Pryor *et al.*, 1997). These episodes, which obscure the view of the surrounding Coast Mountains for a significant portion of the year, are perceived to be most severe approximately 50-80 km east of Vancouver and to be increasing in frequency. Recent perception studies have shown that poor

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visibility episodes in the Fraser Valley are considered by residents and tourists to be unacceptable and are expected to have a detrimental impact on tourism and the local economy (McNeill and Roberge, 2000). The issue of poor visibility in the Fraser Valley is complex, however, and is complicated by the fact that natural factors, such as water vapor and biogenic volatile organic carbon compounds, are also involved in light scattering and hence contribute to reductions in visibility.

Although agricultural practices are believed to be a significant source of ammonia to the Lower Fraser Valley, non agricultural sources such as oil refineries and gasoline combustion, may also be important. Oil refineries emit large amounts of ammonia, mainly from the use of catalyst regenerators in fluid-bed catalytic cracking units. Similarly, automobile exhaust contains a substantial amount of ammonia, which is produced by internal–combustion engines equipped with 3-way catalytic converters (Graham, 1999). On a much smaller scale, but nevertheless important, are natural biogenic emissions of ammonia from oceanic sources. Marine biogenic sources have been shown to account for approximately 5% of the total NHx deposition in parts of the UK (Barret, 1998).

Nitrate (NO_3) and nitrite (NO_2) are derived from reactions involving OH radical oxidation of nitrogen dioxide (NO_2) and nitric oxide (NO) resulting in formation of gaseous nitric (HNO_3) and nitrous (HNO_2) acids. Through condensation processes, these gases further react with atmospheric particles resulting in particulate forms of nitrate (XNO_3) and nitrite (XNO_2) . The parent compounds, NO_2 and NO, are primarily derived from combustion of fossil fuels from automobile and industrial sources (Environment Canada, 2001). NO is also sometimes produced naturally though the nitrification/denitrification process involving soil microorganisms and as a result of wildfires and lightning (Agriculture and Agri-Foods Canada, 1998).

In addition to ammonia and nitrate, sulphate has been identified as a key component of fine optically active atmospheric particles in the Lower Fraser Valley (Pryor et al., 1997). Sulphate sources can be both natural and anthropogenic. Natural sources include dimethyl sulphide (DMS), the breakdown product of an osmoregulatory compound found in phytoplankton and hydrogen sulphide (H₂S) from decomposition of biological material under anoxic conditions. A recent study by Environment Canada has shown that DMS emissions are linked to biological productivity in the Strait of Georgia, with peak emissions occurring during the spring and summer months. DMS emissions from the Strait of Georgia are estimated to be in the order of ~1.1 kilotonnes per year (Sharma et al., in progress) and may contribute significantly to the total sulphur budget in the Georgia Basin airshed during the spring months. On the other hand, cement manufacturing and the combustion of various fossil fuels from the industrial and transportation sectors contribute considerable amounts of sulphur dioxide (SO₂) which becomes oxidized in the atmosphere to chemically active sulphuric acid (H_2SO_4). Sulphuric acid nucleates in the presence of water vapor to form sulphuric acid droplets or condenses on existing particles. These particles are neutralized by ammonia gas to become small optically active particles of ammonium sulphate ((NH4)₂SO₄) or ammonium bisulphate (NH₄HSO₄) (Brost *et al.*, 1988) which are highly effective at light scattering. Efforts are presently underway to characterize the specific chemical composition of fine particulate matter in the Fraser Valley.

In addition to the impact on visibility, fine nutrient rich particles, containing sulphates, nitrates and ammonia, have been associated with human health effects. Particles less than 10 um in diameter are inhalable and able to reach the tracheobronchial area of the respiratory tract, while particles 2-3 um in diameter are respirable and can reach the alveoli in the distal parts of the lung, where absorption takes place. Specifically, sulphate, found primarily in the <2.5 um size fraction, has been shown to be strongly associated with increased mortality and hospitalizations (CEPA/FPAC, 1998), while ammonium based particulates have been linked to acute respiratory pathology (Giroux *et al.*, 1997).

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Atmospherically delivered nutrients may also contribute to ecosystem disruption through deposition to land and water causing eutrophication of waterways, soil acidification and disruption of terrestrial plant growth. For example, a continuous deposition of NHx may reduce plant biodiversity in natural ecosystems, where plant species requiring low nitrogen can no longer compete with plant species which thrive on abundant nitrogen supply (Sutton *et al.*, 1993). Physiological and morphological damage to plant species due to toxic levels of NH₃ has also been widely observed (Holtan-Hartwig and Bockman, 1994). Groundwater contamination is also common and this is especially of concern in the Abbotsford Aquifer, the most extensively used aquifer in the Fraser Valley, where nitrate concentrations continue to exceed the maximum acceptable concentration of the Canadian Drinking Water Guideline (Hii *et al.*, 1999). Studies have shown that agricultural production over the Abbotsford aquifer makes a substantial contribution to nitrate loading of the aquifer (Zebarth *et al.*, 1994).

Another important nutrient controlling plant growth is phosphorus. Prior to urbanization, industrialization and intensive agriculture, phosphorus was added to soils only through the weathering of rocks (Environment Canada, 2001). At present, however, the use of fertilizer from phosphorus-bearing rock, such as apatite, has altered the natural pattern of phosphorus at rates that far exceed natural weathering. This, in addition to smokestack emissions and soil erosion, can increase the biologically reactive phosphorus loading to a level that can disrupt the nutrient balance in fresh water lakes and rivers (IJC, 1980). Because phosphorus can cause eutrophication of freshwater bodies, it is important to characterize the atmospheric loading of phosphorus to land and water surfaces.

The objective of the present study was to evaluate the atmospheric concentrations and deposition rates of ammonia, ammonium, nitrate, nitrite, sulphate and total phosphate in the Elk Creek watershed in the Fraser Valley of British Columbia. Such knowledge will aid in determining the role of atmospheric nutrients in the formation of fine particulates and the atmospheric input of these compounds to aquatic and terrestrial ecosystems within the watershed.

SITE DESCRIPTION

The sampling site was located 49° 10' N and 121° 56' W in the City of Chilliwack (Figure 1) located in the eastern portion of the Fraser Valley. The Fraser Valley is flanked to the north by the Coast Mountains, running east to west, and the Cascade Mountains, running north-east to southwest. The valley takes the form of a triangle with its base on the eastern shore of the Strait of Georgia and its apex in the most eastern portion, in the Chilliwack-Hope area. The topography of the area supports a sea-breeze land-breeze reversing flow of air, especially during the summer months when more frequent high pressure systems cause periods of stagnation, allowing enhanced reaction rates and increased concentrations of atmospheric pollutants.

The sampling platform was located at the eastern end of Chilliwack Airport on the roof of an air quality trailer owned by the Greater Vancouver Regional District. The airport supports light private plane traffic only, in the order of several flights per day, and was not expected to influence the air quality at the sampling site. The site was located in a semi-rural area approximately 1 km from the Trans Canada Highway which runs in a east west direction to the south of the site. Due to influences from both agricultural and vehicle emissions, the site was considered to be representative of the airshed. Sampling equipment was installed at a height of 5 m above the ground (16 m above sea level).

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METHODS

Field Sampling Procedures

Nutrients were measured in both air and precipitation samples as described in Table 1. For air samples, nutrients were measured in both the gas and particulate phases, with the exception of total phosphate which only exists in particulate form. Nutrients in precipitation samples were measured as the sum total of both dissolved and particulate fractions (i.e. unfiltered). The specifics of each measurement technique are detailed below.

Filter/Pack Denuder

A Filter/Pack Denuder sampling cartridge developed by the Harvard School of Medicine (Koutrakis *et al.*, 1993) was used for sampling for gases and particulates (Figure 2). The filter pack/denuder has an impaction plate at the inlet that removes particles <2.3 um in size. This is followed by a sodium carbonate coated section of co-axial glass tubes (NCD), a section of citric acid coated co-axial glass tubes (CAD), a 2 um pore size Teflon filter (TF), a 1 um pore size sodium carbonate coated glass fiber filter (NCF) and a 1 um pore size citric acid coated filter (CAF). The cartridge was operated at a flow rate of 10 L/min to ensure correct particle separation. Flow rates were measured using a Bios Flow meter (Bios International Corporation, New Jersey).

The first denuder (NCD) removes acidic gases such as sulphur dioxide, nitrous and nitric acid. The second denuder (CAD) removes the basic gases such as ammonia. The purpose of the Teflon filter (pore size 2 um) was to capture fine particles including, ammonium sulphate $((NH_4)_2SO4)$ and ammonium nitrate (NH_4NO_3) . Because these ammonium compounds are formed by weak bonds, they may break down into their parent compounds. Therefore, two 1 um glass fiber backup filters are used to capture these break-down products: the sodium carbonate coated filter collects the acidic gases – sulphur dioxide (SO_2) , nitrous acid (HNO_2) and nitric acid (HNO_3) , while the citric acid coated filter collects the basic gas, ammonia (NH_3) .

Fifty-two samples were collected from May 18, 1999 to May 16, 2000 (Table 2). Time integrated samples were collected every seven days and taken to the analytical laboratory for analysis. Flow rates ranged from 9.0-10.8 L/min and sampling volumes from 88.6-114 m³. Five field blanks were taken by mounting the filter/pack denuder cartridge and immediately removing it without pumping air though it. Field blank and raw data results are presented in Table 11.

High Volume Sampler

Total phosphate was measured using a General Metal Works High Volume sampler with a flow capacity of 40 cubic feet per minute (Graseby GMW, Cleves, Ohio). The physical design of the sampler is based on aerodynamic principles which result in the collection of particles of 100 microns and less. The sampler consists of a blower/motor unit and a supporting screen for the filter ahead of the blower/motor unit. The sampler is supported in a protective shelter so that the surface of the filter is in a horizontal position. EPM 2000 8"x10" glass fiber filters of 1 um pore size were used as sampling media. Forty-six time integrated weekly samples were taken from May 18, 1999 to April 4, 2000 (Table 3). Four field blanks were taken by installing and uninstalling clean filters. Field blank and raw data results are shown in Table 17.

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Precipitation Sampler

Rainfall was collected with a MIC precipitation collector type AUMC (MIC Company, Richmond Hill, Ontario). Precipitation samples were collected in chemically clean polyethylene bags placed inside a collector bucket. The collector bucket lid was activated by a moisture sensor which opened only when precipitation occurred. The plastic bucket was 27.2 cm in diameter and 51.0 cm deep with a collection area of 0.058 m².

Twenty-four time integrated precipitation samples were collected every 14 days from May 18, 1999 to May 16, 2000 (Table 4). Two samples were collected for only 7 days (May 18-26, 1999 and July 13-20, 1999) due to technical difficulties. Two field blanks were taken by placing a clean bag inside the sampler and then removing it. Samples were immediately taken to the laboratory for analysis. Field blank and raw data results are presented in Table 19.

Meteorological Instruments

A meteorological tower was used for recording wind direction, wind speed, temperature and relative humidity. Wind speed and direction were measured using an RM Young anemometer mounted at a height of 10 m above the ground. Temperature was measured using an RM Young thermistor. Relative humidity was measured with an RM Young hygrometer. Rainfall amount was measured using an Environment Canada standard rain gauge. Meteorological data were captured on a CR-10 data logger from Campbell Scientific.

Laboratory Methods

Samples were prepared and analyzed at the Analytical Services Laboratory (ASL) in Vancouver, British Columbia.

Filter Pack/Denuder Samples

The preparation and extraction of the sampling media for ammonia, nitrate, nitrite and sulfate were carried out according to procedures obtained from the Harvard School of Public Health, Ogawa & Company (1995).

The extracts prepared from the citric acid filters (CAF) and citric acid denuders (CAD) were analyzed for ammonia only. The extracts prepared from the sodium carbonate filters (NCF) and sodium carbonate denuders (NCD) were analyzed for nitrate, nitrite and sulphate. The extract prepared from the Teflon filter (TF) was analyzed for all four parameters: ammonia, nitrite, nitrate, and sulphate. In total, each filter-pack denuder sample resulted in five prepared extracts.

The ammonia extract was analyzed according to procedures in "Standard Methods for the Examination of Water and Wastewater" (APHA, 1998). Ammonia and ammonium were determined colourimetrically by a reaction with phenol, hypochlorite and an indicating salt (APHA Method 4500-NH₃) and reported as ammonia nitrogen.

Nitrate, nitrite and sulphate were analyzed using a procedure described in "The Determination of Inorganic Anions in Water by Ion Chromatography" (EPA, 1993). The procedure involves analysis of the extract by Dionex Ion Chromatography with a chemically suppressed conductivity detector,

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using an Ion Pac ASA12A Anion Separator column with an Ion Pac AG12A Guard (EPA Method 300.0).

Reagent blanks and spikes were used to check the quality and accuracy of the data. Blanks were generally non-detectable and spikes were all within the accepted range of 60-140% of the target analyte.

High Volume Samples

Total phosphate in high volume samples was analyzed using procedures adapted from NIOSH Method 7903 "Acids – Inorganic" (NMAM, 1994) and the Workers' Compensation Board of British Columbia Method 1401 (WCB, 1995). A 5 x 10 cm portion of the filter media was extracted with deionized water and then analyzed by ion chromatography. Total particulate analysis was carried out in accordance with U.S. EPA Reference Method RFPS-0694-098 "Rupprecht & Patashnick Partisol Model 2000 Air Sampler" (EPA, 1994). Total particulate matter was determined gravimetrically using a five place balance by pre and post-weighing of the filter. Filter blanks were used to check the quality of the data. All blanks were within acceptable limits for total particulate matter. All but one of the blanks were within acceptable limits for total phosphate.

Rainwater Samples

Rainwater analyses were carried out in accordance with procedures described in "Methods for Chemical Analysis of Water and Wastes" (EPA, 1983), "A Laboratory Manual for the Chemical Analysis of Water, Wastewaters, Sediments and Biological Tissues" (Environment Canada, 1976) and "Standard Methods for the Examination of Water and Wastewater" (APHA, 1998). Laboratory blanks were used to check the quality of the data. All blanks were below the method detection limit.

Data Processing and Analysis

The chemical data were reported in terms of micrograms (ug) of chemical extracted from the sample submitted. Raw data were blank corrected based on averaged field blank values. Nitrite nitrogen (Teflon filter) and sulphate (sodium carbonate filter), sampled by filter pack denuder, were generally below the detection limit and were therefore removed from the final dataset. The remaining data were plotted and checked for outliers. No outliers were identified.

Concentrations were calculated from blank corrected data by dividing sample weights by the sample volume. For air samples, the data were converted to concentrations in ug/m³. For precipitation samples, concentrations were reported in mg/L. Data were plotted to examine seasonal patterns and co-occurrence of species. Spearman correlation tests were used to measure strengths of correlation for co-occurring species. Statistical analysis was performed using Sigma Stat 2.0 (Jandel Scientific). Phase partitioning of species was examined for nutrients occurring in both gaseous and particulate forms and results were presented as fractional contributions to total measured amounts.

Deposition rates for particles and gases were calculated as a product of the deposition velocity and measured air concentration. Dry deposition velocity values were chosen from a survey of the literature to most accurately reflect chemical properties, particle size, surface type and

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roughness. Deposition rates for nutrients in precipitation were calculated from the measured weight of the chemical divided by the area of the sampler and time sampled.

The following parameters, sampled with the filter pack denuder, were reported based on the definitions provided below:

<u>Total gaseous sulphate</u>: measured as sulphate on the sodium carbonate denuder. <u>Total particulate sulphate</u>: measured as sulphate on the Teflon filter and sodium carbonate coated filter.

<u>Total gaseous ammonia</u>: measured as ammonia nitrogen on the citric acid coated denuder. <u>Total particulate ammonium</u>: measured as ammonia nitrogen on the Teflon and citric acid coated filters.

<u>Total gaseous nitrate</u>: measured as nitrate nitrogen on the sodium carbonate coated denuder. <u>Total particulate nitrate</u>: measured as nitrate nitrogen on the Teflon filter and sodium carbonate coated filter.

<u>Total gaseous nitrite</u>: measured as nitrite nitrogen on the sodium carbonate coated denuder. <u>Total particulate nitrite</u>: measured as nitrite nitrogen on the Teflon filter and sodium carbonate coated filter.

RESULTS AND DISCUSSION

Meteorological Parameters

Meteorological parameters measured during the sampling period are presented in Figures 3-5. Temperature and relative humidity were reported on an hourly basis, while precipitation was measured weekly. Wind measurements were not available due to instrument failure.

Sulphate Concentrations - Air Samples

Total gaseous sulphate ranged from 0.10-2.8 ug/m³ with a mean of 0.80 ug/m³ (Table 5). Total particulate sulphate ranged from 0.0046-2.3 ug/m³ with a mean of 0.68 ug/m³. Both gaseous and particulate sulphate followed the same temporal trend with concentrations rising in April and maximizing between May and the end of September (Figure 6). Gaseous and particulate sulphate concentrations were lowest during the period of greatest precipitation (November-December). Particulate sulphate concentrations were generally lower than those measured in 1996 in Seattle but similar to those measured at Mt. Rainier, Washington (Chow and Watson, 1998). Both gaseous and particulate sulphate concentrations were similar to those measured by Belzer et al., (1997) at Abbotsford and Agassiz in the Fraser Valley. As in the present study, the latter two studies also reported higher sulphate concentrations during the summer months. Summer peaks occur during periods of maximum yearly temperatures and intensity of solar radiation, both of which accelerate the oxidation of SO₂ to SO₄²⁻. Elevated sulphate levels also appear to coincide with periods of enhanced biological productivity in the Strait of Georgia (Harrison et al., 1983) and correspondingly high dimethylsulphide (DMS) emissions (Sharma et al., in progress). Anthropogenic sources of sulphate may also be important and include a petroleum refinery and an aluminum smelter, approximately 70 km to the south west in Washington state, and two cement plants in the Greater Vancouver area, approximately 50 km to the west of the site. A preliminary estimate of the magnitude of biogenic sulphur emissions in the Georgia Basin airshed indicates that on an annual basis approximately 10-26% of the total atmospheric sulphur budget originates from biogenic DMS emitted from the Strait of Georgia (Sharma et al., in progress).

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Gas-particle phase partitioning of sulphate is shown in Figure 7. Sulphate partitioned relatively equally between the gas and particle phases in most samples, although the gas to particle ratio increased in the fall and winter months. This is likely due to decreased particle formation during the cooler months as a result of slower reaction rates at lower temperatures and increased rain washout of particles during the fall and winter. In the particle phase, sulphate occurs in the form of ammonium sulphate ((NH4)₂SO₄), ammonium bisulphate (NH₄HSO₄), sulphuric acid (H₂SO₄), sodium sulphate (Na₂SO₄) and gypsum (Ca₂SO₄).

Sulphate Deposition Rates

The dry deposition rate for total and gas and particulate phase sulphate was calculated using a annual mean deposition velocity of 0.24 and 0.12 cm/s, respectively, for a mixture of grassland and forest in a temperate region (Voldner and Sirois, 1986). Particle phase sulphate was assumed to reside almost exclusively in the PM 2.5 size fraction (Zhuang *et al.*, 1999). The mean deposition rate was 170 ug/m²/day for gas phase sulphate and 71 ug/m²/day for particulate phase sulphate (Table 5) for a total of 0.24 mg/m²/day in dry sulphate deposition. Since sulphate concentrations were not measured in rainfall in the present study, a deposition rate of 4.4 mg/m²/day was estimated based on measurements reported by Belzer *et al.* (1997) at nearby Abbotsford. Summing these daily dry and wet deposition rates yields a total of 4.6 mg/m²/day of total sulphate. Extending this value to the area of the Elk Creek watershed (28 km²), yields an estimated yearly total of 45 tonnes of total sulphate deposition to the watershed.

Nitrate / Nitrite Concentrations – Air Samples

Total gaseous nitrate ranged between 0.052-0.38 ug/m³ with a mean of 0.15 ug/m³ (Table 5). Concentrations were approximately double in the warmer months, compared to the cooler months (Figure 8). Total particulate nitrate ranged between 0.040-0.98 ug/m³ with a mean of 0.28 ug/m³ (Table 5). Three pronounced peaks occurred in August, September and March-April and coincided with relatively dry periods (Figure 8). The lowest concentrations of both gaseous and particulate nitrate occurred in November-December when precipitation was highest.

Mean particulate nitrate concentrations at Chilliwack were over four times lower than those measured in Seattle in 1996 but identical to those measured at Mt. Rainer in western Washington (Chow and Watson, 1998). As in the present study, nitrate concentrations were reported to be highest during the summer. In Chilliwack, summer maxima are likely due to accelerated reaction rates with resultant secondary particle formation.

Nitrate was found primarily in the particle phase (Figure 9), likely due to the relative ease with which HNO_3 condenses onto both fine and coarse particles. Time series for particulate nitrate and ammonium were plotted together as shown in Figure 10. The concentrations of the two species were positively correlated (Spearman Rank Correlation, $r_s = 0.652$, p<0.001.

Total gaseous nitrite concentrations were similar to total gaseous nitrate concentrations ranging from 0.0043-0.38 ug/m³, with a mean of 0.11 ug/m³ (Table 5). Total particulate nitrite concentrations were considerably lower than total gaseous nitrite concentrations, ranging between 0.00037-0.25 ug/m³ with a mean of 0.030 ug/m³. Peak concentrations of both gaseous and particulate nitrite occurred in October just prior to the onset of the fall rainy period (Figure 11).

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In contrast to nitrate, nitrite partitioned primarily in the gas phase (Figure 12). The ratio of particle to gas partitioning increased to more than 50% in a few samples taken during the summer and early fall.

Nitrate / Nitrite Concentrations – Precipitation Samples

Nitrate concentrations in precipitation ranged between 0.042-0.74 mg/L with a mean of 0.20 mg/L (Table 6). Levels were highest between May and September, with peak concentrations occurring during the week of July 27-August 10 (Figure 13). These levels are similar to those measured at Abbotsford (Belzer *et al.*, 1997) and in the states of Washington, Oregon and northern California (National Atmospheric Deposition Program, 1999) but approximately one order of magnitude lower than those measured at Saturna Island (Ro, 2001), and in the in the eastern states of Michigan, Indiana and Ohio (National Atmospheric Deposition Program, 1999).

High nitrate levels in drinking water represent a health concern due to its association with the condition known as methemoglobinemia (Blue Baby Syndrome) (Amdur *et al.*, 1991). Nitrate nitrogen levels in precipitation samples were well below the provincial maximum nitrate plus nitrite level (as N) of 10 mg/L (BCMELP, 1998). Nitrate nitrogen levels were also well below the water quality criterion for fresh water aquatic life of 200 mg/L as N (BCMELP, 1998).

Nitrite concentrations averaged 0.012 mg/L and ranged between 0.0060-0.039 mg/L (Table 6). These values are almost identical to those measured at Abbotsford in 1996 (Belzer *et al.*, 1997). The seasonal pattern was the same as that for nitrate, with concentrations highest during the warmer months (Figure 14). Nitrite nitrogen levels were well below the provincial maximum concentration for drinking water of 1.0 mg/L as N (BCMELP, 1998). The toxicity of nitrite in aquatic environments is dependent on the concentration of chloride, increasing as the chloride concentration decreases. At chloride concentrations less than 2 mg/L (characteristic of the rainwater samples in the present study), the provincial criterion for the protection of freshwater aquatic life calls for a maximum 30 day average concentration of 0.02 mg/L. Although the mean measured nitrite nitrogen levels in rainwater are below this criterion, three of the 24 rainwater samples exceeded this level. This is significant in view of the fact that nitrite levels in Elk Creek river water have been found to exceed this criterion (Nener and Wernick, 1997). However, it should be noted that more recent sampling in Elk Creek has not found any exceedences of the nitrite criterion (S. Sylvestre, personal comm.).

Nitrate / Nitrite - Dry and Wet Deposition Rates

The dry deposition rate for total gaseous and particulate nitrate/nitrite (NOy) was calculated using a mean yearly deposition velocity of 0.12 and 0.45 cm/s, respectively, for a mixture of grassland and forest in a temperate region (Volder and Sirois, 1986). As indicated in Table 5, the mean deposition rate of total particulate NOy (120 ug/m²/day) was over four times higher than for gaseous NOy (26 ug/m²/day). The larger deposition values for particulate NOy is due to its presence in the coarse particle mode as a result of reactions of gas phase nitric acid with sea salt or soil dust (Zhuang *et al.*, 1999). This results in larger deposition velocities than for compounds, such as sulphate and ammonium, which reside primarily in the submicron particle mode and consequently have lower deposition velocities.

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Wet deposition rates of nitrate nitrogen ranged between 0.18 to 1.6 mg/m²/day with a mean of 0.65 mg/m²/day (Table 6). This value is similar to the annual mean measured at Abbotsford (0.82 mg/m²/day, Belzer *et al.*, 1997). On a larger scale, nitrate deposition values from Chilliwack were in the same range as those reported for most of the western United States but one order of magnitude lower than levels in the industrialized north-eastern United States (National Atmospheric Deposition Program, 1999). Wet deposition rates of nitrite were approximately one order of magnitude lower than for nitrate, ranging between 0.0070-0.090 mg/m²/day, with a mean of 0.040 mg/m²/day. Seasonally, nitrite deposition rates peaked during the rainiest months, November and December (Figure 14).

A comparison of dry and wet deposition rates for nitrate/nitrite is shown in Table 7. As the numbers indicate, dry NOy deposition occurred primarily in particulate form. However, in terms of total deposition, wet deposition dominated over dry deposition. Extending the figures to the entire Elk Creek watershed, a total of 1.5 tonnes /year of total gaseous and particulate nitrate is expected to fall as dry deposition and 7.1 tonnes/year is expected to fall as wet deposition for a total of 8.6 tonnes/year of total NOy deposition to the watershed.

Ammonia / Ammonium Concentrations - Air Samples

Total gaseous ammonia concentrations ranged from 2.3-9.0 ug/m^3 with a mean of 5.2 ug/m^3 (Table 5). These levels were lower than those measured in 1996 at Abbotsford (mean = 11 ug/m^3 , range 8-30 ug/m^3) but were similar to those at nearby Agassiz (mean 4.6 ug/m^3 , range 2-20 ug/m^3 , Belzer *et al.*, 1997) and in Aldergrove (1-8 ug/m^3 , Barthelmie and Pryor, 1998). Ammonia concentrations were well below the Ontario Ministry of Environment ambient air quality standard of 3,600 ug/m^3 (OME, 1999). Peak gaseous ammonia concentrations occurred in the early spring (February to April) and early fall (September-October) as shown in Figure 15. This seasonal trend was also observed by Belzer *et al.*, (1997) in the Lower Fraser Valley and Buijsman *et al.* (1998) in the Netherlands, and it coincides with periods of most intense manure application (Van Vliet, pers. comm.). Lower ammonia concentrations occurred between November and January, reflecting reduced manure application to crop fields but also due to lower temperatures, reduced volatilization and increased washout from the atmosphere.

On a larger scale, mean ammonia levels measured in the Fraser Valley are approximately five times higher than those reported for rural locations of Scotland (Burkhardt *et al.*, 1998; Fowler *et al.*, 1998) and natural settings such as Mt. Mitchell State Park, N.C. (Aneja *et al.*, 1998). On the other hand, levels are similar to those measured in Phoenix, Arizona (mean 9.1 ug/m³, Watson *et al.*, 1994) and urban Chongju, Korea (4.1-7.5 ug/m³, Lee *et al.*, 1997). However, ammonia levels are lower than those reported for and agricultural areas of the Netherlands, where mean concentrations reach 10-25 ug/m³ (Buijsman *et al.*, 1998). The latter represent areas of very intense animal husbandry, where some of the highest maximum ammonia concentrations in Europe have been measured in hourly samples, reaching values as high as 100 ug/m³. It should be noted that these Dutch studies employed a continuous annular denuder system allowing time resolved sampling, as opposed to the weekly time integrated samples provided by the filter-pack denuder system used in the present study. Consequently, the filter pack denuder method does not provide information on maximum peaks but rather provides a time weighted average of concentrations over a given time period.

Particle bound ammonium ion ranged between 0.0065-4.6 ug/m^3 with a mean of 1.8 ug/m^3 (Table 5). Mean ammonium concentrations were lower than those measured at Abbotsford in 1996 (5.0 ug/m^3) but similar to those measured at Agassiz (1.3 ug/m^3 , Belzer *et al.*, 1997) and in Phoenix, Arizona (1.7 ug/m^3 , Watson *et al.*, 1994). As in previous studies in the area, concentrations of

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particulate ammonium were highest during the spring, summer and early fall (Figure 15), reflecting possibly fertilizer use, increased volatilization of its precursor (NH₃) and accelerated reaction rates. Mean ammonium ion concentrations in the Fraser Valley were approximately five times higher than the most recent 10 year mean measured at Saturna Island (0.37 ug/m³, Shaw, 2001) but similar to levels reported for Longwoods in Southern Ontario (Sirois and Fricke, 1992) and for many of the eastern United States (CASTNet, 2001).

Gas-particle phase partitioning of ammonia nitrogen is shown in Figure 16. Gas phase ammonia predominated over particle phase ammonium in all but two of the samples. The ratio of ammonia to ammonium concentrations was greater during the winter months than the summer months, due to increased rain washout of atmospheric particles and decreased secondary particle formation.

Time series of particulate ammonium and sulphate parameters were plotted together as shown in Figure 17. Ammonium concentrations were at least twice as high as sulphate concentrations and statistically significant correlation was found between the two species (Spearman Rank Correlation, $r_s = 0.624$, p<0.001).

To investigate the relationship between particle phase ammonium, sulphate and nitrate concentrations in relation to their role in fine particle formation, molar ratios were calculated for the following ions: NH_4^+/SO_4^{2-} , NH_4^+/NO_3^- and NO_3^-/SO_4^{2-} The abundance of the ammonium ion is clearly seen in the time series shown in Figure 18 which depicts relatively high molar ratios of NH_4^+/SO_4^{2-} (median = 19:1) and NH_4^+/NO_3^- (median = 5:1). In addition, NO_3^-/SO_4^{2-} median ratios were 3.5:1, indicating a predominance of nitrate over sulphate which was especially pronounced . in the late fall/winter period. These ratios suggest the presence of both ammonium sulphate $((NH_4)_2SO_4)$ and ammonium nitrate (NH_4NO_3) complexes, although the latter are more likely to dominate during the late fall and winter period when sulphate concentrations are lowest. The importance of sulphate ion availability in the formation of optically active complexes was studied by Brost et al. (1998) who found that the rate of formation of ammonium sulphate is primarily dependent on the availability of sulphuric acid. When sulphuric acid is readily available, ammonia is first used to form ammonium sulphate or ammonium bisulphate, both of which have high light extinction coefficients. However, if concentrations of nitric acid exceed those of sulphate, ammonium nitrate will dominate. In addition, Russell et al. (1983) have shown that ammonium nitrate is preferentially formed at higher relative humidities and lower temperatures, conditions more common during the late fall and winter periods in the Fraser Valley. In terms of visibility impairment, the light scattering efficiency of ammonium nitrate is higher than that of ammonium sulphate or any other nitrate species (Horvath, 1992). This difference in light extinction capability may result in a greater extent of visibility reduction in the Fraser Valley during the winter months compared to the spring and summer months at a given fine particulate concentration. Moreover, other ammonium complexes, such as ammonium chloride, may be of importance in the Fraser Valley given the fact that the ammonium ion was found in excess compared to sulphate and nitrate. Ammonium chloride aerosols have been detected in significant quantities in the U.K. and the Netherlands in areas where ammonia emissions are high and chlorine is readily available from either marine or anthropogenic sources (Allen et al., 1989). These complexes, if present in the Fraser Valley, would also contribute to visibility degradation due to their optically active size (0.8 um, Harrison and Pio, 1983) and hygroscopic properties (Pio and Harrison, 1987).

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Ammonia / Ammonium Concentrations - Precipitation Samples

Ammonium nitrogen concentrations in precipitation ranged from 0.18-2.2 mg/L with a mean of 0.60 mg/L (Table 6). Maximum ammonium concentrations occurred during the warmest and driest period of the year, May to September (Figure 19), coinciding with observed maxima for ammonia and ammonium concentrations in air samples. Ammonium concentrations were higher than the 11 year mean reported for Saturna Island (0.20 mg/L, Ro, 2001), but similar to those reported for the agricultural Central Plain states of Nebraska, Iowa and South Dakota (National Atmospheric Deposition Program, 1999). Ammonium nitrogen concentrations in rainwater samples did not exceed provincial criterion for the protection of aquatic life (BCMELP, 1998). However, dissolved ammonia nitrogen concentrations in the waters of Elk Creek have been reported to exceed the 30 day provincial criterion for total ammonia nitrogen (max. = 25.7 mg/L, mean = 3.68 mg/L, Nener and Wernick, 1997), which was likely to be largely due to surface runoff from manure-rich fields. However, more recent sampling of Elk Creek between 1999-2001 has not found any exceedences of this criterion (S. Sylvestre, personal comm.).

Ammonia / Ammonium - Dry and Wet Deposition Rates

Deposition velocities for gas phase ammonia and particle bound ammonium were taken from Pryor and Barthelmie (1999) and were based on modeled surface-type specific deposition algorithms for grasslands and forests, respectively. These algorithms incorporated the simple bigleaf model of Hicks et al. (1985) to calculate particle dry deposition fluxes to grassland or other low vegetation surface and the model by Ruijgrok et al. (1997) to estimate the deposition velocity of particle bound ammonium to forested surfaces. For ammonia deposition to grasslands and forests, algorithms were taken from Joffre (1998), Asman (1994) and Duyzer et al. (1994). Surface roughness lengths were estimated to be 0.05 m for grassland and 0.8 m for forests. A mass median diameter of 2 um was assumed for calculating particulate associated NH_4^+ deposition rates. Deposition velocities for ammonia to grass surfaces ranged between 0.49-0.96 cm/s (Table 8). Deposition velocities are higher during the winter and spring relative to the rest of the year, mostly as a result of wetter conditions during the winter and enhanced vegetative growth during the spring. For forests, deposition velocities ranged between 0.5-1.77 cm/s with the highest deposition velocity occurring during the spring growth period. These deposition velocities are comparable to published values in the literature such as 0.5 cm/s for ammonia deposition to sea water (Lee et al., 1998).

Total deposition to the Elk Creek watershed was calculated based on a ratio of 60% grassland to 40% forested land, reflecting the approximate vegetative distribution within the watershed (Litke, 1997). Estimated ammonia dry deposition rates for the Elk Creek watershed ranged from 2,600-6,000 ug/m²/day, with a yearly mean of 3,900 ug/m²/day (Table 8). Deposition rates are larger in forested areas, where higher ammonia uptake occurs during the spring period due to an increase in vegetative growth. Conversely, lower ammonia uptake occurs during the winter season due to limited vegetative growth and decaying vegetation.

Dry deposition rates for particle phase ammonium ion ranged between 222-246 ug/m²/day, with a yearly mean of 232 ug/m²/day (Table 8). These values are approximately one order of magnitude smaller than for ammonia deposition. This is largely due to the comparatively low aerodynamic resistance of gas phase NH₃ compared to particle bound NH₄⁺ ion. Ammonium ion deposition rates were one order of magnitude higher over forests versus grassland, mostly due to the larger roughness length for the former, which has a pronounced effect on reducing the particle aerodynamic resistance. Unlike gas phase ammonia, ammonium deposition rates did not vary

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significantly with time of year, reflecting the difference in stomatal uptake of the two different forms of nitrogen.

Wet deposition rates of ammonium ion ranged between 0.33-3.9 mg/m²/day with a mean of 2.0 mg/m²/day (Table 6). Deposition rates were highest in November, when precipitation was greatest (Figure 19). Mean wet deposition rates of ammonium exceeded those of the agricultural central plain United States (~0.5-1.4 mg/m²/day, National Atmospheric Deposition Program, 1999) but were similar to those reported for North Sea coast locations in the Netherlands (Paerl, 1995).

Table 9 presents a summary of wet and dry deposition rates for ammonia and ammonium. Based on the mean yearly dry deposition rate, approximately 3.9 mg/m²/day of ammonia nitrogen and 0.23 mg/m²/day of ammonium nitrogen are deposited to the Elk Creek watershed as dry deposition, for a total of 4.2 mg/m²/day deposited in the form of NHx. In terms of wet deposition, we can assume that the ammonium ion is the dominating species and that wet deposition of ammonia is negligible. Indeed, if we check this assumption using the Henderson Hasselbalch equation using a pKa of 9.4 and a mean pH of 6.5, we obtain a ratio of ammonia to ammonium concentrations of less than 0.01. In terms of total NHx (ammonia + ammonium), over the course of a year approximately 68% is estimated to be deposited as dry deposition. The dominance of dry versus wet deposition is however seasonally dependent: whereas dry deposition dominates during the spring and summer, wet deposition dominates during the fall and winter (Pryor and Barthelmie, 1999). Overall, the total dry and wet deposition of NHx to the watershed is estimated to be 6.2 mg/m²/day. Extending these values to the area of Elk Creek watershed, on an annual basis, approximately 43 tonnes of NHx is expected to fall as dry deposition and 20 tonnes as wet deposition for a total of 63 tonnes of total NHx deposition to the watershed (Table 9). Deposition values presented here are in the same range as those estimated by Asman and van Jaarsveld (1992) for NHx deposition over continental north-western Europe.

In order to assess effects of wet atmospheric deposition to land and water surfaces, critical loads have been developed by various jurisdictions. Lakes in the Fraser Valley have been rated as having acid sensitivities ranging from low to high (Swain, 1987), while soil sensitivities have been rated as moderate to high (Wiens, 1984). Areas with the highest acid sensitivity are found largely on the north shore of the Fraser Valley and surrounding highlands due to the predominance of bedrock material with a high resistance to weathering and the existence soils with a low cation exchange capacity. Previous studies have shown that coastal streams in the Georgia Basin are sensitive to acidification (Sullivan and Samis, 1988) and that some streams in the UBC Research Forest are moving towards nitrogen saturation (Feller, 2000). Therefore, in order to protect the most sensitive ecosystems in the area, the lowest critical loads need to be applied. A loading of 6.2 kg N/ha/yr was obtained based on ammonia and nitrate wet deposition measurements from the present study. This loading exceeds the critical load of 4 kg N/ha/yr designed to protect acid sensitive lakes in the Colorado Rockies from acidification (Williams and Tonnesson, 2000) and nitrogen saturation (Williams *et al.*, 1996).

Total Phosphate Concentrations - Air and Precipitation Samples

Total particulate phosphate concentrations ranged from 0.061-0.65 ug/m³ with a mean of 0.25 ug/m³. (Table 5). Concentrations tracked closely with total particulate matter and were generally higher during the summer months, when precipitation was low (Figure 20).

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Total phosphate concentrations in precipitation ranged between 0.0020-0.022 mg/L, with a mean of 0.0072 mg/L (Table 6). Peak concentrations occurred in July, August and September (Figure 20).

The primary impact of phosphorus on receiving waters is through eutrophication. Within the Fraser Valley, many of the surface water bodies have extended low-flow periods of up to several months. During these periods there is very little flushing action and with limited riparian cover along many watercourses, the water can become quite warm, thereby enhancing conditions for aquatic plant growth. Information related to acceptable phosphorus concentrations in Lower Fraser Valley watercourses is not readily available, and there are no water quality objectives or criteria proposed for phosphorus concentrations in Fraser Valley streams. Total phosphorus levels in Elk Creek waters have been reported to be high relative to other creeks in the lower Fraser Basin, with maximum values reaching 4.8 mg/L (Nener and Wernick, 1997). Since these maximum values are considerably higher than total phosphate levels measured in precipitation samples in the current study (0.0020-0.022 mg/L), it suggests that a land based source such as agricultural runoff from fertilizer use may be the principal source of phosphate to the waters of Elk Creek.

Total Phosphate - Dry and Wet Deposition Rates

Dry deposition for total phosphate was calculated using an estimated deposition velocity of 0.1 cm/s, based on the particle deposition model by Slinn and Slinn (1980). A mean particle diameter of 4.6 um was assumed, obtained from the frequency distribution for PO₄ in multiple particle size fractions (Belzer, unpublished). Total particulate phosphate dry deposition rates ranged between 5.3-56 ug/m²/day with a mean of 22 ug/m²/day (Table 5). These values are within the range found in central Canada (Schindler *et al.*, 1976) but higher than background levels in remote areas of northern Canada (Schindler *et al.*, 1974).

Wet deposition rates of total phosphate ranged between $0.0018-0.062 \text{ mg/m}^2/\text{day}$ with a mean of $0.020 \text{ mg/m}^2/\text{day}$ (Table 6). Peak deposition rates occurred in the fall during the week of October 19-November 2 (Figure 21). The mean total dry and wet phosphate deposition was $0.042 \text{ mg/m}^2/\text{day}$ with slightly more than half occurring as dry deposition. Extending these values to the area of the Elk Creek watershed, a total of 430 kg of total phosphate is estimated to be deposited via the atmospheric pathway over the course of a year. The source of total phosphate was not investigated in the present study, however a study conducted in coastal Brittany has shown that depending on the meteorology, between 63-92% of the phosphorus was of anthropogenic origin (Morelli *et al.*, 1984).

pH of Precipitation Samples

The pH of rainwater ranged between 5.39-7.29 with a mean of 6.48 (Table 6). The natural pH of rainwater is approximately 5.6 pH units. This compares to an eleven year mean of 4.7 pH units at Saturna Island (Ro, 2001), 5.0-6.1 pH units for the western states of Washington, Oregon and northern California and 4.2-4.9 pH units for the eastern US states which are experiencing acid rain (National Atmospheric Deposition Program, 1999). The elevated mean obtained in the rainwater samples is likely due to a buffering effect from the relatively high ammonia concentrations in the samples. Measured levels, however, are well within BCMELP approved water quality criteria for various water uses, including drinking water, the protection of aquatic life, irrigation and recreation (BCMELP, 1998).

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SUMMARY AND CONCLUSIONS

The present study has generated year long measurements of nutrient levels in air and precipitation samples from Chilliwack, British Columbia. Deposition rates have been calculated for each nutrient and yearly loads have been estimated for the Elk Creek watershed. The key findings of the study are summarized below.

Sulphate, nitrate, nitrite and total phosphate concentrations in air and precipitation samples exhibited a similar seasonal distribution, with maximum concentrations occurring between May and September, coinciding with warmer temperatures, higher solar radiation, relatively dry periods and an increase in total particulate matter. Maximum ammonia concentrations in air samples coincided with the timing of most intense manure application in the spring and fall. Peak total phosphate concentrations in air samples closely followed seasonal oscillations of total particulate matter.

Phase partitioning calculations indicated particle phase species tended to predominate during the drier summer months and gas phase species during the wetter fall and winter months, reflecting decreased secondary particle formation and increased rain washout.

Molar ratios suggested the presence of both ammonium sulphate and ammonium nitrate complexes. Both complexes are optically active components of fine particulates involved in light scattering and visibility impairment. Formation of one species over another is the result of a competitive process which favors the formation of ammonium sulphate complexes at high sulphuric acid concentrations and ammonium nitrate complexes at low sulphuric acid concentrations. Seasonal variation in molar ratios suggested that ammonium nitrate complexes likely predominate during the late fall and winter period when the molar ratio of nitrate to sulphate is higher. An excess of ammonium ion in particulate samples suggests the presence of other types of complexes, such as optically active ammonium chloride, which is common in high ammonia emission areas.

Atmospheric concentrations of sulphate and nitrate measured at Chilliwack were similar to those measured in rural Washington downwind of the urban center of Seattle. In contrast, mean ammonia concentrations were 2-5 times higher than values reported for background areas such as Mount Mitchell State Park in park in North Carolina, but were similar to those reported in Phoenix, Arizona and urban Chongju, Korea. However, levels in the Fraser Valley were lower than those reported for intensely agricultural areas of the Netherlands. Ammonium ion levels in air and precipitation were similar to those reported for southern Ontario and many of the eastern and central United States. The pH level of rainwater was more alkaline than that of natural rainwater, reflecting the buffering effect of ammonia. Nutrient concentrations measured in the present study were in the same range as those measured in preceding studies in the Fraser Valley.

Wet deposition dominated downward fluxes of NOy and NHx, while total phosphate deposition was relatively evenly divided between the dry and wet forms. Wet NOy deposition was similar to that reported for western United States. Total NHx deposition was in the same range as that estimated for continental north-western Europe. Dry total phosphate deposition was above background levels but similar to that found in central Canada. In terms of magnitude of total deposition (dry and wet), nutrient fluxes followed a descending order: NHx> SO₄> NOy> PO₄.

Nutrient concentrations were compared to federal and provincial air and water quality guidelines, criteria and objectives, where available. None of the nutrients measured in air sampled exceeded

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federal or provincial air quality guidelines or objectives. Although three precipitation samples exceeded the provincial nitrite criterion for the protection of aquatic life in freshwater, the primary source of nitrite to freshwater is most likely land based. In terms of effects related to wet deposition, the critical load of nitrogen exceeded the level designed to protect acid sensitive lakes in the Colorado Rockies from acidification and nitrogen saturation. This is significant in view of the fact that the Fraser Valley and surrounding highlands contain acid sensitive ecosystems.

In conclusion, this study has shown that ammonia levels in the eastern portion of the Fraser Valley are relatively high compared to background areas but do not reach levels found in intensely agricultural areas in north western Europe. In terms of secondary particulate formation, an abundance of ammonia should provide adequate precursors for the formation of optically active ammonium sulphate and ammonium nitrate particles as long as both sulphate and nitrate sources are readily available (e.g. fossil fuel combustion, DMS oxidation). In order to prioritize any potential abatement measures, further issues need to be considered, such as the proportion of the fine particulate matter comprised of inorganic sulphur and nitrogen species relative to biogenic organic species, the possible role of ammonium chloride in local aerosol composition and the effect of humidity on hygroscopic particle growth and light extinction. These and other questions are currently being addressed in Environment Canada's Pacific 2001 Air Quality Study. Lastly, in terms of deposition to land and water surfaces, the atmospheric pathway appears to be important, as indicated by estimates of downward fluxes, which for some nutrients, such as ammonia, were shown to be of considerable magnitude.

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Figure 1. Location of the air quality sampling site, Chilliwack, B.C.

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Figure 2. Filter pack/denuder sample head schematic.

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Figure 3. Hourly temperature readings at Chilliwack Airport.

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Figure 4. Weekly precipitation at Chilliwack Airport.

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Figure 5. Hourly relative humidity readings at Chilliwack Airport.

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Figure 6. Total gaseous and particulate sulphate in air samples shown with precipitation, Chilliwack Airport.

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Figure 7. Gas-particle partitioning of sulphate in filter pack denuder samples from Chilliwack Airport.

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Figure 8. Total gaseous and particulate nitrate in air samples shown with precipitation, Chilliwack Airport.

Nutrient Levels in the Atmosphere of the Elk Creek Watershed, Chilliwack, B.C. (1999-2000)



Figure 9. Gas-particle partitioning of nitrate in filter pack denuder samples shown with precipitation, Chilliwack Airport.





Figure 10. Total particulate nitrate and ammonium in air samples shown with precipitation, Chilliwack Airport.

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Figure 11. Total gaseous and particulate nitrite in air samples shown with precipitation, Chilliwack Airport.

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Figure 12. Gas-particle partitioning of nitrite in filter pack denuder samples from Chilliwack Airport.



Figure 13. Nitrate concentrations and deposition rates in precipitation samples from Chilliwack Airport.



Figure 14. Nitrite concentrations and deposition rates in precipitation samples from Chilliwack Airport.



Figure 15. Total gaseous ammonia and particulate ammonium concentrations in air samples shown with precipitation, Chilliwack Airport.

Nutrient Levels in the Atmosphere of the Elk Creek Watershed, Chilliwack, B.C. (1999-2000)



Figure 16. Gas-particle partitioning of ammonia in filter pack denuder samples from Chilliwack Airport.

Nutrient Levels in the Atmosphere of the Elk Creek Watershed, Chilliwack, B.C. (1999-2000)





Nutrient Levels in the Atmosphere of the Elk Creek Watershed, Chilliwack, B.C. (1999-2000)



Figure 18. Molar ratios for particulate phase ammonium/sulphate, ammonium/nitrate and sulphate/nitrate in air samples, Chilliwack Airport.

Nutrient Levels in the Atmosphere of the Elk Creek Watershed, Chilliwack, B.C. (1999-2000)



Figure 19. Ammonium concentrations and deposition rates in precipitation samples from Chilliwack Airport.



Figure 20. Total phosphate and total particulate matter (PM) concentrations in air samples shown with precipitation, Chilliwack Airport.

Nutrient Levels in the Atmosphere of the Elk Creek Watershed, Chilliwack, B.C. (1999-2000)



Figure 21. Total phosphate concentration and deposition rates in precipitation from Chilliwack Airport.

Parameter	Sample Medium	Phase	Field Instrument	Particle Size	Detection Limit	Units
Ammonia Nitrogen (CAD)	air	gas	filter-pack denuder	<2.3 um	0.1	ug/m3
Sulphate (NCD)	air	gas	filter-pack denuder	<2.3 um	0.01	ug/m3
Nitrate Nitrogen (NCD)	air	gas	filter-pack denuder	<2.3 um	0.002	ug/m3
Nitrite Nitrogen (NCD)	air	gas	filter-pack denuder	<2.3 um	0.001	ug/m3
Sulphate (TF)	air	particulate	filter-pack denuder	<2.3 um	0.02	ug/m3
Ammonia Nitrogen (TF)	air	particulate	filter-pack denuder	<2.3 um	0.05	ug/m3
Nitrate Nitrogen (TF)	air	particulate	filter-pack denuder	<2.3 um	0.004	ug/m3
Nitrite Nitrogen (TF)	air	particulate	filter-pack denuder	<2.3 um	0.002	ug/m3
Ammonia Nitrogen (CAF)	air	particulate	filter-pack denuder	<2.3 um	0.05	ug/m3
Sulphate (NCF)	air	particulate	filter-pack denuder	<2.3 um	0.01	ug/m3
Nitrate Nitrogen (NCF)	air	particulate	filter-pack denuder	<2.3 um	0.002	ug/m3
Nitrite Nitrogen (NCF)	air	particulate	filter-pack denuder	<2.3 um	0.001	ug/m3
Total Phosphate	air	particulate	high volume sampler	<100 um	0.0019	ug/m3
Total Particulate Matter	air	particulate	high volume sampler	<100 um	0.00001	mg/m3
Ammonia Nitrogen	precipitation	total dissolved and particulate	inorganic rain sampler	no limit	0.022	mg/L
Nitrate Nitrogen	precipitation	total dissolved and particulate	inorganic rain sampler	no limit	0.005	mg/L
Nitrite Nitrogen	precipitation	total dissolved and particulate	inorganic rain sampler	no limit	0.001	mg/L
Total Phosphate	precipitation	particulate	inorganic rain sampler	no limit	0.002	mg/L
Total Volume Sampled	precipitation	aqueous	inorganic rain sampler	n/a	n/a	mL
рН	precipitation	aqueous	inorganic rain sampler	n/a	n/a	pH units

Table 1. List of target analytes, field instruments and method detection limits.

CAD = citric acid denuder

NCD = sodium carbonate denuder

TF = Teflon filter

CAF = citric acid coated filter

NCF = sodium carbonate coated filter

n/a = not applicable

Date on	Time on	Flow Rate	Date off	Time off	Flow Rate	Timer start	Timer stop	Total time	Total volume	Total volume
	(PST)	(L/min)		(PST)		(min)	(min)	(min)	(L)	(m ³)
May 18/99	12:55	10.0	May 26/99	08:45	11.90	-	-	11750	117500.0	117.5
May 26/99	08:50	10.2	June 1/99	09:40	9.60	-	-	8690	88638.0	88.6
June 1/99	09:45	10.5	June 8/99	08:45	10.30	-	-	10020	105210.0	105.2
June 8/99	08:45	10.6	June 15/99	10:15	10.30	34226	44343	10117	107240.2	107.2
June 15/99	10:15	10.6	June 22/99	08:15	10.20	44343	54302	9959	105565.4	105.6
June 22/99	08:15	9.9	June 29/99	08:15	10.20	54302	64386	10084	99831.6	99.8
June 29/99	08:15	10.2	Julv 6/99	09:05	10.60	64386	74512	10126	103285.2	103.3
July 6/99	09:05	10.2	July 13/99	08:40	9.70	74512	84571	10059	102601.8	102.6
July 13/99	08:40	10.1	July 20/99	08:35	9.60	84571	94644	10073	101737.3	101.7
July 20/99	08:35	10.1	July 27/99	09:50	9.50	94644	4825	10181	102828.1	102.8
July 27/99	10:00	10.8	Aug. 3/99	08:10	10.30	4825	14779	9954	107503.2	107.5
Aug. 3/99	08:10	10.4	Aug. 10/99	08:00	10.00	14782	24849	10067	104696.8	104.7
Aug 10/99	08:00	10.0	Aug. 17/99	08:15	9.60	24849	34947	10098	100980.0	101.0
Aug 17/99	08:15	10.0	Aug 24/99	08:30	9.90	34947	45044	10097	100970.0	101.0
Aug 24/99	08:30	10.2	Aug 31/99	09:00	9.70	45044	55141	10097	102989.4	103.0
Aug 31/99	09:00	10.2	Sept 7/99	08:45	10.20	55141	65212	10071	102724.2	102.7
Sept 7/99	08:45	10.3	Sept 14/99	08:30	10.00	65212	75276	10064	103659.2	103.7
Sept 14/99	08:30	10.3	Sept 21/99	08:15	10.10	75276	85344	10068	103700.4	103.7
Sept21/99	08:30	10.4	Sept28/99	08:30	9.80	85344	95440	10096	104998.4	105.0
Sept28/99	08:30	9.7	Oct 5/99	08:50	9.70	95440	5540	10100	97970.0	98.0
Oct 5/99	09:00	10.0	Oct 12/99	08:15	10.40	5540	5587	10035	100350.0	100.4
Oct 12/99	08:15	10.2	Oct 19/99	08:20	10.60	5587	25671	10085	102867.0	102.9
Oct 19/99	08:20	10.5	Oct 26/99	08:30	9.80	25671	35755	10084	105882.0	105.9
Oct 26/99	08:30	9.7	Nov 2/99	09:30	10.60	35755	45900	10145	98406.5	98.4
Nov 2/99	09:30	10.1	Nov 9/99	10:50	9.30	45900	56065	10165	102666.5	102.7
Nov 9/99	11:00	10.0	Nov 16/99	09:15	10.40	56065	66045	9980	99800.0	99.8
Nov 16/99	09:20	10.2	Nov 23/99	09:20	10.60	66045	76125	10080	102816.0	102.8
Nov 23/99	09.20	9.9	Nov 30/99	09.20	9.30	76125	86212	10087	99861.3	99.9
Nov 30/99	09:30	10.0	Dec 7/99	09:20	10.10	86212	96280	10068	100680.0	100.7
Dec7/99	09:20	9.8	Dec 14/99	09:15	10.20	96280	6355	10075	98735.0	98.7
Dec 14/99	09:15	9.8	Dec 21/99	09:30	10.10	6355	16453	10098	98960.4	99.0
Dec 21/99	09:30	9.9	Dec 29/99	09:40	10.30	16453	27976	11523	114077.7	114.1
Dec 29/99	09:40	10.0	Jan 4/00	09:15	8.10	27976	36593	8617	86170.0	86.2
Jan 4/00	09:15	10.1	Jan 11/00	09:35	10.40	36593	46692	10099	101999.9	102.0
Jan 11/00	09:35	9.9	Jan 18/00	08:55	10.10	46692	56730	10038	99376.2	99.4
Jan18/00	08:55	9.7	Jan 25/00	09:20	9.20	56730	66832	10102	97989.4	98.0
Jan 25/00	09:20	10.1	Feb 1/00	09:15	10.50	66832	76906	10074	101747.4	101.7
Feb 1/00	09:15	10.1	Feb 8/00	09:20	10.50	76906	86990	10084	101848.4	101.8
Feb8/00	09:20	9.0	Feb 15/00	09:20	8.30	86990	97066	10076	90684.0	90.7
Feb 15/00	09:20	10.1	Feb 22/00	09:15	10.50	97066	7137	10071	101717.1	101.7
Feb 22/00	09:15	10.1	Feb 29/00	08:40	10.60	7137	17179	10042	101424.2	101.4
Feb 29/00	08:40	10.0	Mar7/00	09:15	10.30	17179	27292	10113	101130.0	101.1
Mar 7/00	09:15	10.1	Mar14/00	09:00	10.40	27292	37356	10064	101646.4	101.6
Mar 14/00	09:00	10.0	Mar21/00	09:15	10.20	37356	47448	10092	100920.0	100.9
Mar 21/00	09:15	9.8	Mar28/00	09:05	10.00	47448	57517	10069	98676.2	98.7
Mar 28/00	09:05	9.8	Apr4/00	08:00	10.10	57517	67539	10022	98215.6	98.2
Apr4/00	08:00	9.9	Apr 11/00	08:00	10.30	67539	77599	10060	99594.0	99.6
Apr11/00	08:00	10.2	Apr18/00	07:30	10.30	77599	87655	10056	102571.2	102.6
Apr18/00	07:30	10.2	Apr25/00	07:30	10.10	87655	97737	10082	102836.4	102.8
Apr25/00	07:30	10.1	May2/00	08:00	10.30	97737	7837	10100	102010.0	102.0
May 2/00	08:00	10.0	May9/00	07:35	10.20	7837	17888	10051	100510.0	100.5
May9/00	07:35	10.1	May16/00	08:00	10.30	17888	28009	10121	102222.1	102.2

Table 2. Field notes for filter pack denuder samples, Chilliwack Airport.

Table 3. Field notes for high volume samples, Chilliwack Airport.

Date on	Time on	Counter	Flow	Volume	Date	Time	Counter	Flow	Volume	Volume per	Volume per
Duto on	(PST)	on	(Et ³ /min)	Totalizer	off	off	off	(Et ³ /min)	Totalizer	Sample	Sample
	(101)	on	()	(Et ³)	on	(PST)	on	()	(Et ³)	(Et ³)	(m^3)
				(1)		(101)			(1)	(1)	(11)
May 18/99	13:25	30720	40	10054	May 26/99	08:45	41966	40	31826	21772	616.4
May 26/99	08:45	41966	40	31826	June 1/99	09:45	50657	40	49807	17981	509.0
June 1/99	09.55	50657	40	49807	June 8/99	08:30	60638	40	67516	17709	501.3
June 8/99	08:30	60639	40	67516	June 15/99	10.00	70827	40	87664	20148	570.4
June 15/99	10.00	70827	40	87664	June 22/99	08.00	80771	40	106535	18871	534.2
June 22/99	09.00	80771	40	106535	June 29/99	09.00	90849	40	123128	16593	469.7
June 29/99	09:30	90849	40	123128	July 6/99	09.10	901	40	142331	19203	543.6
July 6/99	09.10	901	40	142331	July 13/99	08.45	10953	39	160305	17974	508.8
July 13/99	08:55	10953	40	160305	July 20/99	08:40	21017	38	178607	18302	518 1
July 20/99	08.40	21017	40	178607	July 27/99	10.10	31180	40	198920	20313	575 1
July 27/99	10:50	31180	40	198920	Aug 3/99	08.20	41108	45	218684	19764	559.5
Aug 3/99	08.10	41108	40	218684	Aug 10/99	08:10	51158	48	240504	21818	617.7
Aug 10/99	08.10	51158	40	240502	Aug 17/99	08:25	61237	44	259260	18758	531.0
Aug 17/99	08:30	61237	40	259260	Aug 24/99	08:30	71315	40	276996	17736	502.1
Aug 24/99	08:30	71315	40	276996	Aug 31/99	09:30	81446	42	295532	18536	524.8
Aug 31/99	09:30	81446	40	295532	Sept 7/99	08:45	91483	40	312629	17097	484.0
Sept 7/99	08:45	91483	40	312629	Sept 14/99	08:35	1544	35	326617	13988	396.0
Sept 14/99	08:35	1544	40	326617	Sept 21/99	08:20	11605	40	343804	17187	486.6
Sept 21/99	08:50	11605	40	343804	Sept 28/99	08:35	21669	44	363419	19615	555.3
Sept 28/99	08:35	21669	40	363419	Oct 5/99	08:30	31793	36	380896	17477	494.8
Oct 5/99	09:30	31793	40	380896	Oct 12/99	08:30	41819	42	398805	17909	507.0
Oct 12/99	08:30	41819	40	398805	Oct 19/99	08:35	51894	40	416893	18088	512.1
Oct 19/99	10:00	51894	40	416893	Oct 26/99	08:20	61874	41	434877	17984	509.1
Oct 26/99	08:20	61874	41	434877	Nov 2/99	09:40	72034	40	455009	20132	569.9
Nov 2/99	09:45	72034	40	455009	Nov 9/99	11:00	82190	42	473924	18915	535.5
Nov 9/99	11:00	82190	40	473924	Nov 16/99	09:20	92163	38	491431	17507	495.6
Nov 16/99	09:25	92163	40	491431	Nov 23/99	09:15	2227	39	509259	17828	504.7
Nov 23/99	09:15	2227	39	509259	Nov 30/99	09:15	12309	39	527004	17745	502.4
Nov 30/99	10:15	12309	39	527004	Dec 7/99	09:20	22334	46	547473	20469	579.5
Dec 7/99	09:25	22334	40	547473	Dec 14/99	09:40	32427	37	565907	18434	521.9
Dec 14/99	09:40	32427	40	565907	Dec 21/99	09:25	42489	40	584770	18863	534.0
Dec 21/99	09:25	42489	40	584770	Dec 29/99	09:40	54025	40	606519	21749	615.7
Dec 29/99	09:40	54025	40	606519	Jan 4/99	09:25	62646	38	620780	14261	403.7
Jan 4/00	09:25	62646	40	620780	Jan 11/00	09:40	72736	36	638525	17745	502.4
Jan 11/00	10:15	72736	40	638525	Jan 18/00	09:00	82742	40	656649	18124	513.1
Jan 18/00	09:00	82742	40	656649	Jan 25/00	09:25	92845	40	675474	18825	532.9
Jan 25/00	09:25	92845	40	675474	Feb 1/00	09:20	2918	40	693936	18462	522.7
Feb 1/00	09:20	2918	40	693936	Feb 8/00	09:10	12985	41	710991	17055	482.8
Feb 8/00	09:15	12985	40	710991	Feb 15/00	09:30	23079	40	729757	18766	531.3
Feb 15/00	11:15	23079	40	729757	Feb 22/00	09:20	33040	40	748563	19149	542.1
Feb 22/00	09:20	33040	40	748906	Feb 29/00	08:40	43079	42	768362	19456	550.8
Feb 29/00	08:40	43079	40	768362	Mar 7/00	09:15	53192	36	786465	18103	512.5
Mar 7/00	09:15	53192	40	786465	Mar 14/00	09:45	63295	44	806778	20313	575.1
Mar 14/00	10:45	63295	40	806778	Mar 21/00	09:20	73287	41	825479	18701	529.4

Date on	Time on	Date off	Time off	Sample
	(PST)		(PST)	Volume (mL)
May 18/99	12:30	May 26/99	09:00	118
June 1/99	09:45	June 15/99	10:00	2260
June 29/99	08:30	July 13/99	10:10	2400
July13/99	10:10	July 20/99	08:45	966
July 27/99	11:05	Aug 10/99	08:50	522
Aug 10/99	08:50	Aug 24/99	08:30	1960
Aug 24/99	08:30	Sept 7/99	08:30	4070
Sep 21/99	08:00	Oct 5/99	08:45	1400
Oct 5/99	08:45	Oct 19/99	09:00	5430
Oct 19/99	09:00	Nov 2/99	09:30	10000
Nov 2/99	09:30	Nov 16/99	09:30	14600
Nov 16/99	09:30	Nov 30/99	09:45	8610
Nov 30/99	09:45	Dec 14/99	09:00	5730
Dec 14/99	09:00	Dec 29/99	10:00	7070
Dec 29/99	10:00	Jan 11/00	09:40	2000
Jan11/00	09:40	Jan 25/00	10:00	1500
Jan 25/00	10:00	Feb 8/00	09:30	3310
Feb 8/00	09:30	Feb 22/00	10:00	2560
Feb 22/00	10:00	Mar 7/00	09:30	4280
Mar7/00	09:30	Mar 21/00	09:30	3970
Mar21/00	09:30	Apr4/00	08:40	2840
Apr4/00	08:40	Apr18/00	07:35	6250
Apr18/00	07:35	May 2/00	08:00	2680
May 2/00	08:00	May 16/00	08:00	4610

Table 4. Field notes for rain samples, Chilliwack Airport.

Parameter Measured	Units	Mean	Median	Max	Min	Standard dev.	Standard error	95% confidence
								$(\alpha = 0.05)$
Total gaseous Sulphate (S0 ₂)	ug/m3	0.80	0.55	2.8	0.10	0.68	0.094	0.18
Total particulate Sulphate (X ₂ S0 ₄)	ug/m3	0.68	0.55	2.3	0.0046	0.56	0.078	0.15
Total gaseous Ammonia (NH ₃)	ug/m3	5.2	4.7	9.0	2.3	1.7	0.24	0.47
Total particulate Ammonium (XNH ₄)	ug/m3	1.8	1.5	4.6	0.0065	1.3	0.18	0.36
Total gaseous Nitrate (N0x)	ug/m3	0.15	0.12	0.38	0.052	0.077	0.011	0.021
Total particulate Nitrate (XN0 ₃)	ug/m3	0.28	0.24	0.98	0.040	0.19	0.027	0.052
Total gaseous Nitrite (N0 ₂)	ug/m3	0.11	0.095	0.38	0.0043	0.070	0.0097	0.019
Total particulate Nitrite (XN0 ₂)	ug/m3	0.030	0.017	0.25	0.00037	0.044	0.0062	0.012
Total particulate Phosphate (XP0 ₄)	ug/m3	0.25	0.23	0.65	0.061	0.13	0.019	0.038
Total gaseous Sulphate (S02)	ug/m2/day	170	110	580	20	140	19	37
Total particulate Sulphate (X2S04)	ug/m2/day	71	57	240	0.5	55	8	15
Total gaseous Nitrate and Nitrite (N0x)	ug/m2/day	26	25	50	13	10	1.4	2.8
Total particulate Nitrate and Nitrite (N0x)	ug/m2/day	120	97	390	18	82	11	22
Total particulate Phosphate	ug/m2/day	22	20	56	5.3	11	1.7	3.3
Total gaseous Ammonia (NH3)	ug/m2/day	3900	3600	6900	1800	1300	180	350
Total particulate Ammonium (NH4+)	ug/m2/day	230	190	590	0.84	170	24	46

Table 5. Statistical summary for nutrient concentrations and deposition rates for air samples, Chilliwack Airport.

Notes:

Filter pack denuder n = 52 High volume sampler n = 46

Deposition velocities: SO2 (g) = 0.24 cm/s SO4 (part) = 0.12 cm/s NO3 (part) = 0.45 cm/s NOx (g) = 0.12 cm/s NH3 (g) = 0.88 cm/s NH4 (part) = 0.15 cm/s PO4 (part) = 0.1 cm/s

Parameter	Mean	Median	Max	Min	Standard	Standard	95% Confidence
					Deviation	LIIUI	(alpha=0.03)
Ammonium Nitrogen (mg/L)	0.60	0.44	2.2	0.18	0.43	0.088	0.035
Nitrate Nitrogen (mg/L)	0.20	0.15	0.74	0.042	0.18	0.036	0.014
Nitrite Nitrogen (mg/L)	0.012	0.0090	0.039	0.0060	0.0077	0.0016	0.00063
Total Phosphate (mg/L)	0.0072	0.0045	0.022	0.0020	0.0057	0.0012	0.00047
Total Volume Sampled (mL)	4100	3100	15000	120	3300	680	270
рН	6.48	6.52	7.29	5.39	0.42	0.09	0.03
Ammonium Nitrogen (mg/m²/day)	2.0	2.0	3.9	0.33	0.80	0.16	0.32
Nitrate Nitrogen (mg/m ² /day)	0.65	0.54	1.6	0.18	0.34	0.070	0.14
Nitrite Nitrogen (mg/m²/day)	0.040	0.037	0.090	0.0070	0.021	0.0044	0.0086
Total Phosphate (mg/m ² /day)	0.020	0.014	0.062	0.0018	0.018	0.0036	0.0071

Table 6. Statistical summary for nutrient concentrations and deposition rates in precipitation samples, Chilliwack Airport.

Table 7. Total drv	and wet deposition	rates of nitrate/nitrite	(NOv) a	t Chilliwack Airport.
			(

Parameter	Dry	Wet	Total
Total gaseous NOy (ug/m²/day)	26		
Total particulate NOy (ug/m²/day)	120		
Total gaseous and particulate NOy (ug/m ² /day)	150	690	840
Total gaseous NOy (tonnes/watershed/year)	0.27		
Total particulate NOy (tonnes/watershed/year)	1.2		
Total gaseous and particulate NOy (tonnes/watershed/year)	1.5	7.1	8.6

* Estimates for the Elk Creek Watershed based on an area of 28 km² (Litke, 1997)

Table 8. Dry deposition rates of ammonia and ammonium, Chilliwack Airport.

Parameter	Surface Type	Spring	Summer	Autumn	Winter	Mean (all seasons)
NH3 (mean conc. ug/m3)		5.4	4.4	5.0	5.9	5.18
NH3 (ug/m2/day)	Grass ⁽¹⁾	4492	2948	2293	4399	3533
NH3 (ug/m2/day)	Forests ⁽²⁾	8283	4352	3093	2340	4517
NH3 (ug/m2/day)	Elk Creek Watershed ⁽³⁾	6008	3510	2613	3575	3927
NH4+ (mean conc. ug/m3)		2.2	2.4	1.8	0.8	1.80
NH4+ (ug/m2/day)	Grass ⁽⁴⁾	54	52	54	52	53
NH4+ (ug/m2/day)	Forests ⁽⁵⁾	536	478	517	478	502
NH4+ (ug/m2/day)	Elk Creek Watershed ⁽³⁾	246	222	239	222	232

Based on depositon velocities from Pryor and Barthelmie (1999):

(1) Ammonia dep.to grass: Spring: 0.96 cm/s, Summer: 0.63 cm/s, Autumn: 0.49 cm/s, Winter: 0.94 cm/s.

(2) Ammonia dep. to forest: Spring: 1.77 cm/s, Summer: 0.93 cm/s, Autumn: 0.67 cm/s, Winter: 0.5 cm/s

(3) Based an approximate vegetative distribution in the Elk Creek Watershed of 60% grass, 40% forest (Litke, 1997)

(4) Ammonium deposition to grass: Spring: 0.028 cm/s, Summer: 0.027 cm/s, Autumn: 0.028 cm/s, Winter: 0.027 cm/s

(5) Ammonium deposition to forest: Spring: 0.28 cm/s, Summer: 0.25 cm/s, Autumn: 0.27 cm/s, Winter: 0.25 cm/s)

Parameter	Dry	Wet	Total	Fraction as dry Deposition
				%
Ammonia Nitrogen (mg/m ² /day)	3.9	-	-	
Ammonium Nitrogen (mg/m ² /day)	0.23	2.0	2.2	10
Total NHx (mg/m²/day)	4.2	2.0	6.2	68
Ammonia Nitrogen (tonnes/watershed/year)	40	-	-	
Ammonium Nitrogen (tonnes/watershed/year)	2.4	20	23	
Total NHx (tonnes/watershed/year)	43	20	63	

Table 9. Total dry and wet deposition rates of ammonia and ammonium, Chilliwack Airport.

* Estimates for the Elk Creek Watershed based on an area of 28 km² (Litke, 1997)

Table 10. Summary of total dry and wet deposition rates of sulphate, nitrate (NOy), ammonia (NHx) and total phosphate, Chilliwack Airport (1999-2000)

Parameter	Units	Mean Deposition Rate
Total Sulphate ⁽¹⁾	mg/m²/day	4.6
Total Nitrate + Nitrite (NOy)	mg/m²/day	0.84
Total Ammonia + Ammonium (NHx)	mg/m²/day	6.2
Total Phosphate	mg/m²/day	0.24
Total Sulphate	tonnes/watershed/year ⁽²⁾	45
Total Nitrate + Nitrite (NOy)	tonnes/watershed/year	8.6
Total Ammonia + Ammonium (NHx)	tonnes/watershed/year	63
Total Phosphate	tonnes/watershed/year	2.5

(1) Total sulphate deposition rates estimated from the sum of dry deposition (0.17 mg/m²/day, present study) + estimated wet deposition (4.4 mg/m²/day, Belzer *et al.*, 1997) (2) Estimates for the Elk Creek Watershed based on an area of 28 km² (Litke, 1997)

Table 11. Field blank results for filter pack denuder samples (ug/sample), Chilliwack Airport.

Date	Method Detection Limit	May18/99	June1/99	July20/99	Oct5/99	Mr21/00	Mean
Ammonia Nitrogen (CAD)	0.1	5.8	4	64	_	8	6.05
Sulphate (NCD)	1	8	5	5	42	11	14.2
Nitrate Nitrogen (NCD)	0.2	0.3	ND	0.3	0.2	0.3	0.275
Nitrite Nitrogen (NCD)	0.1	0.7	ND	0.3	0.2	0.4	0.4
Sulphate (TF)	1	2	4	ND	4	29	9.75
Ammonia Nitrogen (TF)	0.1	10	0.2	ND	ND	ND	5.1
Nitrate Nitrogen (TF)	0.2	ND	ND	ND	ND	ND	ND
Nitrite Nitrogen (TF)	0.1	ND	ND	ND	ND	ND	ND
Ammonia Nitrogen (CAF)	0.1	0.7	1.5	1.3	0.8	4	1.66
Sulphate (NCF)	1	34	45	50	47	78	50.8
Nitrate Nitrogen (NCF)	0.2	ND	ND	ND	ND	0.2	0.2
Nitrite Nitrogen (NCF)	0.1	ND	ND	0.2	ND	0.2	0.2

ND denotes value below the specified detection limit

- indicates not measured

Table 12. Raw data for filter pack denuder samples (ug/sample), Chilliwack Airport.

Date	Ammonia-N (CAD)	Sulphate (NCD)	Nitrate-N (NCD)	Nitrite-N (NCD)	Sulphate (TF)	Ammonia-N (TF)	Nitrate-N (TF)	Nitrite-N (TF)	Ammonia-N (CAF)	Sulphate (NCF)
Method Det. Limit	10	1	0.2	0.1	2	5	0.4	0.2	5	1
May 18-26/99	280.95	137.8	25.28	4.48	268.2	52.66	5.8	0.3	68.34	ND
May26-Jn1/99	301.95	222.8	18.78	3.88	80.2	48.46	18	ND	346.34	ND
Jn1-8/99	323.95	112.8	12.48	5.18	88.2	39.66	10.3	ND	249.34	ND
Jn8-15/99	434.95	93.8	25.78	0.78	66.2	16.96	0.6	ND	96.34	ND
Jn15-22/99	540.95	115.8	16.18	1.48	106.2	43.56	11.8	ND	103.34	ND
Jn22-29/99	450.95	56.8	7.38	5.58	67.2	40.46	14.9	ND	131.34	1.2
Jn29-Jul6/99	526.95	71.8	11.88	4.98	71.2	28.76	2.9	ND	125.34	ND
July6-13/99	416.95	265.8	33.48	7.88	99.2	42.66	10.3	ND	29.04	0.2
July13-20/99	396.95	100.8	17.48	5.78	99.2	45.36	18.1	ND	127.34	ND
July20-27/99	523.95	203.8	27.68	11.88	144.2	71.96	22.7	ND	119.34	ND
July27-Aug3/99	526.95	313.8	34.88	16.58	253.2	131.96	49.4	ND	233.34	ND
Aug3-10/99	360.95	294.8	25.98	17.28	247.2	131.96	78	0.2	329.34	5.2
Aug 10-17/99	393.95	109.8	10.68	9.38	134.2	76.46	26.1	ND	288.34	ND
Aug17-24/99	583.95	212.8	29.08	11.98	148.2	76.46	23.1	ND	323.34	ND
Aug24-Aug31/99	420.95	134.8	21.98	9.98	73.2	165.96	10.9	ND	230.34	ND
Aug31-Sep7/99	370.95	72.8	12.88	11.98	64.2	120	11	ND	148.34	ND
Sep7-14/99	516.95	119.8	22.78	7.38	47.2	23.96	1.8	ND	283.34	2.2
Sept14-20/99	860.95	186.8	27.88	22.48	171.2	57.96	58.5	0.2	205.34	ND
Sept21-28/99	463.95	156.8	18.58	10.88	89.2	51.96	35.1	ND	253.34	4.2
Sept28-Oct5/99	646.95	116.8	37.28	9.68	50.2	31.96	15.9	ND	115.34	ND
Oct5-12/00	736.95	76.8	12.58	25.28	82.2	73.96	33.7	ND	258.34	39.2
Oct12-19/00	470.95	65.8	7.28	19.78	33.2	17.96	9.8	ND	285.34	ND
Oct19-26/99	600.95	59.8	9.58	40.98	53.2	17.96	23.3	ND	367.34	1.2
Oct26-Nov2/99	396.95	44.8	7.18	9.58	18.2	3.96	2.9	ND	47.34	15.2
Nov2-9/99	403.95	38.8	12.48	5.78	1.2	2.96	2.7	ND	123.34	ND
Nov9-16/99	343.95	47.8	9.18	6.98	17.2	9.96	5.3	ND	10.34	ND
Nov16-23/99	443.95	50.8	7.68	19.48	ND	21.96	12.9	ND	92.34	ND
Nov23-30/99	430.95	29.8	5.38	15.08	5.2	0.96	0.8	ND	91.34	ND
Nov30-Dec7/99	406.95	39.8	7.68	12.48	12.2	7.96	6.8	ND	10.34	ND
Dec 7-14/99	280.95	30.8	9.98	3.08	17.2	9.96	5.1	ND	32.34	ND
Dec14-21/99	350.95	56.8	14.48	8.78	24.2	18.96	12.5	ND	80.34	0.2
Dec21-29/99	586.95	30.8	11.98	12.08	33.2	19.56	8	ND	34.04	1.2
Dec29-Jan4/00	463.95	42.8	5.48	23.48	8.2	7.96	5.7	ND	187.34	2.2
Jan4-11/00	586.95	63.8	14.48	13.78	25.2	23.96	16.3	ND	78.34	10.2
Jan11-18/00	430.95	41.8	8.88	14.38	32.2	17.96	12	ND	49.34	0.2
Jan18-25/00	360.95	23.8	8.38	4.68	4.2	ND	ND	ND	4.34	ND
Jan25-Feb1/00	783.95	46.8	15.58	15.58	41.2	28.96	16.8	ND	110.34	7.2
Feb1-8/00	876.95	26.8	9.18	8.88	14.2	9.96	7	ND	27.94	9.2
Feb 8-15/99	633.95	27.8	7.28	7.58	1.2	1.06	0.6	ND	27.34	7.2
Feb15-22/00	860.95	47.8	15.68	13.68	31.2	23.36	11.8	0.2	47.34	9.2
Feb22-29/00	893.95	61.8	10.38	14.58	52.2	44.96	24.1	ND	79.34	0.2
Feb29-Mr7/00	633.95	65.8	8.88	16.98	51.2	22.96	13.6	ND	23.34	20.2
Mr7-14/00	736.95	69.8	10.28	17.48	69.2	55.96	30.5	0.3	411.34	15.2
Mr14-21/00	506.95	63.8	6.88	9.58	63.2	34.96	19.3	ND	23.34	27.2
Mr21-28/00	783.95	90.8	11.08	13.68	80.2	53.96	23.4	ND	131.34	31.2
Mr28-Apr4/00	670.95	144.8	16.78	13.28	110.2	101.96	55.6	ND	350.34	28.2
Apr4-11/00	906.95	113.8	11.88	9.98	117.2	58.96	20.9	ND	146.34	28.2
Apr11-18/00	706.95	114.8	14.28	7.88	87.2	45.96	19.3	0.3	175.34	17.2
April18-25/00	473.95	113.8	18.08	2.88	97.2	45.96	14.8	ND	177.34	38.2
April 25-Mav2/00	403.95	45.8	10.98	3.88	39.2	23.96	10.3	ND	155.34	23.2
May2-9/00	430.95	44.8	9.38	6.18	54.2	21.96	4.3	ND	25.34	30.2
Mav9-16/00	653.95	79.8	14.78	5.88	57.2	20.96	4.7	ND	55.34	29.2

ND denotes value below the specified detection limit

Table 13. Nutrient concentrations in filter pack denuder sample	s (ug/m³)	1
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Date	Ammonia-N (CAD)	Sulphate (NCD)	Nitrate-N (NCD)	Nitrite-N (NCD)	Sulphate (TF)	Ammonia-N (TF)	Nitrate-N (TF)	Nitrite-N (TF)	Ammonia-N (CAF)	Sulphate (NCF)
Method Det. Limit	0.1	0.01	0.002	0.001	0.02	0.05	0.004	0.002	0.05	0.01
May 18-26/99	2.3396	1.0519	0.2133	0.0354	2.2162	0.4308	0.0494	ND	0.5675	ND
May26-Jn1/99	3.3397	2.3544	0.2095	0.0402	0.8172	0.5239	0.2032	ND	3.8903	ND
Jn1-8/99	3.0219	0.9373	0.1165	0.0462	0.7643	0.3576	0.0979	ND	2.3544	ND
Jn8-15/99	4.0009	0.7425	0.2384	0.0043	0.5448	0.1392	0.0056	ND	0.8832	ND
Jn15-22/99	5.0653	0.9621	0.1511	0.0110	0.9318	0.3932	0.1117	ND	0.9629	ND
Jn22-29/99	4.4579	0.4269	0.0717	0.0527	0.5952	0.3850	0.1493	ND	1.2994	ND
Jn29-Jul6/99	5.0426	0.5576	0.1129	0.0451	0.6137	0.2587	0.0281	ND	1.1973	ND
July6-13/99	4.0049	2.4522	0.3242	0.0737	0.8908	0.3959	0.1004	ND	0.2669	ND
July13-20/99	3.8437	0.8515	0.1697	0.0537	0.8987	0.4260	0.1780	ND	1.2358	ND
July20-27/99	5.0379	1.8444	0.2671	0.1125	1.3268	0.6802	0.2208	ND	1.1447	ND
July27-Aug3/99	4.8456	2.7870	0.3224	0.1513	2.2828	1.2086	0.4595	ND	2.1552	ND
Aug3-10/99	3.3897	2.6800	0.2460	0.1620	2.2865	1.2409	0.7450	0.0019	3.1297	ND
Aug 10-17/99	3.8406	0.9465	0.1036	0.0897	1.2515	0.7368	0.2584	ND	2.8384	ND
Aug17-24/99	5.7218	1.9663	0.2857	0.1154	1.3901	0.7368	0.2287	ND	3.1850	ND
Aug24-Aug31/99	4.0282	1.1709	0.2113	0.0938	0.6350	1.5915	0.1058	ND	2.2202	ND
Aug31-Sep7/99	3.5531	0.5706	0.1233	0.1135	0.5492	1.1486	0.1071	ND	1.4282	ND
Sep7-14/99	4.9267	1.0183	0.2176	0.0681	0.3799	0.2114	0.0174	ND	2.7163	ND
Sept14-21/99	8.2440	1.6644	0.2667	0.2137	1.5757	0.5392	0.5641	0.0019	1.9641	ND
Sept21-28/99	4.3610	1.3581	0.1749	0.1006	0.7752	0.4754	0.3343	ND	2.3970	ND
Sept28-Oct5/99	6.5398	1.0469	0.3782	0.0955	0.4327	0.3053	0.1622	ND	1,1600	ND
Oct5-12/99	7,2799	0.6235	0.1231	0.2486	0.7410	0.7163	0.3357	ND	2,5566	ND
Oct12-19/99	4.5180	0.5015	0.0686	0.1891	0.2468	0.1547	0.0952	ND	2,7569	ND
Oct19-26/99	5.6176	0.4306	0.0884	0.3839	0.4287	0.1503	0.2200	ND	3.4531	ND
Oct26-Nov2/99	3.9726	0.3110	0.0707	0.0941	0.1057	0.0195	0.0295	ND	0.4642	ND
Nov2-9/99	3.8744	0.2395	0.1194	0.0532	ND	0.0090	0.0263	ND	1.1848	ND
Nov9-16/99	3.3858	0.3367	0.0898	0.0667	0.0942	0.0794	0.0531	ND	0.0870	ND
Nov16-23/99	4,2597	0.3560	0.0726	0.1864	ND	0.1938	0.1255	ND	0.8821	ND
Nov23-30/99	4.2533	0.1562	0.0517	0.1477	ND	ND	0.0080	ND	0.8977	ND
Nov30-Dec7/99	3.9811	0.2542	0.0741	0.1208	0.0437	0.0588	0.0675	ND	0.0862	ND
Dec 7-14/99	2,7852	0.1682	0.0989	0.0280	0.0952	0.0802	0.0517	ND	0.3108	ND
Dec14-21/99	3.4838	0.4303	0.1440	0.0855	0.1657	0.1709	0.1263	ND	0.7947	ND
Dec21-29/99	5 0911	0 1455	0 1031	0 1031	0 2226	0 1535	0.0701	ND	0.2838	ND
Dec29-Jan4/00	5 3121	0.3318	0.0610	0.2687	0.0046	0.0687	0.0661	ND	2 1541	ND
Jan4-11/00	5 6951	0 4863	0 1398	0 1320	0 1706	0 2149	0 1598	ND	0.7518	ND
Jan11-18/00	4 2746	0 2777	0.0871	0 1414	0 2455	0 1602	0 1207	ND	0 4797	ND
Jan18-25/00	3 6214	0.0980	0.0833	0.0445	ND	ND	ND	ND	0.0273	ND
Jan25-Feb1/00	7 6490	0.3206	0 1510	0 1500	0.3284	0 2647	0 1652	ND	1.0686	ND
Feb1-8/00	8 5550	0.1238	0.0880	0.0841	0.0629	0.0778	0.0688	ND	0.2582	ND
Feb 8-15/99	6 9228	0 1499	0.0778	0.0800	ND	ND	0.0066	ND	0.2831	ND
Feb15-22/00	8 4061	0.3304	0 1520	0 1314	0 2301	0 2096	0 1160	0.0020	0 4492	ND
Feb22-29/00	8 7564	0 4694	0 1002	0 1406	0 4379	0 4233	0 2377	ND	0.7661	ND
Feb29-Mr7/00	6 2107	0.5104	0.0857	0 1648	0 4293	0.2069	0 1345	ND	0 2144	ND
Mr7-14/00	7.1939	0.5472	0.0990	0.1689	0.6043	0.5307	0.3002	0.0030	4.0323	ND
Mr14-21/00	4 9643	0.4916	0.0660	0.0918	0.5491	0.3263	0 1913	ND	0 2149	ND
Mr21-28/00	7.8815	0.7761	0.1100	0.1354	0.7335	0.5260	0.2371	ND	1.3139	ND
Mr28-Apr4/00	6.7709	1.3299	0.1686	0.1320	1.0428	1.0175	0.5662	ND	3.5507	ND
Apr4-11/00	9.0452	1.0000	0.1171	0.0970	1.0984	0.5715	0.2098	ND	1.4526	ND
Apr11-18/00	6 8314	0.9805	0 1370	0.0737	0 7739	0 4281	0 1881	0.0029	1 6928	ND
April18-25/00	4 5516	0.9689	0 1737	0.0249	0.8696	0 4272	0 1440	ND	1 7089	ND
April 25-May2/00	3 9010	0.3098	0 1055	0.0349	0.3078	0 2149	0 1010	ND	1.5067	ND
May2-9/00	4 2279	0.3045	0.0911	0.0583	0 4617	0 1982	0.0428	ND	0.2356	ND
May9-16/00	6.3395	0.6419	0.1425	0.0544	0.4834	0.1851	0.0460	ND	0.5252	ND

ND denotes value below the specified detection limit

Date	Total gas.Sulphate (S02)	Total part.Sulphate (X2S04)	Total gas. Ammonia (NH3)	Total part. Ammonium (NH4+)	Total gas.Nitrate (N0x)	Total part. Nitrate (XN03)
May 18-26/99	1.0519	2.2162	2.3396	0.9983	0.2133	0.3261
May26-Jn1/99	2.3544	0.8172	3.3397	4.4142	0.2095	0.3151
Jn1-8/99	0.9373	0.7643	3.0219	2.7120	0.1165	0.2074
Jn8-15/99	0.7425	0.5448	4.0009	1.0224	0.2384	0.1373
Jn15-22/99	0.9621	0.9318	5.0653	1.3561	0.1511	0.3193
Jn22-29/99	0.4269	0.5952	4.4579	1.6844	0.0717	0.2387
.ln29lul6/99	0.5576	0.6137	5 0426	1 4560	0 1129	0.2422
July6-13/99	2 4522	0.8908	4 0049	0.6628	0 3242	0.3072
July13-20/99	0.8515	0.8987	3 8437	1 6618	0 1697	0.3325
luly20-27/99	1 8444	1 3268	5.0379	1 8249	0.2671	0.4409
July27-Aug3/00	2 7870	2 2828	4 8456	3 3637	0.3224	0.4403
July21-Aug3/33	2.6800	2.2020	3 3807	4 3706	0.3224	0.0783
Aug 10 17/00	2.0000	1 2515	3.3097	4.5760	0.2400	0.3020
Aug 10-17/99	1.0662	1.2015	5.0400	3.07.02	0.1050	0.4121
Aug 17-24/99	1.9003	1.3901	5.7218	3.9210	0.2857	0.4580
Aug24-Aug31/99	1.1709	0.6350	4.0282	3.8117	0.2113	0.2885
Aug31-Sep7/99	0.5706	0.5492	3.5531	2.5768	0.1233	0.2018
Sep7-14/99	1.0183	0.3799	4.9267	2.9277	0.2176	0.1236
Sept14-21/99	1.6644	1.5/5/	8.2440	2.5034	0.2667	0.8141
Sept21-28/99	1.3581	0.7752	4.3610	2.8724	0.1749	0.4716
Sept28-Oct5/99	1.0469	0.4327	6.5398	1.4653	0.3782	0.2380
Oct5-12/99	0.6235	0.7410	7.2799	3.2729	0.1231	0.4544
Oct12-19/99	0.5015	0.2468	4.5180	2.9116	0.0686	0.1741
Oct19-26/99	0.4306	0.4287	5.6176	3.6034	0.0884	0.2570
Oct26-Nov2/99	0.3110	0.1057	3.9726	0.4837	0.0707	0.1252
Nov2-9/99	0.2395	ND	3.8744	1.1938	0.1194	0.0421
Nov9-16/99	0.3367	0.0942	3.3858	0.1663	0.0898	0.1395
Nov16-23/99	0.3560	ND	4.2597	1.0759	0.0726	0.1695
Nov23-30/99	0.1562	ND	4.2533	0.8869	0.0517	0.0452
Nov30-Dec7/99	0.2542	0.0437	3.9811	0.1450	0.0741	0.1432
Dec 7-14/99	0.1682	0.0952	2.7852	0.3911	0.0989	0.1309
Dec14-21/99	0.4303	0.1657	3.4838	0.9657	0.1440	0.1638
Dec21-29/99	0.1455	0.2226	5.0911	0.4373	0.1031	0.1124
Dec29-Jan4/00	0.3318	0.0046	5.3121	2.2227	0.0610	0.0919
Jan4-11/00	0.4863	0.1706	5.6951	0.9667	0.1398	0.2012
Jan11-18/00	0.2777	0.2455	4.2746	0.6398	0.0871	0.1732
Jan18-25/00	0.0980	ND	3.6214	0.0065	0.0833	0.0400
Jan25-Feb1/00	0.3206	0.3284	7.6490	1.3333	0.1510	0.2273
Feb1-8/00	0.1238	0.0629	8.5550	0.3360	0.0880	0.1289
Feb 8-15/99	0 1499	ND	6 9228	0 2723	0.0778	0.0421
Feb15-22/00	0.3304	0 2301	8 4061	0.6588	0 1520	0.2077
Feb22-29/00	0 4694	0 4379	8 7564	1 1893	0 1002	0.3089
Feb29-Mr7/00	0 5104	0 4293	6 2107	0 4214	0.0857	0 2455
Mr7_14/00	0.5472	0.4233	7 1939	4 5630	0.0990	0.2455
Mr14-21/00	0.4916	0.5491	4 9643	0.5411	0.0660	0.2876
Mr21_28/00	0.7761	0.3431	7 8815	1 8300	0.1100	0.3467
Mr28_Apr4/00	1 3200	1 0428	6 7709	1.0099	0.1100	0.5407
Apr4 11/00	1.0000	1.0420	0.0452	4.0002	0.1000	0.7575
Apr11 19/00	0.0905	0.7720	9.0402 6.9214	2.0241	0.1171	0.3007
April 19 25/00	0.9003	0.000	0.0314	2.1209	0.1370	0.3520
April 25 May 2/00	0.3009	0.0090	4.0010	2.1302	0.1/5/	0.3040
April 25-Iviay2/00	0.3098	0.3078	3.9010	1.7210	0.1000	0.1010
May2-9/00	0.3045	0.4017	4.2279	0.4338	0.0911	0.1922
way9-16/00	0.6419	0.4834	6.3395	0.7104	0.1425	0.2067

Table 14. Summed nutrient concentrations in filter pack denuder samples (ug/m³), Chilliwack Airport.

ND denotes value below the specified detection limit

Table 15. Seasonal means for nutri	ents in filter pack denuder sa	mples (ug/m³), Chilliwack Airport.
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Parameter	Method	Spring	Summer	Autumn	Winter
	Detection	Mr.7-Jn.8/99	Jn.8-Sep.7/99	Sep.7-Dec.7/99	Dec.7/99-Mr.7/00
	Limit				
Ammonia Nitrogen (CAD)	0.098	5.4	4.4	5.0	5.9
Sulphate (NCD)	0.0098	0.90	1.4	0.64	0.30
Nitrate Nitrogen (NCD)	0.0020	0.13	0.20	0.14	0.11
Nitrite Nitrogen (NCD)	0.0010	0.076	0.083	0.15	0.12
Sulphate (TF)	0.020	0.82	1.09	0.37	0.18
Ammonia Nitrogen (TF)	0.049	0.44	0.72	0.22	0.16
Nitrate Nitrogen (TF)	0.0039	0.18	0.21	0.16	0.10
Nitrite Nitrogen (TF)	0.0020	0.00045	0.00015	0.00015	0.00015
Ammonia Nitrogen (CAF)	0.049	1.8	1.7	1.6	0.60
Sulphate (NCF)	0.0098	ND	ND	ND	ND
Nitrate Nitrogen (NCF)	0.0020	0.15	0.18	0.089	0.058
Nitrite Nitrogen (NCF)	0.0010	0.011	0.034	0.048	0.028
Total gaseous Sulphate (SO2)	-	0.90	1.38	0.64	0.30
Total particulate Sulphate (X2SO4)	-	0.82	1.09	0.37	0.18
Total gaseous Ammonia (NH3)	-	5.4	4.4	5.0	5.9
Total particulate Ammonium (NH4+)	-	2.2	2.4	1.8	0.76
Total gaseous Nitrate (NOx)	-	0.13	0.20	0.14	0.11
Total particulate Nitrate (XN03)	-	0.33	0.39	0.25	0.16
Total gaseous Nitrite (NO2)	-	0.08	0.08	0.15	0.12
Total particulate Nitrite (XNO2)	-	0.011	0.034	0.048	0.028

ND denotes value below the specified detection limit

Date	Total gas. Sulphate (S02)	Total part. Sulphate (X2S04)	Total gas. Nitrate and Nitrite (N0x)	Total part. Nitrate and Nitrite (N0x)	Total gas. Ammonia (NH3)
May 18-26/99	218	230	26	128	1773
Mav26-Jn1/99	488	85	26	126	2531
Jn1-8/99	194	79	17	81	2290
In8-15/99	154	56	25	54	3032
In15-22/99	200	97	17	126	3839
In22-29/99	89	62	13	96	3378
Jn22-23/33	116	64	15	90	3921
July 12/00	500	04	10	50	3021
July0-13/99	177	92	41	123	3033
July 13-20/99	177	93	23	134	2913
July20-27/99	382	138	39	230	3818
July27-Aug3/99	578	237	49	274	3672
Aug3-10/99	556	237	42	391	2569
Aug 10-17/99	196	130	20	167	2911
Aug17-24/99	408	144	42	183	4336
Aug24-Aug31/99	243	66	32	118	3053
Aug31-Sep7/99	118	57	25	139	2693
Sep7-14/99	211	39	30	54	3734
Sept14-21/99	345	163	50	336	6248
Sept21-28/99	282	80	29	189	3305
Sept28-Oct5/99	217	45	49	111	4956
Oct5-12/99	129	77	39	273	5517
Oct12-19/99	104	26	27	86	3424
Oct19-26/99	89	44	49	145	4257
Oct26-Nov2/99	64	11	17	60	3011
Nov2 0/00	64 E0		10	18	2026
Nov0 16/00	30	10	10	10	2930
Nov46 22/00	70		10	38	2000
NOV16-23/99	74	ND	27	75	3228
Nov23-30/99	32	ND	21	24	3223
Nov30-Dec7/99	53	5	20	60	3017
Dec 7-14/99	35	10	13	56	2111
Dec14-21/99	89	17	24	76	2640
Dec21-29/99	30	23	21	56	3858
Dec29-Jan4/00	69	0.48	34	51	4026
Jan4-11/00	101	18	28	88	4316
Jan11-18/00	58	25	24	82	3239
Jan18-25/00	20	ND	13	26	2744
Jan25-Feb1/00	66	34	31	97	5797
Feb1-8/00	26	6.5	18	57	6483
Feb 8-15/99	31	ND	16	26	5246
Feb15-22/00	69	24	29	89	6370
Feb22-29/00	97	45	25	128	6636
Feb29-Mr7/00	106	45	26	117	4707
Mr7-14/00	113	63	28	158	5452
Mr14-21/00	102	57	16	115	3762
Mr21 28/00	162	76	25	149	5073
Mr29 Apr4/00	276	109	20	201	5975
Apr4 11/00	210	114	20	147	6955
Apr4-11/00	207	114	22	147	0000
April 19.25/00	203	80	22	143	51//
April18-25/00	201	90	21	142	3449
April 25-May2/00	64	32	15	73	2956
May2-9/00	63	48	15	76	3204
May9-16/00	133	50	20	82	4804
Deposition velocities:					

Table 16. Deposition rates (ug/m²/day) for nutrients in filter pack denuder samples, Chilliwack Airport.

Deposition velocities:		
SO2 (g) (cm/s)	0.24	(Volder and Sirois, 1986)
SO4 (part) (cm/s)	0.12	(Volder and Sirois, 1986)
NO3 (part) (cm/s)	0.45	(Volder and Sirois, 1986)
NOx (g) (cm/s)	0.12	(Volder and Sirois, 1986)
NH3 (g) (cm/s)	0.88	(Pryor, 1999)
NH4 (part) (cm/s)	0.15	(Pryor, 1999)

ND denotes value below the detection limit

Table 17. Field blank results for high volume samples, Chilliwack Airport.

Parameter	Method Detection Limit	June 1/99 Field Blank	July 20/99 Field blank	Oct 5/99 Field blank	Mar 21/00 Field blank	Average of blanks
Total Particulate Matter (g/filter)	0.000010	ND	0.033	0.0079	ND	0.010
Total Phosphate (ug/filter)	2.0	4.0	14	4.0	1.0	7.3

ND denotes value below the specified detection limit

Date	Total Particulate Matter (g/filter)	Total Phosphate (ug/filter)
Method Detection Limit	0.00001	1.0
May 18-26/99	0.112	116
May26-June1/99	0.139	157
June 1-8/99	0.0776	106
June 8-15/99	0.132	214
June 15-22/99	0.143	216
June 22-29/99	0.0883	153
June 29/99	0.0832	83
July 6-13/99	0.229	196
July 13-20/99	0.305	244
July 20-27/99	0.324	325
July 27-Aug 3/99	0.357	363
Aug 3-10/99	0.328	305
Aug10-17/99	0 181	126
Aug 17-24/99	0.257	185
Aug 24-31/99	0 154	142
Aug 31-Sept7/99	0.0875	85
Sent 7-14/99	0.122	113
Sent 14-21/99	0.257	189
Sen21-27/00	0.188	130
Sop28 Oct5/00	0.160	150
Oct 5 12/00	0.109	104
Oct 3-12/99	0.119	71
Oct 10, 26/00	0.172	144
Oct 19-26/99	0.172	144
OCI 20-INOV2/99	0.0815	71
NOV 2-9/99	0.0675	70
NOV 9-16/99	0.0492	08
Nov 16-23/99	0.0776	74
Nov 23-30/99	0.0652	69
Nov 30-Dec7/99	0.0506	60
Dec 7-14/99	0.071	32
Dec 14-21/99	0.0518	54
Dec 21-28/99	0.137	180
Dec 29-Jan4/00	0.0547	72
Jan 4-11/00	0.0674	115
Jan 11-18/00	0.0637	226
Jan 18-25/00	0.162	143
Jan 25-Feb1/00	0.195	117
Feb 1-8/00	0.115	33
Feb 8-15/00	0.166	88
Feb15-22/00	0.137	124
Feb 22-29/00	0.0903	69
Feb 29-Mr7/00	0.0713	101
Mar7-14/00	0.171	114
Mar14-21/00	0.095	84
Mar21-28/00	0.111	108
Mar 28-Apr4/00	0.143	146

Table 18. Raw data for high volume samples, Chilliwack Airport.

Date	Total Particulate Matter (g/m ³)	Total Phosphate (ug/m ³)	Total Phosphate (ug/m ² /day)
Method Det. Limit	1.9E-08	0.0019	N/A
May 18-26/99	0.00017	0.18	15
May26-June1/99	0.00027	0.31	27
June 1-8/99	0.00015	0.21	18
June 8-15/99	0.00023	0.38	32
June 15-22/99	0.00027	0.40	35
June 22-29/99	0.00019	0.33	28
June 29/99	0.00015	0.15	13
July 6-13/99	0.00045	0.39	33
July 13-20/99	0.00059	0.47	41
July 20-27/99	0.00056	0.57	49
July 27-Aug 3/99	0.00064	0.65	56
Aug 3-10/99	0.00053	0.49	43
Aug10-17/99	0.00034	0.24	21
Aug 17-24/99	0.00051	0.37	32
Aug 24-31/99	0.00029	0.27	23
Aug 31-Sept7/99	0.00018	0.18	15
Sept 7-14/99	0.00031	0.29	25
Sept 14-21/99	0.00053	0.39	34
Sep21-27/99	0.00034	0.23	20
Sep28-Oct5/99	0.00034	0.32	28
Oct 5-12/99	0.00023	0.21	18
Oct12-19/99	0.00024	0.14	12
Oct 19-26/99	0.00034	0.28	24
Oct 26-Nov2/99	0.00014	0.12	11
Nov 2-9/99	0.00013	0.13	11
Nov 9-16/99	0.00010	0.14	12
Nov 16-23/99	0.00015	0.15	13
Nov 23-30/99	0.00013	0.14	12
Nov 30-Dec7/99	0.00009	0.10	9
Dec 7-14/99	0.00014	0.061	5
Dec 14-21/99	0.00010	0.10	9
Dec 21-28/99	0.00022	0.29	25
Dec 29-Jan4/00	0.00014	0.18	15
Jan 4-11/00	0.00013	0.23	20
Jan 11-18/00	0.00012	0.44	38
Jan 18-25/00	0.00030	0.27	23
Jan 25-Feb1/00	0.00037	0.22	19
Feb 1-8/00	0.00024	0.068	6
Feb 8-15/00	0.00031	0.17	14
Feb15-22/00	0.00025	0.23	20
Feb 22-29/00	0.00016	0.13	11
Feb 29-Mr7/00	0.00014	0.20	17
Mar7-14/00	0.00030	0.20	17
Mar14-21/00	0.00018	0.16	14
Mar21-28/00	0.00021	0.20	18
Mar 28-Apr4/00	0.00028	0.28	24

Table 19. Total particulate matter and total phosphate concentration and deposition rates in high volume samples, Chilliwack Airport.

N/A indicates not applicable

Nutrient Levels in the Atmosphere of the Elk Creek Watershed, Chilliwack, B.C. (1999-2000)

Table 20.	Field blank	results for	rain samples	s (rain bags)	, Chilliwack Airport.
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Parameter	Method Detection Concentration	May 18/99 Field blank	Sept 7/99 Field blank	Mean Field blank
Ammonia Nitrogen (mg/L) Nitrate Nitrogen (mg/L) Nitrite Nitrogen (mg/L) Total Phosphate (mg/L) Chloride (mg/L) pH	0.022 0.005 0.001 0.002	0.022 ND 0.0010 0.0020 - 5.16	ND ND 0.0010 0.0040 ND 5.65	0.011 ND 0.0010 0.0030 ND 5.41

ND indicates below the specified detection limit

- indicates not measured
| Date | Ammonia Nitrogen | Nitrate Nitrogen | Nitrite Nitrogen | Total Phosphate | Chloride | Total Volume | pН |
|------------------|------------------|------------------|------------------|-----------------|----------|--------------|------|
| | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mL) | |
| Method Det.Limit | 0.022 | 0.005 | 0.001 | 0.002 | 0.5 | N/A | N/A |
| May18-26/99 | 1.16 | 0.615 | 0.025 | 0.003 | - | 118 | 6.65 |
| June1-15/99 | 0.76 | 0.168 | 0.006 | 0.004 | - | 2260 | 6.58 |
| June29-July13/99 | 0.78 | 0.441 | 0.008 | 0.01 | ND | 2400 | 6.53 |
| July13-20/99 | 1.08 | 0.229 | 0.023 | 0.017 | 1.1 | 966 | 6.51 |
| Jul27-Aug10/99 | 2.16 | 0.735 | 0.039 | 0.017 | ND | 522 | 5.8 |
| Aug10-24/99 | 0.68 | 0.174 | 0.009 | 0.002 | ND | 1960 | 6.8 |
| Aug24-Sept 7/99 | 0.53 | 0.182 | 0.008 | 0.005 | 1.2 | 4070 | 6.05 |
| Sep21-Oct5/99 | 1.1 | 0.309 | 0.019 | 0.022 | 2.1 | 1400 | 6.54 |
| Oct5-19/99 | 0.32 | 0.077 | 0.006 | 0.003 | 1.0 | 5430 | 6.64 |
| Oct19-Nov2/99 | 0.18 | 0.052 | 0.006 | 0.008 | 1.1 | 10000 | 6.44 |
| Nov2-16/99 | 0.23 | 0.042 | 0.006 | 0.002 | ND | 14600 | 6.59 |
| Nov16-30/99 | 0.31 | 0.111 | 0.009 | 0.004 | 0.7 | 8610 | 6.38 |
| Nov30-Dec14/99 | 0.28 | 0.075 | 0.008 | 0.002 | 1.0 | 5730 | 6.83 |
| Dec14-21/99 | 0.23 | 0.072 | 0.009 | ND | 0.5 | 7070 | 6.2 |
| Dec29-Jan11/00 | 0.41 | 0.109 | 0.01 | ND | 0.6 | 2000 | 6.29 |
| Jan11-25/00 | 0.4 | 0.15 | 0.014 | 0.004 | ND | 1500 | 6.99 |
| Jan25-Feb8/00 | 0.43 | 0.13 | 0.011 | ND | 0.5 | 3310 | 7.0 |
| Feb8-22/00 | 0.4 | 0.112 | 0.009 | ND | 1.0 | 2560 | 5.39 |
| Feb22-Mr7/00 | 0.504 | 0.142 | 0.011 | 0.004 | ND | 4280 | 6.51 |
| Mr7-21/00 | 0.38 | 0.094 | 0.009 | 0.009 | 0.6 | 3970 | 6.14 |
| Mr21-Apr4/00 | 0.45 | 0.183 | 0.008 | 0.005 | 0.9 | 2840 | 6.45 |
| Apr4-18/00 | 0.34 | 0.082 | 0.006 | 0.003 | 0.9 | 6250 | 7.29 |
| Apr18-May2/00 | 0.64 | 0.308 | 0.014 | 0.008 | 0.5 | 2680 | 6.97 |
| May2-16/00 | 0.56 | 0.288 | 0.011 | 0.011 | ND | 4610 | 6.02 |

 Table 21. Nutrient concentrations in rain samples, Chilliwack Airport.

N/A indicates not applicable

ND indicates value below the specified detection limit

- indicates not measured

Nutrient Levels in the Atmosphere of the Elk Creek Watershed, Chilliwack, B.C. (1999-2000)

Date	Ammonia Nitrogen	Nitrate Nitrogen	Nitrite Nitrogen	Total Phosphate
	(mg/m²/day)	(mg/m²/day)	(mg/m²/day)	(mg/m²/day)
May18-26/99	0.33	0.18	0.0070	ND
June1-15/99	2.1	0.47	0.014	0.0028
Jun29-Jul13/99	2.3	1.3	0.021	0.021
July13-20/99	2.5	0.54	0.052	0.033
Jul27-Aug10/99	1.4	0.47	0.024	0.0090
Aug10-24/99	1.6	0.42	0.019	ND
Aug24-Sept 7/99	2.6	0.91	0.035	0.010
Sep21-Oct5/99	1.9	0.53	0.031	0.033
Oct5-19/99	2.1	0.51	0.033	ND
Oct19-Nov2/99	2.1	0.64	0.062	0.062
Nov2-16/99	3.9	0.76	0.090	ND
Nov16-30/99	3.2	1.18	0.085	0.011
Nov 30-Dec14/99	1.9	0.53	0.049	ND
Dec14-21/99	1.9	0.63	0.070	ND
Dec29-Jan11/00	0.98	0.27	0.022	ND
Jan11-25/00	0.72	0.28	0.024	0.0018
Jan25-Feb8/00	1.7	0.53	0.041	ND
Feb8-22/00	1.2	0.35	0.025	ND
Feb22-Mr7/00	2.6	0.75	0.053	0.0053
Mr7-21/00	1.8	0.46	0.039	0.029
Mr21-Apr4/00	1.5	0.64	0.024	0.0070
Apr4-18/00	2.5	0.63	0.038	ND
Apr18-May2/00	2.1	1.0	0.043	0.017
May2-16/00	3.1	1.6	0.057	0.045

Table 22. Nutrient deposition rates in rain samples, Chilliwack Airport.

ND indicates value below the detection limit