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THE UNIVERSITY OF ALBERTA

ATMOSPHERIC NUTRIENT LOADING IN CENTRAL ALBERTA

by

ROGER CAIAZZA

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF
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DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA
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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Atmospheric Nutrient Loading in Central Alberta", submitted by Roger Caiazza in partial fulfilment of the requirements for the degree of Master of Science in Meteorology.

Keith D. Hage
Supervisor

E R Reinelt

Donald V. Gallup

Date JULY 29, 1976

DEDICATION

To my wife, Susie,
for her help, her consideration and
her love

ABSTRACT

The results of a sampling program designed to determine the atmospheric contribution to the nutrient loading of Hastings Lake, central Alberta, is described. Wet and dry deposition samples were analyzed for total nitrogen, total phosphorus, the major ionic forms of nitrogen and phosphorus, the silica, sodium, potassium, iron, sulfate, and chloride ions, and several other water property tests (pH, conductivity, hardness, and total residue). Both wet and dry deposition were manually sampled on an event basis. Bulk snow samples were also collected in the winter.

The results showed that the atmospheric contribution to Hastings Lake is significant. Dry deposition is more important than wet deposition during the snow free season. The opposite is true when the ground is covered with snow which implies that dry deposition is influenced by cultivation and other surface sources that do not act when there is a snow cover.

The total phosphorus and total nitrogen annual fluxes were high. There is no indication that, after a reduction factor accounting for biological contamination is applied, the fluxes found are unrealistic. Atmospheric deposition processes contribute over half of the total phosphorus annual load. The proportion varies inversely with the amount of runoff and groundwater seepage to the lake.

An attempt was made to correlate the wet deposition concentrations with meteorological variables. The results were inconclusive. Suggestions to improve this [illegible] and for further study are included.

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CHAPTER 1. INTRODUCION.

1.1 Eutrophication.

Eutrophication is characterized by the overabundant growth of plants in bodies of water (Vallentyne, 1974). These plants are autotrophic, i.e. they use inorganic nutrients to form organic material (Ruttner, 1963). Their lush growth causes a decrease in water quality by increasing the mass of organisms in the water, changing the species present to less desirable forms, decreasing the transparency of the water, and decreasing the oxygen content (Vollenweider, 1968).

Plant production is determined by the concentration and type of nutrients present, the amount of incident sunlight, the water temperature, the health of the plant community, and the effects of animals (Vallentyne, 1974). These growth factors are a function of the climate, the nutrient supply to the lake, the geology of the drainage basin, the configuration of the lake, and the biomass within the lake (Gorham, 1961).

Nutrient supply is the most important factor and the one most likely to be influenced by man's activities (Vallentyne, 1974). The general increase in human population and the resultant wastes have caused some lakes to deteriorate very quickly and others to show initial signs of poorer water quality (Vollenweider, 1968). This has been a problem in the past. For example, one Roman aqueduct had undrinkable water. The first water company in New York City was formed in 1774 to give residents better quality water (Weidner, 1974). In the past it has always been possible to go to new sources of water, but this is increasingly difficult today. We must maintain the quality of the available water supplies.

One simple scheme classifies lakes by water clarity. Dystrophic lakes are stained a brown tea color by rich humic matter. Clear lakes are further classified by production. Oligotrophic lakes are low in production. Eutrophic lakes are highly productive, which often reduces water clarity by the sheer bulk of plants present. Other characteristics of eutrophic lakes are shallow, wide basins, considerable mixing by wind, a reduction of species diversity and tremendous production at all levels of the food chain (Vallentyne, 1974).

1.2 Nutrient Loading.

According to the "law of the minimum", productivity is limited by that essential nutrient which is available in the smallest amount at any given time (Ruttner, 1963). The concentration of nutrients can vary more than any of the other previously mentioned growth factors for a given location. It is therefore very important to accurately determine the lake's nutrient loading, i.e. the mass of nutrients entering the lake.

Inorganic nutrients are present in most bodies of water in quantities large enough for maximum plant production and growth, however, phosphorus, nitrogen, and carbon are the essential elements that normally limit production (Vallentyne, 1974).

Plants utilize nutrients as ions in water solution. Orthophosphate is the most readily assimilated phosphorus ion, although some plants could possibly utilize organic phosphate[1] (Kramer et al., 1972). Ammonium and nitrate are the nitrogen forms used (Brezonik, 1972). Carbon is assimilated as the bi-carbonate ion or as carbon dioxide (Kerr et al., 1972). Hydrogen, oxygen, potassium, magnesium, sulfur, calcium, and silica must be present in fairly large amounts. Elements that must be present in trace amounts are manganese, iron, copper, zinc, boron, molybdenum, chlorine, vanadium, and cobalt (Sanders, 1972).

Phosphates are found in DNA and RNA, while elemental phosphorus is present in many cellular compounds as a structural part of cells and is used in cellular metabolism (Vollenweider, 1968). Organic phosphate is bound in complex

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[1] Appendix A gives a description of the ionic forms and methods of analysis.

biological products, while orthophosphate is in a readily assimilated form. Condensed phosphates must be broken down by acid hydrolysis before use by plants (Kramer et al., 1972).

Ninety five percent of the world's phosphorus is directly or indirectly due to the weathering of rocks, primarily the mineral apatite (Day, 1963). Chemical weathering frees phosphate for use by organisms which in turn concentrate it through a series of trophic levels, e.g., in the guano islands off Peru, in fossil deposits, and by man (Ruttner, 1963). The major source of phosphorus in lakes is from man's activities, as detergent wastes and from agriculture (Kramer et al., 1972).

Biological processes control the nitrogen cycle. Nitrogen is one of the components of protein and as such makes up twelve percent of the dry weight of animals and three percent of plants (Day, 1963). Bacteria on the earth's surface act both as a source and sink for nitrogen. Some fix nitrogen from the atmosphere and others convert amino acids into ammonia. Photochemical oxidation converts the atmospheric ammonia to nitrite and finally into nitrate (Syers, 1966).

Carbon is present in the atmosphere as carbon dioxide, and in the oceans and lakes draining limestone areas as the carbonate ion. Sulfur is an essential component of protein, usually absorbed by plants as the sulfate ion (Day, 1963). Silica is important for some plant species, particularly diatoms (Ruttner, 1963). Potassium, sodium, calcium, iron, and magnesium are essential to life for use in cell metabolism reactions or as constituents of the cell (Hutchinson, 1957). The trace elements mentioned previously are of great significance to productivity, but in ways not entirely understood (Ruttner, 1963).

Eutrophication is too complex to be closely related to nutrient fluxes, but Vollenweider (1968) has established some general threshold values for nitrogen and phosphorus loadings. Table 1.1 shows total nitrogen and total phosphorus threshold loading levels for different mean lake depths in $gm^{-2}year^{-1}$. Total nitrogen is the sum of the total kjeldahl nitrogen, nitrate and nitrite concentrations, both particulate and dissolved (Uttomark et al., 1974). Total phosphorus is calculated by dividing the total

Table 1.1 Specific loading values for lakes expressed as total nitrogen and total phosphorus

Mean Depth up to (m)	Permissible Loadings $(gm^{-2}yr^{-1})$ Total N	$(gm^{-2}yr^{-1})$ Total P	Dangerous Loadings $(gm^{-2}yr^{-1})$ Total N	$(gm^{-2}yr^{-1})$ Total P
5	1.0	0.07	2.0	0.13
10	1.5	0.10	3.0	0.20
50	4.0	0.25	8.0	0.50
100	6.0	0.40	12.0	0.80
150	7.5	0.50	15.0	1.00
200	9.0	0.60	18.0	1.20

After Vollenweider (1968).

phosphate ion by 3.06 (American Public Health Association, 1971).

Nutrient sources are grouped into two large categories, point and area sources. A point source releases effluent from a small region and it diffuses outwards, e.g. a sewage pipe (Vollenweider, 1968). Area sources can be further classified into natural and artificial sources. Unpolluted streams, runoff from grasslands and forests, ground water and atmospheric deposition all add small quantities of nutrients naturally. Some artificial, diffuse sources are agriculture, urban areas, and additions to the natural groundwater and atmospheric loadings by pollution (Uttomark et al., 1974).

Figure 1.1 shows a schematic version of the nutrient sources to a lake. The values assigned to each flux are estimates from literature studies by Vollenweider (1968) and Uttomark et al., (1974). It is important to note that the flushing time or time in which the basin's water is renewed and the configuration of the basin will vary these estimates. Even smaller concentrations will be dangerous if there is little inflow and outflow to the lake and the basin is such as to allow maximum use of light.

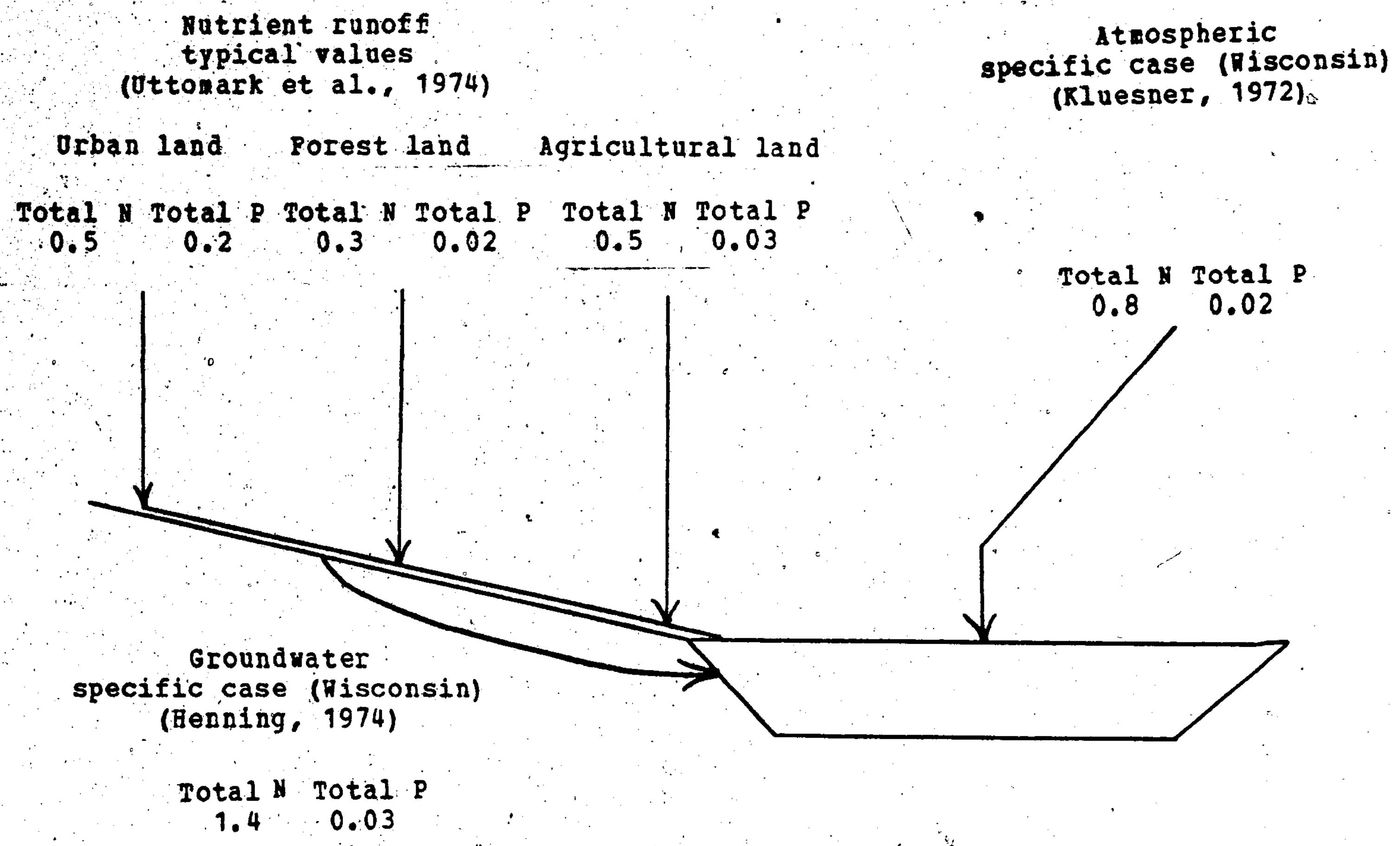


Figure 1.1 Examples of loading fluxes ($gm^{-2}yr^{-1}$).

1.3 Atmospheric Chemistry.

Aerosols are dispersed solids or liquids ranging in size up to 20μ, which, when combined with many different gases, make up the atmosphere. The most abundant constituents of the .tmosphere are nitrogen and oxygen with argon and carbon dioxide present in large and relatively constant amounts. The most important variable constituent is water vapor, but man's activities can locally add many gases and aerosols.

The four major sources of gases and aerosols in the atmosphere are combustion, biological activities, surface disruptions, and conversions within the atmosphere (Cadle, 1966). Wet removal by precipitation, surface removal and chemical transformations within the the atmosphere, all act as sink mechanisms (Slade, 1968). Surface removal can also be called dry deposition and covers any non-precipitation process. The dry-deposition rate (D) is related to air concentration by :

$$D = \chi V_d, \tag{1.1}$$

where χ is the concentration near the ground (gm^{-3}) and V_d (ms^{-1}) is deposition velocity for the contaminant being studied (Chamberlain, 1960).

Wet deposition results when precipitation processes remove contaminants. The wet-deposition rate (D') is determined by :

$$D' = kRA, \tag{1.2}$$

where k is the concentration of the contaminant (gm^{-3}) in precipitation, R is the rainfall amount (m), and A is the area affected (m^2). K can be calculated using

$$K = w \chi \rho^{-1} \tag{1.3}$$

where w is the washout ratio, χ is again the concentration near the ground, and ρ is the density of air ($1200 gm^{-3}$).

The residence time is defined as the period of time in which a specific contaminant remains in the atmosphere and is a function of the properties of the contaminant (Junge, 1963). A large particle normally settles out within a few hours, while insoluble gases can have residence times of several years.

Combustion may be broken down into two processes, sublimation and mechanical disruption. Sublimation occurs when heating causes the volatile constituents of the fuel to be vaporized. This causes a large supersaturation of the volatile material which in turn forms many small particulates (Fletcher, 1969). Release of the volatile component leaves a fragile framework which is broken up by turbulence associated with the release of heat. The mechanical disruption releases a smaller number of large particles.

Nitrogen oxides, sulfur dioxide, and ammonia are released by burning fossil fuels (Mason, 1971). Phosphorus and chlorine may also be liberated while calcium and sodium are present in the fly ash. Sulfur dioxide is primarily released by smelters, natural gas processing, and pulp mills in Canada (Summers and Whelpdale, 1975). Forest fires release sulfur dioxide and ammonia, and volcanoes produce sulfur dioxide (Mason, 1971).

Biological activities continuously cycle different elements. Photosynthesis uses sunlight and inorganic nutrients to produce organic compounds. Other processes e.g., transpiration, respiration, and nitrogen fixation, can change atmospheric components while the organism is alive, as well as produce hydrocarbons such as terpenes. The decomposition of dead organisms and the release of inorganic ions completes the cycle.

Oxygen, carbon dioxide, and nitrogen are the major constituents of the atmosphere related to biological processes. Hydrogen sulfide, ammonia, and many other compounds are released by decay (Mason, 1971). Respiration of animals and plants, and photosynthesis of plants cycle oxygen and carbon dioxide.

Gases released over the oceans and continents are due to biological activities or evaporation. Particulates need mechanical energy to be entrained in the atmosphere. Air bubbles in foam and sea spray from breaking waves produce many particulates over the oceans, and agricultural practises can greatly accelerate the wind scavenging of soil. Sulfate, chlorine, potassium, sodium, aluminum, iron, phosphorus, and nitrogen have all been found in airborne soil particles (Junge and Werby, 1958; and Gorham, 1975). The concentration of a wet-or dry-deposition sample is related to the local soil composition, the available mechanisms for entraining the soil, and the deposition mechanisms. High concentrations of phosphorus have been related to rich soils (Kerekes, 1973). Cultivation in the American midwest is responsible for highly alkaline precipitation samples there (Junge and Werby, 1958). Severe storms can entrain large amounts of soil which causes large loadings, but long-range transport of soil particles is more efficient when there is little precipitation.

Conversions in the atmosphere can vary the concentrations of different compounds. Sulfur dioxide reacts with water to produce sulfuric acid which in turn combines with ammonia to produce ammonium sulfate, the most common aerosol (Mason, 1971). Photochemical reactions, particularly for nitrogen compounds, are important. At high temperatures nitric acid forms if nitrogen, oxygen, and water are present (Eriksson, 1952), and lightning has been considered a source for nitrate by this reaction. Hutchinson (1944) postulated that 14% of the nitrate found in an Oklahoma storm was due to this source. However, Viemeister (1960) did not find any correlation between lightning and nitrate concentration in New York State.

Wet deposition encompasses all sink mechanisms associated with precipitation and precipitation processes. Rainout, caused by condensation of water around an aerosol nucleus, is the most efficient scavenging mechanism (Pruppacher, 1973). Other removal processes within clouds are Brownian motion, coagulation and the water-vapor gradient effect (Junge, 1963).

Precipitation falling beneath clouds removes contaminants by a process called washout. The relationship between this process and radioactive particulates has been studied extensively (Greenfield, 1957). Each drop falls through a volume of air, collecting a fraction of the particulates in that volume as a function of the droplet diameter, the number of particles that actually strike the drop, and the number of particles that are retained after striking the drop (Slade, 1968).

The rainout and washout of particles by snow is about three times as effective as that by rain for the same precipitation rate (Engelmann, 1968). In Alberta, lower sulfur concentrations have been found in snow than in rain (Klemm and Barillot, 1975; and Summers and Hitchon, 1971). The explanation is that precipitation rates in the Alberta winter are much smaller than during the rest of the year, and gaseous absorption by snow is much less than that of rain because the reaction rates are reduced in cold weather (Engelmann, 1968). There is evidence also to suggest that convective showers are the most efficient scavengers (Whelpdale and Summers, 1975).

Gases may also be collected both in the cloud and below it. The efficiency with which gases may be collected is primarily a function of the gas. The solute gas diffusivity and equilibrium solubility of the absorbed gas in water are important, as well as the size of the collecting droplet and the concentration of the gas (Postma, 1970).

Dry deposition occurs at the surface of the earth. The flux of a contaminant to the surface can be expressed by Chamberlain's (1960) expression (1.1). The concentration and dry deposition rates are functions of the mixing height, mixing rates within the atmosphere, and source concentrations (Scriven and Fisher, 1975). Whelpdale (1974) showed dry deposition to be a significant contributor to the total loading of lakes. Whitehead and Feth (1964) and Zeman and Nyborg (1974) both showed that dry fallout was influenced mainly by local sources.

Sedimentation or gravitational settling is important for large (1-20μm) aerosol particles. Particles entrained in the atmosphere but too small to settle out are deposited by impaction. This occurs when the flow around an object is too sharp for entrained particles to follow.

Aerosols coagulate, forming larger particles due to Brownian motion, diffusiophoresis, and thermophoresis. These larger particles are more susceptible to removal by the processes listed above.

Gases may be removed by direct uptake by plants at the surface or even the soil (Nyborg et al., 1975). Removal can also occur to maintain equilibrium in bodies of water.

Removal within the atmosphere has been explained earlier as a source and it is obvious that it can also be a sink. Gases diffusing upwards through the atmosphere can escape into space also.

1.4 Previous Work.

Precipitation chemistry literature is very extensive but, for the most part, is not applicable to nutrient loading studies. Vollenweider (1968) notes three problems with the literature. The use of different analytical techniques makes comparison of results difficult, because the different methods often give incompatible results. For nutrient loading studies the choice of analyses and nomenclature used must be carefully selected. It is also important that application of statistical techniques does not cloud the essential results.

Extensive networks for precipitation chemistry were established in Scandinavia, the United States and, more recently, world-wide by the World Meteorological Organization (WMO). The Scandinavian system measured the ionic content of rain and was particularly useful in determining industrial effects (Eriksson, 1952 and Egnér et al., 1955). In the United States, a nationwide network sampled rain to determine spatial distributions (Junge and Gustafson, 1956 and Lodge et al., 1968). Both programs showed the need for global background data and a study of pollutant transport across international boundaries. The WMO has started a monitoring network to determine the residence time, background concentration, and global distribution of specific contaminants (Olson and Berry, 1975).

Acid rain can adversely affect aquatic systems mainly by changing the water pH such that sensitive plants and animals cannot survive (Gorham, 1975 and Sweden, 1971). In Canada, the Sudbury ore smelters are responsible for the elimination of certain fish species and a general decline in productivity of nearby lakes (Beamish, 1975).

Atmospheric nutrient loadings have been determined in England (Gorham, 1961), New Hampshire (Fisher et al., 1968) and Iowa (Tabatabai and Laflen, 1975). The atmospheric contribution to the total loading of lakes is significant where the chemical weathering in the drainage basin is low (Gorham, 1961), where the lake occupies a large proportion of the drainage basin (Murphy and Dosky, 1975) or where man's influence is small (Kramer et al., 1972).

Despite the importance of nutrient loading, no program has sampled all nutrient sources within a basin for a total budget. The usual approach has been a detailed measurement of one or more nutrient fluxes for a specific lake, combined with a literature survey to obtain the complete budget (Jonásson, Lastein and Rebsdorf, 1974).

Nutrient budgets are calculated by measuring the lake area, drainage basin area and water balance. This information gives the flushing time of the lake, and inflow and outflow rates. Nutrient sources within the drainage basin are estimated as per capita loadings (Vollenweider, 1968) or loadings per specific area (Uttomark et al., 1971). These nutrient loadings combined with the physical lake data give mass budget information. (See, for example, Vollenweider and Dillon (1974).)

In British Columbia, a nutrient balance was calculated on the assumption that the atmospheric contribution was negligible (Patalas and Salki, 1973). A similar study in western New York explicitly calculated the atmospheric contribution which was found to be small (Stewart and Markello, 1974). At least three studies have found the nutrient content of snow to be a significant contribution to the nutrient budget. The concentration of total nitrogen in snow was over twice that of Lake Tahoe water (Dugan and McGauhey, 1974). In Ontario, two separate lakes in the Canadian Shield received large amounts of nutrients in the winter (Schindler and Nighswander, 1970 and Barcia and Armstrong, 1971).

CHAPTER 2. COOKING LAKE AREA STUDY.

2.1 Cooking Lake Area Study.

The Cooking Lake moraine is located in central Alberta about 25km east of Edmonton (Fig. 2.1). The moraine, a remnant of the Keewatin continental glacier, consists of glacial till up to 25m thick. The original coniferous forest was burned or otherwise cleared by the first settlers in the moraine about 1890. Since that time most of the land in the moraine has been used for grazing or has become deciduous forest. Today, the recreational needs of the city are bringing increased development to the moraine. (E.P.E.C., 1971)

The lakes in the moraine are subject to large variations in water level. These variations preclude any large-scale development. Lake levels were high in 1880, 1900, and 1960, but were low in 1865, 1895, and 1930 (Environment Conservation Authority, 1971). In 1970, lake levels were low enough to curtail use of the Cooking Lake seaplane base, and at that time, a petition signed by over 500 people was submitted to the Alberta government asking for action to reclaim the watershed (Environment Conservation Authority, 1971).

An economic analysis of the costs and benefits of a

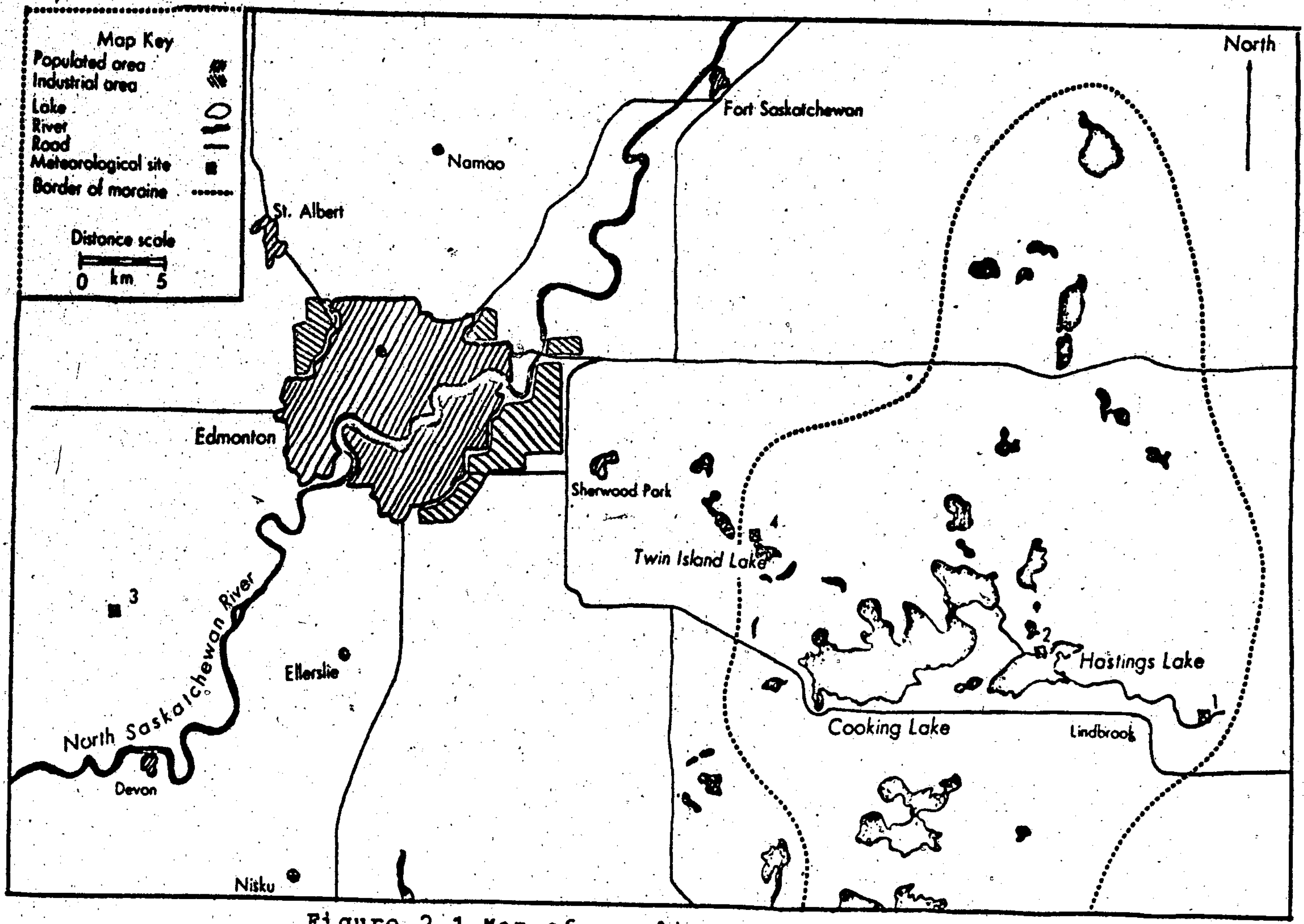


Figure 2.1 Map of sampling area, central Alberta.

water stabilization scheme was prepared in response to the petition (E.P.E.C., 1971). Water importation from the North Saskatchewan and from deep wells was suggested as possible means of augmenting lakewater levels. Public hearings were held in 1971 to explain the proposals and to obtain public input (Environment Conservation Authority, 1971). At that time it became apparent that, in addition to the fluctuating water levels, the water quality and growth of aquatic weeds and algae were also problems.

A large interdisciplinary project was set up in late 1971 to assess the impact of a water-stabilization scheme and to develop a proposal for the conservation of the area's resources. This project was separated into several parts. A comprehensive land inventory and proposal for land zoning, detailed proposals for specific water-stabilization schemes, and several studies of the current status of the lakes were included (Alberta Environment, 1974). At this time (July, 1976), the projects have, for the most part, been completed and are being prepared for submission to the Minister of the Environment.

2.2 Cooking Lake Aquatic Study.

The first section of the aquatic study considered water quality and aquatic weed and algal growth problems on seven lakes in the Cooking Lake Moraine with particular emphasis on the phytoplankton primary production. This research was done on a grant to Dr. D.N. Gallup from the Pollution Control Division of Alberta Environment. The second portion of the study was a detailed investigation centering on the Hastings Lake area. Participants in the program were from the Departments of Botany, Geography, Geology, and Zoology, of the University of Alberta. This was done on a grant to the Water Resources Centre funded jointly by Alberta Environment and Environment Canada.

The second portion of the study concentrated on Hastings Lake where detailed biotic, chemical, and physical sampling programs were centered. The aquatic life in the lake was studied in detail and chemical analyses of water were taken throughout the year. In addition, profiles of temperature, conductivity, and light penetration were taken to describe the physical conditions of the lake. The Geology Department drilled a series of wells around the lake, which measured water flow and nutrient flux in the surrounding acquifer. Studies of the water use and snow melt runoff were conducted by the Geography Department.

This thesis describes a study of the atmospheric contribution to the nutrient loading of these lakes. Although several atmospheric nutrient loading studies have been done in various parts of the world, there are no data for the Prairie Provinces. No other study has included an analysis of such a wide range of compounds and ions.

The final result of the Cooking Lake Aquatic Study will be a comprehensive description of the existing conditions of the lake. It should also be possible to understand the relationship between the aquatic system and local and regional land use.

CHAPTER 3. MEASUREMENT OF ATMOSPHERIC DEPOSITION.

3.1 General Considerations.

Atmospheric chemistry is a study of the natural and artificial components of the atmosphere, the processes that add or remove components, and the motion and interaction of these components while they are present in the atmosphere. Sampling wet and dry deposition can estimate the amount of material being added to the surface from the atmosphere. This project sampled wet and dry deposition for some of the common nutrients necessary for plant production in the Cooking Lake moraine area of central Alberta.

The sampling program was set up to study the seasonal variation of nutrient loading, the relative proportions that are present in wet and dry deposition, the effects of the city and meteorological variables on the nutrient concentrations, and to give a total annual loading flux for the lakes in the Cooking Lake moraine. This information has not yet been studied in detail for the Prairie Provinces; it could be used to determine a nutrient budget for lakes in the moraine.

The possibility of contamination is high because of the low concentrations of nutrients in the samples. It is important that collecting procedures and equipment minimize the possible sources of contamination and that storage does not change the concentrations in the samples. Standard analysis methods of the American Public Health Association (1971) were used to analyze the nutrients. It is expected that errors in the analysis procedure will be much smaller than those introduced by collection and storage (Galloway and Likens, 1975).

The wet- and dry-deposition samples collected were analyzed for major nutrients and several water properties. Primary consideration was given to complete phosphorus and nitrogen tests. Total phosphate, orthophosphate, condensed phosphate, organic phosphate and total kjeldahl nitrogen were analyzed both in filtered and non-filtered form. The nitrate and nitrite ions, ammonia nitrogen, and organic nitrogen completed the primary analysis. In addition the ions of iron, silica, sulfur, potassium, sodium and chlorine were analyzed. Conductivity, pH, total and filtrable residues, total hardness and hardness as calcium completed the water properties measured. A summary of the methods and nomenclature used is in Appendix A.

3.2 Sampling.

The focal point of the study was Hastings Lake, Alberta. The sampling sites were located along a line roughly parallel to the prevailing wind direction, because Hastings Lake is only 40 km from the petrochemical plants, industries and other human activities in Edmonton. One station was located at Hastings Lake with neighboring stations at Twin Island Lake and Lindbrook in a rough line with the city (Fig. 2.1). One site was located on the other side of the city, in Woodland park, as an additional point of reference. The sampling sites are listed in Table 3.1.

Table 3.1 Site Description

Site	Description	Location
1	Uncultivated open field	9 km E of Lindbrook NE 9-51-20 W4
2	Wooded island, Hastings Lake	3 km SSE of Deville NE 20-51-20 W4
3	Woodland Park, acreage subdivision	10 km WNW of Woodbend NE-26-51-27 W4
4	Open field (oats grown)	1 km NE Twin Island Lake NW 10-52-22 W4
5	Residential area within city	78th Ave. off 104th St.

If accurate rainwater concentrations are desired, then separation of wet and dry deposition is essential (Ga[illegible]way and Likens, 1975). This is particularly important for a nutrient loading study. Nutrients in wet deposition are readily available for aquatic system use, but dry deposition adds nutrients that must go into solution before use. A bulk collector does not accurately represent either situation because both wet and dry deposition are mixed within the sample.

Wet- and dry-deposition samples can be separated in several ways. Junge and Gustafson (1957) exposed collecting funnels only during precipitation. Georgii and Weber (1960) excluded the effects of dry deposition by rinsing collecting surfaces with distilled water daily. Large-scale programs with many stations do not lend themselves to these manual procedures. To circumvent handling problems, automatic samplers have been designed that open only during precipitation. Unfortunately, these samplers can introduce a whole new set of problems. (See, for example, Olson and Berry (1975).)

An atmospheric chemistry sampling program has many possible sources of errors. Among the known problems are:

A) Statistical sampling errors due to a limited data base.

B) Modification of samples by sampling methods.

C) Local contamination of samples.

D) Modification of sample by collection and storage materials.

E) Sample changes due to storage.

F) Chemical analysis errors.

Fifty-five precipitation samples, seventeen dry deposition and four bulk snow samples were collected between 15 May 1975 and 2 May 1976. Time, money, and manpower restrictions limited the data base to these samples. The results may not be representative of the long-term normal conditions in the moraine. If this year was abnormally "dirty", e.g. due to local road construction or unusually dry conditions, concentrations could be higher than normal.

Dry deposition can occur by sedimentation, impaction, or gaseous absorption at the surface (Van der Hoven, 1968), which makes its sampling difficult. Rinsing an exposed collecting surface with distilled water (Whitehead and Feth, 1964) measures particulate sedimentation but does not measure impaction or gaseous diffusion. Even as a measure of sedimentation there are difficulties associated with the height of the collecting surface, turbulence caused by the sampling structure, and collecting efficiency of the surface which can alter measured concentrations. High-volume samplers can be used to measure air concentrations which will estimate deposition rates (1.1), if the deposition velocities are known (Nyborg et al., 1975).

Another approach to the problem has been to model the surface by setting out samples with known concentrations and measuring the change after exposure.

This has been done with moss (Nyborg et al., 1975), soil, distilled water (Shipley, 1975) and for a snow surface (Batta and Le Clerc, 1934). All of these studies examined the sulfur dry-deposition flux.

The atmospheric contributions to Hastings Lake were simulated by exposing pans ($0.3m^2$) of distilled water set up on frames (Fig. 3.1). In principle, this method should be capable of including the dry-deposition fluxes due to sedimentation, impaction, and gaseous absorption processes. Problems remain, however. No attempt was made to model the physical characteristics of the water, e.g., temperature and pH, which could affect

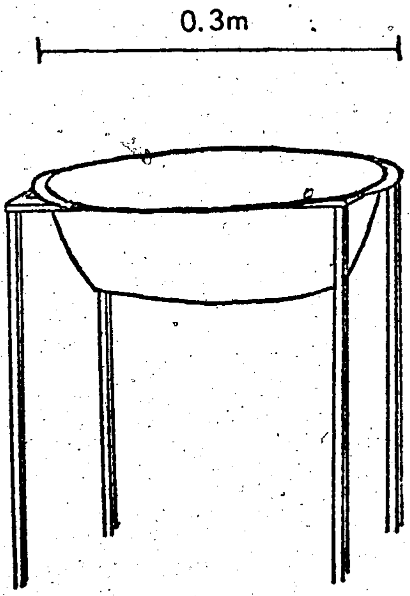


Figure 3.1 Dry deposition sampler

the gaseous absorption rates. Also, turbulence caused by the lip of the sampling pan could affect the sedimentation and impaction of particles on the surface.

Wet-deposition collectors should be designed so that samples large enough to complete the required chemical analysis are obtained, and no changes in the sample occur as a result of collection. A typical automatic sampler can collect six sequential 300ml samples using a funnel (area approximately 0.008m²) for 12.4mm of rain (Zeman and Nyborg, 1975). Splashing water from non-collecting surfaces to the collector can be a problem, particularly in automatic samplers where a build-up of dust occurs (Galloway and Likens, 1975). Organic compounds and pesticides should be sampled on glass, while cationic samples are best sampled on plastic (Galloway and Likens, 1975).

Wet deposition was collected in this study by manually exposing polyethylene sheets (2.7m²) during or at the start of precipitation. The polyethylene sheets were mounted, at the four main sites mentioned previously, on a wooden frame covered with canvas (Fig. 3.2). Manual exposure and the height of the sampling surface minimizes contamination due to dry deposition and ground splashing. The large collecting area was needed because a complete sample required 2400ml. The polyethylene surface should not contaminate the ionic

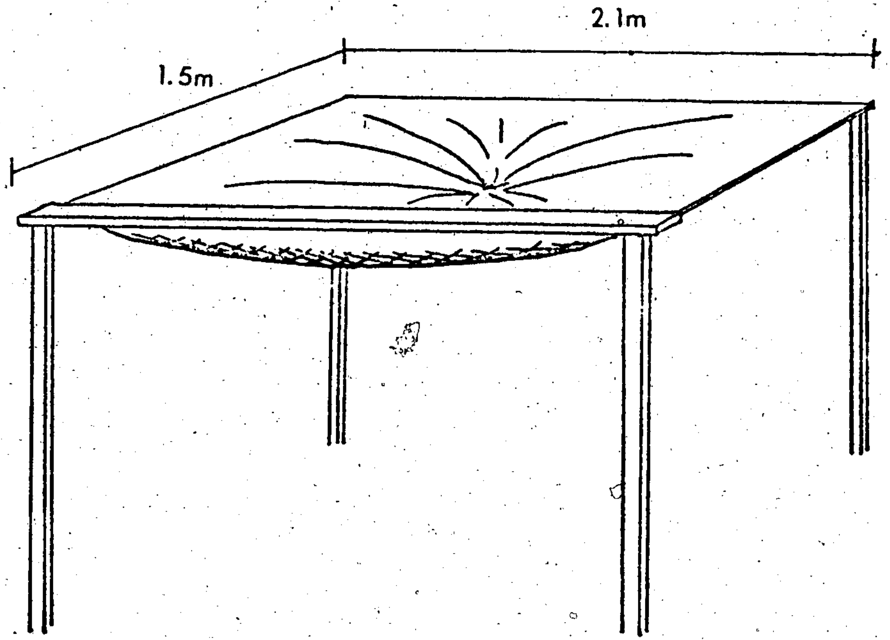


Figure 3.2 Wet deposition sampler

forms that were analyzed. The metal clips that clamped the sheet to the frame could be a source of contamination but most of the time the clamps were placed below the collecting surface. Periodic inspection insured that no contamination resulted from unexpected sources.

Summer precipitation in central Alberta is associated mainly with convective showers (Longley, 1971). A mobile unit was used to intercept showers not passing over the four fixed sites. A quarter ton pick-up truck was used for the mobile unit. At the start of precipitation a polyethylene sheet ($2.7m^2$) was placed on a wooden frame mounted in the truck bed. Contamination due to splash from the cab was minimized by placing the rear of the truck into the wind. All samples collected by the mobile unit were within 1km of a fixed site or within the city of Edmonton.

Fresh snow was collected in this study by sampling the snow either during or immediately after a snow fall. Two samples of dry deposition were taken by sampling the snow several days after it had fallen and had been sampled previously. The entire snow pack was also sampled to measure the combination of wetand dry deposition that had accumulated. During the winter, animals and soil scavenging are not a problem. As long as samples are collected away from roads, minimal contamination was expected.

A total of ninety samples were analyzed (Table 3.2). Seventy six of these samples were collected in the field. The remaining fourteen samples were analyzed to investigate the various sources of error, to check the chemical characteristics of the water used in the dry deposition sampling, and to determine the specific influence of insects and plant debris on sample concentrations.

3.3 Storage and Analysis of the Samples.

Immediate analysis of the sample after collection is best, because it eliminates all possibility of a change in sample concentration due to storage. Normally this is not possible. Sample concentrations may change

Table 3.2 Summary of samples collected.

Type of sample	Number of samples
Wet deposition	
Rain	26
Showers	20
Snow	8
Hail	1
Total	55
Dry Deposition	
In distilled water	15
In fresh snow cover	2
In accumulated snow cover	4
Total	21
Test samples	
Distilled water	10
Contamination test	4
Total	14
Total number of samples analyzed	90

due to adsorption and desorption of material between the sample and the walls of the container, chemical reactions within the sample and between the sample and the container, and micro-biological action (Goulden, 1972).

Linear polyethylene bottles are acceptable as sample containers that minimize reactions between samples and container wall (Goulden, 1972). The other reactions within the sample can be eliminated either by adding chemicals or by low temperature storage. Although no quantitative results were given, freezing was not recommended because the phase change of the water might affect the water chemistry, particularly for the phosphate and chloride ions (Galloway and Likens, 1975). Water chemistry studies in Ontario found that individual analyses could be erratic for frozen samples, but that the averages were reliable, with the exception of silica (Armstrong and Schindler, 1971).

Complete analysis required 2400ml of water in each sample. The samples collected were stored in 1400ml linear polyethylene bottles. Samples were placed in cold storage (-10°C) within three hours of collection and stored, for not over two months, until analysis.

Fifteen samples were incomplete because the volume collected was too small for a complete analysis. The analyses performed were chosen according to an analysis priority scheme (Fig. 3.3). Filtration was performed after the samples were thawed, using a 0.45μm membrane filter. The material that passed through the filter was defined as "soluble" (Goulden, 1972).

The rest of the analysis, done by the Water Chemistry Laboratory, Department of Zoology, University of Alberta, followed procedures listed by the American Public Health Association (1971). These methods are detailed in Appendix A.

3.4 Dry Deposition Contamination.

The sampling program used collectors that did not have shields to prevent contamination by birds, insects, and plant debris. The wet-deposition collectors were

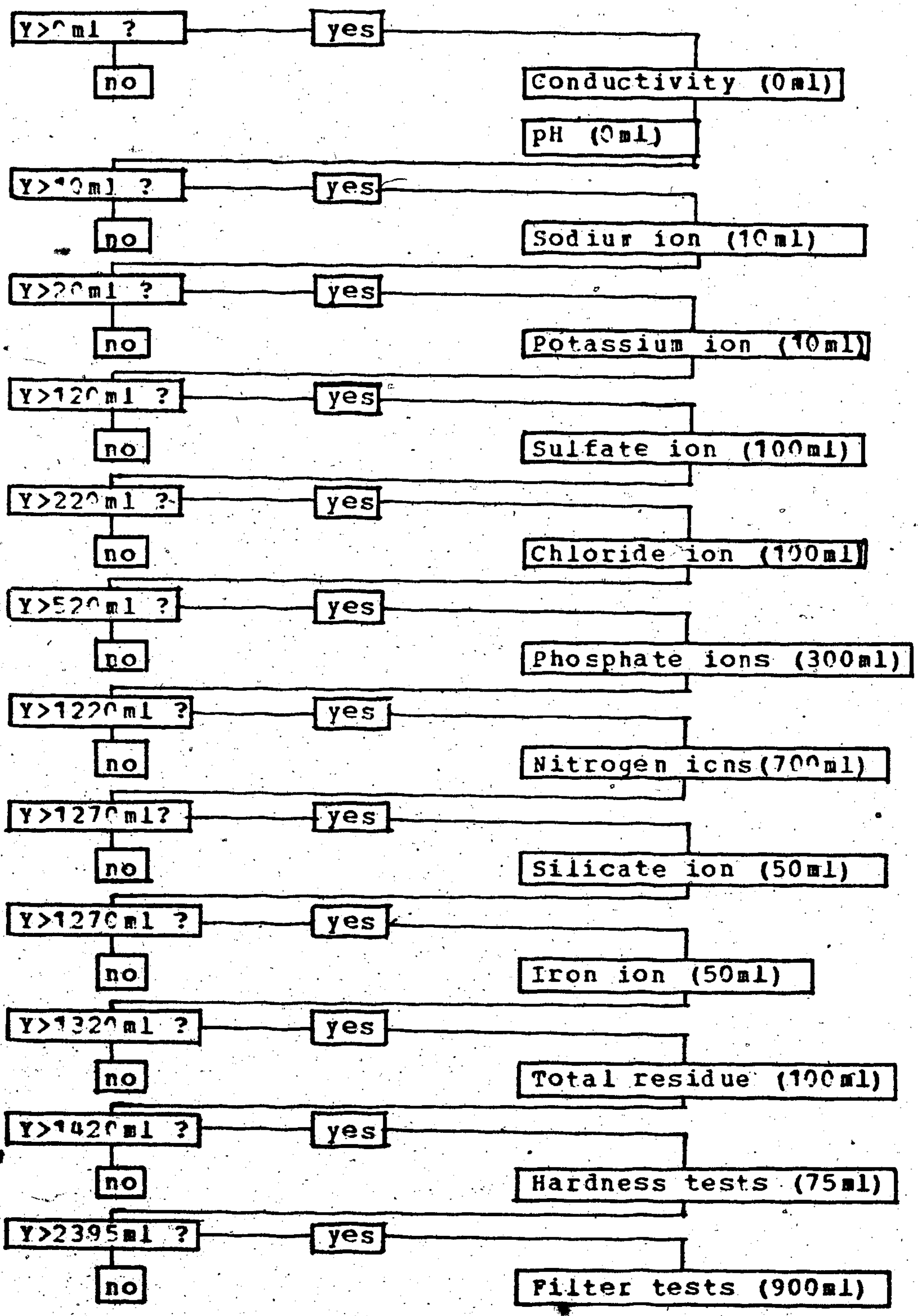


Figure 3.1 Analysis priority scheme
(volume of sample in ml)

exposed up to several days and were checked often, which minimized contamination. The dry-deposition samples were left unattended for long periods of time and many insects were found in several samples.

Attempts were made to remove most of the material before storage, but it was impossible to remove all of the debris. The first step in the analysis was a filtration with a 0.45μm membrane filter. This should have removed all of the particulate matter in the sample that could have caused contamination. The possibility that particulates had broken down before analysis should not be discounted.

Two dry-deposition samples were removed from consideration in any calculations because of gross contamination; one by rain, the other by a bird dropping. The bird-dropping sample was analyzed and it was found to have a total phosphate concentration ten times higher than the next highest sample. Because no comparable concentrations were found in other samples, it was assumed that no other bird droppings were present.

An experiment was run to study the effect of insects and plant debris on the dry deposition sample concentration. Four samples were analyzed in the experiment. The first was a standard test of the water and polyethylene sheets used. Distilled water was placed on the test surface, bottled, and frozen before analysis.

The rest of the experiment consisted of three closed basins with various combinations of insects and plant debris (Table 3.3). The samples were collected after 67 hours of exposure, frozen immediately, and analyzed several days later.

Table 3.3 Sample summary of contamination test.

Sample	Description
Sample 1	12 insects[1] added at intervals All removed at end of test.
Sample 2	11 insects[1] added at intervals All left in sample at end of test
Sample 3	50 plant fragments[2] added at intervals All left in sample at end of test
Sample 4	Test sample for water

[1] Insects included mosquitoes, flies, beetle and spider.
[2] Plant fragments included seeds and leaf fragments.

The raw data (Table 3.4) were "corrected" by subtracting out the original test sample, since it was assumed that all the samples had the same original concentration. Definite effects were found for total phosphate, organic phosphate, filterable condensed phosphate, sulfate, and total hardness. The complex phosphorus compounds in the insects and plant material are probably resposible for the high phosphate concentrations, but the other effects are not readily explained.

Table 3.4 Contamination test data ($mg\ell^{-1}$ unless otherwise noted).

	Insects removed (1)	Insects remain (2)	Plant debris remains (3)	Test sample (4)
Total phosphate	0.19	0.42	0.53	0.18
Orthophosphate	0.13	0.05	0.05	<0.05
Condensed phosphate	0.01	0.29	0.20	0.18
Organic phosphate	0.05	0.08	0.28	0.0
Total kjeldahl nitrogen	0.37	0.42	0.30	0.24
Ammonia nitrogen	0.02	0.04	0.01	0.02
Organic nitrogen	0.35	0.40	0.29	0.22
Nitrate nitrogen	0.01	0.04	0.01	0.04
Nitrite nitrogen	0.003	0.002	0.006	0.001
Silica ion	0.29	0.30	0.36	0.23
Iron ion	0.02	0.01	0.02	0.02
Chloride ion	2.18	1.64	1.64	3.27
Sulfate ion	----	2.00	2.00	0.00
Sodium ion	0.00	0.00	0.00	0.00
Potassium ion	0.00	0.00	0.00	0.00
Hardness as calcium	0.00	0.00	0.00	0.00
Total hardness	6.00	6.00	25.00	4.00
pH (log H^+ icn conc.)	6.20	5.26	6.16	6.37
Conductivity (μmhoscm^{-1})	2.3	5.6	2.4	2.7
Total residue	0.00	0.00	4.00	4.00
Filtered samples				
Total phosphate	0.14	0.30	0.29	0.18
Orthophosphate	<0.05	<0.05	<0.05	<0.05
Condensed phosphate	0.10	0.08	0.07	<0.05
Organic phosphate	0.04	0.22	0.22	0.18
Total kjeldahl nitrogen	0.18	0.40	0.27	0.24
Total residue	0.00	0.00	0.00	2.00

The two highest results were averaged to obtain a sample representative of moderately high contamination and normal handling. The average flux was also calculated and has been used to determine the maximum effect of the contamination on the concentrations (Table 3.5). The first three columns list the changes in concentration caused by the contaminants added to each

Table 3.5 Corrected contamination test samples $(mg\ell^{-1})$.

	1	2	3	4	5
Total phosphate	0.01	0.24	0.3[illegible]	0.295	0.62
Orthophosphate	0.10	0.02	0.02	0.02	0.04
Condensed phosphate	-0.17	0.11	0.02	0.065	0.14
Organic phosphate	0.05	0.08	0.28	0.18	0.38
Kjeldahl nitrogen	0.13	0.18	0.06	0.12	0.25
Ammonia nitrogen	0.0	0.0	-.01	-.005	---
Organic nitrogen	0.13	0.18	0.07	0.125	0.26
Nitrate nitrogen	-0.03	0.0	-.03	-.015	----
Nitrite nitrogen	0.002	0.001	0.005	0.003	.006
Silica ion	0.06	0.07	0.13	0.10	0.21
Iron ion	0.0	-0.01	0.0	-.005	----
Chloride ion	-1.09	-1.63	-1.63	0.0	----
Sulfate ion	----	2.00	2.00	2.00	4.20
Sodium ion	0.0	0.0	0.0	0.0	----
Potassium ion	0.0	0.0	0.0	0.0	----

1. Sample exposed to insects, but all were removed before analysis.
2. Sample exposed to insects which were not removed before analysis.
3. Sample exposed to plant debris which was not removed before analysis.
4. Average of columns 2 and 3.
5. Average annual flux for columns 2 and 3 (mgm^{-2})

concentration of the exposed samples. If the concentration of the test sample was larger than the concentration of the exposed sample, a negative number resulted. The chloride ion was the major problem in this regard because all three columns are negative. This implies that the test sample was contaminated with chloride, probably due to incomplete rinsing of the sample bottles after the acid bath.

Column 4 is an average of columns 2 and 3 and represents the change in concentration caused by serious contamination from these sources. Table C-4 (Appendix C) lists dry deposition sampling data, including contamination on a scale of 1 to 10. The samples were scaled on the basis of the organic material present. Low values correspond to "clean" samples with few organic fragments present. The contamination represented by column 4 of Table 3.4 is equivalent to 8 on that scale. The last column gives the contamination flux for our samplers on the basis of the test. If these fluxes are compared to the average fluxes calculated using the summer dry deposition data, it will be seen that five constituents have contamination fluxes greater than 10 percent of the total flux. Total phosphate (28.2%), condensed phosphate (15%), organic phosphate (30.6%), silicon (12.1%), and sulfate (18.9%) are the constituents that have large contamination fluxes. The other constituents were not affected significantly by serious contamination of the samples with organic material.

3.5 Dry Deposition Sampling Procedure Test.

Dry deposition was sampled by exposing distilled water. A test sample was analyzed for each set of dry-deposition samples. The test sample was treated like a dry-deposition sample, i.e., it was transported, set out, taken in, stored, and analyzed except that it was not exposed for more than ten minutes. The mean concentrations of the test samples and of the dry-deposition samples were tested to see if there was a significant difference after exposure (Table 3.6). This

Table 3.6 Comparison of dry deposition and test samples. (All averages are in $\text{mg}\,\ell^{-1}$ unless otherwise noted.)

Constituents	Dry deposition mean	Test sample mean	T-test comparison
Total phosphate	0.371	0.203	0.025
Orthophosphate	0.120	0.013	0.005
Condensed phosphate	0.114	0.071	0.10
Organic phosphate	0.138	0.124	0.25
Total kjeldahl nitrogen	0.851	0.167	0.0005
Ammonia nitrogen	0.350	0.081	0.025
Organic nitrogen	0.501	0.091	0.025
Nitrate nitrogen	0.030	0.014	0.025
Nitrite nitrogen	.0025	0.003	0.05
Silica ion	0.723	0.531	0.10
Iron ion	0.116	0.02	0.0005
Chloride ion	3.23	5.21	0.025
Sulfate ion	2.31	0.00	0.005
Sodium ion	0.085	0.067	0.10
Potassium ion	0.200	0.056	0.005
Hardness as calcium	0.214	0.00	0.25
Total hardness	19.1	13.4	0.10
pH (log of H^+ ion conc.)	6.09	6.37	0.25
Conductivity (μmhoscm^{-1})	15.6	2.02	0.0005
Total residue	6.11	2.23	0.25
Filtered samples			
Total phosphate	0.081	0.150	0.05
Orthophospahte	0.248	0.005	0.025
Condensed phosphate	0.054	0.038	0.10
Total kjeldahl nitrogen	0.385	0.120	0.0005
Total residue	0.72	0.50	0.40

table lists the raw-data means for comparison, but the t-test statistic was calculated after a logarithmic transformation of the data. This transformation is appropriate for precipitation chemistry data and ensures that the population distribution is roughly normal

(Gorham, 1961). The t-test comparison column lists the significance levels which, when multiplied by 100, are the percentage probabilities that the difference between the sample means could be obtained by chance. The t-test results show that most of the samples are significantly different ($P<0.05$) or extremely unlikely to have been taken from the same population (Panofsky and Brier, 1958).

The insoluble particulates that comprise the filtered total residue are very small because they must be able to pass through a 0.45μm filter. Particles with diameters of 1μm or less are not affected by sedimentation processes, so dry-deposition exposure should increase the filtered total residue by impaction only. Impaction is only important over rough terrain, thus the filtered total residue should not be high (Van der Hoven, 1968).

Condensed phosphate and pH are not expected to change much on the basis of local sources. Detergents are the main source of condensed phosphate, and no local sources exist that would increase the atmospheric load. The pH remains relatively constant because two compensating factors act to change it. Soil particles loaded to the sample are basic and carbon dioxide absorption from the atmosphere is an acidification process, so the two tend to balance each other.

Chlorides and filtered total phosphate are significantly different in an unexpected way. The limited data set contributes to this problem. Both constituents have one high sample that raises the average significantly, although removal of this sample still does not give a dry-deposition mean higher than a test-sample mean. The chloride appears to be due to contamination, probably in the washing process when hydrochloric acid was used. The filtered total phosphate does not appear to be due to filtered orthophosphate or condensed phosphate because both have larger means after exposure. This would imply an organic contamination source.

CHAPTER 4. RESULTS.

4.1 Total Atmospheric Flux.

The fundamental objective of this thesis was to establish the best estimates of atmospheric deposition of nutrients in central Alberta for the period May 1975-April 1976. The results were extrapolated in an attempt to estimate the average rate of deposition on an annual basis, and during the periods of snow-cover and no snow-cover. The rates of deposition were also broken down into wet- and dry-deposition fluxes. The total atmospheric deposition was broken down into four general classes (snow, liquid precipitation, snow-cover dry deposition, and non-snow-cover dry deposition) on the basis of the processes involved. There was one hail sample included in the liquid precipitation set.

Table 4.1 lists the raw-data means and t-test comparisons as calculated before, for snow versus non-snow and for showers versus rain. It is difficult to draw many conclusions from these results. In general, it appears that convective showers are more efficient scavengers than synoptic rain storms. The snow-rain means compare well with the Alberta work mentioned before, but the phosphate concentrations are puzzling. No phosphate sources have been

Table 4.1 Average wet-deposition concentrations ($mg\ell^{-1}$)

Constituent	Snow	Liquid	T-test comparison	Liquid precipitation rain	Liquid precipitation shower	T-test comparison
Total phosphate	0.236	0.173	0.025	0.160	0.189	>.40
Orthophosphate	0.026	0.048	0.250	0.043	0.053	>.40
Condensed phosphate	0.110	0.070	0.250	0.062	0.078	0.25
Organic phosphate	0.104	0.061	0.40	0.058	0.063	>.40
Total kjeldahl nitrogen	0.259	0.628	0.10	0.421	0.879	0.01
Ammonia nitrogen	0.159	0.373	0.25	0.21	0.552	0.025
Organic nitrogen	0.105	0.292	>.40	0.211	0.329	0.10
Nitrate nitrogen	0.216	0.138	0.005	0.099	0.181	0.025
Nitrite nitrogen	0.003	0.002	0.05	0.002	0.002	>.40
Silica ion	0.216	0.924	0.005	0.949	0.894	0.25
Iron ion	0.100	0.233	0.025	0.144	0.342	0.0005
Chloride ion	2.47	2.30	0.25	2.29	2.32	0.25
Sulfate ion	0.625	2.750	0.005	1.32	4.63	0.0005
Sodium ion	0.262	0.265	0.40	0.336	0.181	0.25
Potassium ion	0.612	0.617	0.10	0.564	0.681	0.25
Hardness as calcium	0.0	0.333	0.40	0.0	0.700	0.10
Total hardness	10.6	3.60	0.10	22.3	25.1	0.25
pH (log of H^+ ion conc.)	5.95	5.12	0.005	5.39	4.81	0.005
Conductivity (μ mhoscm^{-1})	7.73	18.13	0.01	11.63	25.9	0.0005
Total residue	18.0	21.1	0.05	20.4	21.8	>.40
Filtered samples						
Total phosphate	0.191	0.139	0.10	0.127	0.153	0.40
Orthophosphate	0.005	0.033	0.40	0.034	0.032	0.25
Condensed phosphate	0.101	0.062	0.40	0.047	0.078	0.025
Organic phosphate	0.090	0.062	0.25	0.054	0.072	0.40
Total kjeldahl nitrogen	0.179	0.480	0.10	0.280	0.735	0.005
Total residue	9.77	9.92	0.25	8.97	11.2	0.40

found to explain a winter maximum.

Dry-deposition rates should be different in the winter than in the summer for two reasons. Gaseous absorption is slower in cold weather and local sources of dust, e.g., cultivation, construction and traffic on dirt roads, are reduced in the winter.

Table 4.2 shows the distribution of the particulates in this sampling program. Particulate is defined as that portion of the total removed by filtration through a 0.45μm membrane filter. Several of the results are probably not significant because of the small sample size. It is important to note that both dry-deposition categories have higher particulate precentages than the corresponding precipitation categories for all constituents. This is expected because the particulate proportion of dry deposition is relatively more important than that of precipitation.

The different forms of phosphate and nitrogen are indicators of the portion of the total that is available for use by organisms (Table 4.3) Orthophosphate is the most important phosphate form, and ammonia nitrogen is the most important kjeldahl nitrogen form. More orthophosphate was found in the summer precipitation than in snow but the opposite was true for nitrogen. There was more organic phosphate and ammonia nitrogen in the dry-deposition samples because of contamination by organic material.

Table 4.2 Distribution of particulates.

Sample type		Total phosphate	Ortho phosphate	Condensed phosphate	Organic phosphate	Kjeldahl nitrogen	Total residue
Liquid precipitation	Number of samples	33	27	26	16	33	28
	Percentage particulates	19.8	18.8	19.3	39.4	23.9	48.3
Snow	Number of samples	7	5	5	4	4	6
	Percentage particulates	19.8	0.0	16.7	53.9	18.5	49.7
Summer dry deposition	Number of samples	7	8	3	1	10	1
	Percentage particulates	43.0	61.9	54.4	100.0	42.8	80.0
Winter bulk deposition	Number of samples	1	5	1	0	5	2
	Percentage particulates	91.4	81.7	87.0	?	48.3	52.3

Table 4.3 Distribution of phosphate and nitrogen forms.

		Phosphate			Nitrogen	
		Total as ortho phosphate	Total as acid phosphate	Total as organic phosphate	Total as ammonia nitrogen	Total as organic nitrogen
Liquid precipitation	Number of samples	19	19	19	38	38
	Percentage	37.8	25.9	36.3	52.7	47.3
Snow	Number of samples	2	2	2	6	6
	Percentage	21.7	29.8	48.5	62.2	37.8
Summer dry deposition	Number of samples	5	5	5	14	14
	Percentage	37.6	21.6	40.8	28.8	71.2

The concentrations of the various constituents in precipitation were converted to fluxes using meteorological data from climatological stations surrounding the moraine

Table 4.4a Meteorological summaries May 1975-April 1976. (After Atmospheric Environment Service, 1975b, 1975c)

Month	Hours of precip.	Hours of dry deposition	Total precipitation rain (mm)	snow (w.eq.) (mm)
May 1975[1]	107.4	636.6	44.5	0.0
June 1975[1]	106.4	613.6	95.8	0.0
July 1975[2]	65.5	678.5	46.2	0.0
Aug. 1975[1]	96.5	647.5	134.1	0.0
Sept. 1975[1]	31.7	688.3	8.3	0.0
Oct. 1975[1]	69.5	674.5	9.0	10.1
Nov. 1975[2]	120.0	600.0	T	6.2
Dec. 1975[2]	221.5	522.5	1.0	35.4
Jan. 1976[3]	138.0	606.0	T	13.3
Feb. 1976[3]	163.1	532.9	T	20.5
Mar. 1976[3]	86.5	657.5	T	11.9
Apr. 1976[4]	50.0	670.0	7.7	4.8
Totals	1256.1	7527.9	346.6	102.2

[1] Stations at Nisku, Ellerslie, Edmonton, Namao, Woodbend and Tofield used.

[2] Stations at Nisku, Ellerslie, Edmonton, Namao and Woodbend used.

[3] Stations at Nisku, Edmonton and Namao used.

[4] Station at Nisku used.

(Table 4.4a and Table 4.4b). The estimates D_w (mgm^{-2}) of total wet deposition were obtained for the summer and winter months from

$$D_w = C_w P, \tag{4.1}$$

where C_w is the average measured concentration (mgℓ$^{-1}$) in

Table 4.4b Meteorological summaries May 1975-April 1976.

Continuous snow cover
21 Nov. 1975-9 Apr. 1976

Total time	3384 hours.
Precipitation time	726.3 hours
Dry deposition time	2657.7 hours
Total snow (water eq.)	87.3mm
Total rain	1.0mm

Non-permanent snow cover

1 May 1975-21 Nov. 1975, 10 Apr. 1976-30 Apr. 1976.

Total time	5400 hours
Precipitation time	529.8 hours
Dry deposition time	4870.2 hours
Total snow (water eq.)	14.7mm
Total rain	344.6

Annual precipitation

1 May 1975-30 Apr. 1976	447.6mm
Long-term normal	473.5mm

the rain or snow samples and P (mm) is the total precipitation (snow expressed as water equivalent) for both periods.

The estimates D_D (mgm^{-2}) of the dry deposition on a snow-free surface were calculated using

$$D_D = \frac{C_D V_P T}{A_P T_S} \qquad (4.2)$$

In this equation C_D is the average measured concentration ($mg\ell^{-1}$) in the dry-deposition samples, V_P is the average volume of water in the collection pan (ℓ), T is the time (hours) without precipitation occuring at Edmonton International Airport (Nisku), A_P is the surface area of the sample water exposed (m^2), and T_S is the average pan sampling time (hours).

The dry-deposition concentrations were calculated by subtracting the concentration of a test sample from the concentration of the water after exposure. The concentrating effect of evaporation is compensated for by using the average rather than the final collection sample volume. The closest first-order weather reporting station was used to determine the length of time of precipitation (Atmospheric Environment Service, 1975c). This was subtracted from the total to determine the dry-deposition time for the snow-free period.

The winter bulk deposition D_S (mgm^{-2}) was calculated using

$$D_S = \frac{C_S V_C T}{A_S T_S} \qquad (4.3)$$

C_S is the concentration ($mg\,\ell^{-1}$) in the snow sample collected from the ground, V_C is the average volume of snow collected (ℓ) as water equivalent, T is the length of time of "permanent" snow cover (hours), A_S is the average surface area (m^2) over which the sample was collected and T_S is the average sampling time (hours). The winter-dry deposition samples can be divided into two types: bulk and non-mixed. The bulk samples include wet and dry deposition. The average concentration in fresh snow was subtracted from the bulk snow samples to get the concentration change due to dry deposition. Two samples were taken of snow previously sampled as fresh snow with no intervening precipitation.

Both methods gave very small fluxes and could be used together when calculating the total flux.

Table 4.5 lists the total atmospheric fluxes for the sampling period. No attempt was made in this table to correct for the organic material contamination. Such corrections are shown in Section 4.2. The large dry-deposition percentages are due to several factors. Total annual precipitation in central Alberta is approximately

Table 4.5 Total atmospheric flux May 1,1975 to April 30,1976.
(All concentrations are in $mg\ell^{-1}$ unless otherwise noted.)

Constituents	Total aeolian flux (mgm^{-2})	No permanent snow cover wet %	No permanent snow cover dry %	permanent snow cover wet %	permanent snow cover dry %
Total phosphate	456	17.0	77.4	5.4	0.2
Orthophosphate	191	11.2	87.3	1.4	0.1
Condensed phosphate	193	16.1	77.7	6.0	0.2
Organic phosphate	238	11.5	84.0	4.5	0.0
Total kjeldahl nitrogen	1291	21.8	75.9	2.1	0.2
Ammonia nitrogen	544	30.7	66.2	3.0	0.1
Organic nitrogen	983	13.3	85.4	1.1	0.2
Nitrate nitrogen	134	46.0	37.2	16.8	0.0
Nitrite nitrogen	5	18.3	81.3	0.0	0.4
Silica ion	718	57.6	39.0	3.1	0.3
Iron ion	266	39.1	56.4	3.9	0.6
Chloride ion	2933	35.1	55.9	8.8	0.2
Sulfate ion	4895	25.1	72.7	1.4	0.8
Sodium ion	287	41.5	45.3	9.5	3.7
Potassium ion	627	44.0	44.7	10.2	1.1
Filtered constituents					
Total phosphate	262	23.8	68.6	7.6	0.0
Orthophosphate	85	17.2	82.4	0.4	0.0
Condensed phosphate	118	23.4	67.6	9.0	0.0
Organic phosphate	137	20.3	73.0	6.7	0.0
Total kjeldahl nitrogen	595	36.1	60.5	3.1	0.3

500mm and part of the total (~⅓) comes from localized convective storms. The total ~~dry~~-deposition loading decreases with an increase in total precipitation and areal extent of the precipitation. Intensive agriculture increases the dry-deposition rate by disturbing soil which entrains particulates (Uttomark et al., 1972). This increases the regional dry-deposition rate.

Dry-to-wet deposition ratios for different areas are compared to the Hastings Lake ratios in Table 4.6. The

Table 4.6 Ratio of dry-to-wet deposition annual fluxes.

Constituent	1	2	3	4	5	6
Sodium ion	0.89	0.33				0.96
Potassium ion	0.89	1.61				0.84
Ammonia nitrogen			1.45			1.97
Nitrate nitrogen			1.08			0.59
Organic nitrogen			4.23			5.96
Total phosphate			3.44			3.46
Sulfate ion				0.82	2.75	2.78
Iron ion				0.50	2.50	1.33
Total precipitation	1872mm	1038mm	766mm			448mm

1. Fayetteville, Arkansas. (Wagner and Holloway, 1975)
2. St. Louis, Missouri. (Huff,1975)
3. Madison, Wisconsin. (Kluesner,1972)
4. Low pollution, Great Lakes. (Whelpdale,1974)
5. High pollution, Great lakes. (Whelpdale,1974)
6. Hastings Lake

ratios were calculated by dividing the dry-deposition flux by the wet-deposition flux. The dry-deposition fluxes used in Table 4.6 were all determined in different ways. Kluesner (1972) measured the dry-deposition flux in the same way as was done in this project. Wagner and Holloway (1975) extrapolated measured monthly fluxes versus rainfall data back to zero rainfall per month. Huff (1975) calculated the amount of dry deposition in bulk samples collected by using measured wet-to-dry deposition ratios. Whelpdale (1974) derived the dry-deposition flux by using a bulk-transfer equation for the gaseous absorption process. An exponential-decay equation was used to calculate the particulate loadings. It is interesting to note that none of these studies mentioned a correction factor for contamination.

For the same length and amount of precipitation, the ratio should decrease for ions on small particles. As the precipitation amount and length decreases, these ratios should increase. Good agreement was found especially between the measured rates in columns 3 and 6. Sodium and potassium ratios in columns 1 and 6 were roughly 1 to 1. The large difference between the sodium and potassium ratios of column 2 and those of columns 1 and 6 is suspect because sodium is usually associated with potassium away from the coast (Junge and Werby, 1958).

4.2 Variations in the Results.

The estimates of total fluxes are dependent upon the variables involved in the calculations. According to (4.1), wet deposition varies with the mean sample concentration and the amount of precipitation. Dry deposition (4.2) is a function of the sample concentration, the hours without precipitation, and the average sample volume. Although the area of the sample exposed and the average pan sampling time affect the fluxes, neither should vary as much as the others, e.g., the maximum water area and the minimum water area differ only by 25%.

The major flux variations are due to changes in the concentration caused by source changes and diffusion. The relative importance of wet and dry deposition is a function of the amount and length of precipitation. These variations were examined by substituting different values for the amount of precipitation and dry-deposition time into the flux equations (Table 4.7)

The maximum and minimum values were taken from a graph of ten-year running average precipitation in the South Saskatchewan River basin (Longley, 1972). The long-term normal data was for the Edmonton Industrial Airport (Atmospheric Environment Service, 1975a). The normal value calculated for the summer dry deposition was determined by a simple proportionality, i.e., it was assumed that the hours of precipitation were directly proportional to the number of

Table 4.7 Effect of precipitation climatolcgy on total annual nutrient loading.

Concentrations

	Total P ($mg\ell^{-1}$)	Total N ($mg\ell^{-1}$)
Liquid wet deposition	0.056	0.768
Snow wet deposition	0.077	0.478
No snow cover dry deposition	0.054	0.679
Snow cover dry deposition	0.057	0.880

Fluxes

Wet deposition	Snow (mm)	Total P (mgm^{-2})	Total N (mgm^{-2})	Liquid (mm)	Total P (mgm^{-2})	Total N (mgm^{-2})
May 1975- Apr. 1976	102.2	7.9	48.9	346.6	19.4	266.2
Long-term normal	122.0	9.4	58.3	324.5	18.2	249.2
Maximum	134.6	10.4	64.3	403.9	22.6	310.2
Minimum	78.7	6.1	37.6	236.2	13.2	181.4

Summer dry deposition	(V_P) (ℓ)	(A_P) (m^2)	(T_S) (hrs)	(T) (hrs)	Total P (mgm^{-2})	Total N (mgm^{-2})
May 1975-Apr. 1976	3.3	0.094	69.8	4870.2	132.3	1663.0
Long-term normal	3.3	0.094	69.8	4631.0	125.7	1581.7
Maximum	3.3	0.094	69.8	5160.0	140.2	1762.3
Minimum	3.3	0.094	69.8	2580.0	70.1	881.3

Winter dry deposition	(V_c) (ℓ)	(A_s) (m^2)	(T_S) (hrs)	(T) (hrs)	Total P (mgm^{-2})	Total N (mgm^{-2})
May 1975-Apr. 1976	2.6	1.0	1613	2657.7	0.24	3.7
Long-term normal	2.6	1.0	1613	2628.0	0.24	3.7
Maximum	2.6	1.0	1613	3000.0	0.2[illegible]	4.2
Minimum	2.6	1.0	1613	2000.0	0.18	2.8

days of precipitation.

An experimental error casts some doubt on the validity of the winter dry-deposition fluxes. The average surface area (A_S) sampled was estimated, not accurately measured and this area is vital to the flux (mass per unit area and unit time). Fortunately, the winter flux was so small that even an estimation error of 100% has little effect on the total annual flux.

The total atmospheric fluxes measured for 1975-1976 and the estimated mean annual fluxes are roughly equal. Table 4.8 compares the atmospheric loading of nitrogen and phosphorus with Vollenweider's (1968) permissible and dangerous loadings. The results show that the atmospheric contribution is significant. Its relative importance in relation to other sources will be examined later.

The precipitation concentrations are high but are not outside the ranges reported by Gorham (1975) and Sanders (1972). The dry-deposition results are comparable to work in Wisconsin (Kluesner, 1972). The Atmospheric Environment Service of Canada has two WMO Background Air Pollution Monitoring Network stations located in the Prairie Provinces. Both sites (Edson, Alberta and Wynyard, Saskatchewan) use a modified Wong ARC Mark V automatic collector to sample wet deposition. The samples are collected once a month and analyzed for some of the same constituents as in this program.

Table 4.8 Nutrient loadings and thresholds.

No permanent snow cover
1 May 1970-20 Nov. 1975 and 9 Apr. 1976-30 Apr. 1976

	Total P $(gm^{-2}yr^{-1})$	Total N $(gm^{-2}yr^{-1})$
Dry deposition	0.132	1.663
Wet deposition	0.019	0.266

Permanent snow cover
21 Nov. 1975-9 Apr. 1976

	Total P $(gm^{-2}yr^{-1})$	Total N $(gm^{-2}yr^{-1})$
Dry deposition	0.00	0.004
Wet deposition	0.008	0.049

	Total P $(gm^{-2}yr^{-1})$	Total N $(gm^{-2}yr^{-1})$
Total	0.159	1.982

Vollenweider's (1968) threshold levels (lake mean depth to 5m)

	Total P $(gm^{-2}yr^{-1})$	Total N $(gm^{-2}yr^{-1})$
Permissible	0.070	1.0
Dangerous	0.130	2.0

The WMO data and data from this thesis are quite comparable except for the chloride and nitrate ions (Table 4.9). The high nitrate average for Wynyard is a result of one month's high concentration. It is reasonable to assume that it was caused by local contamination. The Wynyard average nitrate concentration without the high sample is 0.7 $mg\ell^{-1}$. The chloride average for Hastings Lake is also high. It is possible that the HCl used for cleaning the collecting surfaces and the sample bottles was not completely removed.

The chloride ion average is reduced to 2.11 $mg\ell^{-1}$

Table 4.9 Wet deposition averages June 1975-Sept.1975. (All concentrations are in $mg\ell^{-1}$ unless otherwise noted.)

Constituents	Edson	Wynyard	Hastings Lake	Average Edson & Wynyard
Ammonia nitrogen	0.68	0.53	0.39	0.60
Nitrate nitrogen	0.38	2.60	0.14	1.49
Chloride ion	0.42	0.60	2.46	0.51
Sulfate ion	2.92	3.12	2.91	3.02
Sodium ion	0.45	0.42	0.16	0.44
Potassium ion	0.57	0.62	0.46	0.59
pH (H^+ ion conc.)	6.32	7.09	4.81	6.70
conductivity (μmhoscm^{-1})	15.8	25.2	19.7	20.5

from 2.46 $mg\ell^{-1}$ if four samples that were greater than 2 standard deviations from the mean are removed (27, 28, 40, 54; Table C-3). A t-test was used to compare the mean of the original set without the four samples included and the mean of the four deleted variables. The chloride ion means in the two samples were not from the same population at the .0005 significance level. This means that there is a significant difference in the two sets, probably caused by contamination.

The pH of rainwater in equilibrium with atmospheric carbon dioxide is 5.7 (Gorham, 1975). The difference in the pH of the WMO samples and the average pH in this study is mostly likely due to differences in the sampling procedures. The WMO samples were collected with the Wong sampler which does not make a tight seal with the sample container (Berry et al., 1975). The higher earth cation concentrations (Na^+ and K^+) indicates that this loose seal allowed dry-deposition contamination. The higher concentrations of these cations may have raised the pH. The low average pH in the present study was influenced by the high chloride concentrations, but the difference of the pH means between the four contaminated samples mentioned previously and the original set of four was not significant at the 0.10 level. This shows that the chloride ion concentration is not the main cause of the low pH.

Previous investigations have found relationships between the ionic composition of precipitation and the type of air mass, the season, the time interval between showers, the type of precipitation, the trajectory of the air mass, and the strength of the wind. Twelve different variables were chosen to examine the effects of the meteorological situation on the concentration of the samples. Appendix B lists all the results of these tests.

The linear correlation coefficient was used because it is a non-dimensional measure of the association between two variables (Panofsky and Brier, 1958). If the correlation between the two variables is perfect the coefficient is one. When the correlation coefficient is minus one, a perfect negative correlation exists, and if it is equal to zero, no linear relationship exists between the variables. The linear correlation coefficient may indicate that there is a relationship between two variables, but this variation may exist because of the influence of a third variable.

The results of the nitrogen constituents and the correlation variables listed in Table B-1 were chosen for closer scrutiny because of the possibility of a relationship between lightning and the production of nitrate (Table 4.10). The t-test comparison of the nitrate ion in rain and in showers compared storms with lightning (showers) and without (rain). Nitrate means in the two samples were different (P<0.025). If this is a result of lightning, we would expect that the lightning variable (2) would be significantly correlated with the nitrate concentration.

Table 4.10 Significant correlation coefficients between selected variables and nitrogen concentrations.

Constituents	Mean concentration $(mg\ell^{-1})$ Shower	Rain	Significant correlations Showers	Rain
Total kjeldahl nitrogen	0.88	0.42	12,8	
Filtered total kjeldahl nitrogen	0.73	0.28	12,8	-5,12[1]
Ammonia nitrogen	0.55	0.21	12,8	
Organic nitrogen	0.39	0.21	-2,-9,12[1]	
Nitrate nitrogen	0.18	0.10	12,-4,3,8[1]	
Nitrite nitrogen	.002	.002	6	12,-9,-5[1]

Number	Parameter	Scale maximum
2	Associated lightning	intense
3	Collection site	urban
4	Storm trajectory	rural
5	Wind direction	rural
6	Sampling date	late in season
8	Contamination	dirty
9	Surface wind strength	$20ms^{-1}$
12	Time since last precipitation	170hrs.

[1] Negative numbers imply a negative correlation coefficient.

This was not the case for rain or showers. Instead the nitrate concentration in showers was correlated significantly with an urban effect, (the more urban the location and trajectory of a shower, the higher the nitrate concentration), contamination, and the time since the last precipitation. These results imply that a storm passing over the city after a long dry spell will be high in nitrate. In general, the nitrogen constituents were correlated significantly with the length of time since the last significant precipitation, and with the contamination variable. This indicates that the nitrogen constituents are associated with particulates that are easily washed out and are associated with dry-deposition contamination.

4.3 Nutrient Budget.

The atmospheric deposition fluxes determined in this study can be used in a nutrient budget for Hastings Lake. Budgets have been calculated in two ways in the past. The first method uses nutrient-export fluxes for each source of nutrients within the basin. The other method uses a mass balance to calculate the total annual nutrient load. Neither method is ideal, but both can give rough estimates of the comparative importance of each source within the basin.

The nutrient-export flux method requires a breakdown of the area encompassed by each land-use type within the basin, an export-flux value for each of these land-use types, and values for the lake area, discharge in and out of the lake, and the population within the basin (Patalas and Salki, 1973). Multiplying the area in the basin of each land-use type by the export flux gives the mass of each nutrient added to the lake. A per-capita correction is added for human population within the basin (Vollenweider and Dillon, 1974). The budget is found by summing each source and subtracting each sink.

This method has not been used in a water-deficit region like central Alberta. The use of nutrient-export fluxes from more humid areas is not recommended because there are such great differences in the amounts of runoff. For example, the nutrient-export flux from the same type of land-use and soil-type plots will not be the same if the runoff from one is half the runoff of the other.

The mass-balance method allows for variations in the transporting medium. This method has been used in a small drainage area with limited sources (Schindler and Nighswander, 1970), but, with minor modifications, should be usable here. A water balance is calculated for the lake using:

$$L = P + R + S - E - Q \qquad (4.4)$$

In this equation, P is the precipitation, R is the surface runoff, S is the groundwater seepage, E is the evaporation, Q is the discharge, and L is the lake-level change. The incident volumes of water added to the lake multiplied by the concentrations, either measured or assumed, give the nutrient mass going into the lake. The balance is determined after the sinks are subtracted.

The Thornthwaite and Mather (1957) procedure used by Laycock (1968) in central Alberta was used to estimate the water balance of Hastings Lake (Table 4.11). This method estimates the volume entering the lake and leaving the lake based on climatic and land-use data. It has limitations here because the total runoff is calculated from monthly data. For example, precipitation associated with a summer storm could cause runoff into the lake, but because precipitation and evapotranspiration are averaged over a monthly time period, this procedure would not show that.

The drainage-basin boundaries are hard to define. In periods of high water, Cooking and Hastings Lake are connected by streams, but this is not the case today. In the period May 1975-April 1976, there were no permanent streams in or out of Hastings Lake, although there was a brief flow during the spring runoff (D. Potter, personal communication). The calculations for this budget have assumed that during the sampling period and the long-term-normal period used in the tables, streamflow was negligible and that the only sink was groundwater flow. This was given a value equal to five percent of the the total groundwater

Table 4.11 Hastings Lake water balance.

Land-use type	Map symbol	Area (km²)	% area	Storage level	1975	1972-1975	Long-term normal
Lake basin	(W)	7.8	12.8		$3.49 \times 10^6 m^3$	$4.06 \times 10^6 m^3$	$3.65 \times 10^6 m^3$
Forest	(F)	29.8	48.9	10in.	0.0	$0.53 \times 10^6 m^3$	0.0
Cultivated	(C)	7.8	12.8	4in.	0.0	$0.44 \times 10^6 m^3$	$0.01 \times 10^6 m^3$
Pasture	(P)	15.5	25.5	6in.	0.0	$0.67 \times 10^6 m^3$	0.0
Total		60.9			$3.49 \times 10^6 m^3$	$5.70 \times 10^6 m^3$	$3.66 \times 10^6 m^3$
Evaporation from lake surface					$3.54 \times 10^6 m^3$	$3.79 \times 10^6 m^3$	$3.95 \times 10^6 m^3$
Change in lake volume					$0.05 \times 10^6 m^3$	$1.91 \times 10^6 m^3$	$0.29 \times 10^6 m^3$

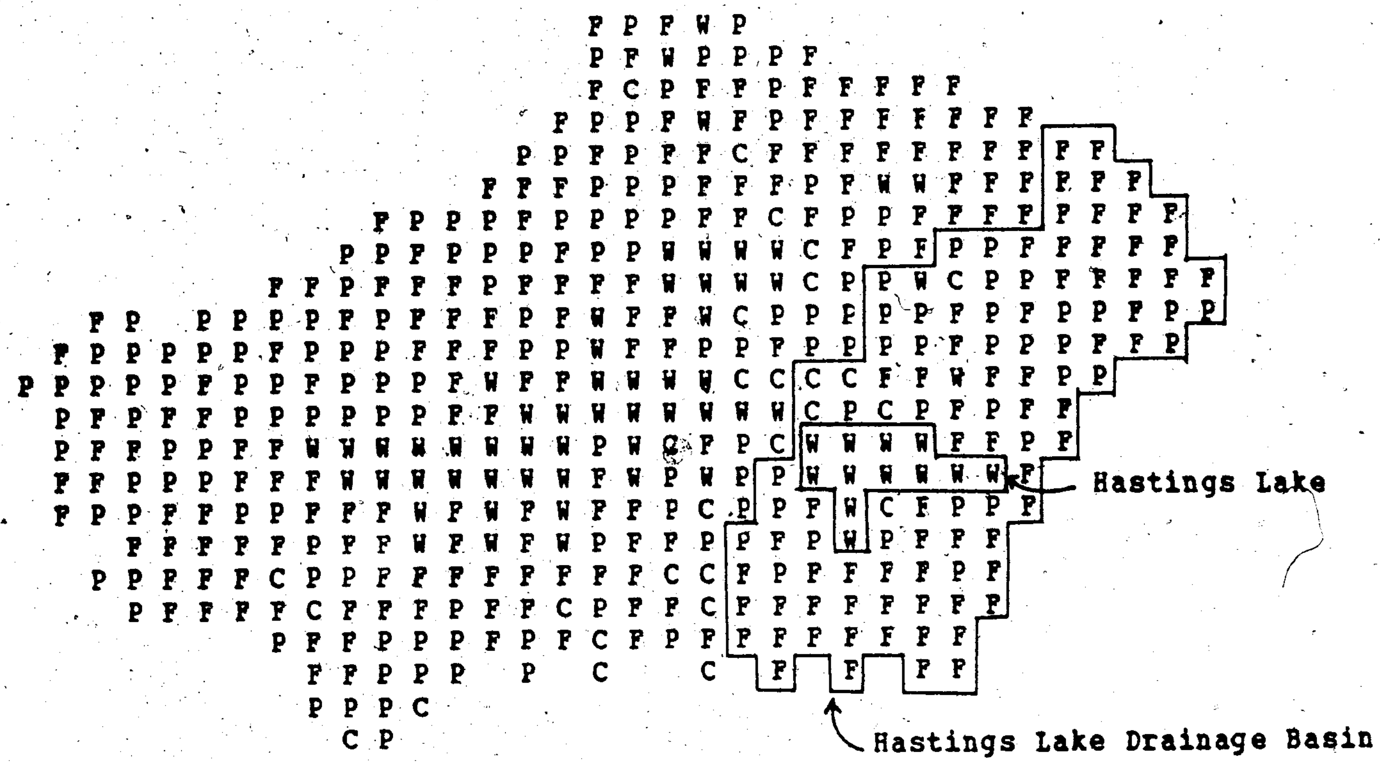
flow because the outlet area is five percent of the total. It was assumed that all the surplus water in the 1972-1975 period left the lake as stream flow although the lake level rose during the period.

The different land-use areas were estimated from the land-use map (Figure 4.1) which was based on air photos taken in 1972. The lake data were calculated by Kerekes (1965) and modified slightly to match the physical data (Table 4.12). Climatic data for the International Airport (Nisku) were used for the Thornthwaite tables (R. Winterburn, unpublished data). Fifty-five percent of the total water volume available enters Hastings Lake as runoff and the other forty-five percent enters as ground water (F. Schwartz, personal communication). For the purposes of this study streamflow in and discharge out were considered negligible.

Table 4.12 Hastings Lake physical data.

	(Kerekes, 1965)	This study
Drainage basin	----	60.9km²
Lake surface area	8.71km²	7.77km²
Maximum depth	7.9m	---
Mean depth	3.03m	---
Volume	$26.4 \times 10^6 m^3$	$23.6 \times 10^6 m^3$

The atmospheric fluxes calculated in Section 4.3 were used in the budget. Total phosphorus concentrations were available for the groundwater (F. Schwartz, unpublished data) and the lake itself (D. Gallup, unpublished data).



Key for Land-Use Map.

F........Quarter section predominantly forest
P........Quarter section predominantly pasture land
C........Quarter section predominantly cultivated land
W........Quarter section predominantly water

Figure 4.1 Hastings Lake land-use.

As a gross approximation, a total phosphorus loading of $0.077 gm^{-2}yr^{-1}$ for surface runoff from an agricultural watershed and a groundwater loading of $0.033\ gm^{-2}yr^{-1}$ (Uttomark et al., 1974), were used to estimate the surface-runoff to groundwater-seepage concentration ratio. For the purposes of this budget, the groundwater concentration was assumed to be 40% of the surface runoff concentration. The sink terms were calculated using the measured concentration of Hastings Lake in the spring for the streamflow out and 40% of that figure for the groundwater-seepage concentration.

Table 4.13 lists the total phosphorus budget of Hastings Lake calculated using the water-balance method. Also included are two steady-state calculations that assume there was no waterlevel change in 1975 or over the long-term. Both water balances calculated for these time periods showed a water deficit. This was compensated for by a runoff and seepage volume large enough to reduce the deficit to zero.

The atmospheric load is relatively constant, but the total load is dependent upon the volume of water available in the spring. If the spring runoff is large, then the total load reflects this with a higher value. There is a limit to this effect, though. Eventually, the runoff will fill the basin and there will be discharge from the lake. This dampens the effect of extremely high spring runoffs.

Table 4.13 Water-balance budget for total phosphorus in Hastings Lake.

	Sources			Sinks			
	Groundwater seepage	Surface runoff	Atmospheric	Groundwater seepage	Surface discharge	Atmospheric	Total mass
Non-steady-state balance							
1975							
Concentration Total-P (mgl-1)	0.56	1.40		0.26	0.64		
Volume ($10^6 m^3$)	0.0	0.0		0.0	0.0		
Mass ($kgyr^{-1}$)	0.0	0.0	1240	0.0	0.0	0.0	+1240
1972-1975							
Concentration Total-P (mgl-1)	0.56	1.40		0.26	0.64		
Volume ($10^6 m^3$)	0.74	0.90		0.037	1.91		
Mass ($kgyr^{-1}$)	414	1260	1092	10	1222	0.0	+1534
Long-term normal							
Concentration Total-P (mgl-1)	0.56	1.40		0.26	0.64		
Volume ($10^6 m^3$)	0.045	0.055		0.003	0.00		
Mass ($kgyr^{-1}$)	25	77	1201	1	0.0	0.0	+1302
Steady-state assumption							
1975							
Concentration Total-P (mgl-1)	0.56	1.40		0.26	0.64		
Volume ($10^6 m^3$)	0.022	0.028		0.001	0.0		
Mass ($kgyr^{-1}$)	12	39	1240	0.0	0.0	0.0	+1291
Long-term normal							
Concentration Total-P (mgl-1)	0.56	1.40		0.26	0.64		
Volume ($10^6 m^3$)	0.130	0.160		0.006	0.0		
Mass ($kgyr^{-1}$)	73	224	1201	2	0.0	0.0	+1496

The la a physical transport mechanism, i.e., stream flow out of the lake, implies that the organic cycle within the lake is the major total phosphorus sink.

The nutrient-export flux method was also used to calculate two budgets (Table 4.14). The procedure

Table 4.14 Nutrient-export flux total phosphorus budget for Hastings Lake.

Patalas and Salki (1973) method

Area of lake (A_o)	$7.8 \times 10^6 m^2$
Area of lake drainage basin (A_d)	$60.9 \times 10^6 m^2$
Ratio of basin to lake (A_d/A_o)	7.8
Mean depth	3.03m
Volume	$23.6 \times 10^6 m^3$
Discharge	0
Basin population (C)	1000
Export of phosphorus from soil (E_s)	$0.01 gm^{-2}$
Per-capita discharge of phosphorus (E_c)	$1700\ gyr^{-1}$
Phosphorus load from soil	$0.078 gm^{-2} yr^{-1}$
Human loading	$0.218 gm^{-2} yr^{-1}$
Atmospheric	$0.159 gm^{-2} yr^{-1}$
Total	$0.0455\ gm^{-2}$
Annual total to lake	3549 kg
Annual total from lake	0 kg

Uttomark et al. (1974) method

	Flux $gm^{-2} yr^{-1}$	Area $10^6 m^2$	Mass (kg)
Agricultural land	0.03	23.3	699
Forest land	0.02	29.8	596
Groundwater	0.03	7.8	234
Atmospheric	0.16	7.8	1248
Annual total to lake			2777
Annual total from lake			0

recommended by Vollenweider (1968) and the nutrient-export fluxes used by Patalas and Salki (1973) were used with minor modification (an atmospheric-flux term was added and the streamflow term was subtracted). The formula for total phosphorus (g) into the lake (L_p) can be written as:

$$L_p = \frac{E_s A_d}{A_o} + \frac{E_c C}{A_o} + D_A A_o \qquad (4.5)$$

where E_S is the export of phosphorus (gm^{-2} of drainage basin yr^{-1}), A_d is the area of the drainage basin (m^2), A_o is the area of the lake (m^2), E_c is the per-capita discharge of phosphorus to the lake (g), C is the basin population, and D_A is the total atmospheric deposition rate ($gm^{-2}yr^{-1}$). The total flux calculated is larger than any calculated using the balance method and comparable only to the 1972-1975 flux. The second budget assigned fluxes to each land-use type within the basin, following Uttomark et al., (1974). The export fluxes shown in Figure 1.1 were used except for the atmospheric flux. The sources in this budget are approximately equal to the 1972-1975 water-balance budget. Both nutrient-export flux methods use the streamflow out as the sink term. The fluxes calculated remain constant for a given basin as long as the land-use within the basin does not change. This assumes that the runoff and groundwater flow are constants. Note that the best agreement between the flux- and balance-methods occurs for years with appreciable runoff.

The atmospheric contribution to the total nutrient budget is listed for seven different budgets (Table 4.15). This table demonstrates that the atmospheric contribution is

Table 4.15 Relative atmospheric contributions to the total phosphorus budget.

Method	Time period	Atmospheric (%)	Total (kgyr^{-1})
Nutrient-export flux[1]	1975	35	3549
Nutrient-export flux[2]	1975	45	2777
Water balance	1975	100	1240
Water balance	1972-1975	39	2766
Water balance	L-T-N[3]	92	1303
Steady-state balance	1975	96	1291
Steady-state balance	L-T-N[3]	80	1498

[1] Patalas and Salki (1973) method.
[2] Uttomark et al. (1974) method.
[3] Long-term normal.

significant. It is reasonable to assume that at least half the total phosphorus load in Hastings Lake is from the atmosphere. This proportion varies with the amount of runoff. There is also some indication that the choice of nutrient-export flux coefficients should reflect the inadequate transport mechanisms in dry regions.

CHAPTER 5. CONCLUSIONS.

5.1 Atmospheric Nutrient Loading in Central Alberta.

The wet- and dry-deposition values measured in this study are an important part of the total nutrient flux into Hastings Lake. The atmospheric contribution is over half the total. This proportion varies with the amount of spring runoff, which in turn is related to the amount of precipitation.

The atmospheric total phosphorus loading exceeded Vollenweider's (1968) threshold for dangerous loading and the total nitrogen approached the same level. This implies that water treatment of anthropogenic sources in the basin will not be sufficient alone to reduce the nutrient loading to non-critical levels. The large values appear to be caused by man. Agriculture was thought to be the cause of similar high concentrations in the midwestern United States (Junge and Werby, 1958) and in western Ontario (Kerekes, 1973). Fertilization probably contributes to the problem, but it is not the main factor (J. Robertson, personal communication). Therefore, it seems likely that cultivation entrains particulates into the atmosphere, increasing the atmospheric deposition rates.

The atmospheric contribution has been shown to be significant when the lake occupies a large proportion of the drainage basin (Murphy and Dosky, 1975). These results show that the effective catch area of the basin is important in water-deficit regions, because nutrients can only be exported when there is water available to transport them. The atmospheric contribution increases in importance as the total water volume into the lake decreases.

The nutrient-export flux coefficents chosen must reflect the inadequate transport mechanisms in central Alberta. The water-balance method used approximates nutrient-transport mechanisms. It indicates that the [illegible] runoff and groundwater flow to Hastings Lake is small and concentrated during spring runoff. Therefore, the atmospheric contribution is important because most of the time it is the only effective contribution.

The precipitation patterns during the sampling period were approximately equal to the long-term normal patterns. Therefore, it is not expected that the total atmospheric deposition should vary much due to this factor. There is no way to check the actual measured fluxes to see if they are 'normal' without more sampling. This should be kept in mind if these data are used elsewhere.

5.2 Dry Deposition.

Dry deposition is an important loading process in central Alberta. It was a significant factor in the total atmospheric load of the phosphate ions, the kjeldahl nitrogen ions, and the sulfate ion. The importance of dry deposition, relative to wet deposition as a removal process, is related to the dry continental climate. The annual amount of precipitation and the total number of days with significant precipitation are small. Both factors decrease the amount of wet deposition relative to more humid climates. Even the type of precipitation favors dry deposition. Convective storms in Alberta are frequent and are efficient removal mechanisms because the intense rain washes out most suspended particles. But they are localized and often are associated with gusty winds. For each area that is dampened on the ground decreasing the wind scavenging of soil, an additional area has strong winds and more than normal scavenging.

Dry deposition during the permanent snow-cover period was much less than during the snow-free period which implies a surface source. The most likely sources in this area are cultivation, construction, or any other activity that disturbs the soil and entrains particulates into the atmosphere. Oil and natural gas industries may be a factor for sulfate (Nyborg et al., 1975).

The contamination test gives an indication of the constituents that are affected by insects and plant debris. It is believed that the measured dry-deposition flux with the contamination flux removed is an accurate estimate of the actual flux. It should be emphasized, however, that dry-deposition measurement is a difficult problem with no simple solution.

Table (4.9) lists the the dry-to-wet deposition ratios measured, calculated, or estimated in several different studies. The measured ratios, columns 3 and 6, are the best indicators of the actual situation. Despite the many assumptions and approximations involved, Whelpdale's (1974) calculations (columns 4 and 5) reflect the influence of pollution on the ratios. The dry-deposition flux estimated by Huff (1975), column 2, used ratios measured for a fourteen-week period to estimate the wet-to-dry breakdown of bulk samples over an eighteen-month period. These ratios do not appear to be constant in this study, so that may not be a good approximation.

Both Huff (1975) and Wagner and Holloway (1975) collected bulk samples. This procedure was not recommended for accurate precipitation chemistry measurements (Galloway and Likens, 1975). The dry-deposition flux in column 2 was estimated by extrapolating the flux ($\mu g cm^{-2} month^{-1}$) for several earth cations and the monthly rainfall back to zero rainfall per month (Wagner and Holloway, 1975). Monthly dry-deposition rates determined in this way may be inaccurate because the extrapolation is dependent upon the low precipitation values. The dry-deposition flux is also assumed to be a constant with a decrease in the amount of precipitation. The monthly dry-deposition flux is related to the number of days with no significant precipitation in a month, so it must increase if the precipitation amount and number of days of precipitation are positively correlated. On this basis, the sodium and potassium ratios may be overestimates not comparable with the Hastings Lake ratios.

5.3 Wet Deposition.

Wet and dry deposition contributed equally to the loading of the sodium, potassium, and iron ions. This result suggests that these ions are associated with small particles that are not easily removed by dry deposition.

The variations in the concentrations of the samples with individual storms is a complicated problem. Junge (1963) states that;

> Most of the rainwater data in the literature refer to average values over a certain time period, e.g., a month or year. The reason for this is that concentrations in individual storms vary so considerably with time and amount of rainfall that it is difficult to correlate them in a meaningful way with other meteorological parameters[1].

Attempts were made in this study to correlate individual

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[1] Junge (1963), page 311.

nutrient concentrations with selected meteorological parameters. The simplest method tried was a t-test comparison of the means of different wet-deposition sub-samples. The comparison of the nitrate concentration in storms with lightning and without lightning showed a significant difference. Further testing with linear correlation coefficients indicated that the nitrate increase was due to an urban effect rather than a lightning effect.

The most important variable in the correlation tests was the time since the last significant precipitation. This implies that washout is an important factor in the precipitation chemistry of central Alberta.

CHAPTER 6. RECOMMENDATIONS FOR FUTURE WORK.

The relative importance of the atmospheric contribution to the total flux of nutrients to Hasting's Lake could be a result of a temporary local source. If the water quality in any of the lakes in the Cooking Lake moraine is to be improved by a water importation scheme, this should be checked. This program has estimated that the atmospheric flux alone is sufficient for dangerous total phosphorus loadings. A program of the same scope would not be necessary. Measurements of total phosphate, total kjeldahl nitrogen, the nitrate and nitrite ions would be sufficient, but both wet and dry deposition should be sampled.

A complete nutrient-budget measurement study would eliminate the need for many of the assumptions commonly used in this and many other studies. In particular, surface runoff concentration measurements in the spring would improve the accuracy of a budget for Hastings Lake. The present work suggests that dry deposition is an important process, but measurements of dry deposition to bare and vegetated land and to a water surface are very difficult. Simulation of all relevant physical properties of the lake needs more attention. The contamination caused by birds and insects is an additional problem that should be studied with a more elaborate laboratory simulation and considered during sampler design.

An experimental consideration of the dry deposition on an entire lake or pond is recommended. Sampling the lake upwind and downwind with instrumentation capable of sampling particulates and gases would permit calculation of vertical fluxes to the lake. In addition, samplers similar to the ones used in this thesis set out on the lake would provide a check on the vertical fluxes and on the collection efficiency of the pans. Note that sampling in the middle of the lake would reduce biological contamination.

It is recommended that in any future work the number of samples should be increased and the number of constituents decreased. The choice of the constituents should be made on the basis of the purpose of the program.

If meteorological variables are to be correlated with the concentrations then quantitative measurements of all the variables should be made. This would eliminate the need for subjective scales. Air-mass trajectories should also be included in such a program.

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APPENDIX A.

Sample Analysis.

The chemical analysis of the wet and dry deposition samples measured the concentrations of the major ionic forms of nitrogen and phosphorus; the common ions of silica, iron, chloride, sodium, and potassium; the sulfate ion; and miscellaneous tests of water properties (conductivity, pH, total hardness, and total residue). Complete samples were filtered to obtain the "soluble" fraction with [illegible] membrane filter. Incomplete samples were analyzed according to the priority scheme (Fig. 3.3) shown in Chapter three.

The chemical analysis was performed by the University of Alberta Department of Zoology's water laboratory following the "Standard Methods for the Treatment of Water and Wastewater" of the American Public Health Association (1971). Table A-1 lists the methods used. A summary of the range and accuracy in the standard methods as well as the results of our test samples follows in Table A-2.

Most of the results of ion analyses were expressed simply as measures of concentration. Since the measurement of phosphorus and nitrogen is so important in this study, a discussion of the forms analyzed follows. Also included is a brief summary of the miscellaneous water property tests.

Table A-1 Methods of chemical analysis.

Constituent	Method of analysis
Total phosphate	Persulfate digestion, then stannous chloride colorimetric method[1]
Orthophosphate	Stannous chloride colorimetric method[1]
Condensed phosphate	Acid hydrolysis, then stannous chloride method[1]
Organic phosphate	Total-(Ortho-Condensed)=Organic[1]
Total kjeldahl nitrogen	Organic nitrogen method[1]
Ammonia nitrogen	Orion ammonia electrode
Organic nitrogen	Total-Ammonia=Organic
Nitrate ion	Brucine method[1]
Nitrite ion	Nitrite method[1]
Silica ion	Molybdosilicate method[1]
Iron ion	Phenanthroline method[1]
Chloride ion	Argentometric method[1]
Sulfate ion	Turbidometric method[1]
Sodium ion	Flame emission, Jarrel-Ash atomic absorption
Potassium ion	Flame emission, Jarrel-Ash atomic absorption
Hardness as calcium	EDTA titrimetric method[1]
Total hardness	EDTA titrimetric method[1]
pH	Model 250 Fisher acument pH method
Conductivity	YSI model 31 conductivity bridge
Residue	Total residue method[1]
Filtration tests	0.45μm membrane filter before analysis as above

[1] American Public Health Association (1971) method.

Table A-2 Analysis accuracy summary.

	American Public Health Association		Test Samples (this study)		
	range (mgℓ^{-1})	relative standard deviation	average (mgℓ^{-1})	standard deviation (mgℓ^{-1})	number of samples
Total phosphate	0.05-3.0	14%	0.203	0.193	9
Orthophosphate	0.05-3.0	14%	0.013	0.025	9
Condensed phosphate	0.05-3.0	14%	0.071	0.070	9
Total kjeldahl nitrogen		45%	0.110	0.109	7
Organic phopsphate			0.124	0.182	9
Ammonia nitrogen			0.081	0.073	9
Organic nitrogen			0.091	0.065	9
Nitrate nitrogen	0.1-2.0	6%	0.014	0.016	9
Nitrite nitrogen			0.003	0.0064	9
Silica ion	1.0-	14%	0.531	0.0331	9
Iron ion	0.02-4.0	25%	0.02	0.011	9
Chloride ion		4%	5.21	3.55	9
Sulfate ion	1.0-	9%	0.00	0.00	8
Sodium ion	0.1-10.0	17%	0.067	0.166	9
Potassium icn	0.1-	15%	0.056	0.113	9
Hardness as calcium			0.00	0.00	9
Total hardness		3%	13.4	17.3	9
pH (log of H⁺ icn conc.)			6.37	0.27	9
conductivity (μmhos)			2.02	0.40	9
Total residue			2.23	2.16	9

Phosphorus occurs in water as the phosphate ion. This ion is classified into one of three major forms (orthophosphate, condensed or acid phosphate, and organic phosphate) on the basis of its reactivity with an indicator chemical, in these analyses stannous chloride. The analysis of the phosphate ion starts by determining the concentration of total phosphate. Polymeric phosphate ions and phosphate bound in complex organic compounds will not react with stannous chloride without pre-treatment. Acid hydrolysis breaks down these bonds, stannous chloride is added, and a colorimetric test determines the concentration of the ion.

Orthophosphate is a single-bonded structure that will react with stannous chloride with no pre-treatment. Condensed phosphates are the polymeric chains and rings of phosphate ions that react after a persulfate digestion is performed. Although some of the tightly-bonded organic phosphate is released by the digestion, most remains.

A second sample is analyzed to determine the concentrations of these forms. Orthophosphate is determined with a colorimetric test with no pre-treatment. The condensed phosphate is treated first with a standard acid bath and then tested with the colorimetric test. The organic phosphate is calculated as the residual of the sum of the orthophosphate and acid phosphate subtracted from the previously calculated total phosphate. The filtrable or soluble phosphate tests are done in the same manner after filtration.

Total nitrogen is the sum of the total kjeldahl nitrogen, the nitrate ion, and the nitrite ion (Uttomark et al., 1974) The total kjeldahl nitrogen is a measure of the organically bound nitrogen. This fraction of the total nitrogen can be further divided into ammonia nitrogen and organic nitrogen. This is similar to the phosphate tests, i.e., the organic nitrogen is bound too tightly to react. Nitrate is the most highly oxidized phase in the nitrogen cycle. Nitrite is a transition phase between nitrate and ammonia in the nitrogen cycle.

The specific conductance is a measure of the capacity of the water to conduct an electric current. It is a function of the substances dissolved in the water, the concentrations and ratios of concentrations of those substances, and the ionic strength of the water. Distilled water will have a conductance of 2-4 μmhos cm^{-1} after absorption of carbon dioxide and ammonia (American Public Health Association, 1971). The residue is a measure of the material suspended in the water. A sample is evaporated and weighed to determine the concentration. Specific conductance is closely related to total residue.

The hardness of the water is a measure of the ability of the water to precipitate soap. Calcium and magnesium are the main ions causing precipitation. Measurement of hardness is also an indication of the concentration of aluminum, iron, manganese, strontium and zinc. (American Public Health Association, 1971). The analysis done in this study separated the total hardness into hardness as calcium which gives a rough breakdown of the ions present.

The pH is a measure of the hydrogen ion concentration in a sample. This is important since acidic rain can be a major ecological factor (Gorham,1975) and can vary the amount of orthophosphate in a sample (Murphy and Dosky, 1975).

APPENDIX B

Sample Concentration and Meteorological Parameter Comparisons

Twelve variables were chosen to study the effects that the meteorological situation had on the sample concentrations. Some of the variables are not usable in all classes. Only variables 3,6,8,11 (Table B-1) were used for the dry-deposition samples. The snow-cover dry deposition and precipitation were not included because there were fewer than ten samples in each set. For the precipitation samples, the date of the sample (6) can be used to determine if the concentration of a sample is dependent upon a seasonal time factor in the summer, but it is not valid for samples in the winter. The variable 1 scale is high for snow and low for rain associated with synoptic features. Lightning has been postulated as a source for nitrogen (Hutchinson, 1944). Variable 2 scales storms on a qualitative intensity scale. The intensity and duration of lightning associated with the storm determined the value assigned. High values were given to intense storms with a lot of lightning that passed near the sampler.

The city may influence concentrations when a storm moves over an urban area incorporating particulates and gases or when urban pollutants are blown into the storm

Table B-1 Correlation variables.

Number	Parameter	Scale	
		Maximum	Minimum
1	Type of precipitation	snow (8)	rain (2)
2	Associated lightning	intense (9)	none (0)
3	Collection site	urban (5)	rural (1)
4	Storm trajectory	rural (8)	urban (2)
5	Wind direction	rural (8)	urban (2)
6	Sample date (Days)	31 Dec. (365)	1 Jan. (1)
7	Sampling time (MST)	Night (2300)	Day (0700)
8	Contamination	Dirty (9)	Clean (1)
9	Surface wind strength (ms^{-1})	Strong (20)	Calm (0)
10	Start of precipitation (hours)	(84.)	(0)
11	Duration of sampling (hours)	(24.1)	(0.1)
12	Time since last precipitation (hours)	(170.0)	(0.0)

(Huff, 1975). These effects were accounted for by grading storm characteristics such as movement (4), the wind direction at the surface during sampling (5), and the location of the sampler (3) according to the urban influence on each.

Seasonal changes have also been noted (Fisher et al., 1968). Variable 6 assigns each day with a number, consecutive from January first. Variable 7 is also a time variable, which measures diurnal effects.

The contamination problem was examined using variable 8, which scaled samples on the basis of notes made during collection. The dry-deposition samples were considered highly contaminated when over 25 insects or bits of plant debris were in the sample after exposure and not all the fragments were removed before analysis. The main source of contamination in the precipitation samples was dry deposition. The highest contamination value was given to a sample taken when winds associated with an intense shower blew dust onto the collecting surface.

Strong winds at the surface entrain more particles which will increase the sample concentrations (Murphy and Dosky, 1975). Variable 9 was scaled using the Beaufort scale. Light winds were scaled low and strong winds were scaled high.

Three precipitation time-dependent variables were included. Progressive washout within storms decreases the concentration with time since the precipitation started (Georgii and Weber, 1960). Variable 10 is the sampling time since the start of precipitation. Dry-deposition and bulk-deposition sample concentrations increase as the duration of sampling increases. This effect was measured by variable 11. The concentration of rain samples increases with the time since the last significant precipitation (Georgii and Weber, 1960), and is measured by variable 12 in this work.

Tables B-2, B-3, B-4, and B-5 list the significant ($P<0.05$) correlation coefficients for four sets of wet- and dry-deposition samples. The significant correlation coefficients were determined using a t-test comparison (Weatherburn, 1949). These results should be used with caution because additional sampling could change the coefficients, not all the samples are independent which limits the sample size, and the choice of variables and values assigned were fairly arbitrary. These factors decrease the significance of the relationships found (Panofsky and Brier, 1958).

Table B-2 Correlation coefficients for precipitation with no-snow-cover.

	Mean (mgℓ^{-1})	Stnd. Dev.	Significant correlation coefficients				
Total phosphate	0.1731	0.1221	8 0.4936	12 0.3299			
Orthophosphate	0.0174	0.0922	8 0.4059				
Condensed phosphate	0.0655	0.0488	10 -0.5630	8 0.4367	9 0.3281	2 0.2889	
Organic phosphate	0.0605	0.0350	1 0.3267				
Filtered total phosphate	0.1391	0.1214	8 0.5605	12 0.5029			
Filtered ortho-phosphate	-0.0039	0.0780	8 0.5100	12 0.4220	6 -0.3166		
Filtered condensed phosphate	0.0565	0.0433	2 0.4995	10 -0.4611	8 0.3423	7 0.3141	
Filtered organic phosphate	0.0621	0.1008	8 0.5302	12 0.5135			
Total kjeldahl nitrogen	0.6275	0.6085	8 0.3937	2 0.3515	5 -0.3043		
Filtered total kjeldahl nitrogen	0.4803	0.5447	2 0.4378	8 0.3940	12 0.3618	5 -0.3548	1 0.3185
Ammonia nitrogen	0.3729	0.5204	8 0.5417	2 0.3729	12 0.3499	3 0.2896	
Organic nitrogen	0.2915	0.3113	5 -0.3273	7 0.2896			
Nitrate nitrogen	0.1379	0.0877	2 0.4305	5 -0.4249	1 0.3845	3 0.2936	
Nitrite nitrogen	0.0020	0.0012	7 0.3964	2 0.3465	5 -0.3137	9 -0.3015	
Silica ion	0.9245	0.2826	6 -0.4849	8 0.3215			
Iron ion	0.2326	0.2954	12 0.4936	8 0.4214	2 0.3595		
Chloride ion	2.2998	1.1544	11 0.5554	6 0.3335			
Sulfate ion	2.7500	3.4649	5 -0.4668	2 0.4521	8 0.4110	1 0.3810	4 -0.3759
Sodium ion	0.2652	0.4488	4 -0.3535	6 -0.3451			
Potassium ion	0.6174	1.1689	12 0.4705	4 -0.3794	8 0.3209	5 -0.2844	
Hardness as calcium	0.3323	1.4907	8 0.6480	12 0.5071	3 0.3160	4 -0.3157	
Total hardness	23.6046	18.846	10 0.3011				
pH (H^+ion conc.)	5.1222	0.7215	6 -0.5858	2 -0.4072	12 0.3794	5 -0.2926	
Conductivity (μmhoscm^{-1})	18.1284	14.743	1 0.4782	2 0.4565			
Total residues	21.0582	16.354	12 0.3133				
Filtered residues	9.9225	9.8567					

Table B-3 Correlation coefficients for rain.

	Mean (mgℓ^{-1})	Stnd. Dev.	Significant correlation coefficients				
Total phosphate	0.1600	0.0860	6 -0.4468				
Orthophosphate	0.0430	0.0567	6 -0.4257				
Condensed phosphate	0.0624	0.0345	10 -0.6427	1 -0.5974	4 0.4395		
Organic phosphate	0.0583	0.0262					
Filtered total phosphate	0.1274	0.0718	6 -0.5203	4 0.4404	12 0.4040		
Filtered ortho-phosphate	0.0335	0.0380	6 -0.4989	11 -0.4282			
Filtered condensed phosphate	0.0466	0.0261	10 -0.5038	12 0.4389	4 0.4154	3 -0.3862	
Filtered organic phosphate	0.0539	0.0373	6 -0.6458				
Total kjeldahl nitrogen	0.4214	0.3247					
Filtered total kjeldahl nitrogen	0.2795	0.2670	5 -0.5821	12 0.4755			
Ammonia nitrogen	0.2100	0.1926					
Organic nitrogen	0.2114	0.2024					
Nitrate nitrogen	0.0991	0.0577					
Nitrite nitrogen	0.0016	0.0012	12 0.5225	9 -0.4433	5 -0.3990		
Silica ion	0.9491	0.1926	6 -0.6423				
Iron ion	0.1443	0.1576	1 0.4871	10 0.4822	5 -0.4642		
Chloride ion	2.2864	1.3737	11 0.7685	6 0.4687	5 0.3967		
Sulfate ion	1.3200	2.1113	4 -0.6394	5 -0.5370	10 0.4721		
Sodium ion	0.3360	0.5635	4 -0.4437				
Potassium ion	0.5640	1.0453					
Hardness as calcium	0.0	-0.0					
Total hardness	22.347	18.9544	1 0.6512	6 0.4704	10 0.4516		
pH (H$^+$ion conc.)	5.385	0.6830	6 -0.6051	1 -0.4589	10 -0.4368	11 -0.4045	5 -0.3895
Conductivity (μmhoscm^{-1})	11.628	7.4833					
Total residues	20.406	15.1776					
Filtered residues	8.967	10.1336	3 0.4075				

Table B-4 Correlation coefficients for convective showers.

	Mean (mgl^{-1})	Stnd. Dev.	Significant correlation coefficients				
Total phosphate	0.1889	0.1535	12 0.9588	8 0.8411			
Orthophosphate	0.0529	0.0868	12 0.9539	8 0.8421			
Condensed phosphate	0.0779	0.0461	8 0.7857	12 0.7290			
Organic phosphate	0.0632	0.0432	12 0.6946	2 -0.4869	7 -0.4839	8 0.4419	6 -0.4256
Filtered total phosphate	0.1531	0.1605	12 0.9613	8 0.9364			
Filtered ortho-phosphate	0.0319	0.0736	12 0.9571	8 0.9286			
Filtered condensed Phosphate	0.0780	0.0290	12 0.7159	8 0.6967			
Filtered organic phosphate	0.0720	0.1432	12 0.9551	8 0.9306			
Total kjeldahl nitrogen	0.8794	0.7606	12 0.9019	8 0.7612			
Filtered total kjeldahl nitrogen	0.7347	0.6830	12 0.8997	8 0.8527			
Ammonia nitrogen	0.5520	0.6830	12 0.8428	8 0.7998			
Organic nitrogen	0.3894	0.3844	2 -0.5510	9 -0.4438			
Nitrate nitrogen	0.1805	0.0951	12 0.5833	4 -0.5475	3 0.4939	8 0.4659	
Nitrite nitrogen	0.0024	0.0011	6 0.4230				
Silica ion	0.8984	0.3613	10 -0.5791	12 0.5735	8 0.5643	6 -0.5035	
Iron ion	0.3418	0.3780	12 0.8968	8 0.8928			
Chloride ion	2.3165	0.7995					
Sulfate ion	4.6316	3.9631	12 0.8256	8 0.7737	4 -0.5984		
Sodium ion	0.1810	0.2239	12 0.6534	8 0.5713	9 0.4313		
Potassium ion	0.6810	1.2978	12 0.8240	8 0.7929	4 -0.4479		
Hardness as calcium	0.7000	2.1000	12 0.9477	8 0.9288	4 -0.5092		
Total hardness	25.0500	18.6158	1 -0.4488				
pH (H$^+$ion conc.)	4.8086	0.6357	8 0.5578	4 -0.5271	5 -0.4977	12 0.4801	3 0.4710
Conductivity (μmhoscm^{-1})	25.8666	17.299	11 0.6613	10 -0.4801	12 0.4544		
Total residues	21.7789	17.535	12 0.6376	8 0.5311			
Filtered residues	1.1500	9.3466	2 0.6329				

Table B-5 Non-snow-cover dry deposition.

	Mean (mgℓ$^{-1}$)	Stnd. Dev.	Significant correlation coefficients	
Total phosphate	0.2179	0.1447	3 -0.6028	8 0.5352
Orthophosphate	0.1093	0.1070		
Condensed phosphate	0.0868	0.1052	3 -0.6078	
Organic phosphate	0.1071	0.0855	6 -0.6256	3 -0.5296
total phosphate	0.1200	0.1364	3 -0.5485	Filtered
Filtered ortho-phosphate	0.0415	0.0903		
Filtered condensed phosphate	0.0429	0.0416	8 0.5046	
Filtered organic phosphate	0.0567	0.0813	3 -0.5016	
Total kjeldahl nitrogen	0.6429	0.5146		
Filtered total kjeldahl nitrogen	0.2369	0.1803		
Ammonia nitrogen	0.2914	0.2761	6 0.6189	
Organic nitrogen	0.4386	0.4965		
Nitrate ion	0.0300	0.0446	11 0.4880	
Nitrite ion	0.0025	0.0016	11 0.8340	6 0.6537
Silica ion	0.1829	0.1731		
Iron ion	0.0993	0.0904		
Chloride ion	2.2143	2.1503		
Sulfate ion	2.3077	2.1974	3 -0.6432	
Sodium ion	0.0846	0.1099		
Potassium ion	0.1714	0.1943	3 -0.4848	
Hardness as calcium	3.2143	0.7726		
Total hardness	9.7143	7.9231		
pH (H^+ ion conc.)	4.2843	2.7664	11 0.5815	
Conductivity (μmhoscm^{-1})	13.664	2.9942		
Total residue	5.1500	4.2750		
Filtered residue	25.360	2.8941		

APPENDIX C

Sample Concentration Data

This appendix lists all the wet- and dry-deposition data. Table C-1 lists the physical wet-deposition sample data and Table C-9 the dry-deposition sampling data. The wet-deposition analysis results are listed in tables C-2 through C-7. The dry-deposition analyses are listed in Table C-10. Table C-8 lists the averages calculated by sites.

The following conventions were followed in the data presentation. The symbol ** represents a constituent not analyzed because of a small sample volume. A concentration of 0.0 represents a constituent below the limit of detection and does not imply that the constituent was not present in the sample. The dry-deposition negative numbers indicate that the test sample concentration was larger than the concentration after exposure. The phosphate concentrations followed a special convention. Negative numbers in the wet-deposition data represent concentrations below the limit of detection. These samples were assigned a concentration of 0.005 $mg\ell^{-1}$ for further analysis. Note that in the dry deposition corrections the value 0.005 has already been assigned to concentrations below the limit of detection.

Table C-1 Physical data for samples.

Sample number	Site number	Date	Time period of sample (MST)	Type of precipitation
34	1	6-7-75	1550-1605	shower
35	1	6-7-75	1605-1635	shower
46	1	18-7-75	2105 2200	rain
57	1	28-8-75	1900-1925	shower
58	1	28-8-75	1925-1945	shower
59	1	28-8-75	1945-2000	shower
60	1	28-8-75	2000-2030	shower
68	1	28-10-75	-1130	snow
4	2	17-5-75	1235-1250	hail
6	2	23-5-75	1045-1215	rain
14	2	6-6-75	0800-0820	shower
20	2	13-6-75	1015-1320	rain
23	2	27-6-75	0630-0830	rain
25	2	27-6-75	1245-1545	rain
42	2	17-7-75	1730-1900	rain
43	2	17-7-75	0805-1130	rain
49	2	2-8-75	1620-1626	shower
50	2	2-8-75	1626-1634	shower
51	2	2-8-75	1634-1650	shower
52	2	5-8-75	1925-2000	shower
53	2	5-8-75	2000-2025	shower
70	2	3-12-75	-1200	snow
74	2	27-2-76	-1324	snow
1	3	15-5-75	1810-1850	rain
2	3	15-5-75	1850-1915	rain
3	3	15-5-75	2025-2125	rain
5	3	23-5-75	0645-0713	rain
10	3	24-5-75	1630-1747	rain
13	3	6-6-75	0657-0715	shower
26	3	26-6-75	2145-2220	rain
27	3	27-6-75	2220-0710	rain
28	3	27-6-75	0740-1145	rain
54	3	17-8-75	0902-1835	rain
55	3	17-8-75	1835-2230	rain
56	3	20-8-75	1912-2000	shower
65	3	4-10-75	0810-1010	rain
72	3	4-12-75	-2115	snow
73	3	29-12-75	-1830	snow
76	3	28-2-76	-2000	snow

Table C-1. Physical data for samples (continued)

Sample number	Site number	Date	Time period of sample (MST)	Type of precipitation
7	4	23-5-75	1115-1225	rain
21	4	13-6-75	1040-1245	rain
22	4	27-6-75	0715-0800	rain
24	4	27-6-75	1345-1515	rain
69	4	3-12-75	-1130	snow
75	4	28-2-76	-1230	snow
8	5	24-5-75	1435-1620	rain
9	5	24-5-75	1620-1815	rain
37	5	16-7-75	1805-1810	shower
38	5	16-7-75	1810-1815	shower
39	5	16-7-75	1815-1830	shower
40	5	16-7-75	1830-1840	shower
41	5	16-7-75	1840-1850	shower
48	5	31-7-75	2005-2025	shower

Table C-2. Wet-deposition phosphate concentrations $(\mathrm{mg}\,\ell^{-1})$ listed by sites.

Sample Number	Site #	Total Phosphate	Ortho Phosphate	Condensed Phosphate	Organic Phosphate
35	1	0.81	0.4	0.24	0.17
46	1	0.09	<0.05	<0.05	0.09
57	1	0.18	0.06	0.04	0.08
58	1	0.15	0.05	0.04	0.06
59	1	0.11	<0.05	0.08	0.03
60	1	0.16	<0.05	0.08	0.08
68	1	0.43	0.13	0.11	0.19
14	2	0.22	0.07	0.07	0.08
20	2	0.12	<0.05	0.10	0.02
23	2	0.13	<0.05	0.05	0.08
25	2	0.13	<0.05	0.06	0.07
42	2	0.09	<0.05	0.06	0.03
43	2	0.10	0.05	0.0	0.05
49	2	0.13	<0.05	0.10	0.03
50	2	0.10	<0.05	0.10	0.0
51	2	0.11	<0.05	0.07	0.04
52	2	0.20	0.05	0.12	0.08
53	2	0.14	<0.05	0.11	0.03
70	2	0.20	<0.05	0.09	0.11
74	2	0.38	0.05	0.13	0.20
1	3	0.25	0.10	0.08	0.07
2	3	0.32	0.15	0.09	0.08
3	3	0.20	0.07	0.11	0.02
5	3	0.06	<0.05	<0.05	0.06
10	3	0.30	0.13	0.11	0.06
13	3	0.27	0.08	0.02	0.17
26	3	0.12	<0.05	0.06	0.06
27	3	0.14	<0.05	0.07	0.07
28	3	0.10	<0.05	0.05	0.05
54	3	0.12	<0.05	0.11	0.01
55	3	0.07	<0.05	0.05	0.02
56	3	0.19	0.05	0.07	0.07
65	3	0.12	<0.05	0.07	0.05
72	3	0.28	<0.05	0.13	0.15
73	3	0.12	<0.05	0.09	0.03
76	3	0.19	<0.05	0.12	0.07
21	4	0.18	0.05	0.04	0.09
22	4	0.40	0.21	0.09	0.10
24	4	0.22	0.08	0.06	0.08
69	4	0.15	<0.05	0.15	0.0
75	4	0.14	<0.05	0.06	0.08
8	5	0.21	0.08	0.05	0.08
9	5	0.13	<0.05	0.11	0.02
27	5	0.18	0.07	0.05	0.06
38	5	0.13	0.05	0.04	0.04
39	5	0.10	<0.05	0.08	0.02
40	5	0.14	<0.05	0.07	0.07
41	5	0.08	<0.05	0.05	0.03
48	5	0.19	0.08	0.05	0.06

Table C-3. Wet-deposition filtered phosphate concentrations ($mg\ell^{-1}$) listed by sites.

Sample Number	Site #	Total Phosphate Filtered	Ortho Phosphate Filtered	Condensed Phosphate Filtered	Organic Phosphate Filtered
35	1	0.76	0.31	0.16	0.600
46	1	0.08	<0.05	<0.05	0.080
57	1	0.11	0.05	0.04	0.020
58	1	0.11	<0.05	0.08	0.030
59	1	0.09	<0.05	0.05	0.040
60	1	0.16	<0.05	0.08	0.080
68	1	0.4	<0.05	0.10	0.30
14	2	0.13	<0.05	0.07	0.060
23	2	0.07	<0.05	<0.05	0.070
25	2	0.08	<0.05	*****	0.080
42	2	0.12	0.05	0.06	0.010
43	2	0.10	0.05	0.02	0.040
49	2	0.08	<0.05	0.08	0.0
50	2	0.08	<0.05	0.07	0.010
51	2	0.06	<0.05	*****	*****
52	2	0.18	<0.05	0.12	0.060
53	2	0.13	<0.05	0.08	0.050
74	2	0.18	<0.05	0.15	0.030
1	3	0.24	0.07	0.07	0.100
2	3	0.32	0.13	0.06	0.130
3	3	0.17	0.06	0.07	0.040
5	3	0.06	<0.05	<0.05	0.060
10	3	0.27	0.09	0.06	0.120
26	3	0.12	*****	*****	*****
27	3	0.10	<0.05	0.05	0.050
28	3	0.10	<0.05	0.05	0.050
54	3	0.11	<0.05	0.09	0.020
55	3	0.06	<0.05	0.05	0.010
56	3	0.11	0.05	0.04	0.020
65	3	0.10	<0.05	0.07	0.010
72	3	0.28	<0.05	0.12	0.160
73	3	0.11	<0.05	0.08	0.030
76	3	0.15	<0.05	0.11	0.040
22	4	0.16	0.07	0.02	0.070
69	4	0.14	<0.05	0.08	0.060
75	4	0.08	<0.05	0.07	0.010
9	5	0.09	<0.05	0.06	0.030
37	5	0.18	0.04	0.07	0.070
38	5	0.09	<0.05	0.09	0.0
39	5	0.10	<0.05	0.07	0.030
40	5	0.08	<0.05	0.07	0.010

Table C-4. Wet-deposition nitrogen concentrations (mg ℓ^{-1}) listed by sites.

Sample Number	Site #	Total Kjeldahl Nitrogen	Total Nitrogen Filtered	Ammonia Nitrogen	Organic Nitrogen
34	1	*****	*****	1.90	*****
35	1	3.42	2.97	2.70	0.72
46	1	0.32	0.25	0.10	0.22
57	1	0.68	0.62	0.09	0.59
58	1	0.71	0.70	0.07	0.64
59	1	0.38	0.38	0.30	0.08
60	1	0.41	0.35	0.05	0.36
68	1	0.55	0.51	0.52	0.30
14	2	0.52	0.41	0.27	0.25
20	2	0.17	*****	0.17	0.0
23	2	0.07	0.05	0.06	0.01
25	2	0.18	0.16	0.06	0.12
42	2	0.46	0.40	0.17	0.29
43	2	0.56	0.45	0.28	0.28
49	2	0.91	0.83	0.80	0.11
50	2	0.67	0.31	0.55	0.12
51	2	0.53	*****	0.40	0.13
52	2	1.75	1.67	1.60	0.15
53	2	0.56	0.47	0.40	0.16
70	2	0.40	*****	0.40	0.0
74	2	0.36	0.21	0.02	0.34
1	3	0.92	0.52	0.25	0.67
2	3	0.58	0.48	0.40	0.18
3	3	1.25	1.16	0.80	0.45
5	3	*****	*****	0.74	*****
10	3	0.55	0.24	0.30	0.25
13	3	*****	*****	0.32	*****
26	3	0.12	0.03	0.06	0.06
27	3	0.28	0.09	0.12	0.16
28	3	0.02	0.02	0.02	0.0
54	3	0.45	0.40	0.40	0.05
55	3	0.16	0.13	0.10	0.06
56	3	0.62	0.62	0.09	0.53
65	3	0.24	0.15	0.04	0.20
72	3	0.0	0.0	0.0	0.0
73	3	0.12	0.0	0.10	0.02
76	3	0.0	0.0	0.04	0.0

Table C-4. Wet-deposition nitrogen concentrations $(mg\ell^{-1})$ listed by sites (continued).

Sample Number	Site #	Total Kjeldahl Nitrogen	Total Nitrogen Filtered	Ammonia Nitrogen	Organic Nitrogen
21	4	0.32	*****	0.12	0.20
22	4	0.76	0.05	0.60	0.16
24	4	1.04	*****	0.23	0.81
69	4	0.20	0.20	0.17	0.03
75	4	0.44	0.33	0.02	0.42
9	5	0.35	0.32	0.12	0.23
37	5	1.25	0.62	0.18	1.07
38	5	0.61	0.45	0.17	0.44
39	5	0.36	0.36	0.30	0.06
40	5	0.35	0.26	0.25	0.10
41	5	0.22	*****	0.20	0.02
48	5	1.88	*****	0.40	1.48

Table C-5. Wet-deposition nutrient ion concentrations $(mg\ell^{-1})$ listed by sites.

Sample Number	Site #	Silicon ion	Iron ion	Chloride ion	Sodium ion	Potassium ion
34	1	2.00	*****	2.45	0.80	6.20
35	1	0.95	1.75	1.17	0.40	1.90
46	1	1.07	0.33	2.64	0.0	0.0
57	1	0.27	0.17	2.20	0.10	0.40
58	1	0.52	0.10	3.08	0.0	0.40
59	1	0.90	0.07	2.54	0.0	0.30
60	1	0.24	0.17	2.54	0.10	0.40
68	1	0.24	0.54	0.69	0.00	0.03
4	2	*****	*****	2.98	0.40	0.90
6	2	*****	*****	2.35	2.60	5.20
14	2	0.94	0.11	0.88	0.20	0.20
20	2	0.90	*****	2.40	0.0	0.0
23	2	0.90	0.06	2.54	0.20	0.50
25	2	0.95	0.04	1.66	0.30	0.0
42	2	0.94	0.20	1.47	0.50	0.40
43	2	0.92	0.11	2.00	0.0	0.10
49	2	0.91	0.25	1.96	0.30	0.50
50	2	0.94	0.30	1.56	0.50	0.30
51	2	0.90	0.31	1.86	0.30	0.20
52	2	0.94	0.37	2.15	0.20	0.50
53	2	0.90	0.12	2.54	0.0	0.20
70	2	0.17	0.07	2.45	0.0	0.20
74	2	0.23	0.04	2.18	0.0	2.30
1	3	1.20	0.54	0.69	0.0	0.60
2	3	1.11	0.22	0.0	0.0	0.60
3	3	1.01	0.11	0.93	0.0	0.60
5	3	0.87	0.02	1.21	0.60	0.0
10	3	1.14	0.10	1.96	0.10	0.20
13	3	*****	*****	2.81	0.0	0.10
26	3	0.90	0.05	2.25	0.10	0.20
27	3	0.90	0.03	5.18	0.10	0.10
28	3	0.83	0.02	5.58	0.20	0.20
54	3	0.95	0.04	5.38	0.0	0.30
55	3	0.85	0.02	2.93	0.0	0.0
56	3	1.20	0.54	2.69	0.0	0.50
65	3	0.21	0.04	3.03	0.10	0.20
72	3	0.17	0.02	2.45	0.0	0.20
73	3	0.33	0.25	5.63	0.40	0.0
76	3	0.25	0.36	1.09	0.0	0.0

Table C-5. Wet-deposition nutrient ion concentrations $(\mathrm{mg}\,\ell^{-1})$ listed by sites (continued).

Sample Number	Site #	Silicon ion	Iron ion	Chloride ion	Sodium ion	Potassium ion
7	4	*****	*****	2.98	0.50	1.70
21	4	*****	*****	0.93	0.10	0.10
22	4	1.08	0.17	0.88	0.40	0.30
24	4	1.13	0.25	1.81	0.40	0.30
69	4	0.17	0.02	1.22	0.0	0.0
75	4	0.17	0.02	3.27	1.40	1.90
8	5	0.98	0.05	1.81	1.40	1.70
9	5	0.91	0.06	1.81	0.80	0.70
37	5	1.03	0.55	0.98	0.0	0.20
38	5	1.04	0.32	1.86	0.0	0.10
39	5	0.79	0.28	2.84	0.0	0.10
40	5	0.85	0.12	4.40	0.0	0.0
41	5	0.78	0.28	2.84	0.0	0.10
48	5	*****	*****	*****	0.50	0.80

Table C-6. Wet-deposition water properties ($mg\ell^{-1}$, unless noted) listed by sites.

Sample Number	Site #	Hardness as Calcium	Total Hardness	Conductivity (μmhos cm^{-1})	Total Residue	Total Residue Filtered
34	1	7.0	24.0	46.8	60.6	****
35	1	7.0	32.0	43.6	51.9	22.5
46	1	0.0	31.0	8.9	23.4	****
57	1	0.0	14.0	27.9	12.0	1.1
58	1	0.0	15.0	20.0	8.0	0.6
59	1	0.0	26.0	13.6	10.5	****
60	1	0.0	11.0	9.6	0.5	0.0
68	1	0.0	14.0	8.2	7.5	2.0
4	2	*****	****	14.2	****	****
6	2	*****	****	33.8	****	****
14	2	0.0	17.0	44.0	2.0	0.3
20	2	0.0	23.0	12.2	****	****
23	2	0.0	14.0	3.4	34.4	30.7
25	2	0.0	14.0	7.3	11.5	6.8
42	2	0.0	54.0	6.2	16.0	9.3
43	2	0.0	33.0	18.0	26.0	9.0
49	2	0.0	24.0	19.9	8.2	6.6
50	2	0.0	19.0	17.2	12.2	10.5
51	2	0.0	23.0	22.5	3.0	****
52	2	0.0	29.0	38.0	23.8	23.2
53	2	0.0	27.0	25.0	20.0	20.7
70	2	0.0	12.0	15.3	24.2	****
74	2	0.0	4.0	3.0	29.3	12.1
1	3	0.0	12.0	9.0	53.0	28.1
2	3	0.0	4.0	12.0	26.9	15.2
3	3	0.0	6.0	17.0	6.8	0.2
5	3	0.0	6.0	2.5	25.6	7.0
10	3	0.0	23.0	4.4	2.6	0.6
13	3	0.0	8.0	32.8	10.5	****
26	3	0.0	8.0	9.3	33.6	30.8
27	3	0.0	60.0	7.4	6.2	4.3
28	3	0.0	10.0	2.8	31.2	7.1
54	3	0.0	16.0	22.0	8.5	5.2
55	3	*****	31.0	4.8	2.8	2.7
56	3	0.0	10.0	84.4	38.7	5.6
65	3	0.0	34.0	9.8	0.3	4.2
72	3	0.0	7.0	4.8	14.6	8.4
73	3	0.0	4.0	3.3	18.8	15.5
76	3	0.0	8.0	2.9	26.1	9.8

Table C-6. Wet-deposition water properties (mgℓ^{-1}, unless noted) listed by sites (continued).

Sample Number	Site #	Hardness as Calcium	Total Hardness	Conductivity (μmhos cm^{-1})	Total Residue	Total Residue Filtered
7	4	*****	****	17.4	****	****
21	4	0.0	17.0	9.9	2.0	0.0
22	4	0.0	9.0	8.8	30.7	0.0
24	4	0.0	16.0	14.4	50.9	****
69	4	0.0	26.0	19.5	4.2	****
75	4	0.0	10.0	4.9	19.3	10.8
8	5	0.0	7.0	20.0	****	****
9	5	0.0	7.0	5.4	26.3	0.2
37	5	0.0	99.0	15.5	26.2	22.2
38	5	0.0	38.0	11.4	11.4	10.0
39	5	0.0	17.0	15.5	32.4	7.1
40	5	0.0	22.0	12.2	49.5	25.7
41	5	0.0	16.0	15.5	32.4	****
48	5	0.0	30.0	13.6	****	****

Table C-7. Wet-deposition miscellaneous constituents ($mg\ell^{-1}$) listed by sites.

Sample Number	Site #	Nitrate Ion	Nitrite Ion	Sulfate Ion	pH
34	1	0.30	*****	17.00	6.38
35	1	0.34	0.002	11.00	5.48
46	1	0.12	0.001	4.00	4.88
57	1	0.39	0.004	5.00	4.74
58	1	0.26	0.003	5.00	4.89
59	1	0.16	0.001	*****	5.28
60	1	0.11	0.002	5.00	5.26
68	1	0.10	0.009	5.00	6.14
4	2	*****	*****	6.00	6.41
6	2	*****	*****	7.00	6.13
14	2	0.11	0.002	0.0	4.57
20	2	0.05	0.001	0.0	4.77
23	2	0.04	0.001	0.0	4.72
25	2	0.07	0.001	0.0	5.16
42	2	0.05	0.002	1.00	5.22
43	2	0.08	0.002	4.00	4.55
49	2	0.10	0.002	1.00	3.93
50	2	0.09	0.003	0.0	4.64
51	2	0.09	0.003	2.00	4.47
52	2	0.33	0.005	7.00	4.31
53	2	0.22	0.003	3.00	4.46
70	2	0.52	0.005	0.0	4.90
74	2	0.09	0.002	0.0	6.53
1	3	0.17	0.006	0.0	6.45
2	3	0.12	0.002	0.0	5.78
3	3	0.20	0.004	0.0	5.65
5	3	0.04	0.001	0.0	6.05
10	3	0.05	0.001	0.0	6.19
13	3	0.25	0.0008	6.00	4.30
26	3	0.07	0.001	0.0	4.93
27	3	0.04	0.001	0.0	4.99
28	3	0.06	0.001	0.0	5.57
54	3	0.25	0.002	1.00	4.56
55	3	0.10	0.002	0.0	5.22
56	3	0.13	0.003	5.00	3.94
65	3	0.10	0.001	2.00	5.34
72	3	0.10	*****	0.0	6.63
73	3	0.07	0.001	0.0	5.85
76	3	0.08	0.002	0.0	6.61

Table C-7. Wet-deposition miscellaneous constituents (mgℓ^{-1}) listed by sites (continued).

Sample Number	Site #	Nitrate Ion	Nitrite Ion	Sulfate Ion	pH
7	4	*****	*****	6.00	6.41
21	4	0.06	0.001	0.0	4.92
22	4	0.08	0.001	0.0	5.33
24	4	0.10	0.002	0.0	4.99
69	4	0.60	0.002	0.0	4.54
75	4	0.17	0.003	0.0	6.44
8	5	*****	*****	4.00	6.81
9	5	0.20	0.0008	0.0	6.00
37	5	0.13	0.002	5.00	4.62
38	5	0.09	0.002	2.00	4.69
39	5	0.12	0.001	4.00	4.70
40	5	0.14	0.003	0.0	4.77
41	5	0.08	0.001	4.00	4.70
48	5	0.17	*****	*****	4.44

Table C-8 Wet-deposition averages listed by site.
(All concentrations listed in $mg\ell^{-1}$ unless otherwise noted.)

Constituents	Site 1	Site 2	Site 3	Site 4	Site 5
Total phosphate	0.250	0.158	0.178	0.218	0.145
Orthophosphate	0.087	0.020	0.039	0.070	0.037
Condensed phosphate	0.081	0.082	0.077	0.080	0.062
Organic phosphate	0.085	0.063	0.065	0.070	0.047
Total kjeldahl nitrogen	0.987	0.549	0.354	0.552	0.717
Ammonia nitrogen	0.744	0.398	0.190	0.228	0.231
Organic nitrogen	0.435	0.151	0.175	0.324	0.485
Nitrate nitrogen	0.240	0.142	0.114	0.202	0.133
Nitrite nitrogen	0.002	0.002	0.002	0.002	0.002
Silica ion	0.850	0.811	0.795	0.637	0.911
Iron ion	0.432	0.165	0.157	0.115	0.237
Chloride ion	2.374	2.065	2.738	1.848	2.363
Sulfate ion	7.833	2.067	0.875	1.00	2.714
Sodium ion	0.200	0.367	0.100	0.467	0.337
Potassium ion	1.371	0.767	0.237	0.717	0.462
Hardness as calcium	2.00	0.0	0.0	0.0	0.0
Total hardness	21.9	22.5	15.4	15.6	29.5
pH (log of H^+ ion conc.)	5.27	4.98	5.50	5.44	5.09
Conductivity (μ mhos)	24.3	18.7	14.3	12.5	29.7
Total residue	23.8	17.6	19.1	21.4	29.7
Filtered samples					
Total phosphate	0.218	0.110	0.153	0.127	0.108
Orthophosphate	0.063	0.013	0.032	0.027	0.012
Condensed phosphate	0.069	0.073	0.066	0.057	0.072
Organic nitrogen	0.142	0.041	0.060	0.047	0.0028
Total kjeldahl nitrogen	0.878	0.496	0.256	0.193	0.402
Total residue	6.05	12.9	9.65	3.60	13.0

Table C-9 Dry-deposition sample data.

Sample Number	Date Collected	Site	Length Exposed (hours)	Contamination
11	2-6-75	3	60.8	3
16	10-6-75	3	24.8	5
17	10-6-75	4	27.4	7
18	10-6-75	1	29.5	5
30	6-7-75	3	140.1	7
31	4-7-75	4	54.4	5
32	4-7-75	2	52.3	7
33	4-7-75	1	50.8	9
62	24-9-75	4	121.0	5
63	24-9-75	1	118.9	7
67	12-10-75	3	104.3	4
84	1-4-75	3	71.8	1
86	29-4-76	1	45.3	3
87	2-4-76	1	77.0	4

Table C-10 Dry-deposition sample concentrations.

Total Phosphate no-snow-cover dry-deposition concentrations (mgℓ^{-1})

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.35	12	0.05	0.30
16	0.18	15	0.21	-0.03
17	0.51	15	0.21	0.30
18	0.28	15	0.21	0.07
30	0.37	29	0.11	0.26
31	0.23	29	0.11	0.12
32	0.47	29	0.11	0.36
33	0.44	29	0.11	0.33
62	0.13	61	0.07	0.06
63	0.650	61	0.07	0.58
67	0.090	66	0.23	-0.14
83	0.240	82	0.21	0.03
85	0.830	84	0.68	0.15
86	0.430	82	0.21	0.22

Total phosphate snow-cover dry-deposition concentrations (mgℓ^{-1})

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.12	70	0.20	-0.08
77	0.17	76	0.19	-0.02
78	0.59	92	0.24	0.35
79	0.20	92	0.24	-0.04
80	0.24	92	0.24	0.0
81	0.13	92	0.24	-0.11

Table C-10 Dry-deposition sample concentrations (continued).

Orthophosphate no-snow-cover dry-deposition concentrations (mgℓ^{-1})

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.120	12	0.005	0.115
16	0.040	15	0.005	0.035
17	0.190	15	0.005	0.185
18	0.150	15	0.005	0.145
30	0.160	29	0.005	0.155
31	0.040	29	0.005	0.035
32	0.080	29	0.005	0.075
33	0.060	29	0.005	0.055
62	0.050	61	0.005	0.045
63	0.450	61	0.005	0.445
67	0.005	66	0.005	0.0
83	0.090	82	0.005	0.085
85	0.110	84	0.080	0.030
86	0.130	82	0.005	0.125

Orthophosphate snow-cover dry-deposition concentrations (mgℓ^{-1})

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.005	70	0.005	0.0
77	0.050	76	0.005	0.045
78	0.200	92	0.030	0.170
79	0.120	92	0.030	0.090
80	0.090	92	0.030	0.060
81	0.050	92	0.030	0.020

Table C-10 Dry-deposition sample concentrations (continued)

Condensed phosphate no-snow-cover dry-deposition concentrations ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.01	12	0.05	-0.04
16	0.07	15	0.005	0.065
17	0.10	15	0.005	0.095
18	0.05	15	0.005	0.045
30	0.09	29	0.06	0.03
31	0.08	29	0.06	0.02
32	0.19	29	0.06	0.13
33	0.10	29	0.06	0.04
62	0.04	61	0.005	0.035
63	0.20	61	0.005	0.195
67	0.08	66	0.08	0.0
83	0.04	82	0.20	-0.16
85	0.46	84	0.04	0.42
86	0.09	82	0.20	-0.11

Condensed phosphate snow-cover dry-deposition concentrations ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.12	70	0.09	0.03
77	0.05	76	0.12	-0.07
78	0.34	92	0.11	0.23
79	0.04	92	0.11	-0.07
80	0.13	92	0.11	0.02
81	0.05	92	0.11	-0.06

Table C-10 Dry-deposition sample concentrations (continued).

Organic phosphate no-snow-cover dry-deposition concentrations ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.22	12	0.0	0.22
16	0.07	15	0.21	-0.14
17	0.22	15	0.21	0.01
18	0.08	15	0.21	-0.13
30	0.12	29	0.05	0.07
31	0.11	29	0.05	0.06
32	0.20	29	0.05	0.15
33	0.28	29	0.05	0.23
62	0.04	61	0.07	-0.03
63	0.0	61	0.07	-0.07
67	0.01	66	0.14	-0.13
83	0.11	82	0.01	0.10
85	0.26	84	0.56	-0.30
86	0.21	82	0.01	0.20

Organic phosphate snow-cover dry-deposition concentration ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.0	70	0.11	-0.11
77	0.07	76	0.07	0.0
78	0.05	92	0.10	-0.05
79	0.02	92	0.10	-0.08
80	0.02	92	0.10	-0.08
81	0.03	92	0.10	-0.07

Table C-10 Dry-deposition sample concentrations (continued).

Filtered total phosphate no-snow-cover dry-deposition concentrations (mgℓ⁻¹).

Original sample number	Original* concentration	Test sample number	Test concentration	Corrected concentration
11	*****	12	0.05	*****
16	0.15	15	*****	*****
17	*****	15	*****	0.0
18	*****	15	*****	0.0
30	0.14	29	0.10	0.04
31	0.22	29	0.10	0.12
32	0.18	29	0.10	0.08
33	0.22	29	0.10	0.12
62	0.13	61	0.07	0.06
63	0.60	61	0.07	0.53
67	0.08	66	0.13	-0.05
83	0.19	82	0.13	0.06
85	0.42	84	0.37	0.05
86	0.40	82	0.13	0.27

Filtered total phosphate snow-cover dry-deposition concentration (mgℓ⁻¹).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.10	70	*****	*****
77	0.07	76	0.15	-0.08
78	0.18	92	0.15	0.03
79	0.14	92	0.15	-0.01
80	0.08	92	0.15	-0.07
81	0.10	92	0.15	-0.05

Table C-10 Dry-deposition sample concentrations (continued).

Filtered orthophosphate no-snow-cover dry-deposition concentrations (mgℓ^{-1}).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	******	12	0.005	******
16	0.005	15	******	******
17	******	15	******	0.0
18	******	15	******	0.0
30	0.005	29	0.005	0.0
31	0.04	29	0.005	0.035
32	0.005	29	0.005	0.0
33	0.005	29	0.005	0.0
62	0.005	61	0.005	0.0
63	0.35	61	0.005	0.345
67	0.005	66	0.005	0.0
83	0.05	82	0.005	0.045
85	0.05	84	0.005	0.04
86	0.07	82	0.005	0.065

Filtered orthophosphate snow-cover dry-deposition concentration (mgℓ^{-1}).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.005	70	******	******
77	0.005	76	0.005	0.0
78	0.005	92	0.005	0.0
79	0.06	92	0.005	0.055
80	0.005	92	0.005	0.0
81	0.005	92	0.005	0.0

Table C-10 Dry-deposition sample concentrations (continued).

Filtered condensed phosphate no-snow-cover dry-deposition concentrations ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	*****	12	0.05	*****
16	0.05	15	*****	*****
17	*****	15	******	0.0
18	*****	15	******	0.0
30	0.12	29	0.005	0.115
31	*****	29	0.005	******
32	0.09	29	0.005	0.085
33	0.12	29	0.005	0.115
62	0.03	61	0.005	0.025
63	0.07	61	0.005	0.065
67	0.08	66	0.08	0.0
83	0.14	82	0.10	0.04
85	0.01	84	0.05	-0.04
86	0.01	82	0.10	-0.09

Filtered condensed phosphate snow-cover dry-deposition concentration ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.10	70	*****	*****
77	0.05	76	0.11	-0.06
78	0.13	92	0.10	0.03
79	0.05	92	0.10	-0.05
80	0.08	92	0.10	-0.02
81	0.08	92	0.10	-0.02

Table C-10 Dry-deposition sample concentrations (continued).

Filtered organic phosphate no-snow-cover dry-deposition concentrations $(mg\ell^{-1})$.

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	*****	12	0.0	*****
16	0.10	15	*****	*****
17	*****	15	*****	0.0
18	*****	15	*****	0.0
30	0.02	29	0.10	-0.08
31	*****	29	0.10	*****
32	0.09	29	0.10	-0.01
33	0.10	29	0.10	0.0
62	0.10	61	0.07	0.03
63	0.18	61	0.070	0.11
67	0.0	66	0.05	-0.05
83	0.0	82	0.03	-0.03
85	0.36	84	0.32	0.04
86	0.32	82	0.03	0.29

Filtered organic phosphate snow-cover dry-deposition concentration $(mg\ell^{-1})$.

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.0	70	*****	*****
77	0.02	76	0.04	-0.02
78	0.05	92	0.09	-0.04
79	0.03	92	0.09	-0.06
80	0.0	92	0.09	-0.09
81	0.02	92	0.09	-0.07

Table C-10 Dry-deposition sample concentrations (continued).

Total kjeldahl nitrogen no-snow-cover dry-deposition concentrations ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.69	12	0.16	0.53
16	0.63	15	0.22	0.41
17	1.31	15	0.22	1.09
18	0.73	15	0.22	0.51
30	0.35	29	0.11	0.24
31	0.74	29	0.11	0.63
32	1.00	29	0.11	0.89
33	0.28	29	0.11	0.17
62	0.98	61	0.14	0.84
63	2.38	61	0.14	2.24
67	1.36	66	1.17	0.19
83	0.38	82	0.09	0.29
85	0.46	84	0.03	0.43
86	0.63	82	0.09	0.54

Total kjeldahl nitrogen snow-cover dry-deposition concentration ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.2[illegible]	70	0.40	-0.20
77	0.52	76	0.0	0.52
78	2.01	92	0.26	1.75
79	1.11	92	0.26	0.85
80	0.98	92	0.26	0.72
81	0.56	92	0.26	0.30

Table C-10 Dry-deposition sample concentrations (continued).

Filtered kjeldahl nitrogen no-snow-cover dry-deposition concentrations (mgℓ^{-1})

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	*****	12	0.14	*****
16	0.23	15	*****	*****
17	*****	15	*****	0.0
18	*****	15	*****	0.0
30	0.28	29	0.11	0.17
31	0.56	29	0.11	0.45
32	0.19	29	0.11	0.08
33	0.23	29	0.11	0.12
62	0.54	61	0.14	0.40
63	0.68	61	0.14	0.54
67	0.38	66	0.29	0.09
83	0.27	82	0.06	0.21
85	0.30	84	0.03	0.27
86	0.58	82	0.06	0.52

Filtered kjeldahl nitrogen snow-cover dry-deposition concentration (mgℓ^{-1}).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.17	70	*****	*****
77	0.20	76	0.0	0.20
78	0.76	92	0.18	0.58
79	0.87	92	0.18	0.69
80	0.34	92	0.18	0.16
81	0.43	92	0.18	0.25

Table C-10 Dry-deposition sample concentrations (continued).

Ammonia nitrogen no-snow-cover dry-deposition concentrations ($mg\,\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.32	12	0.08	0.24
16	0.54	15	0.06	0.48
17	0.45	15	0.06	0.39
18	0.30	15	0.06	0.24
30	0.28	29	0.08	0.20
31	0.72	29	0.08	0.64
32	0.19	29	0.08	0.11
33	0.27	29	0.08	0.19
62	0.44	61	0.08	0.36
63	0.25	61	0.08	0.17
67	1.05	66	1.10	-0.05
83	0.04	82	0.03	0.01
85	0.02	84	0.02	0.0
86	0.03	82	0.03	0.0

Ammonia nitrogen snow-cover dry-deposition concentration ($mg\,\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.20	70	0.40	-0.20
77	0.05	76	0.04	0.01
78	0.03	92	0.16	-0.13
79	0.46	92	0.16	0.30
80	0.10	92	0.16	-0.06
81	0.14	92	0.16	-0.02

Table C-10 Dry-deposition sample concentrations (continued).

Organic nitrogen no-snow-cover dry-deposition concentrations (mgℓ^{-1}).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.37	12	0.08	0.29
16	0.09	15	0.16	-0.07
17	0.86	15	0.16	0.70
18	0.43	15	0.16	0.27
30	0.07	29	0.03	0.04
31	0.02	29	0.03	-0.01
32	0.81	29	0.03	0.78
33	0.01	29	0.03	-0.02
62	0.54	61	0.11	0.43
63	2.13	61	0.11	2.02
67	0.31	66	0.07	0.24
83	0.34	82	0.06	0.28
85	0.44	84	0.01	0.43
86	0.600	82	0.060	0.54

Organic nitrogen snow-cover dry-deposition concentration (mgℓ^{-1}).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.0	70	0.0	0.0
77	0.47	76	0.0	0.47
78	1.98	92	0.10	1.88
79	0.65	92	0.10	0.55
80	0.88	92	0.10	0.78
81	0.42	92	0.10	0.32

Table C-10 Dry-deposition sample concentrations (continued).

Nitrate nitrogen no-snow-cover dry-deposition concentrations ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.0	12	0.0	0.0
16	0.07	15	0.02	0.05
17	0.02	15	0.02	0.0
18	0.0	15	0.02	-0.02
30	0.18	29	0.0	0.18
31	0.03	29	0.0	0.03
32	0.0	29	0.0	0.0
33	0.0	29	0.0	0.0
62	0.03	61	0.03	0.0
63	0.05	61	0.03	0.02
67	0.02	66	0.0	0.02
83	0.03	82	0.0	0.03
85	0.04	84	0.01	0.03
86	0.04	82	0.0	0.04

Nitrate nitrogen snow-cover dry-deposition concentration ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.29	70	0.52	-0.23
77	0.06	76	0.08	-0.02
78	0.14	92	0.22	-0.08
79	0.35	92	0.22	0.13
80	0.23	92	0.22	0.01
81	0.22	92	0.22	0.0

Table C-10 Dry-deposition sample concentrations (continued).

Nitrite nitrogen no-snow-cover dry-deposition concentrations ($mg\,\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.002	12	0.000	0.002
16	0.002	15	0.000	0.002
17	0.001	15	0.000	0.001
18	0.001	15	0.000	0.001
30	0.005	29	0.001	0.004
31	0.004	29	0.001	0.003
32	0.003	29	0.001	0.002
33	0.002	29	0.001	0.001
62	0.006	61	0.020	-0.014
63	0.005	61	0.020	-0.015
67	0.003	66	0.0	0.003
83	0.003	82	0.001	0.002
85	0.002	84	0.001	0.001
86	0.003	82	0.001	0.002

Nitrite nitrogen snow-cover dry-deposition concentration ($mg\,\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.001	70	0.005	-0.004
77	0.004	76	0.002	0.002
78	0.007	92	0.003	0.004
79	0.018	92	0.003	0.015
80	0.005	92	0.003	0.002
81	0.004	92	0.003	0.001

Table C-10 Dry-deposition sample concentrations (continued).

Silica ion no-snow-cover dry-deposition concentrations ($mg \ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.92	12	0.84	0.08
16	0.85	15	0.84	0.01
17	0.88	15	0.84	0.04
18	0.91	15	0.84	0.07
30	1.33	29	0.80	0.53
31	1.11	29	0.80	0.31
32	1.33	29	0.80	0.53
33	0.96	29	0.80	0.16
62	0.18	61	0.10	0.08
63	0.40	61	0.10	0.30
67	0.21	66	0.20	0.01
83	0.23	82	0.19	0.04
85	0.34	84	0.22	0.12
86	0.47	82	0.19	0.28

Silica ion snow-cover dry-deposition concentration ($mg \ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.30	70	0.17	0.13
77	0.16	76	0.25	-0.09
78	1.05	92	0.22	0.83
79	0.71	92	0.22	0.49
80	0.87	92	0.22	0.65
81	0.30	92	0.22	0.08

Table C-10 Dry-deposition sample concentrations (continued).

Iron ion no-snow-cover dry-deposition concentrations ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.20	12	0.03	0.17
16	0.05	15	0.02	0.03
17	0.08	15	0.02	0.06
18	0.15	15	0.02	0.13
30	0.11	29	0.02	0.09
31	0.04	29	0.02	0.02
32	0.04	29	0.02	0.02
33	0.15	29	0.02	0.13
62	0.15	61	0.02	0.13
63	0.12	61	0.02	0.10
67	0.02	66	0.01	0.01
83	0.02	82	0.0	0.02
85	0.12	84	0.01	0.11
86	0.37	82	0.0	0.37

Iron ion snow-cover dry-deposition concentration ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.42	70	0.07	0.35
77	0.02	76	0.36	-0.34
78	0.90	92	0.10	0.80
79	0.32	92	0.10	0.22
80	0.70	92	0.10	0.60
81	0.06	92	0.10	-0.04

Table C-10 Dry-deposition sample concentrations (continued).

Chloride ion no-snow-cover dry-deposition concentrations ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	2.74	12	3.96	-1.22
16	1.66	15	4.06	-2.40
17	4.99	15	4.06	0.93
18	12.23	15	4.06	8.17
30	1.22	29	5.63	-4.41
31	0.98	29	5.63	-4.65
32	0.29	29	5.63	-5.34
33	1.27	29	5.63	-4.36
62	5.68	61	13.9	-8.22
63	3.32	61	13.9	*****
67	6.94	66	6.16	0.78
83	2.18	82	3.82	-1.64
85	0.14	84	2.73	-2.59
86	1.64	82	3.82	-2.18

Chloride ion snow-cover dry-deposition concentration ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	3.17	70	2.45	0.72
77	3.82	76	1.09	2.73
78	2.73	92	2.47	0.26
79	4.91	92	2.47	2.44
80	1.36	92	2.47	-1.11
81	1.64	92	2.47	-0.83

Table C-10 Dry-deposition sample concentrations (continued).

Sulfate ion no-snow-cover dry-deposition concentrations ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	******	12	0.0	*****
16	0.0	15	0.0	0.0
17	0.0	15	0.0	0.0
18	0.0	15	0.0	0.0
30	5.0	29	0.0	5.0
31	0.0	29	0.0	0.0
32	5.0	29	0.0	5.0
33	5.0	29	0.0	5.0
62	2.0	61	0.0	2.0
63	6.0	61	0.0	6.0
67	0.0	66	0.0	0.0
83	2.0	82	0.0	2.0
85	2.0	84	****	****
86	3.0	82	0.0	3.0

Sulfate ion snow-cover dry-deposition concentration ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.0	70	0.0	0.0
77	0.0	76	0.0	0.0
78	7.0	92	0.63	6.37
79	14.0	92	0.63	13.37
80	9.0	92	0.63	8.37
81	37.0	92	0.63	36.37

Table C-10 Dry-deposition sample concentrations (continued).

Sodium ion no-snow-cover dry-deposition concentrations (mgℓ^{-1}).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	*****	12	0.0	*****
16	0.20	15	0.0	0.20
17	0.10	15	0.0	0.10
18	0.10	15	0.0	0.10
30	0.0	29	0.0	0.0
31	0.10	29	0.0	0.10
32	0.10	29	0.0	0.10
33	0.10	29	0.0	0.10
62	0.0	61	0.0	0.0
63	0.40	61	0.0	0.40
67	0.0	66	0.0	0.0
83	0.0	[illegible]2	0.0	0.0
85	0.0	84	0.0	0.0
86	0.0	82	0.0	0.0

Sodium ion snow-cover dry-deposition concentration (mgℓ^{-1}).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.80	70	0.0	0.80
77	0.20	76	0.0	0.20
78	0.10	92	0.26	-0.16
79	3.00	92	0.26	2.74
80	1.00	92	0.26	0.74
81	11.00	92	0.26	10.74

Table C-10 Dry-deposition sample concentrations (continued).

Potassium ion no-snow-cover dry-deposition concentrations (mgℓ-1).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.10	12	0.30	-0.20
16	0.10	15	0.20	-0.10
17	0.30	15	0.20	0.10
18	0.30	15	0.20	0.10
30	0.10	29	0.0	0.10
31	0.20	29	0.0	0.20
32	0.30	29	0.0	0.30
33	0.10	29	0.0	0.10
62	0.10	61	0.0	0.10
63	0.70	61	0.0	0.70
67	0.0	66	0.0	0.0
83	0.0	82	0.0	0.0
85	0.0	84	0.0	0.0
86	0.50	82	0.0	0.50

Potassium ion snow-cover dry-deposition concentration (mgℓ-1).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.0	70	0.20	-0.20
77	1.50	76	0.0	1.50
78	0.50	92	0.61	-0.11
79	1.90	92	0.61	1.29
80	0.50	92	0.61	-0.11
81	3.60	92	0.61	2.99

Table C-10 Dry-deposition sample concentrations (continued).

Hardness as calcium no-snow-cover dry-deposition concentrations ($mg\,\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	0.0	12	0.0	0.0
16	0.0	15	0.0	0.0
17	0.0	15	0.0	0.0
18	0.0	15	0.0	0.0
30	0.0	29	0.0	0.0
31	0.0	29	0.0	0.0
32	0.0	29	0.0	0.0
33	0.0	29	0.0	0.0
62	0.0	61	0.0	0.0
63	0.0	61	0.0	0.0
67	0.0	66	0.0	0.0
83	0.0	82	0.0	0.0
85	0.0	84	0.0	0.0
86	3.0	82	0.0	3.00

Hardness as calcium snow-cover dry-deposition concentration ($mg\,\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	0.0	70	0.0	0.0
77	0.0	76	0.0	0.0
78	0.0	92	0.0	0.0
79	5.0	92	0.0	5.0
80	3.0	92	0.0	3.0
81	3.0	92	0.0	3.0

Table C-10 Dry-deposition sample concentrations (continued).

Total hardness no-snow-cover dry-deposition concentrations ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	6.0	12	11.0	-5.0
16	28.0	15	6.0	22.0
17	17.0	15	6.0	11.0
18	21.0	15	6.0	15.0
30	12.0	29	20.0	-8.0
31	23.0	29	20.0	3.0
32	28.0	29	20.0	8.0
33	28.0	29	20.0	8.0
62	29.0	61	31.0	-2.0
63	33.0	61	31.0	2.0
67	7.0	66	7.0	0.0
83	4.0	82	4.0	0.0
85	16.0	84	8.0	8.0
86	16.0	82	4.0	12.0

Total hardness snow-cover dry-deposition concentration ($mg\ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	10.0	70	12.0	-2.0
77	6.0	76	8.0	-2.0
78	12.0	92	10.6	1.4
79	18.0	92	10.6	7.4
80	12.0	92	10.6	1.4
81	35.0	92	10.6	24.4

Table C-10 Dry-de[illegible]n sample concentrations (continued).

pH no-snow-cover dry-deposition (H⁺ion concentration)

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	6.540	12	6.540	0.0
16	6.490	15	6.2	0.29
17	4.120	15	6.2	-2.08
18	3.570	15	6.2	-2.63
30	6.1	29	6.34	-0.24
31	6.59	29	6.34	0.25
32	6.04	29	6.34	-0.3
33	6.24	29	6.34	-0.1
62	6.5	61	6.56	-0.06
63	6.51	61	6.56	-0.05
67	6.87	66	6.93	-0.06
83	6.72	82	6.92	-0.02
85	6.25	84	6.16	0.09
86	6.68	82	6.92	-0.24

pH snow-cover dry-deposition (H⁺ ion concentration).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	5.89	70	4.9	0.99
77	6.98	76	6.61	0.37
78	7.14	92	5.96	1.18
79	6.9	92	5.96	0.94
80	6.77	92	5.96	0.81
81	7.47	92	5.96	1.51

Table C-10 Dry-deposition sample concentrations (continued).

Conductivity no-snow-cover dry-deposition (μmhoscm^{-1})

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	6.2	12	2.1	4.1
16	4.2	15	2.2	2.0
17	19.6	15	2.2	17.4
18	*****	15	2.2	*****
30	5.6	29	1.8	3.8
31	5.9	29	1.8	4.1
32	4.5	29	1.8	2.7
33	3.3	29	1.8	1.5
62	7.9	61	2.0	5.9
63	9.2	61	2.0	7.2
67	4.1	66	2.6	1.5
83	4.6	82	1.8	2.8
85	3.8	84	1.3	2.5
86	5.8	82	1.8	4.0

Conductivity snow-cover dry-deposition (μmhoscm^{-1})

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	9.0	70	15.3	-6.3
77	2.5	76	2.89	-0.39
78	8.2	92	7.74	0.46
79	49.0	92	7.74	41.26
80	25.3	92	7.74	17.56
81	*****	92	7.74	*****

Table C-10 Dry-deposition sample concentrations (continued).

Filtrable residue no-snow-cover dry-deposition concentrations ($mg \ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	*****	12	0.0	*****
16	2.6	15	*****	*****
17	*****	15	*****	*****
18	*****	15	*****	0.0
30	*****	29	0.7	*****
31	*****	29	0.7	*****
32	*****	29	0.7	*****
33	*****	29	0.7	*****
62	*****	61	0.0	*****
63	*****	61	0.0	*****
67	0.0	66	12.8	*****
83	0.0	82	0.0	0.0
85	0.0	84	0.3	-0.3
86	1.0	82	0.0	1.0

Filtrable residue snow-cover dry-deposition concentration ($mg \ell^{-1}$).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	16.35	70	24.2	-7.85
77	25.7	76	26.1	-0.4
78	89.9	92	18.0	71.9
79	28.1	92	18.0	10.1
80	56.5	92	18.0	38.5
81	37.3	92	18.0	19.3

Table C-10 Dry-deposition sample concentrations (continued).

Total residue no-snow-cover dry-deposition concentrations (mgℓ⁻¹).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
11	6.7	12	7.0	-0.3
16	4.8	15	2.2	2.6
17	5.6	15	2.2	3.4
18	2.3	15	2.2	0.1
30	7.9	29	1.0	6.9
31	0.9	29	1.0	-0.1
32	5.3	29	1.0	4.3
33	2.5	29	1.0	1.5
62	11.4	61	1.6	9.8
63	5.9	61	1.6	4.3
67	14.5	66	19.4	-4.9
83	0.0	82	0.0	0.0
85	12.7	84	0.7	12.0
86	5.1	82	0.0	5.1

Total residue snow-cover dry-deposition concentration (mgℓ⁻¹).

Original sample number	Original concentration	Test sample number	Test concentration	Corrected concentration
71	11.850	70	*****	*****
77	11.6	76	9.8	1.8
78	48.9	92	9.77	39.13
79	23.2	92	9.77	13.43
80	25.6	92	9.77	15.83
81	30.6	92	9.77	20.83