1990

The effect of mid-winter snowmelt events on nitrate and ammonium concentration in the unsaturated and shallow saturated zones: A case study

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Recommended Citation

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The Effect of Mid-winter Snowmelt Events on Nitrate and Ammonium Concentration in the Unsaturated and Shallow Saturated Zones: A Case Study

BY

Richard J. Elgood

B.A., Wilfrid Laurier University, 1986

THESIS

Submitted to the Department of Geography
in partial fulfilment of the requirements
for the Master of Arts degree

Wilfrid Laurier University
1990

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ISBN 0-315-58911-6

ABSTRACT

During the period December 19, 1987 to March 28, 1988, the unsaturated and shallow saturated groundwater zones under two agricultural land use sites, near Waterloo Ontario, were investigated to determine the effect of snowmelt percolation on the groundwater quality.

Periods of widely fluctuating temperatures and sporadic rain events produced large changes in snowpack water equivalence. The resulting infiltration of snowmelt significantly altered the extent of the saturated area and the concentration of N (nitrogen) ions in both the soil column and percolate water.

An N flux from the vadose (unsaturated) zone to the shallow phreatic (saturated) zone, occurring in association with snowmelt events, suggests that mineralization of organic soil N and N fertilizer residues occurred during wetting/drying and freeze/thaw cycles. It is demonstrated that N input from precipitation is minor in respect to the total mass of N exported from the vadose zone.

ACKNOWLEDGEMENTS

I would like thank all those who participated in the production of this thesis. A special thanks to my advisor Dr. M. English, his advice, encouragement and critical review of the manuscript is greatly appreciated. I also wish to acknowledge Dr. H. Saunderson, Dr. D. Peirson and Dr. R. Kominar (out-side reader) for their constructive comments.

The study sites were located on the property of Mr. J. Snyder and I am very grateful for access to the property. Dr. D. Peirson provided access to the analytical equipment used. Mr. M. Stone helped install field equipment, his advice and encouragement is greatly appreciated.

Thanks Marty, Larry and Mike, for your endurance of freezing temperatures, rain and snow while collecting field data. Thanks also to fellow grad students who assisted with computing, and too Elizabeth Macey who drafted several of the figures.

Yes Cory, its really finished!

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CHAPTER ONE
INTRODUCTION

1.0 Introduction

It is widely recognized that the problem of eutrophication is linked to increased nutrient levels in aquatic ecosystems. Eutrophication may be accelerated by human activities. The result of excessive nutrient loading, and associated increases in plant productivity, is often observed in the reduction of water quality for municipal water supplies, recreational use, and fish habitat (Thomann, 1987; Waite, 1984; Gower,1980; Wiens, 1980).

In recent years response to the problem of eutrophication is illustrated by numerous studies emphasising the relationship between human activities and nutrient export from drainage basins (Switzer-Howse, 1983; Beaulac and Reckhow, 1982; Neilsen, 1982; Hill, 1978; Dillon and Rigler, 1974). Of the different land uses, agricultural land is most susceptible to natural processes, such as erosion and leaching, which alter the cycling of nutrients and chemicals through the soil system and its biogeochemical cycles (Kennedy, 1978; Park, 1980). Consequently, the net effect of different agricultural practices on water quality has been examined in some detail (Hubbard, 1983; Caporali *et al.*, 1981; Hill, 1978; Asmussen *et al.*, 1975; Schuman *et al.*, 1975; Romkens *et al.*, 1973).

1.1 *Statement of the problem*

Nitrate (NO_3-) enrichment of surface and groundwater remains an increasingly serious problem and nitrate-nitrogen (NO_3^--N) is found to be the most common contaminant in groundwater (Freeze and Cherry, 1979). Furthermore, there is a limited amount of information pertaining to the amount of N lost from soils during winter months. If soil sources are responsible for large fall and winter increases in river nitrate concentration (Haynes, 1986; Edwards, 1986), and NO_3^--N export from agricultural areas is to be minimized, it is important that factors which influence the availability of soil N, and potential loss, during winter months are well understood. Development of measures which will minimize the impact of agricultural practices on water quality requires a better understanding of nutrient transport under varying cropping and tillage conditions, and soil types (MOE, 1986; Sheppard, 1985). Knowledge of factors affecting N loss during snowmelt, and flowpaths through which N may be transported, is critical in constructing chemical mass balances and assessing the winter contribution of agricultural drainage to the N content of surface waters. The remainder of this chapter provides a review of the N cycle and of some of the literature related to over-winter changes in soil N content.

1.2 *Nitrogen Cycle*

In the environment nitrogen is continuously being converted from one form to another through biological and physical processes. In combination all of these processes constitute the nitrogen cycle (Figure 1).

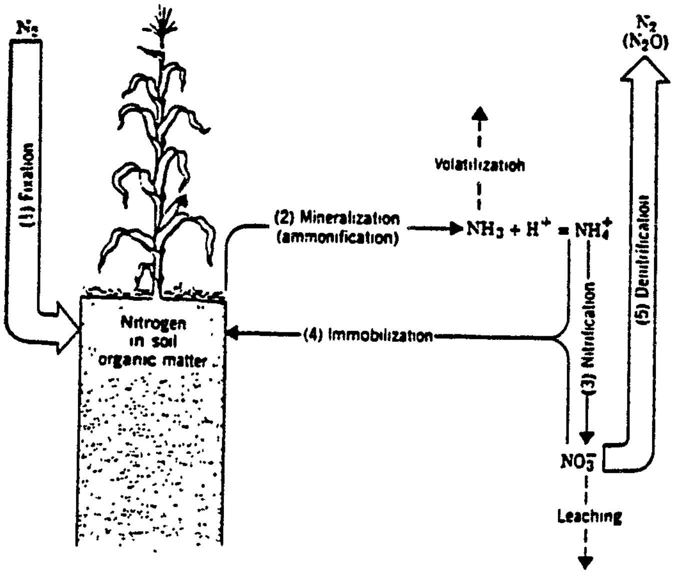


Figure 1. Nitrogen cycle. (After Foth, 1984)

The two primary conversions in the nitrogen cycle are nitrogen fixation and denitrification. Nitrogen fixation is the process where N_2 gas is converted to chemical compounds containing plant usable forms of nitrogen. This process is performed primarily by nitrogen fixing bacteria blue-green algae some of which have a symbiotic association with plants. Nitrogen is returned to the atmosphere through the process of denitrification in which denitrifying bacteria in the soil convert nitrogen back into gaseous forms. The processes of nitrogen fixation and denitrification explain the general cycling of nitrogen from the atmosphere, its addition to the soil, and its subsequent return to the atmosphere.

As indicated in Figure 1, a subcycle exists within the soil where following fixation nitrogen may undergo transformations through the processes of mineralization and nitrification. Nitrogen mineralization, the decomposition of nitrogen containing compounds, results in the release of potentially mobile inorganic nitrogen in the form of ammonium (NH_4^+). Nitrification, a two step process in which ammonium is converted to nitrite (NO_2^-, and then to nitrate (NO_3^- occurs as the result of the oxidation of NH_4^+. Uptake of NH_4^+ and NO_3^- by roots and organisms is referred to as immobilization, and is the process whereby nitrogen is re-incorporated in organic form.

1.3 *Nitrogen Loss*

There are three ways in which nitrogen can be transported from the soil and into surface streams, these are:

1) in solution in subsurface drainage;

2) in solution in surface runoff;

3) in association with sediment in surface runoff.

The loss of nitrogen is not limited to the soluble fraction removed by leaching and/or runoff. Denitrification may sometimes account for a considerable loss of N in addition to that removed by drainage and/or plant uptake. The process of denitrification is most likely to occur when nitrate or nitrite is present together with decomposable organic matter under conditions of oxygen deficiency (Hesse, 1971).

Factors determining the amount of N loss include; the amount and location of N in the soil profile; the degree to which chemical transformations occur within the soil, which are affected by various parameters including temperature, pH, moisture content etc.; and the timing and relative volume of water flowing through the soil profile (Bergstrom, 1987; Stevenson, 1986; Haynes, 1986; Lund, 1974)

1.3.1 *Nitrogen Availability*

As suggested in section 1.1 there are three major forms of N occurring in mineral soils, these include:

1) organic N associated with soil humus;

2) ammonium N fixed by certain clay minerals;

3) soluble inorganic ammonium and nitrate compounds.

The largest proportion of N in soil is associated with organic matter, is unavailable for plant use, and is protected against rapid microbial release. The amount fixed by clays varies depending upon the amount and nature of clay present. NH_4^+ ions are absorbed or adsorbed by mineral fractions in such a way that ions are relatively water insoluble and unexchangeable (Brady, 1974). Dissolved inorganic N (NO_2^-, NO_3^- and NH_4^+) constitutes a small percentage of Total N, seldom more than 1-2%, the exception being where large applications of inorganic fertilizer are made. Although N which occurs as dissolved inorganic N represents only a small proportion of total N it is the form most directly available to plants (Brady, 1974). Other forms of N in soil may include traces in the gaseous forms of dinitrogen, and nitrogen oxides.

Reviews of N forms and their bioavailabilty have found that the most commonly found form of N in groundwater is soluble inorganic NO_3^--N (Freeze and Cherry, 1979). Nitrate originates from organic N or ammonium which occur naturally or are introduced to the soil zone by human activities. Biological availability of N is determined by the rate at which organic N is converted to plant usable (inorganic) forms of nitrate and ammonium, which is a function of rates of mineralization, nitrification, denitrification, and the rate of immobilization.

Nearly all changes in soil N are due to microbial activity, which itself is strongly influenced by micro-climate conditions. To a large degree mineralization, ammonification and nitrification, of organic N is controlled by soil temperature and moisture content (Foth, 1984; Myers, 1982; Brady, 1974). Production of NO_3^- decreases with decreasing temperature; below 5 °C very little NO_3^- is formed. Moisture content of the soil is of major importance since the source of O_2 and CO_2 required by nitrifying bacteria is present in the solution phase of the soil. In conditions of excess moisture, soil pores become saturated thereby restricting the recharge of O_2. This results in anaerobic conditions which provide an environment favourable for denitrification and gaseous loss of N.

A number of other factors also contribute to the determination of the relative proportions of soil N. These include:

- climate - temperature
  - precipitation - type, amount and distribution
    - N content

- soil properties - physical properties
  - organic N content
  - C/N ratio
  - moisture content
  - soil substrates

- land management - land use: crop type, tillage etc.
  - drainage
  - fertilizer applications
    - amount/timing
    - manure/chemical

Stevenson (1986) provides a good review of the influence of these factors in *Cycles of Soil.*

1.3.2 *Temporal Variation in N Export from Soil*

It is recognized that Nitrogen (N) export from terrestrial systems is strongly linked to the hydrologic cycle, and is biotically regulated, resulting in clearly defined seasonal variations in the output of ions (Likens and Bormann, 1977). During the growing season biological utilization and denitrification limit the amount of soluble inorganic N in the soil. Therefore the output of N ions to surface water is generally low during summer months. In the northern temperate climatic region the majority of N is lost to surface waters between January and April (Haynes, 1986; Sharpley, 1981; Chichester, 1977). During this period active plant growth is minimal and large volumes of runoff and infiltrating water result from winter and spring thaws. Given these conditions snowmelt events may act to displace N ions which may have accumulated in the soil as the result of the mineralization of soil nitrogen and crop residues, animal excreta or of excess fertilizer dressings (Bergstom, 1987; Neilsen *et al.*, 1982; Gower, 1980; Kauppl, 1979; Brady, 1974). Furthermore, it is recognized that alternate drying and wetting of soils can account for a significant portion of the variability in nitrogen mineralization; where wetting of a soil is often accompanied by a surge of microbial activity and N mineralization (Haynes, 1986; Myers *et al.*, 1982; Cassman and Munns, 1980; Kowalenko and Cameron, 1976; Campbell *et al.*, 1970; Mack, 1963). This flush is due to the remineralization of dead, nitrogen-rich microbial biomass (Campbell *et al.*, 1978). Thus as yearly maxima in percolate volume often occur during winter months (Haynes, 1986), a major proportion of annual nutrient losses can be expected to occur during snowmelt and spring runoff (Hill, 1986; Neilson, 1982; Burwell, 1977).

Similarly freeze/thaw cycles have been identified as an important factor contributing to the availability of inorganic N in soil. Often in association with freeze/thaw events there is a flush of microbial activity and N mineralization, and therefore these cycles also promote nitrification and thus nitrate mobilization (Edwards, 1986; Haynes, 1986; Dorman and Evans, 1983; Likens and Bormann, 1977).

1.3.3 *Over-winter change in mineral N content*

Nitrogen loss associated with leaching or runoff is not only a water quality concern, it is also an economic concern as increased losses necessitate increased fertilizer applications (Burwell, 1977; Cameron, 1978). In the attempt to maximize production potential and reduce fertilizer use research has been conducted to determine the reliability of soil tests in the prediction of spring fertilizer requirements (Read, 1979; Bauder, 1979).

Soper *et al.*, (1971) found that spring determination of NO_3^--N content in the soil profile was a good test for predicting cereal responses to N fertilization for certain Manitoban soils. However predictions of fertilizer requirement are often based on soil sampling conducted during the fall on the assumption that little change will occur between fall and spring (Malhi, 1985). Research in various geographical regions, and under different soils, indicates that variable changes may occur in soils during winter months and that significantly different nutrient concentrations can occur between fall and spring sampling (Cameron, 1978; MacLean, 1977; Campbell, 1970). Soils may contain more N in spring reflecting mineralization of organic N from crop residues and soil organic matter (Malhi, 1983, 1985), but losses occurring through leaching and denitrification may also reduce available N content in spring (Sheppard and Bates; 1985;

MacLean, 1977; Read and Cameron, 1977). It has been demonstrated that the principle movement of solutes occurs during percolation of winter rainfall and/or snowmelt water (Bergstrom 1987; Haynes, 1986; Bauder, 1979; Chichester, 1977).

In addition to climatic influences, particle size and soil texture have been demonstrated as important factors in controlling leaching and removal of soil NO_3^--N and NH_4^+-N. In general terms leaching from sandy soils results in greater losses than from clay soils since in a sandy soil the entire water input quickly reaches the groundwater table (Lind, 1979; Bauder and Montgomery, 1979; Devitt *et al.*, 1976; Lund, 1974). In clayey soils not only is percolation slower but there is also a greater nutrient adsorbing capacity (Sowden, *et al.*, 1977; Brady 1974). Profiles with high clay content or layers of clay also tend to restrict water movement thereby reducing the leaching factor (Devitt *et al.*, 1976). Sheppard and Bates (1985) suggest that, given the semi-humid climate of southern Ontario, sandy loam and silt loam soils may generally be depleted of available nitrate through the over-winter processes of leaching and denitrification. However their research also found that spring and fall soil NO_3^--N content were almost equal in a clay loam soil.

1.4 STUDY OBJECTIVES

Nitrogen losses from leaching and direct runoff in agricultural areas significantly influence the amount and temporal pattern of N export in surface waters. Research has delineated factors which influence N loss. However it remains difficult to predict the behaviour of soil N under winter field conditions. Changes between fall and spring soil N content may vary significantly from one area to another depending upon variations in the hydrologic cycle and ionic concentration of precipitation; differences in land use management practices and soil type.

This work examines over winter change in NO_3^--N and NH_4^+-N concentration of soil and shallow ground water at a study site in Southwestern Ontario. To determine the importance of snowmelt events and their contribution to the export of soil N, particular attention is paid to the periodic mid-winter thaw events commonly experienced in this area.

Specific objectives of this research are:

1) to examine the net change in the content of available soil N in the unsaturated zone of a silt loam during the winter months;

2) to examine the effects of freeze thaw events and associated snowmelt events upon movement of soil N, as reflected in the N concentration (NO_3^--N and NH_4^+-N) of groundwater;

3) to determine whether the atmospheric contribution of N is a significant factor contributing to the N concentration of percolate water in the soil zone under consideration.

To achieve these objectives field work serves to determine:

1) total volume of precipitation;

2) concentration of NO_3^--N and NH_4^+-N in precipitation (rain and snowfall);

3) changes in snowpack water equivalence and N (NO_3^--N and NH_4^+-N) content of the snowpack;

4) N content of meltwater prior to interaction with the ground surface;

5) changes in N concentration of shallow groundwater;

6) changes in soil moisture and N content (NO_3^--N and exchangeable NH_4^+-N).

CHAPTER TWO

METHODS OF INVESTIGATION

2.0 Introduction

Winter weather conditions have a strong influence on the temporal distribution of available nitrogen (NO_3^--N and NH_4^+-N) in agricultural soils (Haynes 1986; Sheppard and Bates 1985). During snowmelt events there is the potential for large quantities of water to be released from temporary storage in the snowpack. Initially, melt water may not be able to infiltrate frozen or partially frozen ground, but once initiated, percolation of melt water can induce changes in the forms of nitrogen present in the soil (Read and Cameron, 1979; Malhi, 1985). Inorganic nitrogen may subsequently be leached from the soil, altering not only the N content of the soil column, but also increasing the export of N in drainage waters (Bergstrom 1987; Chichester, 1977). Although factors affecting mineralization and leaching of nitrogen have been extensively researched, few studies have examined the specific timing and magnitude of winter N loss in Southern Ontario.

To contribute to the understanding of the effect of melt events on winter loss of available N, this research investigates N dynamics during snowmelt; and examines the nitrogen content of precipitation, the accumulated snowpack, soil, and groundwater.

2.1 *Study Area*

The study area is located outside the village of Winterbourne, Ontario, approximately 25 km north of Waterloo (Figure 2). Due to poor drainage, soils in this

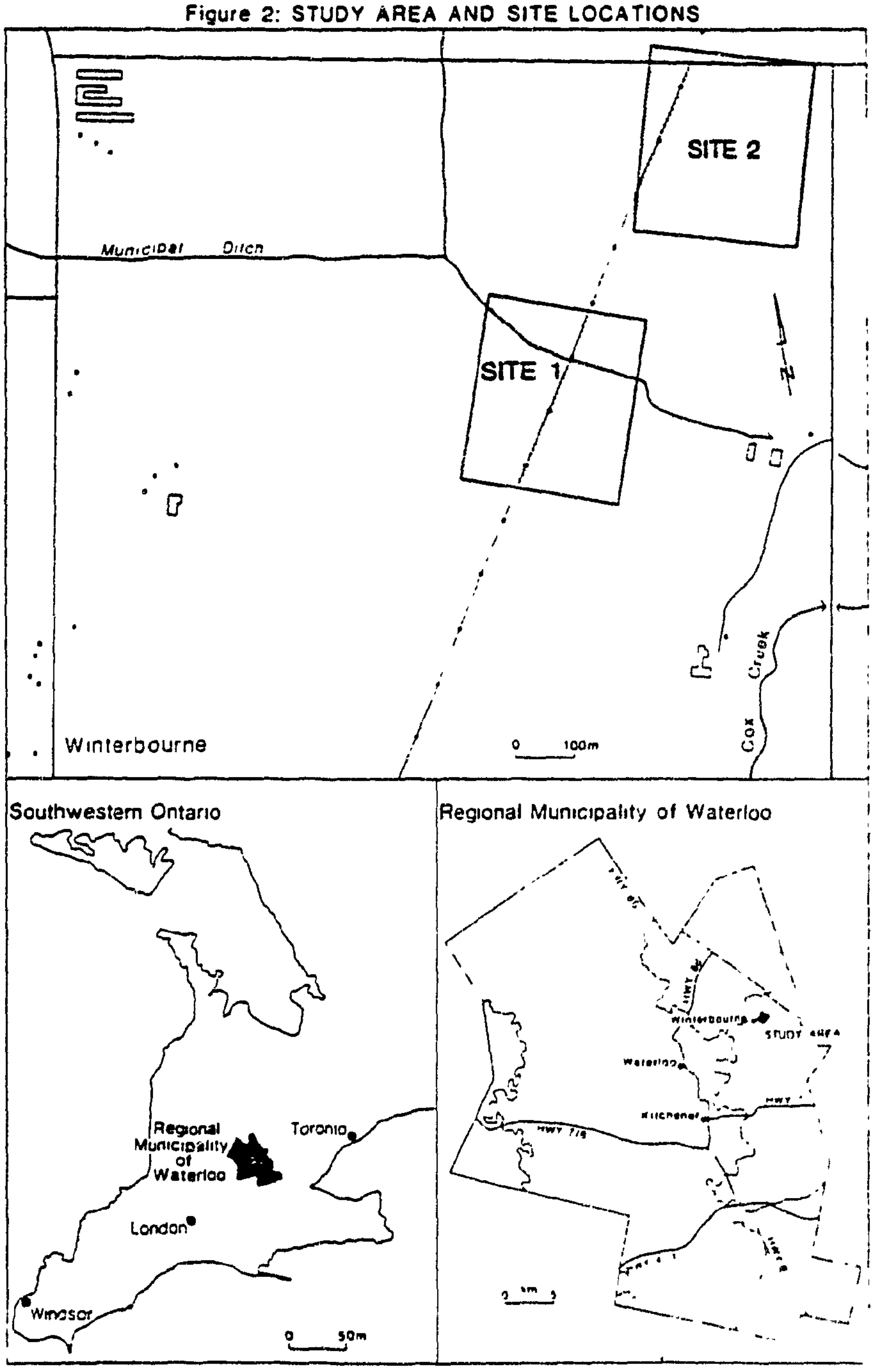


Figure 2. Study area and site location.

area generally have a seasonably high water table and are highly susceptible to frost (Preasant and Wicklund, 1971). This particular site was chosen for several reasons, the most significant being, proximity to Waterloo, a mixture of land use, gently sloping topography, and the existence of tile drainage lines. A variety of land use allows the comparison of N change under two different management conditions, and the combination of low slope and subsurface drainage increase potential infiltration by minimizing ponding and surface runoff.

2.2 *Site Location*

On the basis of land use and over winter tillage condition, two separate sites were chosen within the study area. Site 1 was established in a field that is cropped in rotation with a mixture of grains and forage crops. During this particular season a combination of hay stubble and red clover was maintained as a cover crop during the fall and winter months. Site 2 was located in a field which is continuously cropped with corn. This site had been plowed in late November prior to instrumentation. The two sites are adjacent, both draining into a County Municipal Drainage ditch which bisects the study area (Figure 2).

2.3 Precipitation Measurement and Collection

2.3.1 *Rain*

Two gauges (P1,P2) consisting of polyethylene buckets (inside diameter = 24cm) were installed to measure rainfall during the study period (Figure 3). The buckets were mounted on wooden posts with the orifice 1.0m above the ground surface. The readings from P1 and P2 varied minimally (+/- 0.03cm), and further comparison with values obtained when rain fell in the empty snow lysimeter indicate that the catch in all three instruments was strongly correlated. Table 2 presents the precipitation measurements used to determine the accuracy of the data collection. Based on these results, the mean value obtained from gauges P1+P2 will be reported as the depth of rainfall (cm) for each event.

The volume of precipitation was measured and a sample for N analyses was collected from both rain gauges within 24 hours of each precipitation event. On most occasions each gauge provided more than the minimum 30 ml required for analyses. On certain occasions the minimum was collected as a composite of the catch in both containers.

Water Equivalence cm

Date	P1	P2	L1	Mean
09/12/87	0.88	0.91	0.93	0.91
12/12/87	0.28	0.28	0.30	0.29
20/01/88	0.43	0.43	0.47	0.44
01/02/88	1.02	1.03	1.06	1.04
26/03/88	1.01	1.01	1.11	1.04
04/04/88	2.66	2.68	2.75	2.69

Table 1. Comparison of Precipitation Catch by Rain Gauge (P1.P2) and Lysimeter (L1) during rainfall.

2.3.2 *Snow*

Due to equipment constraints the rain gauges were also used as snow gauges. After each snowfall, samples were collected in clean plastic bags, transported to the lab, melted at room temperature, the volume measured and then analyzed for NO_3^--N and NH_4^+-N content.

2.3.3 *Snow Survey*

To measure the change in water content of the snowpack snow surveys were conducted along the snow courses shown in Figures 3 and 4. A snow profile was exposed at each sampling location and the depth of each distinct layer was recorded to the nearest 0.1cm. Three measurements were performed for each layer and the average value recorded. Water equivalence values for each layer were also determined in the field by weighing samples of a known volume (100cc). After measurements were completed, the snow pit was back-filled to prevent exposure to radiation and/or precipitation. Total water equivalence was later determined by multiplying the mean water equivalence of each layer with its corresponding depth, and summing the values of all layers in the profile.

Composite snow samples were obtained from beside each snow pit, placed in clean plastic bags and stored in a cooler for transportation to the laboratory. Samples were subsequently melted at room temperature, filtered through a pre-rinsed 0.45 μm glass microfibre filter and analyzed immediately using the methods reported in section

2.5.2.

At the time of the first snow survey on December 19, the values obtained for water equivalence at Site 1 provided a mean value of 5.5cm ($n = 10$) with a standard deviation of 0.9cm. Individual water equivalence values ranged from 3.9cm to 7.0cm; variation in the pattern of accumulation occurring due to differences in the type of ground cover (hay stubble vs. compacted clover), and variations in surface topography. To determine whether the sample size provided a statistically acceptable mean water equivalent, the original values were substituted into the equation

$$N = (s/e * t)^2 \qquad \text{Equation 1.,}$$

where N = number of samples required, s = standard deviation of the original sample set, e = error deemed acceptable and t = the desired confidence level (Avery, 1975).

$N = (s/e * t)^2$ where $s = 0.95$
$e = 5\%$ (0.25 cm weq)
$t = 0.01$

$N = 11.59$

The result of this calculation indicates that a sample size of 12 is required to provide a mean value acceptable at a 99% confidence level as having an error of +/- 5% water equivalence.

At Site 2, the ridge/furrow topography created by plowing results in disproportionate accumulation of snow in furrows. At the time of the first survey, and for most of the study period, snow accumulated in the furrows while the soil remained bare along ridges between furrows. This condition, coupled with the fact that numerous crevasses occur in the uppermost soil layer, makes it difficult to calculate water equivalence of the snowpack at this site. To provide the best estimate of water potential, the mean water equivalent was determined between furrows, and this value was applied mathematically to the ratio of area between furrows and the area along the ridges between furrows (2:1).

On February 5, an extensive snow survey was conducted to verify whether this methodology, and the method used at Site 1, was appropriate, and whether values obtained on previous sampling dates were statistically acceptable. During this survey 2 samples were obtained from 26 locations at site 1 and 3 values were recorded at each of 18 locations at site 2.

The survey at Site 1 was designed to obtain an equal number of samples from areas containing hay stubble and from those without. At Site 2, the survey provided an equal number of samples from furrows and ridge tops. The mean values obtained are presented below as Table 2, and a complete record of the values obtained may be found in Appendix A.

	Site 1		**Site 2**	
	Stubble	Open	Furrow	Ridge
No. of observations	18	18	26	26
Mean value	1.5	1.3	1.2	0.7
Maximum value	2.3	1.6	2.1	1.2
Minimum value	1.1	0.7	0.5	0.1
Standard deviation	0.3	0.2	0.4	0.3

Table 2. Values of Water Equivalence (cm) Determined During Extensive Snow Survey (Feb. 5 1988).

Using the t-test to compare mean values (Freund, 1981), the results derived from

Site 1 data indicate no significant difference ($P=0.01$) between the water equivalence of samples from open areas and areas containing hay stubble (Table 3). At Site 2, a significant difference was observed between the snowpack water equivalence in the furrows and that which accumulates on top of the ridges between the furrows. The difference between the mean values (57%) is approximately equal to the ratio of the area between furrows and on ridge tops and the factor used in the mathematical calculation of water equivalence (2:1). It is therefore suggested that the methodology employed to calculate snowpack water equivalence at Site 2 provides an acceptable mean value.

Site 1 $t = 1.853$
$df = 32$
critical value of [t] ($P = 0.01$) = 2.75

Site 2 $t = 5.733$
$df = 50$
critical value of [t] ($P = 0.01$) = 2.68

Table 3. t-values used in analysis of Snowpack Water Equivalence.

2.3.4 *Snow Lysimeter*

Variation in the volume and chemical concentration of meltwater is an important consideration when assessing the temporal change in N content of soil and groundwater. A snowmelt lysimeter may be used to estimate the amount of melt and the downward flux of solutes moving through the snowpack. In this study three snowmelt lysimeters were installed at site 1 (Figure 3), to estimate the loss of volume and NO_3^--N and NH_4^+-

N from the snowpack during snowmelt events. These devices consisted of plastic lined boxes ($0.81m^2$), with outlet pipes draining into collection chambers below ground level. Snowmelt was channelled through the outlet and collected in a 22 litre polyethylene bucket. Volume was measured on each sampling date, and two 125 ml samples were taken for N analyses.

Due to frost action and an unusually high water table, two of the snowmelt lysimeters (L2 and L3) were no longer functional on December 23, 1987. Lysimeter 1 (L1) was located closer to the drainage ditch in an area of more highly permeable material, and there was no disturbance of the lysimeter or collection barrel at this location. A reduction in the water table elevation at this location results from greater drawdown to the stream, and higher permeability is due to alteration of the natural soil profile during construction and maintenance of the drainage ditch.

2.4 Groundwater

2.4.1 *Measurement and Collection*

A network of groundwater wells was installed at each site to monitor changes in the elevation of the water table (Figures 3 and 4). These wells also provided water samples for N analyses. Two lengths of well casings were utilized: the first reached a depth of 30-40cm; the second a depth of 95-105cm, passing into the saturated zone.

The well casings were constructed from polyvinyl chloride pipe (PVC), with an inside diameter of 5cm. The bottom 30cm of the pipe was slotted with 0.2cm openings to allow lateral flow into the well. The bottoms were capped and wrapped in vinyl mesh and nylon screen to prevent sedimentation in the base (Lowrance *et al.*, 1984). The above ground ends were also capped to prevent direct deposition into the wells.

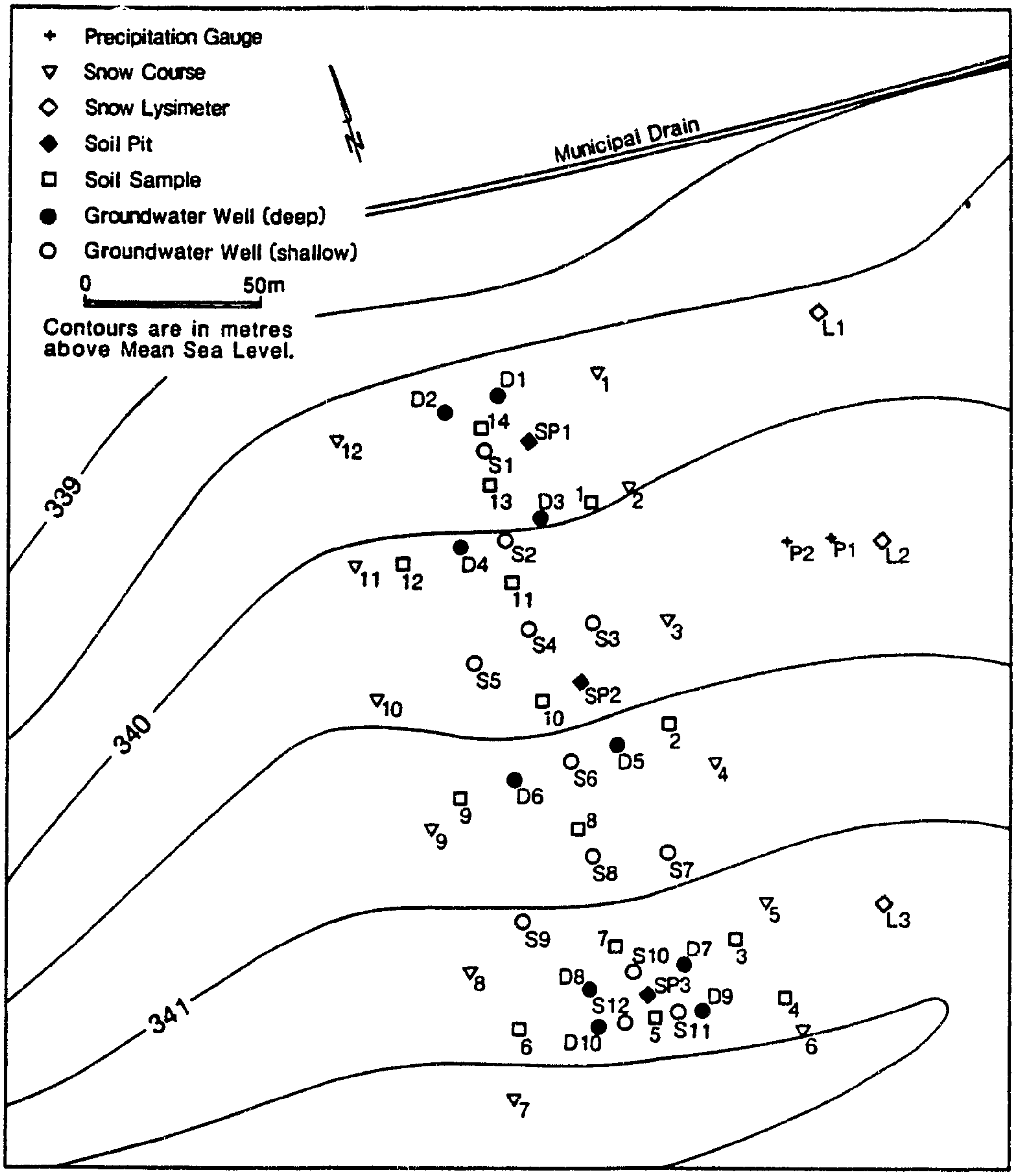


Figure 3. Site 1, instrumentation and sampling locations.

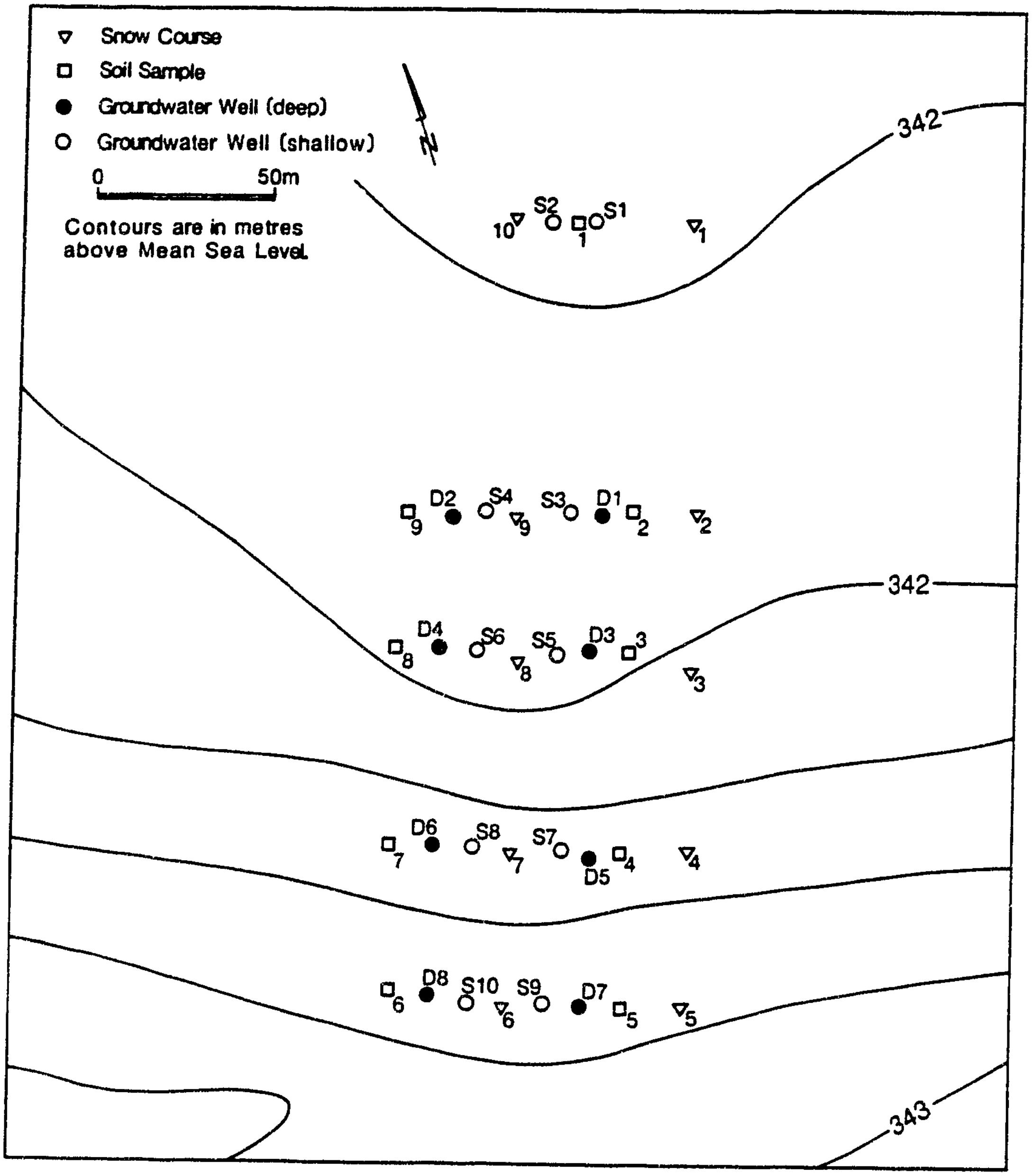


Figure 4. Site 2, instrumentation and sampling locations.

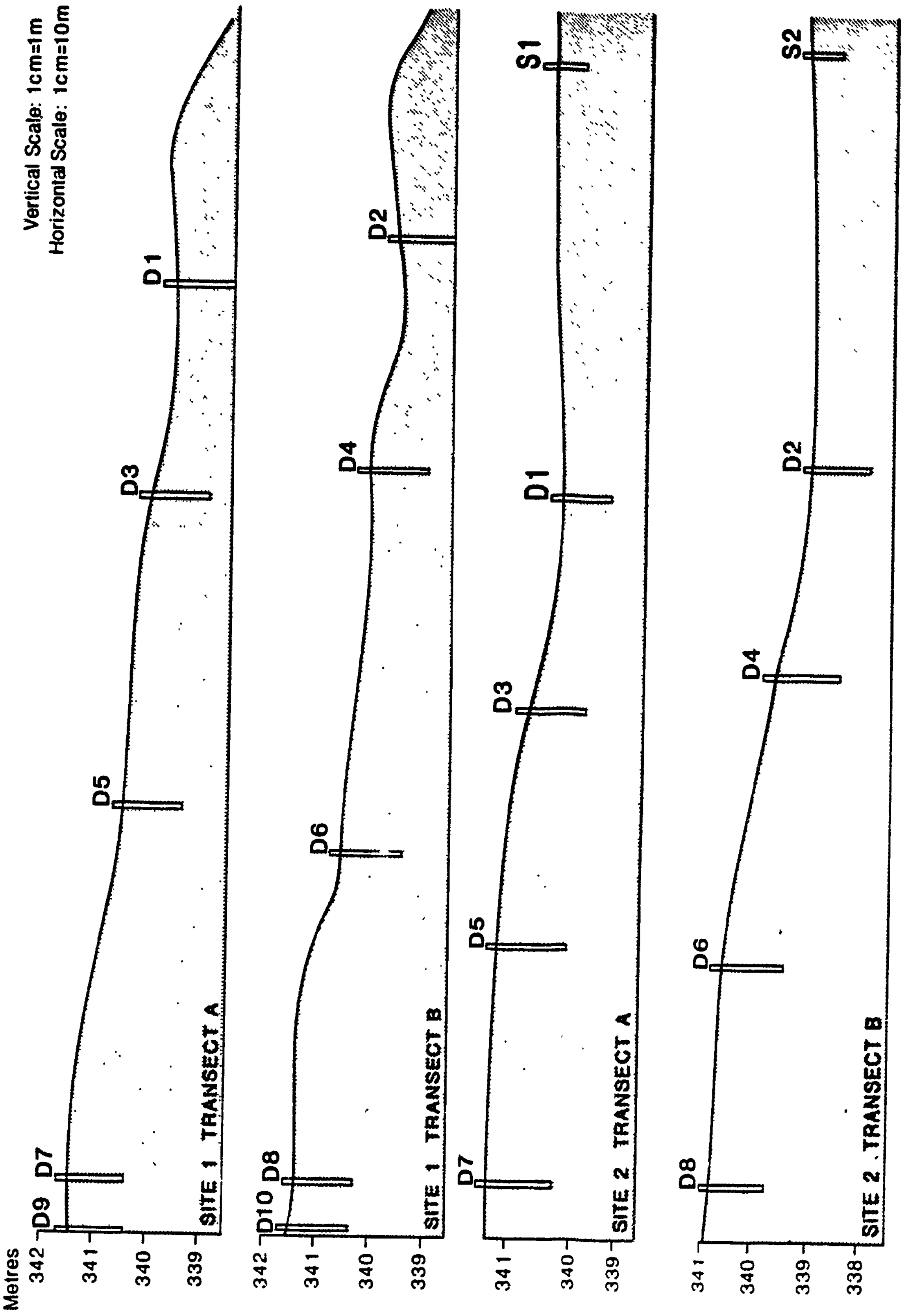


Figure 5. Location and base elevation of groundwater wells.

2.4.2 *Location of Groundwater Wells*

The positioning of wells was determined after an on-site inspection and was based on the assumption that ground water flow paths can in part be attributed to, and determined by, surface topography.

At site 1, the deeper wells (wells D1 to D10) were located along two transects, which rise approximately 2m over a distance of 190m, between the drainage ditch and the field boundary. Figure 5 illustrates the positioning of these wells in relation to changes in surface topography. The 'deep' wells were coupled with shallower wells (wells S1, S2, S6, S10, S11, and S12) which were positioned to provide samples from the 0-30cm depth. Additional samples were obtained from wells S3, S4, S5, S7, S8, and S9 (Figure 3).

At site 2, the deep wells (wells D1 to D8) were located along two transects between the highest and lowest areas of a gentle swale rising approximately 1m in a distance of 220m (Figure 5). At this site, each deep well was also coupled with a shallow well (Figure 4).

2.4.3 *Sampling Procedure*

When sampling, each well was pumped dry and allowed to recharge prior to observations being recorded. Elevation of the water table was measured using a weighted tape, and a 125ml sample, for chemical analyses, was collected using a peristaltic pump.

2.5 Water Chemistry

2.5.1 *Sample Collection, Preparation and Storage*

Groundwater, rain and snow lysimeter samples were collected in 250 ml polyethylene bottles (Env. Can., 1979). To minimize the possibility of contamination all sample bottles and lab equipment were routinely washed in 20% sulphuric acid and rinsed thoroughly with distilled water.

At the laboratory, a portion of each sample (25-30ml) was filtered through a 0.45 micron glass fibre filter which was pre-washed with 30 ml of distilled water and 20 ml of the sample. The filtrate was transferred to a 30 ml screw top test tube, capped and refrigerated at 2-4 degrees Celsius until all samples were ready for analysis.

2.5.2 *Analytical Methods*

A review of the literature indicates that preferred methods for the analysis of NO_3^--N and NH_4^+-N include colorimetric methods and the use of ion specific electrodes following nitrate reduction and ammonium distillation. In this study ammonium contents were determined colorimetrically using the Berthlot Ammonium Test (Peirson, 1987), while Nitrate contents were determined by ultraviolet spectrophotometry. It is recognized that the potential for interference by organic matter exists in this method, however it has been demonstrated that the Nitrate content of waters, sewage effluents and soil solutions determined using ultraviolet spectrophotometric methods are in good agreement with the nitrate reduction and ammonium distillation method (Bastien *et al.*, 1957; Hoather and Rackman, 1959; Crawse, 1967).

Analyses for NO_3^--N and NH_4^+-N were conducted within 48 hours of collection (Env. Can., 1979). Replicate determinations (N = 3) were averaged to provide the final concentration of both NO_3^--N and NH_4^+-N. When necessary samples were diluted by as much as 20:1 to provide accurate measurement.

Standard solutions were analyzed to determine the level of variation which would normally be encountered during analyses of NO_3^--N and NH_4^+-N concentration. Determination of standards using the Berthlot Ammonium Test found a maximum error of +/- 0.05 mg/l, while the average error range was determined as +/- 0.03 mg/l. The average error observed in the ultraviolet spectrophotometry analysis of NO_3^--N was calculated as +/- 0.14 mg/l and the maximum +/-0.32 mg/l.

2.6 Pedological Methods

2.6.1 *Sample Location*

In order to follow temporal changes in exchangeable NO_3^--N and NH_4^+-N, and moisture content, soil samples were collected on six separate occasions during the study period. The first samples were collected in early January just after soils had frozen, and the fifth set of samples were taken in late March after soils had thawed. A final sixth sampling was conducted in April, providing an indication of potential change in N content after spring melt and prior to fertilization.

At sites 1 and 2, soils were sampled at ten locations adjacent to the 'deep' wells (Figures 3 and 4), and were chosen in order that soil data could be examined in conjunction with data obtained from the analyses of groundwater samples. Four additional sampling locations were added at Site 1 to provide better coverage of this site which showed greater variation in its topography and surface drainage patterns.

Soil samples, obtained using a hand auger (diameter = 4cm), were placed in plastic bags and transported to the laboratory in a Coleman cooler and refrigerated prior to analysis. Composite samples were obtained from three depths: 0-30cm, 30-60cm, and 60-90cm. The excavation of 6 soil pits showed that the topsoil and first subsoil horizons were approximately 30cm deep, thus demonstrating a relatively uniform profile along the instrumented transects. On dates following the initial sampling, samples were taken from within 1.0m of the original location.

2.6.2 *Soil Analyses*

2.6.2.1 *Moisture Content*

Moisture content, expressed as a percentage of water on an oven dry basis, was determined after drying for 24 hours at 50 degrees Celsius (Foth, 1984). The dried samples were ground to pass through a 2mm sieve and sealed in plastic bags for subsequent chemical analyses.

2.6.2.2 *Nitrate and Ammonium Determination*

NO_3^--N and exchangeable NH_4^+-N content were determined by extracting 5 grams of oven dry soil in 50 ml of 2N KCL (Hesse, 1971). The solution was shaken for 1 hour at a rate of 80 cycles per minute, and the filtrate from this extraction analyzed using colorimetric and ultraviolet spectrophotometry as previously outlined in section 2.5.2.

Although replicate analyses were not conducted on the entire sample set, the values obtained from five pairs of replicate samples demonstrate a reasonable level of precision. Table 4 indicates the difference observed between two individual extractions of the same sample and in each case the difference falls within the range of the maximum error of the method (see section 2.5.2).

NO_3^--N	A (mg/l)	B (mg/l)	A-B (mg/l)	A-B (µg/g)
1)	2.62	2.62	0.00	0.00
2)	2.91	2.62	0.29	2.90
3)	2.62	2.47	0.15	1.50
4)	2.62	2.91	0.29	2.90
5)	2.62	2.35	0.27	2.70

Range of difference: x_1-x_2: 0.0 - 2.9 µg/g
Replication of Standards +/- 0.28 mg/l = +/- 2.8 µg/g

NH_4^+-N	A (mg/l)	B (mg/l)	A-B (mg/l)	A-B (µg/g)
1)	0.350	0.336	0.014	0.14
2)	0.490	0.511	0.021	0.21
3)	1.036	1.054	0.018	0.18
4)	1.050	1.071	0.021	0.21
5)	1.320	1.316	0.004	0.04

Range of difference: x_1-x_2 : 0.04 to 0.21 µg/g
Replication of Standards +/- 0.039 mg/l = 0.39 µg/g

Table 4. Results of Soil Chemistry Precision Tests.

CHAPTER THREE

RESULTS

3.0 Introduction

The study site was fully instrumented by December 15, 1987, and field work was conducted from December 18, 1987, until March 28, 1988. The results of this work, and subsequent laboratory studies, are presented here.

3.1 *Hydrology*

3.1.1 ***Precipitation: Temporal distribution, type and total water equivalence of precipitation events.***

Precipitation events deposited a total water equivalence of 12.8 cm at the study site during the period December 19 to March 26. Of this total, 3.7cm (29.1%) occurred as snowfall, 3.3cm (25.8%) as rainfall and 5.8cm (45.1%) as a combination of rain and snow. Figure 6 illustrates the distribution, type, and water equivalence (cm) of precipitation events. A complete record of precipitation data is provided in Appendix B.

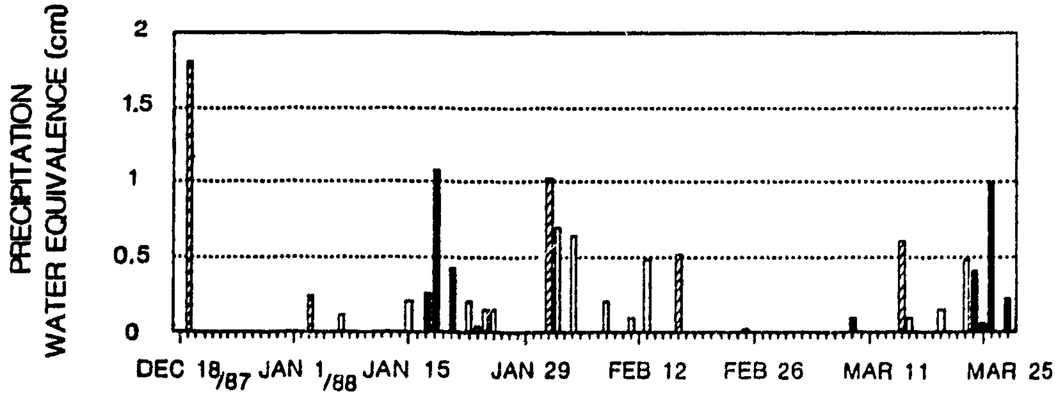


Figure 6. Precipitation recorded at P1/P2.

■ rain

□ snow

▨ combination

3.1.2 Snowpack Water Equivalence: Snow Surveys

Sudden thaws can release large quantities of water from temporary storage in the snowpack. To monitor changes in snowpack water equivalence, and to provide a measure of water potentially available for infiltration, snow surveys were conducted approximately every six to eight days. Dates of the snow surveys included December 19, 1987, January 7, and 15, February 2, 5, 16, 23, 29, and March 8, 1988. Figure 7 illustrates change in mean standing water equivalent values obtained from snow surveys at site 1 and site 2. A complete record of the data obtained at individual sampling locations on each survey date is provided in Appendix C.

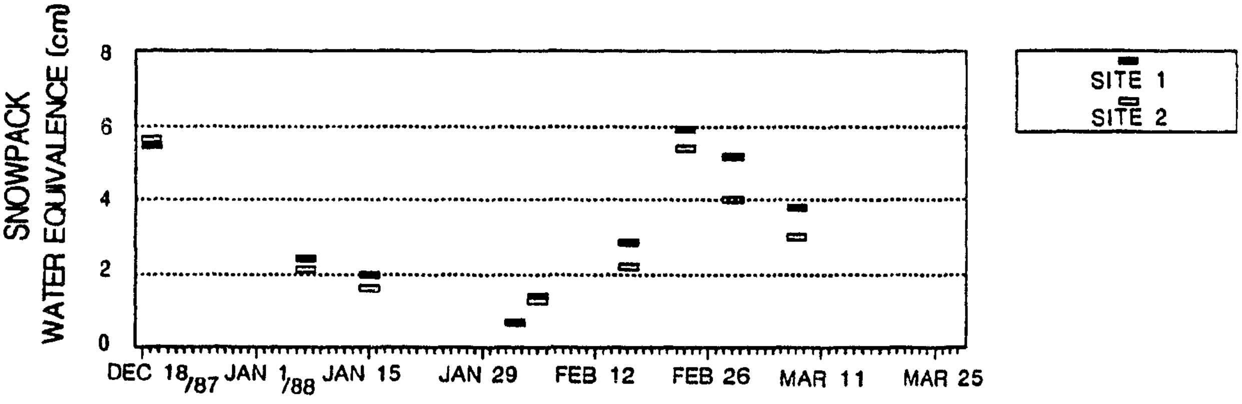


Figure 7. Standing Water Equivalent (cm).

3.1.3 *Snowmelt: Snow Lysimeter Data*

Melt water input to the soil from the snowpack is an important factor which contributes to the determination of the mineral N content of the soil. Although snow course measurements provide information regarding the average change in snowpack water equivalence between two dates, due to their nature, they do not allow for the easy collection of a daily record of snowmelt. The use of snow lysimeters can overcome this sampling problem by allowing snowmelt volume to be sampled daily. In this way, melting and potential meltwater input to the soil from the snowpack can be monitored through time. Water equivalence values obtained at L1 during daily sampling are depicted in Figure 8, a further numerical record of the data is provided in Appendix D.

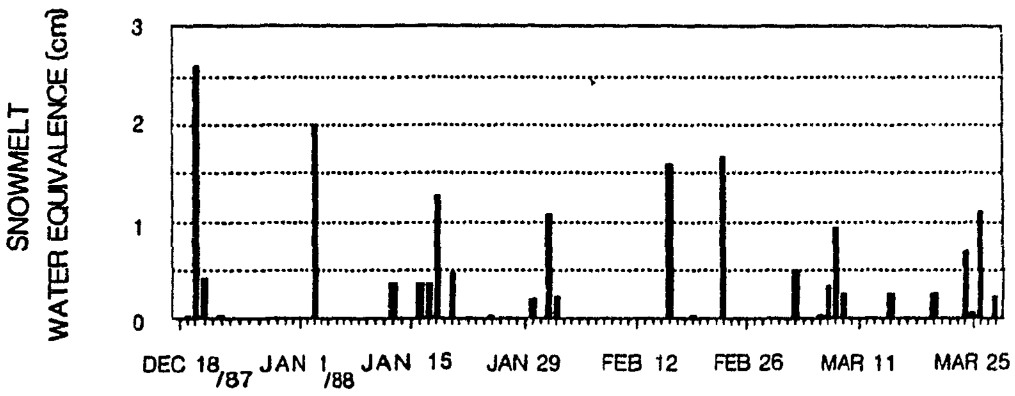


Figure 8. Reduction in Snowpack Water Equivalence.

To provide average values of daily snowmelt three snow lysimeters were installed at site 1 (see Figure 3); due to the combination of an extremely high water table and frost action, only one lysimeter (L1) remained functional throughout the study period (see section 2.4.4). While the data is limited to one location, Table 5 indicates that a calculated water equivalence based on measurement of the decrease in snowpack water equivalence recorded at L1, and increases recorded at P1/P2 during precipitation events, compares well with the data obtained during snow surveys.

	SC WEQ (cm)	PREC (cm)	MELT (cm)	CALC WEQ (cm)
Dec. 19	5.5	2.0	5.0	
Jan. 7	2.4	0.2	0.7	2.5
Jan. 15	1.7	2.6	3.8	1.9
Jan. 30*	0.0	2.3	0.2	0.5
Feb. 5	1.4	1.3	1.6	1.9
Feb. 16	2.8	3.6	1.7	1.7
Feb. 23	5.9	0.0	0.0	4.7
Feb. 29	5.2	0.0	1.9	5.9
Mar. 8*	3.6	2.8	2.6	3.3
Mar. 28	0.0			3.8[1]

Table 5. Observed and Calculated Snowpack Water Equivalence.

Note:

* Snow lysimeter empty
SC WEQ - Snowpack water equivalence determined from snow survey
Prec - Precipitation recorded at gauges P1 and P2
Melt - Snowmelt recorded at snow lysimeter L1
Calc. Weq = SC Weq at time of previous sampling + Prec and - Melt during interval between sampling dates

[1] Snow course data obtained March 8 indicate average standing water equivalence of 3.6 cm at site 1. At this time 25% of the site including the snow lysimeter had no snow cover. This would explain the discrepancy observed between SC Weq and Calc. Weq on March 28.

3.1.4 *Soil Moisture Content*

The infiltration of melt water is an important factor in the determination of soil N content. Times of soil sampling were therefore chosen to correspond with decreases in the water table elevation following infiltration of melt water (Figure 9).

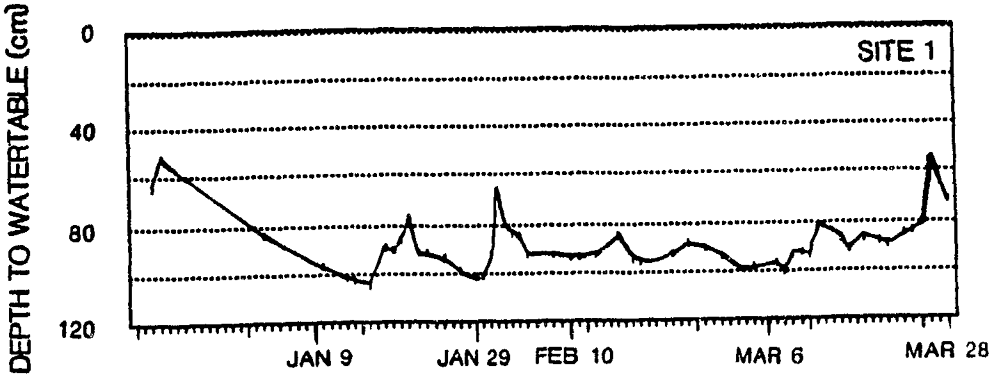


Figure 9. Soil Sampling Dates.

Soil moisture content was determined on six occasions during the study period. Water content was found to be variable with depth, the quantity decreasing with depth and being most variable in the 0-30 cm depth. Moisture content at each depth also demonstrates variation in both time and space. Figure 10 illustrates temporal variation in soil N content with spatial variation indicated by bars representing the standard error of the mean. A complete record of individual samples is provided in Appendix E.

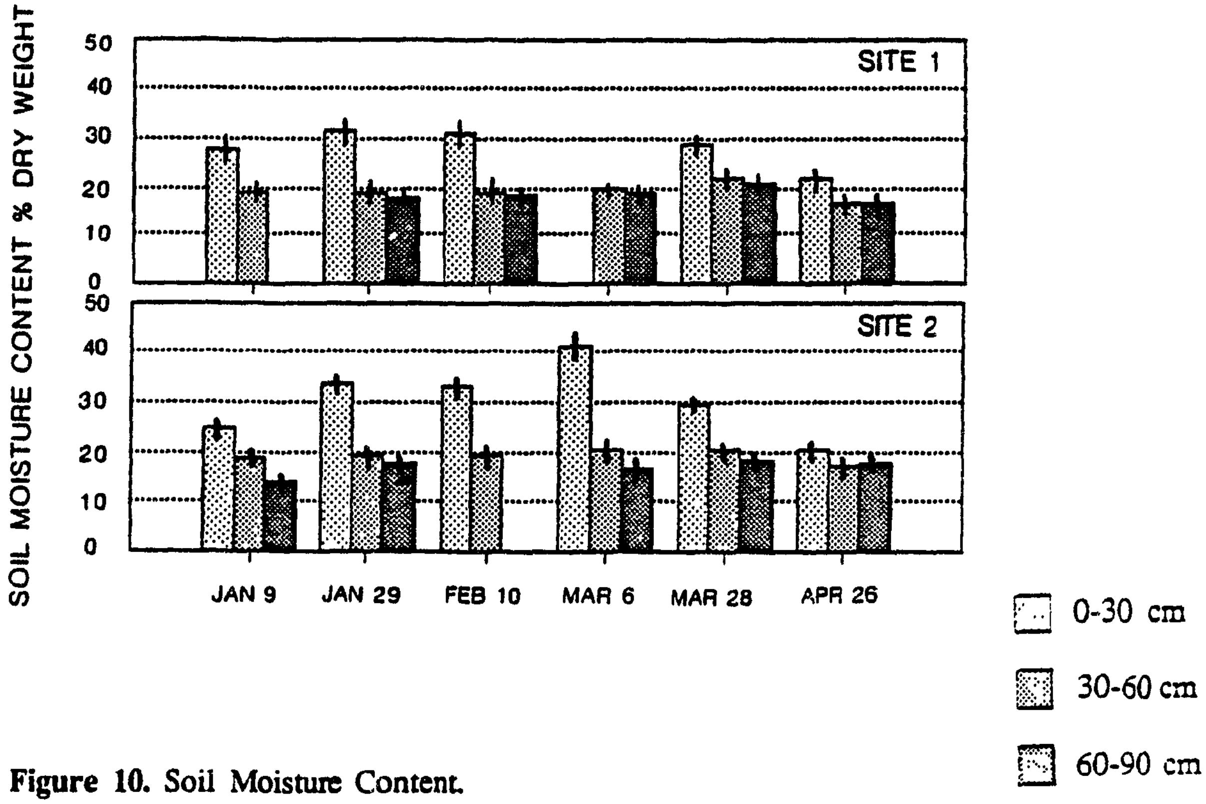


Figure 10. Soil Moisture Content.

3.1.5 *Water Table Fluctuation*

Water table elevation was measured 55 times from December 19 to March 28. The elapsed time between measurements varied depending on antecedent conditions. When daily maximum temperature remained above 0° Celsius, producing significant snowmelt, wells were monitored daily. Wells were monitored less frequently (each 2-3 days) during periods of extended low temperatures. Due to a period during which the water table dropped below well depth at Site 2 the number of observations vary between Site 1 and Site 2.

Figure 11 illustrates the average depth to the water surface at site 1 and site 2. Although all wells do not respond identically they generally follow a similar pattern at both sites. A complete record of depth to the water table is presented in Appendix F, accompanied by a series of hydrographs depicting change through time at individual groundwater wells.

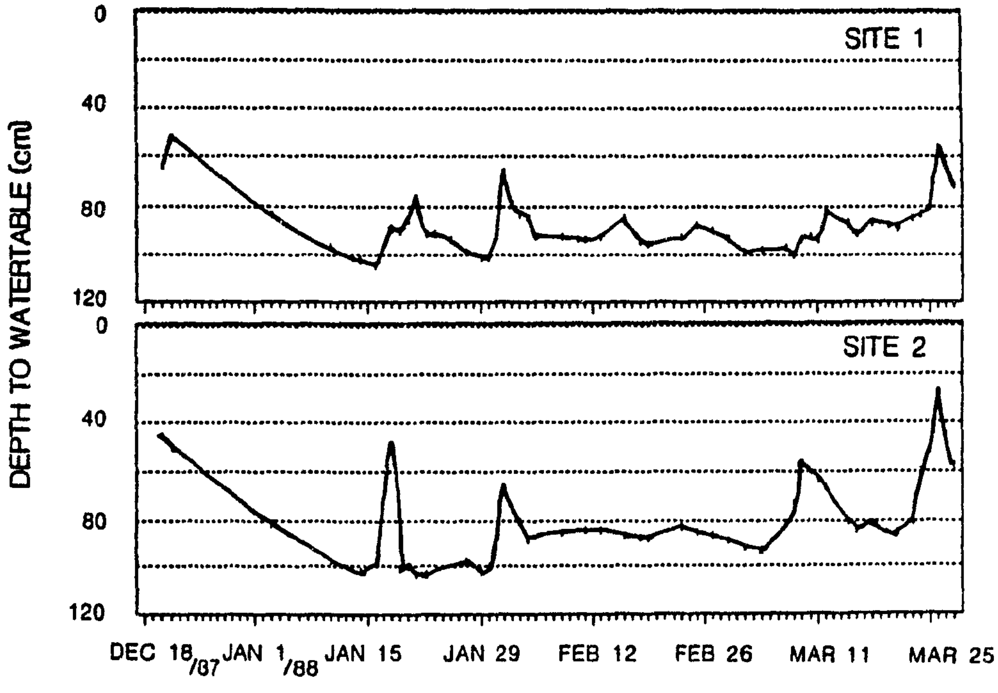


Figure 11. Average Depth to the Water Table (cm).

3.2 Nitrogen Chemistry

3.2.1 *Precipitation: Concentration of Nitrate and Ammonium*

Concentrations of soluble inorganic N in precipitation are summarized in Table 6. Variation in the N concentration of precipitation observed during the study period is illustrated in Figure 12. The complete data set is listed in tabular form in Appendix B.

	No. of Samples	Mean (mg/l) NO_3^--N	Mean (mg/l) NH_4^+-N	Range (mg/l) NO_3^--N	Range (mg/l) NH_4^+-N
Snow[1]	16	1.25	1.98	0.06 - 2.70	0.11 - 5.87
Rain	6	2.93	3.37	0.56 - 9.79	0.73 - 10.5

Table 6. N Concentration of Precipitation.

Note: [1] Includes events when a combination of rain and snow was recorded

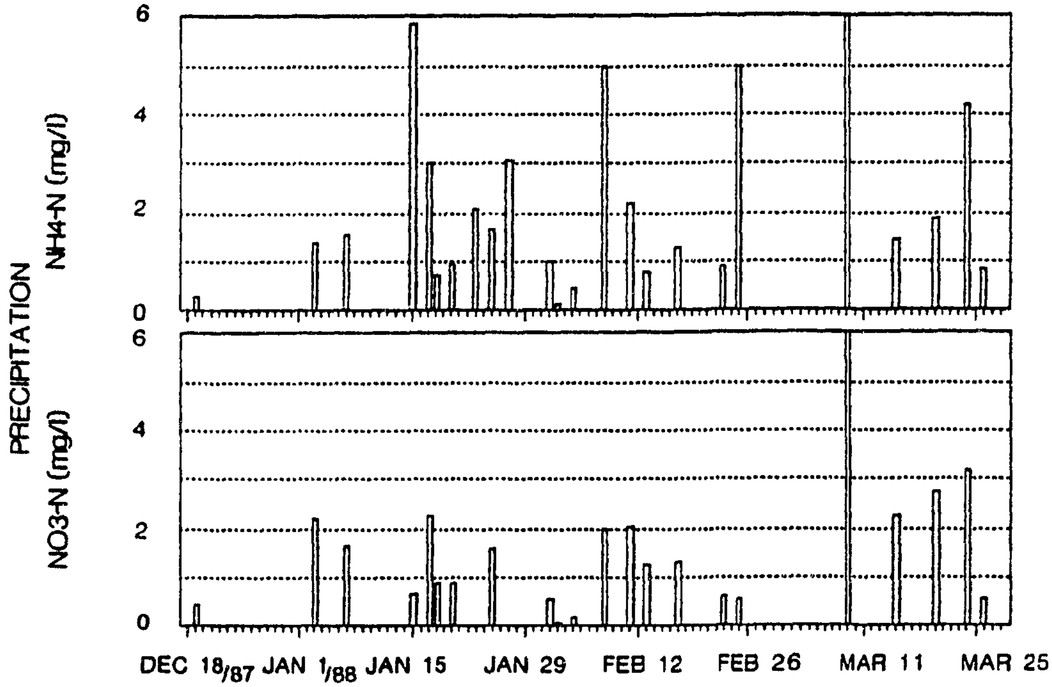


Figure 12. N Content of Precipitation (mg/l).

3.2.2 *Snowpack Nitrogen*

During each snow survey, composite snowpack samples were collected at the edge of pits dug to determine snowpack water equivalence. These were subsequently melted and analyzed to determine the concentration of N ions (NO_3^--N and NH_4^+-N) in the snowpack. Temporal variation in snowpack N concentration (mg/l NO_3^--N and NH_4^+-N) is depicted in Figure 13. Snowpack NO_3^--N concentration was generally higher than NH_4^+-N at both sites, however during mid-winter a reversal in this trend was observed at site 1 when NH_4^+-N became the dominant ion. A complete list of the results of each survey is presented in Appendix C.

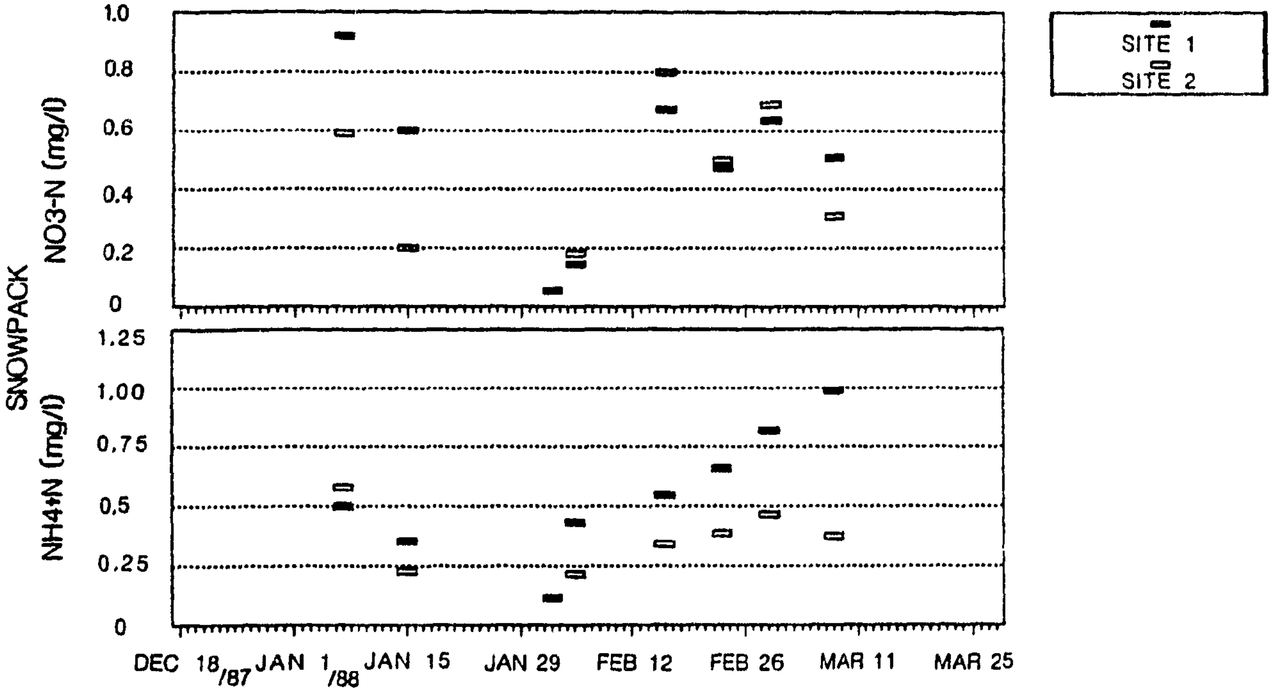


Figure 13. Snowpack N Content: Mean NO_3^--N and NH_4^+-N Concentration.

3.2.3 *N Content of Snow Melt: Lysimeter Results*

In addition to monitoring the rate of loss of water from the snowpack and potential contribution to soil moisture content the snow lysimeter allows analyses of the chemical characteristics of meltwater. The range of N concentrations (NO_3^--N and NH_4^+-N) in meltwater collected at the snowmelt lysimeter (L1) are presented in Table 7. The data presented in Figure 14 indicate that the highest concentrations of N occur during the initial stages of a melt event or in association with periodic and characteristically small melt events. A complete record of numerical data is presented in Appendix D.

No. of	Mean (mg/l)		Range (mg/l)	
Samples	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N
27	1.63	1.81	0.00[1]-6.02	0.00[1]- 6.55

Table 7. N Concentration of Snow melt water at L1.

Note: [1] Below Detection Limits

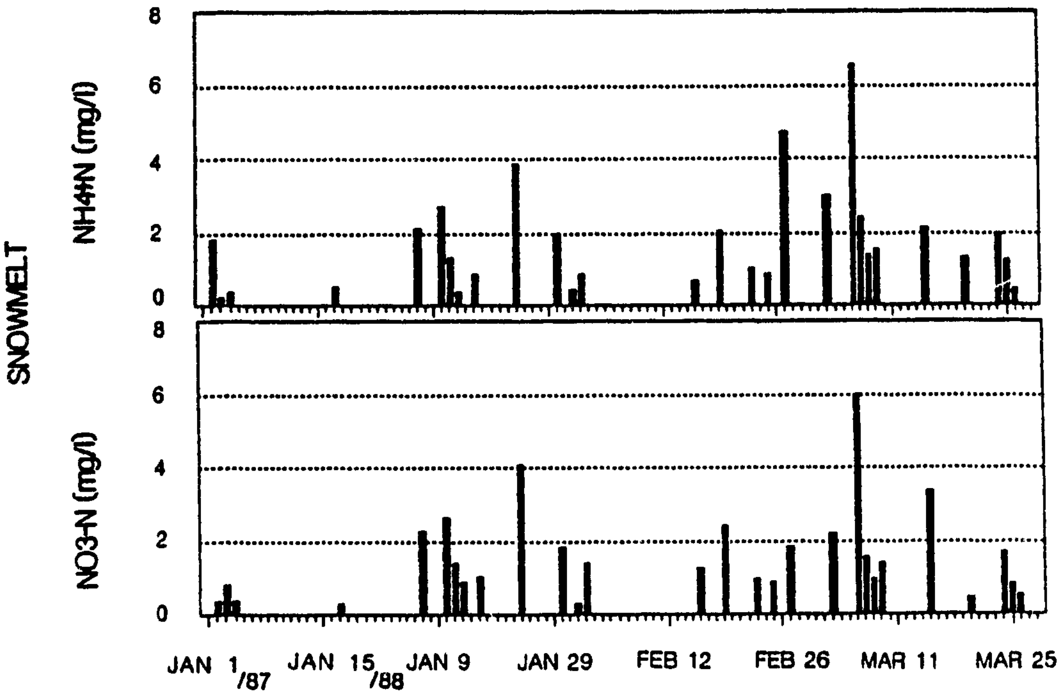


Figure 14. Snowpack Lysimeter: Concentration of NO_3^--N and NH_4^+-N in melt water collected at L1.

3.2.4 *Mean* N (NO_3^--N and NH_4^+-N) *Concentration of Groundwater*

Groundwater samples were collected for N analyses on a maximum of 43 of the 55 days on which water table elevation was recorded. Results of NO_3^--N and NH_4^+-N analyses are summarized in Table 8. The data from individual wells show a range of NO_3^--N concentration from 0.8 mg/l and 2.6 mg/l to maximums of 129.8 mg/l and 74.5 mg/l at sites 1 and 2 respectively. NH_4^+-N concentrations range from 0.06 mg/l at both sites to maximums of 1.3 mg/l and 0.9 mg/l at sites 1 and 2 respectively. Concentrations of both NO_3^--N and NH_4^+-N demonstrate considerable variation, both in space and time. Average concentrations through time are depicted in Figures 15 and 16. The number of observations varies among wells and between sites, suggesting differences in the pattern of infiltration and hydraulic conductivity. A complete record of the data may be found in Appendix G and is accompanied by figures depicting change in N concentration at individual groundwater wells through time.

NO_3^--N (mg/l)

Site 1	S1D1	S2D2	S1D3	S1D4	S1D5	S1D6	S1D7	S1D8	S1D9	S1D10
NO.OBS[1]	16	11	43	13	31	42	41	19	41	37
MEAN	15.29	18.63	17.27	10.94	9.06	10.04	36.95	6.71	78.46	53.16
MAX.	25.63	40.48	29.70	16.31	30.38	26.40	62.90	18.35	97.26	129.78
MIN.	4.59	10.77	7.28	7.47	3.47	1.46	18.64	0.87	52.76	6.21

Site 2	S2D1	S2D2	S2D3	S2D4	S2D5	S2D6	S2D7	S2D8
NO.OBS[1]	36	36	33	32	31	10	10	31
MEAN	10.28	10.05	13.97	10.55	17.33	8.56	46.79	14.41
MAX.	18.05	31.45	48.02	35.52	57.68	11.75	74.54	32.03
MIN.	2.62	3.39	6.89	2.62	6.21	4.08	19.51	4.95

NH_4^+-N (mg/l)

Site 1	S1D1	S2D2	S1D3	S1D4	S1D5	S1D6	S1D7	S1D8	S1D9	S1D10
NO.OBS[1]	16	10	43	13	30	41	42	18	41	19
MEAN	0.40	0.48	0.22	0.71	0.19	0.22	0.28	0.28	0.29	0.28
MAX.	0.75	1.31	0.50	1.09	0.37	0.47	0.60	0.41	0.46	0.40
MIN.	0.12	0.17	0.11	0.16	0.06	0.06	0.15	0.16	0.15	0.15

Site 2	S2D1	S2D2	S2D3	S2D4	S2D5	S2D6	S2D7	S2D8
NO.OBS[1]	36	36	32	32	31	10	10	31
MEAN	0.16	0.18	0.18	0.15	0.17	0.17	0.29	0.16
MAX.	0.95	0.45	0.26	0.23	0.28	0.31	0.43	0.28
MIN.	0.08	0.06	0.11	0.06	0.09	0.07	0.16	0.08

Table 8. N Concentration of Groundwater.

[1] : Number of Observations reflects the number of times water available in wells

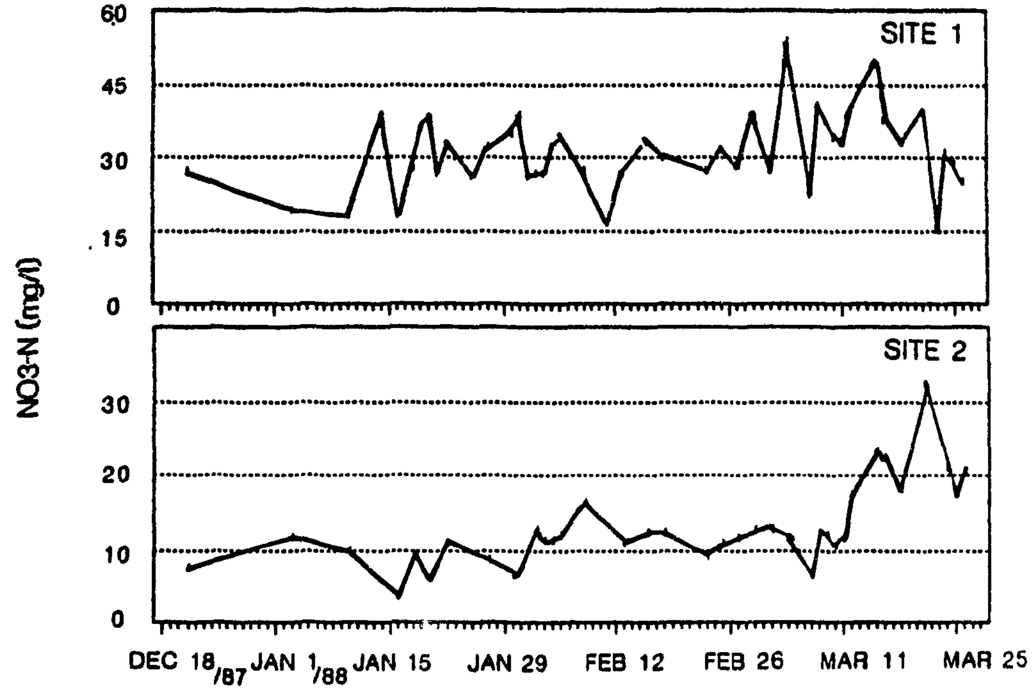


Figure 15. Mean NO_3^--N Concentration in Groundwater.

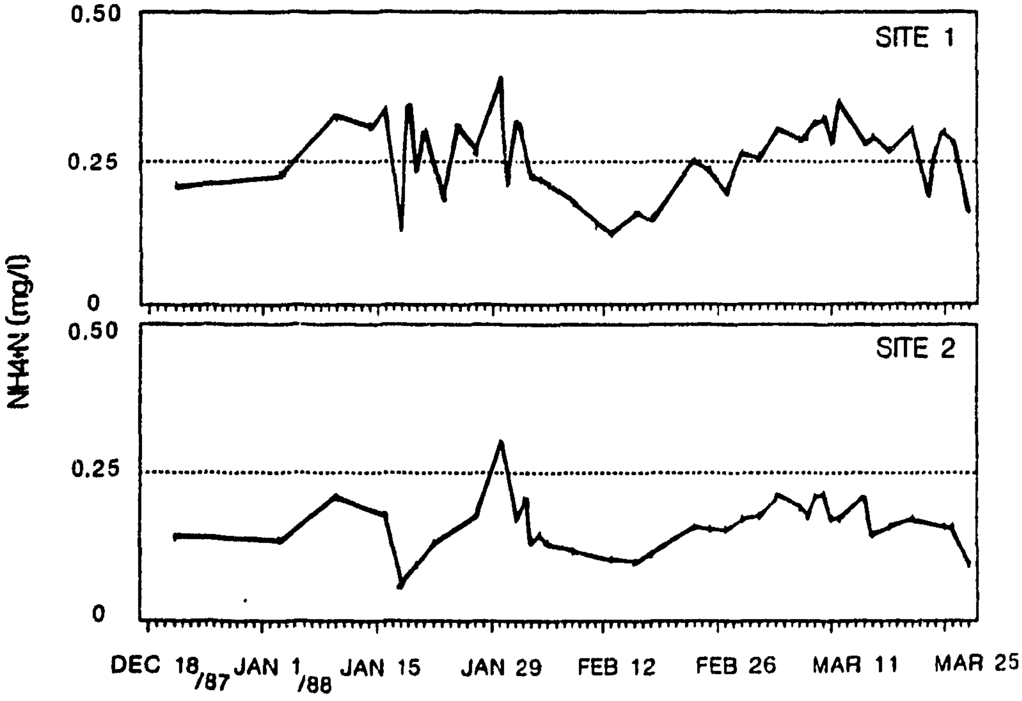


Figure 16. Mean NH_4^+-N Concentration in Groundwater.

3.2.5 Soil N: Mineral NO_3^--N and NH_4^+-N Content

Analyses of soil samples examine changes in available N (NO_3^--N and NH_4^+-N) during the study period. Soil samples were obtained on five occasions during the study: January 9 and 29, February 10, March 6 and 28; and one month after other data collection had been suspended (April 26).

As indicated in section 3.1.5, dates of soil sampling coincide with the end of infiltration from snowmelt events (see Figure 9), and are characterized as periods during which minimum water table elevations were recorded.

The average NO_3^--N and NH_4^+-N content, expressed in µg/g dry weight of soil, of extracts obtained from 0-30, 30-60 and 60-90 cm depths are depicted in Figure 17. N content is variable both in time and space. The distribution of NO_3^--N and NH_4^+-N generally show a decline from the surface soil layer to the layers below. Throughout the study, the quantity of NO_3^--N exceeded that of NH_4^+-N at both sites. This condition suggests that favourable conditions resulted in the rapid transformation of NH_4^+-N to NO_3^--N, or that NH_4^+-N was clay fixed or lost in gaseous form and consequently, the percentage of mineral-N present in soil in the form of NH_4^+-N represents only a fraction of total mineral N. A summary and complete record of data from individual sampling locations is presented in Appendix H.

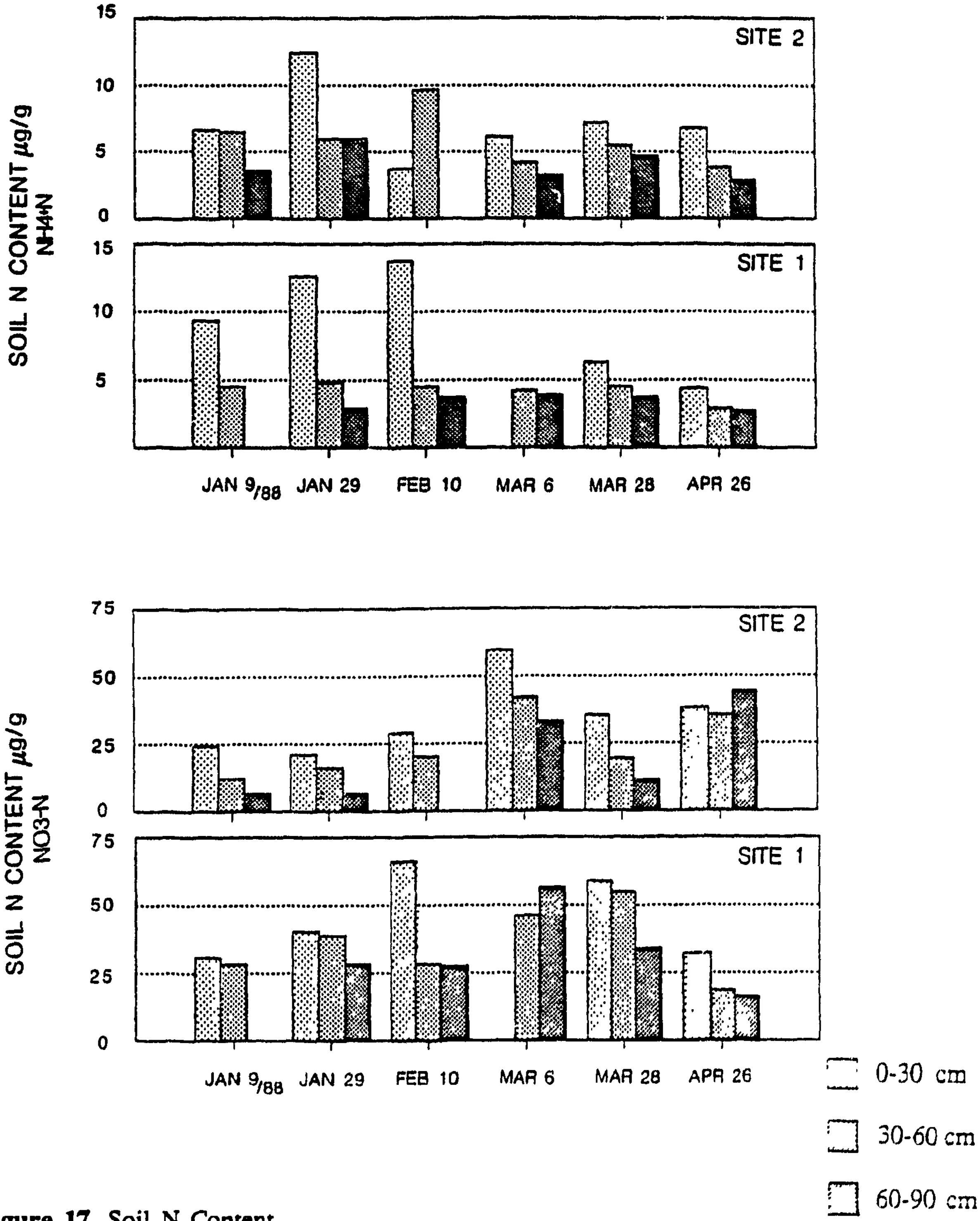


Figure 17. Soil N Content.

CHAPTER FOUR

INTERPRETATION AND DISCUSSION

The purpose of this chapter is to discuss temporal variation observed in: total water equivalence of the snowpack and water table elevation; and change in the Nitrogen content (NO_3^--N and NH_4^+-N) of snowmelt water, groundwater and the soil column.

4.1 Hydrology

4.1.1 *Snowpack accumulation: Changes in total water equivalence*

In the period prior to implementation of a continuous sampling schedule (December 9 - December 18), precipitation events resulted in total accumulation of 5.5 cm. During the actual time limit of the study, December 18, 1987 to March 28, 1988, precipitation events deposited an additional 12.8 cm water equivalence. Snowpack accumulation was controlled by widely fluctuating temperatures and sporadic rain events. Variable meteorological conditions resulted in large changes in the water equivalence of the snowpack (Figure 18). This phenomenon is not uncommon in Southern Ontario which is a "region characteristic of the continental accumulation zone, where winter ablation and winter rain may interrupt the continuous development of a snowpack" (Goodison, 1978).

Prior to spring melt there were two periods (December 23 - January 3 and January 19 - January 29) during which there was substantial loss of the snowcover at the study site (Figure 18). The final melt began during early March when rain and warm temperatures combined to greatly reduce snowpack water equivalence. Most of the snowcover had melted by March 9 leaving only scattered patches of ice and pools of

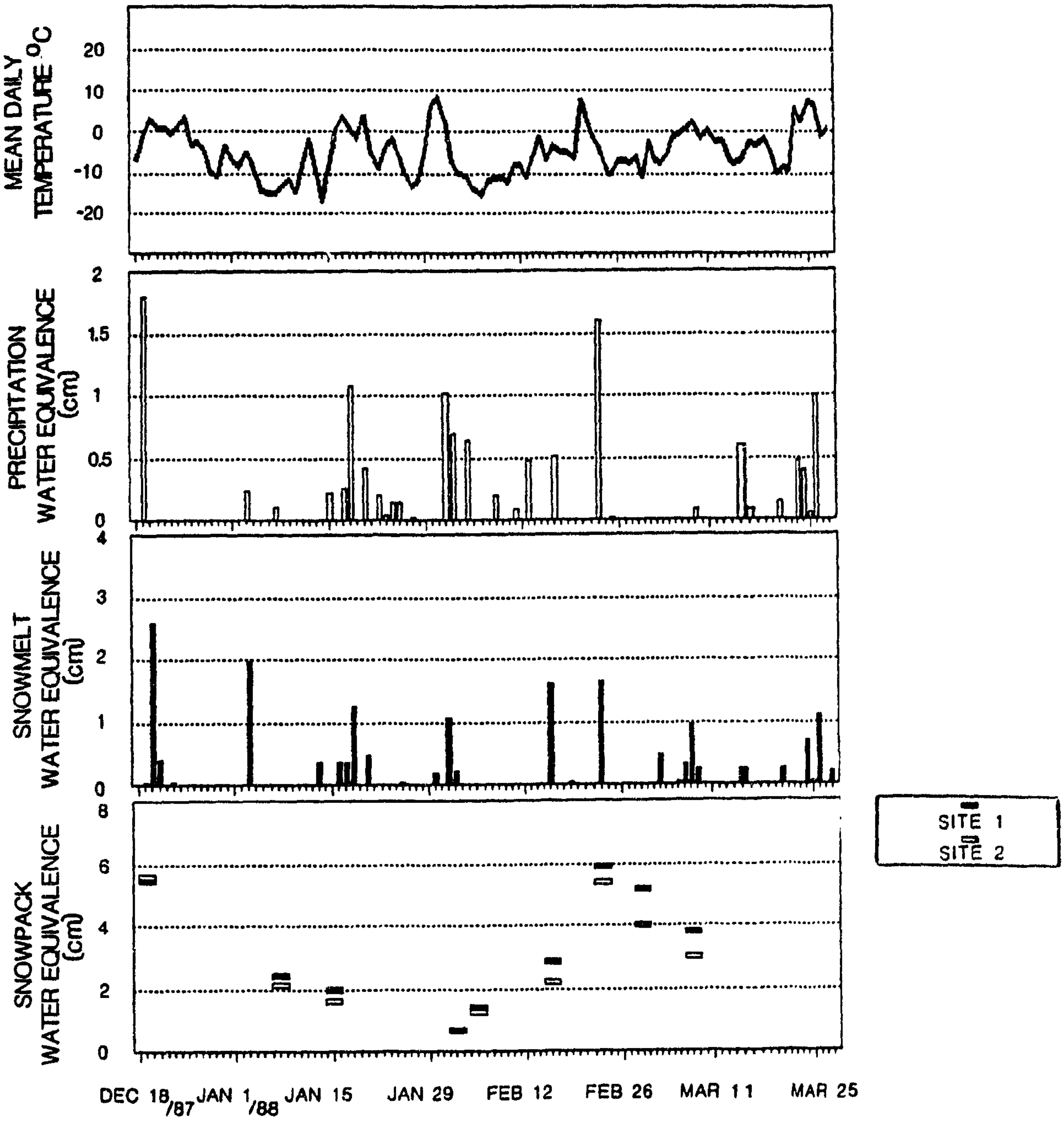


Figure 18. Temporal variation in snowpack water equivalence as related to precipitation, melt, and temperature.

water standing on the ground surface. Though minor amounts of accumulation occurred after March 9 by March 25 all snowcover and ice lenses had melted, and all standing water had infiltrated the ground surface.

Periods of accumulation were interspersed with cycles of melting and refreezing associated with periods of mild temperatures and rain on snow events. These cycles produced significant changes in snowpack water equivalence and resulted in distinct stratification of the snow pack. Figure 19 illustrates mean water equivalence recorded during snow surveys and change observed in snowpack stratification.

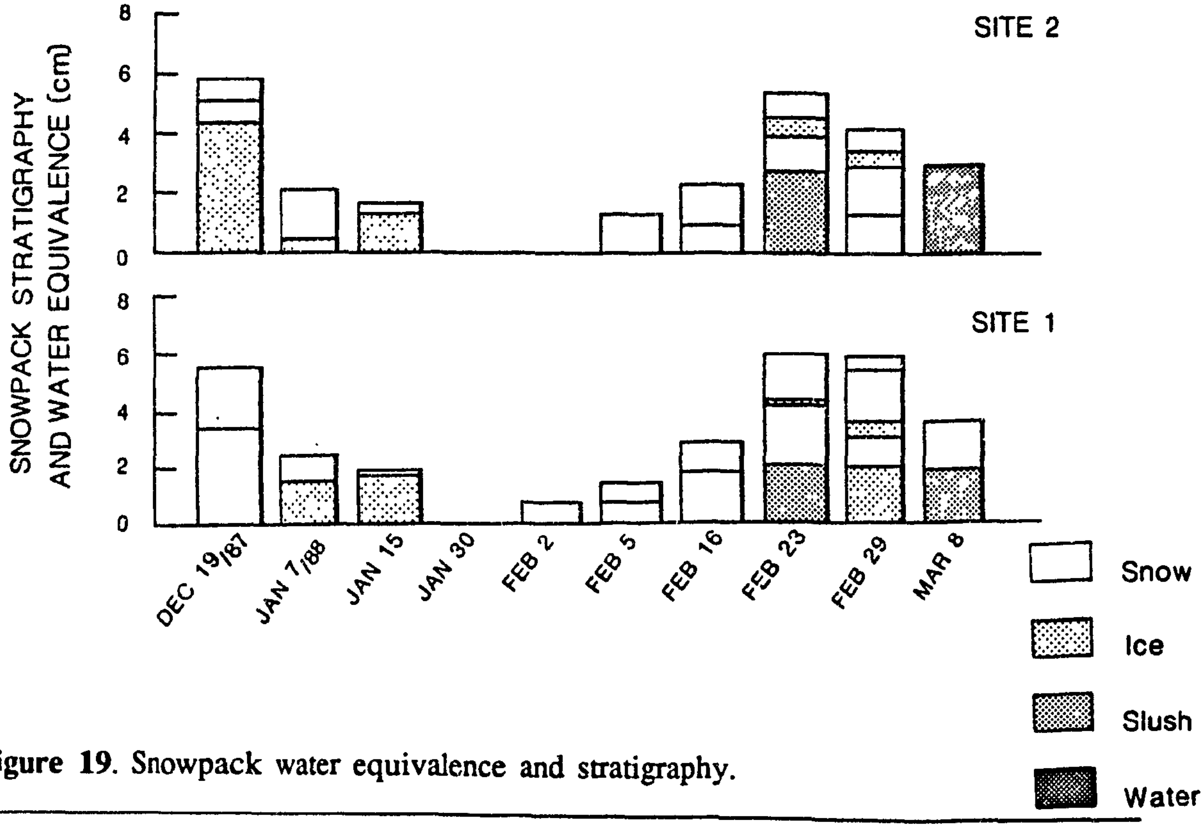


Figure 19. Snowpack water equivalence and stratigraphy.

Changes in snowpack water equivalence and granular structure will be demonstrated to have an important influence on hydrological response observed at the study site; where the development of ice lenses impede the downward percolation of melt water thereby delaying infiltration of water into the soil below. The development of a basal ice lens and saturation at the base of the snowpack also contributed to downslope flow of meltwater. Depression storage resulting from ponding of melt water led to subsequent increases in snowpack water equivalence at certain locations.

Variation is common in the absolute water equivalent values obtained in a shallow snowpack (Goodison, 1978). Differences in the spatial pattern of snowpack accumulation occurred as a result of minor changes in surface topography, redistribution of snow by wind and the aforementioned cycles of melting, percolation and refreezing within the snowpack.

4.1.2 *Soil Moisture Content*

Soil samples were obtained for chemical analyses at times of low water table elevation. With the exception of March 28, the water table at these times was close to or below the 60-90 cm sampling depth (Table 9). Determination of the moisture content in these samples indicates that the soil condition was similar on each sampling date.

	Site 1	Site 2
Jan. 9	96	98
Jan. 29	101	102
Feb. 10	94	88
Mar. 6	97	87
Mar. 28	56	57
Apr. 26	88	94

Table 9. Mean Depth to Water Table (cm)

Soil moisture data from successive sampling dates between January 9 and March 28 exhibits moderate variation (Table 10). Greatest variation is generally observed in the 0-30 cm depth where the moisture content at times of sampling varied by as much as (11%) of the samples dry weight. Variation is a function of available melt water and temperature conditions prior to sampling.

The calculation of variation in soil moisture among sampling dates (Table 10) is based on soil moisture content values expressed as a percentage of the sample's oven dry weight (Section 3.1.5). The percentage of water calculated on an oven dry basis can be converted to the volume basis as follows:

$$\text{\% water on oven dry basis} \times \frac{\text{bulk density of soil}}{\text{density of water}} = \text{\% water on volume basis}$$

(Foth, 1984)

Bulk density, the weight of a given volume of soil in its natural condition is expressed as the samples weight (g) per cubic centimetre and is calculated using the formula

$$\text{Bulk Density} = \frac{\text{dry soil weight (g)}}{\text{soil volume (cm}^3\text{)}}$$

Site #1		Depth	
Interval	0-30cm	30-60cm	60-90cm
Jan 9 - 29	+ 3.7*	+ 0.1^{NS}	NA
Jan 29 - Feb 10	- 0.2^{NS}	- 0.4^{NS}	+ 0.5^{NS}
Feb 10 - Mar 6	NA	+ 1.1*	+ 0.6^{NS}
Mar 6 - Mar 28	- 2.4[2]	+ 2.3^{NS}	+ 2.3^{NS}
Mar 28 - Apr 26	- 7.0*	- 5.4*	- 4.5*

Site #2		Depth	
Interval	0-30cm	30-60cm	60-90cm
Jan 9 - 29	+ 9.3*	+ 0.3^{NS}	+ 3.8*
Jan 29 - Feb 10	- 0.4^{NS}	+ 0.2^{NS}	NA
Feb 10 - Mar 6	+ 7.7*	+ 0.7^{NS}	- 1.2^{NS}[3]
Mar 6 - Mar 28	-11.6*	+ 0.1^{NS}	+ 1.2^{NS}
Mar 28 - Apr 26	- 9.4*	- 3.0*	- 0.2^{NS}

Table 10. Soil Moisture Content[1]; Change between Successive Sampling Events.

[1] Change in soil moisture expressed as percent sample dry weight
[2] Based on change between Feb 10 and Mar 26
[3] Based on change between Jan 29 and Mar 6

Confidence Level

* P = 0.1 Significant at 90%
^{NS} No Significant Difference

In a field situation soil density varies spatially, horizontally and vertically with a tendency to increase as the profile is penetrated (Foth, 1984). Tillage conditions that temporarily loosen surface soil lower bulk density; an increase in density with depth results from compaction by overlying soils and the downward migration of clay (Foth, 1984). Samples for bulk density determinations were obtained from three soil pits at Site 1 (Figure 3). The data presented in Table 11 exhibit both horizontal and vertical variation among the samples, however a measure of the standard error of the mean at each sampling depth suggests that mean values are representative of soil conditions at the site.

Depth (cm)	Pit 1	Pit 2	Pit 3	Mean	$\sigma/\sqrt{N}$
00-30	1.57	1.52	1.31	1.47	0.08
30-60	1.45	1.76	1.85	1.69	0.12
60-90	1.63	1.81	1.93	1.79	0.08

Table 11. Bulk Density of soil at Site 1.

Table 12 presents values of soil water content calculated on a volume basis for site 1 and site 2 respectively.

Site 1	Jan. 9	Jan. 29	Feb. 10	Mar. 6	Mar. 28	Apr. 26
00-30cm	41.7	47.3	46.9	ND	43.4	32.9
30-60cm	32.3	32.5	31.8	33.7	37.6	28.4
60-90cm	ND	31.7	32.6	33.7	37.8*	29.7

Site 2	Jan. 9	Jan. 29	Feb. 10	Mar. 6	Mar. 28	Apr. 26
0-30cm	36.9	50.7	50.3	61.8	44.4	30.8
30-60cm	32.3	32.9	33.3	34.5	34.7	29.7
60-90cm	25.6	32.4	ND	30.2	32.4	32.0

Table 12. Soil Water Content: Percent Calculated on a Volume Basis.

Comparison of the values in Table 12 with values of percentage pore space, which is calculated using the soil bulk density and an assumed soil particle density of 2.65 (Bowles) in the formula:

$$\text{Percent Pore Space} = 100 - \frac{\text{Bulk density}}{\text{Particle density}} \times 100$$

indicates that soil at both Site 1 and Site 2 was at near saturated conditions throughout the study period.

Depth (cm)	Bulk Density	% Pore Space
00-30	1.47	43
30-60	1.69	36
60-90	1.79	33
Mean	1.65	38

Table 13. Relationship between Bulk Density and Percent Pore Space.

On January 29, February 10 and March 6 the water content in the 0-30 cm depth is seen to exceed the calculated volume given a porosity of 43%. It is thought that this phenomenon can be attributed to ground frost conditions and the sampling method which may have inadvertently resulted in an over-estimation at site 1. At site 2 the tillage condition of the upper 30 cm results in a greater pore space which results in an increase in the capacity for soil water retention.

As previously indicated, the small degree of variation in the 30-60 and 60-90 cm depths, with the exception of samples obtained from 60-90 cm on January 9 and April 26, suggests that the soil profile at both sites was near saturation throughout the study period. Lower water content on January 9 and April 26 is a function of antecedent conditions; the period prior to January 9 was characterized by cold temperatures and reduced soil water input while in the period prior to the April 26 sampling rainfall associated with warmer temperatures rapidly infiltrated the ground surface and percolated through the vadose layer.

4.1.3 *Groundwater Table Fluctuation*

For discussion purposes the study period has been broken into five time intervals. These intervals, which are depicted in Figure 20, represent periods in which fluctuations of the temperature and corresponding changes in the rate of infiltration result in major fluctuations of the water table elevation.

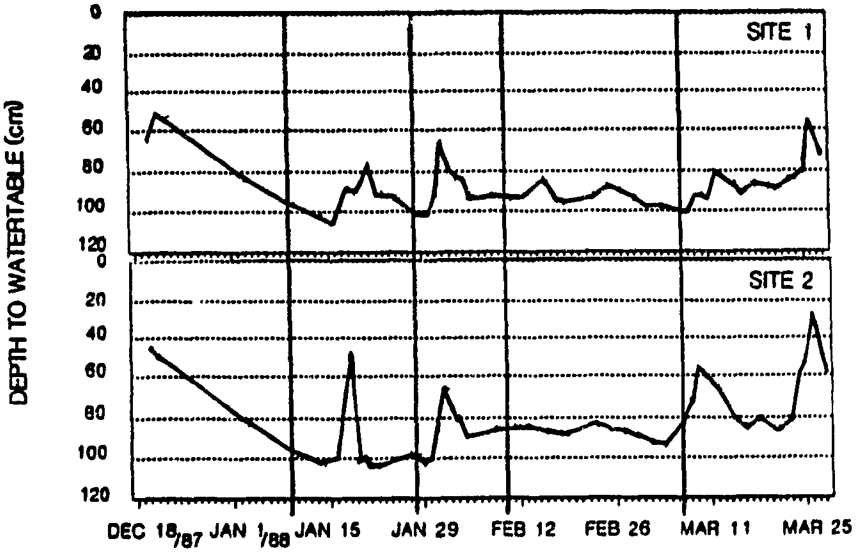


Figure 20. Mean Depth to Groundwater table (cm).

Average depth to the water table, at both sites, is shown in Figure 21 and can be seen to be time linked with snowmelt and rain on snow events. Snowmelt and resulting percolation is variable within the study site, and consequently small scale differences were observed in the timing and magnitude of change in depth to the water table among wells. However, as indicated in Figure 21, the pattern of well response generally follows a similar trend at both site 1 and site 2. The timing of infiltration is generally

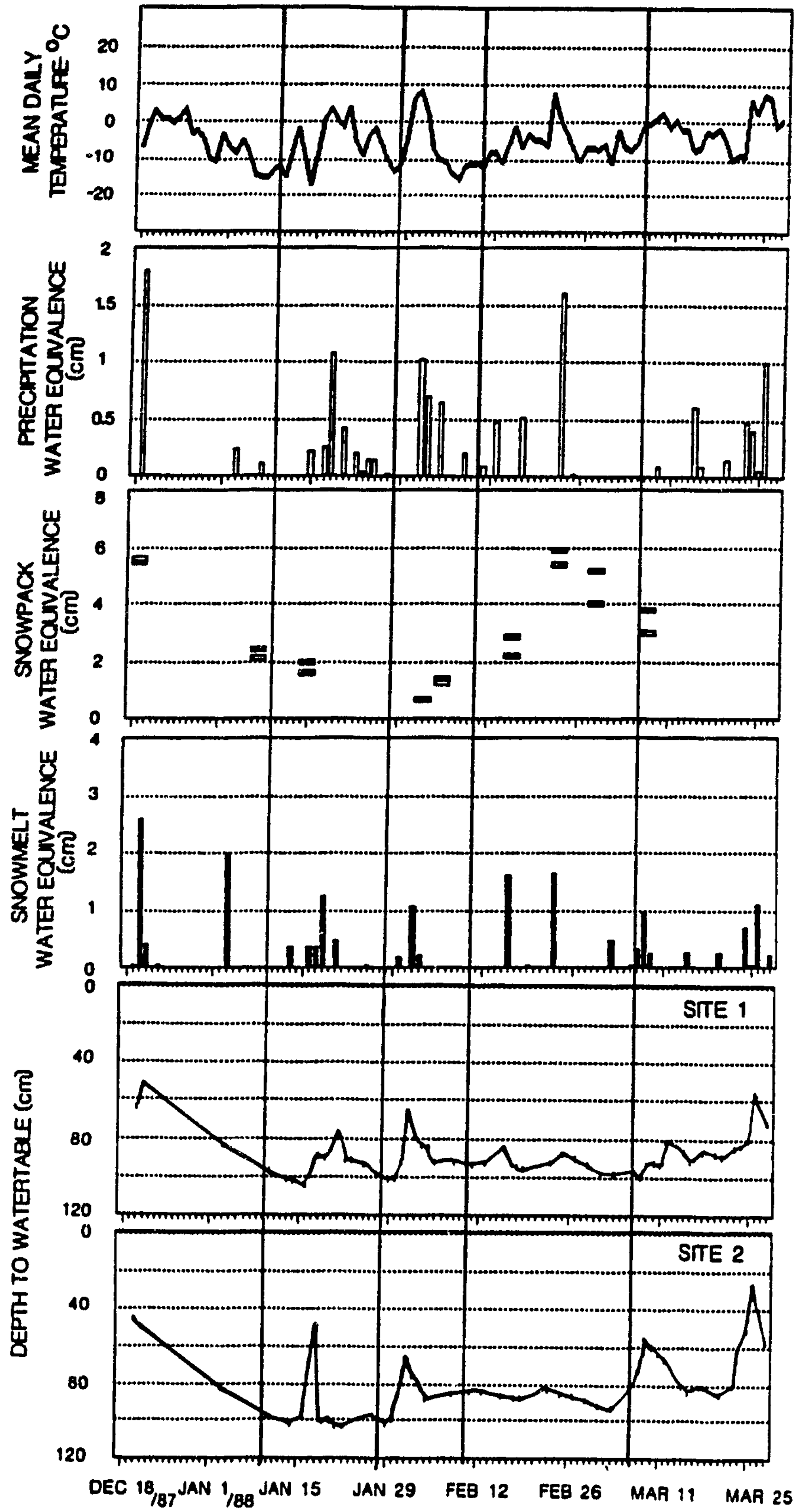


Figure 21. Average depth to water table as related to temperature, precipitation, and snowmelt.

▬ SITE 1
▭ SITE 2

uniform throughout each site and the earliest response to the pulse of water is observed where the water table is closest to the ground surface prior to melting (Appendix I). The responsiveness of the groundwater table to soil water inputs suggested by Figure 21 is a function of the shallowness of the water table due in part to the capillary fringe effect (Price et. al., 1978), antecedent soil moisture conditions, and the volume of melt water available during a melt episode.

As indicated in Figure 21 there are periods which are characterized by significantly different response at site 1 and site 2. These differences are discussed in the following section which summarises the relationship between temperature, snowmelt and change in groundwater table elevation.

I1 - December 18 to January 9

Discussion of the fluctuation of the water table elevation during I1 is limited by the available data, however temperature data suggest that the infiltration of meltwater would have produced peak water table elevations, at both sites, on or about December 25. It is thought that cooler temperatures between December 27 and January 9, would have effectively ended melting and infiltration and thus this period would have been characterized by a continual decline in the elevation of the water table.

I2 - January 10 to January 28

In combination with increased temperatures, rain on snow events occurring between January 13 and January 19 resulted in a major depletion of the snow cover. The surface of the groundwater table at Site 1 remained below a measurable depth at most wells until January 16 when infiltration of melt water resulted in a rising water table elevation. Continued infiltration and percolation was associated with continued warm temperatures and melting of the snowpack and wells continued to rise with highest levels being observed January 21. With little additional melting, and a reduction in infiltration associated with cooler temperatures, well levels show a distinct pattern of decline throughout the remainder of I2. Without additional soil water inputs, drainage from the unsaturated area of the soil column resulted in most percolate water draining from the sampled depth of the soil profile and by January 27-28 water levels stabilized at near pre-event elevations.

Unlike Site 1 where an increase was observed in the extent of the saturated area, conditions at Site 2 were characterized by a significant reduction in the water table. The water table dropped after January 10 leaving only the two wells at the base of the slope below water level. Occasional observations were possible at midslope locations, however upslope wells remained dry throughout the interval. The differences observed between site 1 and site 2 are a function of differences in the amount and rate of infiltration which are influenced by the characteristics of the ground surface.

At site 1 meltwater infiltrated uniformly, and standing water which pooled in surface depressions upslope of wells during the initial phase of the interval continued to provide soil water inputs at all well locations. While an equivalent reduction of the snowpack occurred at both sites, most of the meltwater at site 2 was observed as overland flow. This diversion of meltwater flow was created by a layer of ice in the base of the furrows. The furrows ran parallel to the transects of wells and no significant depressions existed along the slope. Thus overland flow severely reduced infiltration in the vicinity of all wells except S2D1 and S2D2 (Figure 4) where significant pooling of water occurred.

I3 - January 29 to February 10

Well levels began to rise January 30, at both Site 1 and Site 2, in response to the infiltration of meltwater associated with rain events and rapid depletion of the snow cover. The resulting increase in the saturated zone produced high water table levels between January 30 and February 1. A precipitation event on January 31 contributed to depression storage at site 1 and the infiltration of this water maintained elevated well levels for a longer duration than observed at site 2. Within 48 hours of peak water table elevations the water surface had dropped approximately 20 cm at both sites. Continued percolation from the vadose zone and reduced infiltration resulted in the stabilization of all wells by February 5, and water levels remained at a relatively constant elevation throughout the remainder of the interval.

I4 - February 11 to March 7

During the initial stages of I4 (February 11 to February 18) well levels demonstrate a slightly different trend at the two sites. At site 2 a general reduction in the elevation of the groundwater table was observed between February 11 and February 18 when cool temperatures ended snowmelt and infiltration. In contrast well levels remained stable until February 16 at Site 1 before receding February 18. Between February 18 and February 23 melting of the snowpack associated with warmer temperatures and the infiltration of meltwater resulted in a steady rise in water table elevations. Infiltration was reduced and well levels began to decrease as temperatures dropped February 25, this decrease marked the beginning of decline of the water table at both site 1 and site 2. Water table elevation stabilized at both sites March 2 and March 4.

I5 - March 8 to March 27

Consistently warm daily temperatures characterize the period between March 8 and March 16; during which time most of the snowpack melted. Decreased albedo produced greater and earlier melting at site 2; groundwater well response was rapid with peak levels observed on March 9. Within 24 hours levels began to recede and the water table continued to drop reaching a low on March 16. At site 1, earlier development of ice lenses at the ground surface (Figure 19) delayed response until March 11-12. With the exception of a small time lag well response followed a similar pattern at both sites during the remainder of the interval.

The final period of record, March 17 to March 27, constitutes the end of the spring melt. Infiltration of snowmelt began March 17 producing a continuous rise of the groundwater table. On March 23 a second more rapid rise resulted from a rain on snow event melting the remaining snow cover. Subsequent rain events (March 25- 27) substantially increased the saturated zone with peak levels observed March 26 (Figure 21). On March 27 the majority of the water being observed in the wells resulted from spring rainfall and not snowmelt and thus following the collection of soil samples the study was suspended on March 28.

The preceding discussion indicates that the percentage of available melt water infiltrating the ground surface varied among melt events. At times when melt water percolates through the snowpack and is unimpeded by ice lenses and/or ground ice the soil rapidly becomes saturated and noticeably large increases occur in the elevation of the water table. Groundwater observations from both sites suggest that between January 30 and February 2, and March 15 and March 26 most event water rapidly infiltrated the ground surface and contributed to a rise in water table elevation. A similar pattern was observed at Site 1 between January 16 and January 21. Confirmation that most melt water infiltrated during these events is provided in Table 14 which indicates that measurement of precipitation and snowmelt correlate well with changes observed in snowpack water equivalence.

	SC WEQ (cm)	PREC (cm)	MELT (cm)	CALC WEQ (cm)
Dec. 19	5.5	2.0	5.0	
Jan. 7	2.4	0.2	0.7	2.5
Jan. 15	1.7	2.6	3.8	1.9
Jan. 30*	0.0	2.3	0.2	0.5
Feb. 5	1.4	1.3	1.6	1.9
Feb. 16	2.8	3.6	1.7	1.7
Feb. 23	5.9	0.0	0.0	4.7
Feb. 29	5.2	0.0	1.9	5.9
Mar. 8*	3.6	2.8	2.6	3.3
Mar. 28	0.0			3.8[1]

Table 14. Observed and Calculated Snowpack Water Equivalence.

Note:

* Snow lysimeter empty
SC WEQ - Snowpack water equivalence determined from snow survey
Prec - Precipitation recorded at gauges P1 and P2
Melt - Snowmelt recorded at snow lysimeter L1
Calc. Weq - SC Weq + Prec - Melt

[1] Snow course data obtained March 8 indicate average standing water equivalence of 3.6 cm at site 1. At this time 25% of the site including the snow lysimeter had no snow cover. This would explain the discrepancy observed between SC Weq and Calc. Weq on March 28.

The periods February 5 to February 16, February 29 to March 8 were characterized by snowmelt events, however water table response indicates that most melt water did not infiltrate the ground surface during these events. Reduced infiltration during both periods is attributed to freeze thaw processes which contributed to the formation of ice lenses within the snowpack and at the ground surface (Figure 19). Development of ice lenses reduced the rate of infiltration and contributed to ponding of standing water which maintained the water equivalence of the snowpack. Reduced infiltration between February 5 and February 16 is reflected in the snow course data; where snowpack water equivalence is not reduced to the extent suggested by the snow lysimeter data (Table 14). Frost conditions, ice lenses and rapid saturation of the uppermost soil also resulted in overland flow during early March, when rapid melting occurred above partially frozen ground. At this time an undetermined amount of direct surface runoff contributed to flow in the drainage ditch separating the study site (Figure 2).

4.2 *Precipitation and snowmelt N content*

Precipitation events resulted in a measured deposition of approximately 118 mg/m^2 NO_3^--N and 149 mg/m^2 NH_4^+-N at the study site between December 19, 1987 and March 26, 1988. When comparing N input and loss during this period the data indicate that the total mass (mg/m^2) of N (NO_3^--N and NH_4^+-N) in snowmelt, as recorded at L1, was greater than observed in precipitation samples collected at gauges P1 and P2 (Table 15).

	NO_3^--N (mg/m^2)	NH_4^+-N (mg/m^2)
[1]Precipitation	118.1	149.2
[2]Snowmelt	174.2	160.5

Table 15: Comparison of total N input and release from the snowpack December 19, 1987 to March 26, 1988.

[1] Precipitation recorded at gauges P1 and P2

[2] Snowmelt recorded at snow lysimeter L1

This disparity is thought to be, in large part, due to the N content of the snowpack which had accumulated prior to December 19. Although analyses of snowpack N content were not conducted on December 19, reconstruction of the snowpack N content suggests that N accumulated prior to December 19 accounts for most of the difference observed between NO_3^--N and NH_4^+-N input to the snowpack and loss during melt events (Table 16).

	NO_3^--N (mg/m^2)	NH_4^+-N (mg/m^2)
Snowpack Mass Jan. 7	+29.0	+14.6
Snowmelt Dec. 19 - Jan. 7	+27.5	+17.2
Precipitation Dec. 19 - Jan. 7	-15.2	-10.3
Snowpack Mass Dec. 19	41.3	21.5
Precipitation Input	118.1	149.2
Snowpack Contribution	41.3	21.5
Total Input	159.4	170.7
Snowmelt Output	174.2	160.5

Table 16. Determination of Snowpack N Content 12/19/87.

The data in Table 16 indicate that the mass of NO_3^--N in snowmelt recorded at the snow lysimeter (L1) remains greater than that observed in precipitation. In contrast the mass of NH_4^+-N measured at L1 is less than the calculated input. The degree of accuracy obtained in the measurement of precipitation may contribute to the difference observed between NO_3^--N input and output. Because trace amounts of precipitation which were observed during several snowfall events (Appendix A) could not be accurately quantified it is suggested that the available precipitation data represent an under-estimation of N input. Disparity in NH_4^+-N input and output is attributed to in-situ volatilization and loss of N in a gaseous form from the sample on collection.

The fact that the snowmelt lysimeter provides a measure of melt at a single location might be expected to contribute to the difference observed in NO_3^--N values; the lysimeter yielding a greater volume of melt water than an unprotected location as snow which accumulates within the snow lysimeter is protected against redistribution by wind. This suggestion does not appear to explain the difference as the total water yield at the lysimeter closely approximates input (see Table 14).

The disparity in NO_3^--N content is in part attributed to post depositional dry deposition. It is not uncommon for the snowpack to accumulate particulate matter in large concentrations (Pierson, 1983). Barica and Armstrong (1971) have demonstrated that the particulate matter concentration of the snowpack may increase 15-40 fold over the course of the winter. On several occasions during this study, redistribution and/or melting of the shallow snowpack resulted in partial or total exposure of the ground surface. Associated with the occurrence of high winds during these periods was the deflation and deposition of particulate matter from surrounding fields. Potential enrichment of the snowpack by particulate matter was investigated on one occasion, when the concentration of particulate matter was determined in conjunction with regular analyses of snowpack NO_3^--N and NH_4^+-N content. Data from a small number of samples (n=10) is summarized in Table 17. These values may reflect additional leaching during preparation for analyses as it is impossible to remove particulate matter prior to melting the sample. However the data indicate that dry deposition contributes to the N content of the snowpack; this would account for some of the variation observed between input and output while also potentially providing an explanation for a portion of the variation observed among sampling sites.

Site 1				Site 2			
No.	PM_1 (g/l)	NO_3^- (mg/l)	NH_4^+ (mg/l)	No.	PM (g/l)	NO_3^- (mg/l)	NH_4^+ (mg/l)
SN1.1	0.4	0.38	0.24	SN2.3	12.4	0.75	0.15
SN1.3	0.4	0.34	0.38	SN2.4	10.4	0.75	0.29
SN1.4	2.0	0.38	0.22	SN2.5	19.2	0.84	0.24
SN1.5	5.6	0.72	0.40	SN2.6	2.0	0.33	0.21
SN1.6	17.2	0.97	0.35	SN2.9	16.8	0.77	0.20
Mean	5.1	0.56	0.32		12.2	0.69	0.22

Table 17. Particulate Matter, Nitrate and Ammonium Concentration of snow samples obtained January 15 1988

PM Particulate Matter
NO_3^--N Nitrate-Nitrogen
NH_4^+-N Ammonium-Nitrogen

4.2.1 *Variation in snowpack N content*

Conversion of water equivalence (cm) and concentration (mg/l) to an areal loading provides a measure of temporal variation in the mass (mg/m^2) of N (NO_3^--N and NH_4^+-N) in the snowpack. Figure 22 illustrates temporal variation in snowpack N load and water equivalence with spatial variation among sites indicated by bars representing the standard error of the mean. A complete record of numerical data is provided in Appendix C.

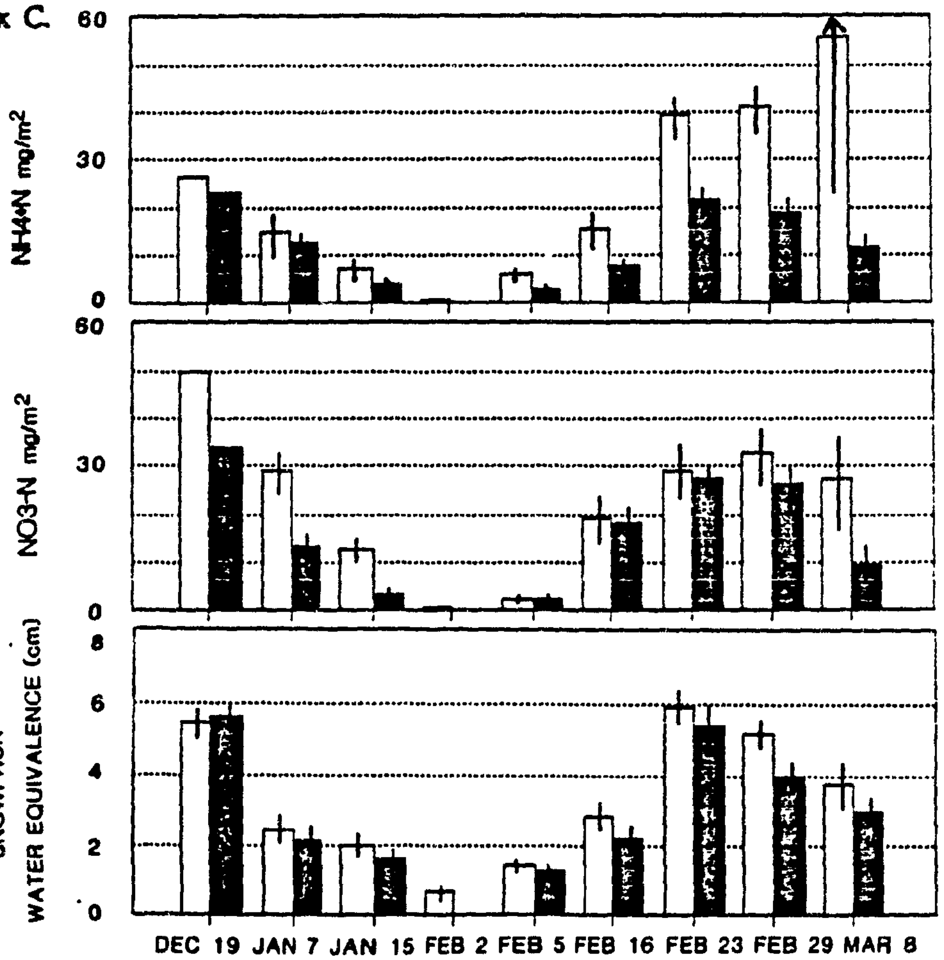


Figure 22. Snowpack Water Equivalence and Nitrogen Content

☐ SITE 1
■ SITE 2

Temporal variation in snowpack N content occurs in conjunction with change in total water equivalence, increases occurring during precipitation, and loss during snowmelt events. Analysis of snow melt water collected at the snow lysimeter (L1) indicates that on a weight to volume basis N is lost from the snowpack at a greater rate than meltwater. This phenomenon is known as preferential elution, a process which has been documented in experiments conducted both in the laboratory and under field conditions (Johanneson and Henrikson, 1978; Skartvelt and Gjessing, 1979). It has been demonstrated that nitrate is quickly eluted from the snowpack and that high concentrations are commonly found in the early fractions of meltwater (Seip, 1980). Consistent with these findings, the data recorded at the snow lysimeter (L1) indicate that high concentrations of NO_3^--N and NH_4^+-N were associated with short duration low volume melt events, rain on snow events and with the onset of major thaw events (Figure 23). A good example of elution is observed between January 7 and January 15 when a 57% (16.5 mg/m^2) and 50% (7.3 mg/m^2) loss of NO_3^--N and NH_4^+-N was associated with a 19% reduction in snowpack water equivalence.

Spatial variability in the mass of N in the snowpack depends largely on differences in water equivalence among sampling locations. On each date variation in the mass of N occurs as a result of the pattern of snow accumulation and resulting differences in snowpack water equivalence. Differences in snowpack water equivalence result from minor changes in surface topography, redistribution by wind and the influence of melting and percolation of water through the snowpack. Redistribution and melting not only affect the water equivalence of the snowpack but also the chemical composition.

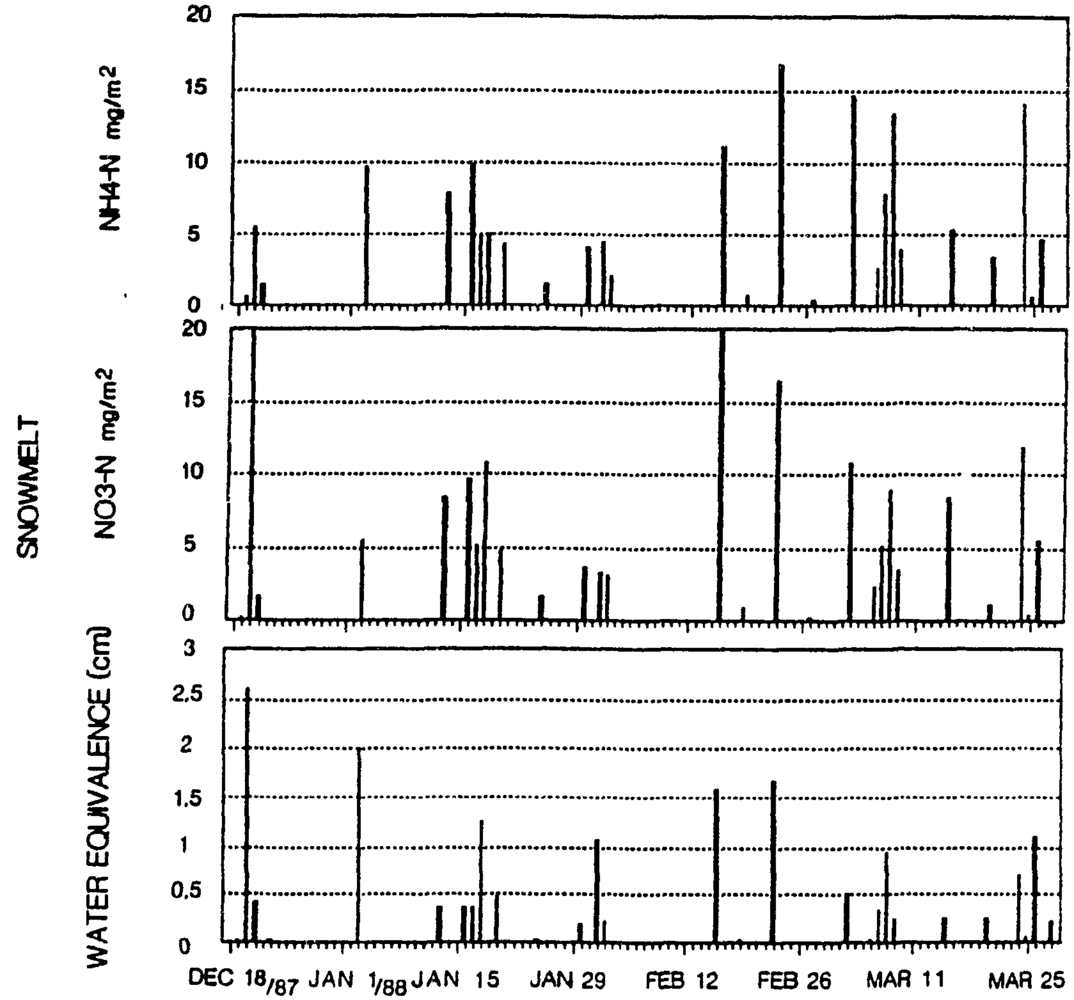


Figure 23. Snow lysimeter data: Water equivalence and N content

Additional N input or loss among sites may occur in association with redistribution of snow within the site. Melt water percolation may result in the loss of N ions through the process of elution or an enrichment due to saturation at the base of the profile. Differences observed in water equivalence among sites cannot explain the variation in concentration of NO_3^--N and NH_4^+-N in snow samples. Concentration is the result of several factors which include; elution during percolation of meltwater; the concentration of particulate matter; interaction with organic matter, and possibly enrichment by the upward capillary flow of N enriched meltwater (Peck, 1978). The effect of these processes is not of significance to this study; the importance of the data is in the identification of the timing and approximate measure of N loss from the snowpack to the soils below. The significance of these losses will be discussed in section 4.4 which deals with the change in the N content of water in the vadose and shallow groundwater zones.

4.3 *Soil* N *Content*

The values of soil N content (NO_3^--N and exchangeable NH_4^+-N) reported in section 3.2.4 demonstrate variation at each sampling depth in both time and space. It has been demonstrated that the chemical properties of soil may vary spatially due to variability of soil properties (section 4.1.2), and in agricultural soils variability may be increased due to residual effects of fertilizer application (Selles, 1986). The technique used to obtain samples may also contribute to the variation observed; as composite samples obtained from a standard 30 cm depth (see section 2.6.1) cannot account for potential differences in the depth of individual soil horizons. To determine whether temporal changes in exchangeable N content were statistically significant, t-tests were performed using the mean values obtained on successive sampling dates. The results of this analysis are presented in Tables 18 and 19.

4.3.1 *Soil* NO_3^--N *Content*

Changes in Nitrate-Nitrogen content follow a similar trend at both sites during most of the study. Calculations of net change in NO_3^--N content between successive sampling dates (Table 18) indicate a progressive increase in N content resulting in maximum levels March 6. The observed increases reflect mineralization of Organic N from crop and fertilizer residues and soil organic matter during periods of wetting and drying associated with periodic melting of the snowpack (Malhi and Nyborg, 1983; Malhi, 1985; Sheppard and Bates, 1986; Bergstrom, 1986). Soil samples obtained in the spring (March 28) also contained more NO_3^--N than the original mid-winter samples (January 9) however the values indicate a reduction in available NO_3^--N since March 6 (Figure 17). Given the variation observed in the 0-60cm depth the average change at site 1 was not significant. At site 2 the change was marked with a significant reduction in content at all sampling depths (Table 18). This decrease suggests; reduced mineralization, increased leaching of soluble mineral N during springmelt, and nitrate reduction. Earlier melting in the period prior to the March 28 sampling produced an elevated water table at site 2 (Figure 21), given this condition it is possible that a portion of the large decrease in NO_3^--N results from denitrification and a loss of N in gaseous form.

The last series of soil samples were obtained approximately one month after the monitoring of groundwater wells had been suspended (April 26). At this time a significant quantity of water, the result of heavy spring rains, had drained through the soil profile. The reason for including these samples is to demonstrate the potential change in N availability during the period following snowmelt and prior to spring fertilization and seeding. At the time of sampling the NO_3^--N content was significantly different than that observed March 28 and the pattern of change was opposite at the two sites; a large reduction was observed at site 1 while a substantial increase was recorded in the 30-90cm depth at site 2. It is suggested that the difference between sites is a function of land use. At site 1 plant uptake associated with early spring growth could account for the reduction in available N whereas the availability of organic material in a decaying state would contribute to an increase in the pool of available N at site 2.

Site 1 Interval	0-30cm	30-60cm	60-90cm
Jan 9 - Jan 29	$+ 9.6^{*}$	$+ 10.4^{*}$	NA
Jan 29 - Feb 10	$+ 25.6^{***}$	$- 11.0^{***}$	$- 0.2^{NS}$
Feb 10 - Mar 6	NA	$+ 18.0^{***}$	$+ 29.3^{***}$
Mar 6 - Mar 28	$- 7.3^{NS}{}_{1}$	$+ 8.6^{NS}$	$- 22.3^{*}$
Mar 28 - Apr 26	$- 26.4^{***}$	$- 36.1^{***}$	$- 18.0^{***}$

Site 2 Interval	0-30cm	30-60cm	60-90cm
Jan 9 - 29	$+ 0.7^{NS}$	$- 3.6^{NS}$	$- 0.3^{NS}$
Jan 29 - Feb 10	$+ 6.0^{**}$	$+ 4.3^{NS}$	NA
Feb 10 - Mar 6	$+ 30.5^{***}$	$+ 21.4^{***}$	$+ 26.8^{***}{}_{2}$
Mar 6 - Mar 28	$- 23.9^{***}$	$- 22.7^{***}$	$- 21.8^{***}$
Mar 28 - Apr 26	$+ 2.2^{NS}$	$+ 16.1^{**}$	$- 1.7^{***}$

Table 18. Average change in soil NO_3^--N content (µg/g).

$_1$ Based on change between Feb 10 and Mar 28
$_2$ Based on change between Jan 29 and Mar 6
Confidence Level
* Significant at 90%
** Significant at 95%
*** Significant at 99%
^{NS} No Significant Difference

4.3.2 *Soil* NH_4^+-N *Content*

Unlike change observed in NO_3^--N content, NH_4^+-N content does not demonstrate a general trend and also differs between site 1 and site 2 (Table 19). Although a trend of increase or decrease in NH_4^+-N content is not clear, a pattern is observed where; at site 1 significant changes in NH_4^+-N content generally correspond with similar increases or decreases in NO_3^--N content; at site 2 when a significant increase in NO_3^--N was observed it was usually associated with a decrease in NH_4^+-N content and visa versa. At site 1, with the exception of change in the 0-30cm depth on January 29 and March 28, NH_4^+-N content was not significantly different at times of sampling prior to April 26. At site 2, values exhibit moderate change however a clear trend is not demonstrated. As previously indicated the transformation of NH_4^+-N to NO_3^--N requires that soils be adequately aerated and the increase in levels of NH_4^+-N at site 2 between March 6 and March 28 may reflect mineralization of organic N which can continue even under rather anaerobic conditions (Kuo, 1981), however lower rates of nitrification result from the wetter and more reduced environment (Lowrance et. al., 1984). The increase may also be attributed to denitrification which occurs under water saturated conditions if appreciable NO_3^--N is present, this is consistent with the decrease observed in NO_3^--N during the same period.

Site 1	Interval	0-30cm	30-60cm	60-90cm
	Jan 9 - Jan 29	$+ 3.2^{***}$	$+ 0.4^{NS}$	NA
	Jan 29 - Feb 10	$+ 1.0^{NS}$	$- 0.4^{NS}$	$+ 0.8^{*}$
	Feb 10 - Mar 6	NA	$- 0.3^{NS}$	$+ 0.1^{NS}$
	Mar 6 - Mar 28	$- 7.3^{***}_{1}$	$+ 0.4^{NS}$	$+ 0.0^{NS}$
	Mar 28 - Apr 26	$- 1.9^{***}$	$- 1.7^{***}$	$- 1.0^{***}$

Site 2	Interval	0-30cm	30-60cm	60-90cm
	Jan 9 - 29	$+ 5.7^{***}$	$- 0.5^{NS}$	$+ 2.5^{*}$
	Jan 29 - Feb 10	$- 8.6^{***}$	$+ 3.6^{***}$	NA
	Feb 10 - Mar 6	$+ 2.5^{***}$	$- 5.5^{***}$	$- 2.7^{*}_{2}$
	Mar 6 - Mar 28	$+ 1.1^{*}$	$+ 1.3^{NS}$	$+ 1.3^{NS}$
	Mar 28 - Apr 26	$- 0.5^{NS}$	$- 1.5^{*}$	$- 1.7^{*}$

Table 19. Average change in soil exchangeable NH_4^+-N content (µg/g).

$_1$ Based on change between Feb 10 and Mar 28
$_2$ Based on change between Jan 29 and Mar 6
Confidence Level
* Significant at 90%
** Significant at 95%
*** Significant at 99%
^{NS} No Significant Difference

4.3.3 *Net Change in Soil* N *Content*

The following section provides an indication of the net change during the study period by comparing the mean NO_3^--N and NH_4^+-N content of the original samples (January 9) and samples obtained in the spring (March 28 and April 26). Tables 20 and 21 summarize the changes observed.

The data indicate a significant increase in mineral NO_3^--N content at both sites between January 9 and March 28. Losses at site 1 between March 28 and April 26 result in a net loss in the 30-90 cm depth while in the same period an increase at all depths results in a net gain at site 2; this in comparison to the N content of the initial samples (January 9). Nitrogen present in the form of NH_4^+-N represents a small fraction of the total mineral N and in the final analysis the data suggest minimal differences in the content measured January 9 and April 26.

		0-30cm	30-60cm	60-90cm
Jan 9	NO_3^--N	30.7	28.4	NA
	NH_4^+-N	9.4	4.5	NA
Mar 28	NO_3^--N	58.6	54.4	34.2
	NH_4^+-N	6.3	4.6	3.8
Apr 26	NO_3^--N	32.2	18.3	16.2
	NH_4^+-N	4.4	2.9	2.8
Jan 9 - Mar 28	NO_3^--N	$+ 27.9^{***}$	$+ 26.0^{***}$	$+ 6.3_1$
	NH_4^+-N	-3.1^{***}	$+ 0.1^{NS}$	$+ 0.9^{*}_1$
Mar 28 - Apr 26	NO_3^--N	$- 26.4^{***}$	$- 36.1^{***}$	$- 18.0^{***}$
	NH_4^+-N	-1.9^{***}	$- 1.7^{***}$	$- 1.0^{***}$
Jan 9 - Apr 26	NO_3^--N	$+ 1.5^{NS}$	$- 10.1^{*}$	-11.7^{**}_2
	NH_4^+-N	$- 5.0^{***}$	$- 1.6^{*}$	$- 0.1^{NS}_2$

Table 20. Average NO_3^--N and NH_4^+-N Content in 0-90 cm of soil at Site 1: mid-winter (January 9) and spring March 28/April 26).

Level of Confidence
* Significant at 90%
** Significant at 95%
*** Significant at 99%
^{NS} No Significant Difference

$_1$ Based on difference between Jan 29 and Mar 28
$_2$ Based on difference between Jan 29 and Apr 26

		0-30cm	30-60cm	60-90cm
Jan 9	NO_3^--N	23.9	12.5	6.3
	NH_4^+-N	6.6	6.5	3.5
Mar 28	NO_3^--N	35.8	19.1	11.6
	NH_4^+-N	7.2	5.4	4.6
Apr 26	NO_3^--N	38.0	35.2	44.4
	NH_4^+-N	6.7	3.9	2.9
Jan 9 - Mar 28	NO_3^--N	$+ 11.9^{**}$	$+ 6.6^{NS}$	$+ 5.3^{**}$
	NH_4^+-N	$+ 0.6^{*}$	$- 0.9$	$+ 0.9$
Mar 28 - Apr 26	NO_3^--N	$+ 2.2^{NS}$	$+ 16.1^{*}$	$+ 32.8^{***}$
	NH_4^+-N	$- 0.5^{NS}$	$- 1.5^{*}$	$- 1.7^{*}$
Jan 9 - Apr 26	NO_3^--N	$+ 14.1^{***}$	$+ 24.7^{***}$	$+ 38.1^{***}$
	NH_4^+-N	$+ 0.1^{NS}$	$- 2.6^{***}$	$- 0.6^{NS}$

Table 21. Average NO_3^--N and NH_4^+-N Content in 0-90 cm of soil at Site 2: mid-winter (January 9) and spring (March 28/April 26).

Level of Confidence for T-test Comparing Means
* Significant at 90%
** Significant at 95%
*** Significant at 99%
^{NS} No Significant Difference

The soil data reported up to this point provide a measure of change based on the N content of a known dry weight of soil. These results allow the chemical characteristics of the material obtained from different depths to be compared. However as the bulk density of soil varies with depth the mass of N present varies proportionately. To provide an indication of net change at each depth the data were converted to a mass of exchangeable N based on the mean dry sample concentration and bulk density (Section 4.1.2). Results of these calculations are presented in Tables 22 and 23.

	0-30 cm		30-60 cm		60-90 cm	
	Site 1 g/m^2_{30}	Site 2 g/m^2_{30}	Site 1 g/m^2_{30}	Site 2 g/m^2_{30}	Site 1 g/m^2_{30}	Site 2 g/m^2_{30}
Jan. 09	13.8	10.8	14.2	6.4	ND	3.4
Jan. 29	18.1	19.8	19.8	8.2	15.0	3.6
Feb. 10	29.6	13.1	14.2	10.4	14.7	ND
Mar. 06	ND	26.9	23.4	21.3	30.5	18.0
Mar. 28	26.3	16.1	27.7	9.7	18.5	6.3
Apr. 26	14.4	17.1	9.3	17.9	8.7	23.9

Table 22. Temporal Variation in Soil NO_3^--N Content (g/m^2_{30})

g/m^2_{30} value expressed as grams per square meter in 30 cm sampling depth
* site 2 based on density observed at site 1

	0-30 cm		30-60 cm		60-90 cm	
	Site 1 g/m^2_{30}	Site 2 g/m^2_{30}	Site 1 g/m^2_{30}	Site 2 g/m^2_{30}	Site 1 g/m^2_{30}	Site 2 g/m^2_{30}
Jan. 09	4.2	2.0	2.3	3.3	ND	1.9
Jan. 29	5.7	5.5	2.5	3.1	1.6	3.2
Feb. 10	6.1	1.7	2.3	4.9	2.0	ND
Mar. 06	ND	2.7	2.1	2.1	2.0	1.8
Mar. 28	2.8	3.2	2.3	2.8	2.0	2.5
Apr. 26	2.0	3.0	1.5	2.0	1.5	2.0

Table 23. Temporal Variation in Soil NH_4^+-N Content (g/m^2_{30})

g/m^2_{30} value expressed as grams per square meter in 30 cm sampling depth
* site 2 based on density observed at site 1

4.3.4 *Summary*

Calculation of a net loss or gain of N per m^2 indicates that NO_3^--N levels increased by approximately 34 g/m^2 at site 1, and 12 g/m^2 at site 2, between January 9 and March 28. As data is unavailable from 60-90 cm at site 1 the calculation of change at that site is based on the assumption that the increase between January 9 and January 29 was proportional at all depths. If this was the case the NO_3^--N content in the 60-90 cm depth on January 9 would have been approximately 10 g/m^2.

The change in N in the NH_4^+-N form during the same period is based on a January 9 content of 2 g/m^2 as the content of NH_4^+-N varies only slightly in the 60-90 cm depth at site 1 (Table 23). Therefore a loss of 1.4 g/m^2 is suggested to have occurred at site 1 between January 9 and March 28 while an increase of approximately 1.3 g/m^2 was observed at site 2.

April rainfall and plant uptake reduced the increase of both forms of N at site 1. The combination of these factors resulting in a decrease in N of approximately 40 g/m^2 and 2 g/m^2 NO_3^--N and NH_4^+-N respectively between March 28 and April 26. The data from site 2 suggest an increase of approximately 27 g/m^2 NO_3^--N and a reduction of approximately 1.5 g/m^2 NH_4^+-N. As previously noted the increase in NO_3^--N is attributed to possible oxidation of NH_4^+-N and a high level of organic matter in a decaying state.

4.4 Groundwater: NO_3^--N and NH_4^+-N Content

Comparison of the range of N (NO_3^--N and NH_4-N) concentrations in groundwater wells reported in section 3.2.4 indicates notable differences between Site 1 and Site 2. Examination of the data collected from Site 1 shows that the higher concentrations are the result of high values observed at wells D7, D9 and D10 (see Figure 3 for well location). Samples obtained from these wells consistently contained 4-8 times the N content recorded at the remaining wells. Excluding wells D7, D9 and D10, a plot of the remaining data demonstrates a trend which more closely approximates the change observed at Site 2 (Figure 24). Furthermore a plot of the mean N concentration recorded at wells D7, D9 and D10 illustrates that although on an elevated scale the change through time follows a similar trend as observed at the other wells (Figure 24). It is noteworthy that wells D7, D9 and D10 were located in close proximity to one another in an area bordering the edge of the study site, and that the adjacent field was broadcast with liquid manure in the late fall and winter. It is thought that the concentrations observed at wells D7, D9 and D10 are representative of a difference in N availability associated with a different agricultural management technique.

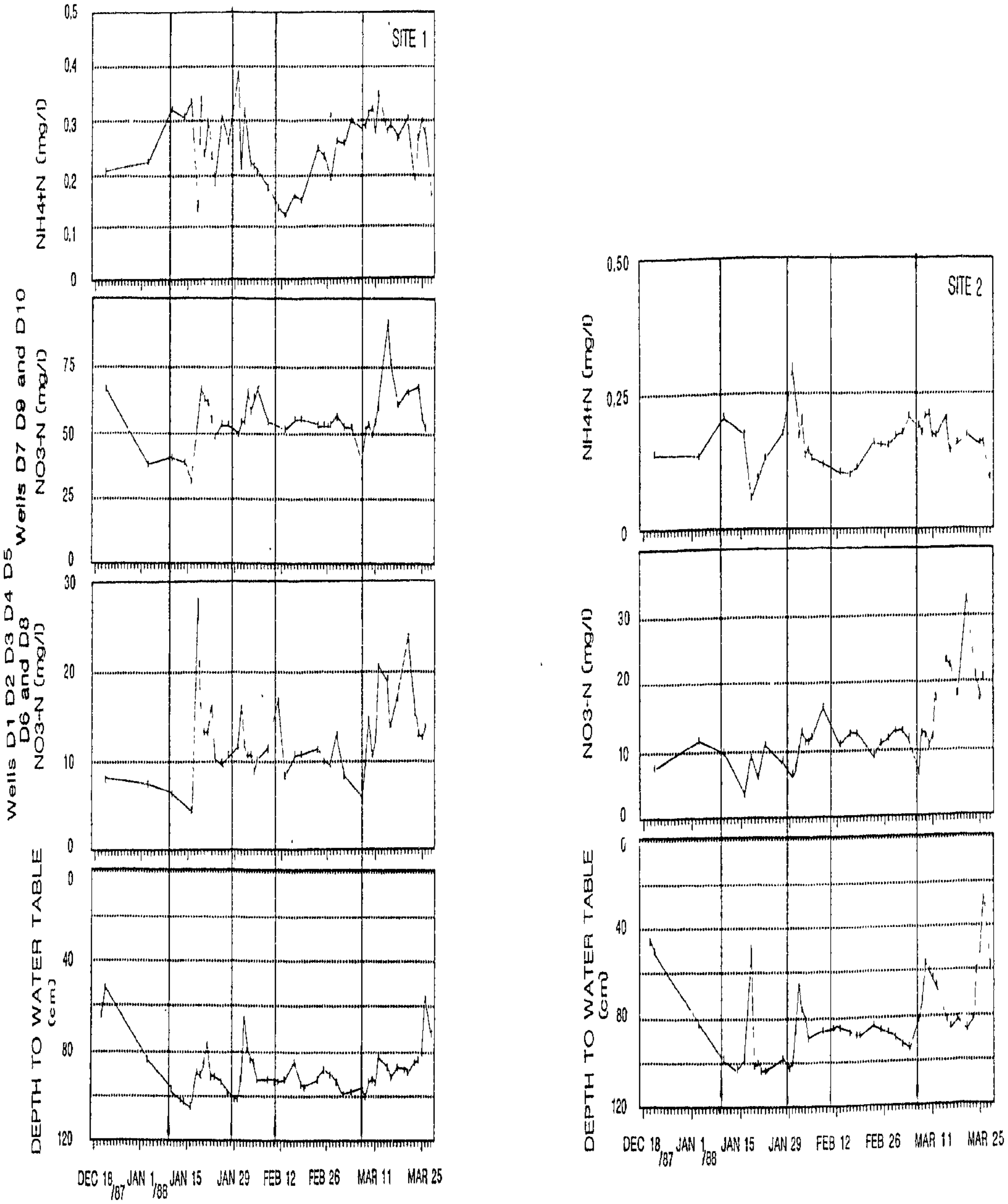


Figure 24. N Concentrations in Groundwater.

Differences in N (NO_3^--N and NH_4^+-N) concentration were observed among the wells on all sampling dates, however analysis of the range recorded on any particular date suggests that the mean values are representative of the changes observed. Although differences in concentration exist between the two sites as the result of different cropping and management systems (Owens, 1983), the majority of dissolved inorganic N occurs as NO_3^--N at both sites, as is common for drainage water from agricultural lands (Bergstrom, 1987).

4.4.1 *Temporal Variation in Groundwater* N *Content*

Changes in groundwater NO_3^--N concentration follow a similar trend at both sites where, as indicated in Figure 24, a major increase in concentration was observed at least once during each interval (see Section 4.1.3). Generally speaking this trend of increase and decrease is linked with snowmelt events and corresponding fluctuations in water table elevation (Figure 21). The data indicate that an increase in NO_3^--N concentration usually occurs in association with, or immediately following, an increase in the saturated area during the initial stages of a melt event (Figure 24). Downward displacement of pre-event N enriched water from the capillary fringe by meltwater results in an increase in N content in the saturated zone. This is indicative of scouring of NO_3^--N ions produced by mineralization in the unsaturated zone and capillary fringe area. As the water table recedes NO_3^--N concentration generally decreases as the initial pulse of water, which displaced the pre-event water, is followed by more recent event water. The concentration of soil water may remain elevated as mineral N is continuously leached during percolation, however a general reduction is observed as event water mixes with and dilutes the water in the saturated zone. In association with the reduction in available N, and reduction in the volume of water infiltrating the ground surface, a continual dilution is observed during the final recession of the water table. Concentration generally begins to increase toward the end of an event when infiltration is reduced and percolation less rapid. A continual flux of water occurs from the phreatic zone and consequently during periods in which little or no melt water is generated the water table elevation is maintained by percolation from the vadose zone. At these times, the percolating soil water having longer residence time has greater contact time with soil and therefore increased potential to come into chemical equilibrium with the soil.

The change observed in NH_4^+-N concentration generally follows a similar trend as NO_3^--N. Under conditions favourable for nitrification decreases in concentration suggest rapid transformation of NH_4^+-N to NO_3^--N and/or potential volatilization of NH_4^+-N to gaseous forms of N. Differences in the pattern of change are observed during periods of prolonged saturation. It has been demonstrated that the transformation of ammonia to nitrate is hindered in water-saturated soils (Kuo, 1981) and that in these conditions denitrification of nitrate may be pronounced. Although it is not possible to account for NO_3^- loss by denitrification, increases in NH_4^+-N content were observed during periods of prolonged saturated conditions. Examples of such increases are most noticeable in the periods January 3 to January 16, January 27 to January 30, and February 29 to March 8 (Figure 24).

4.4.2 N *Mass in the shallow saturated zone*

Water held under tension in the unsaturated layer and capillary fringe is eventually lost via subsurface tile drainage, or becomes phreatic water, as it is displaced by event water or drained from the saturated zone under gravity. The N in solution will therefore contribute to an increase in the N content of the phreatic zone and to the content observed in throughflow water and stream discharge. To assess the change in soluble N content and potential loss via sub-surface drainage, and/or deep percolation, an analysis of N content in the saturated area was conducted (Tables 24 and 25). This analysis is based on the volume and N concentration of phreatic water in the zone of saturation which existed above maximum well depth (105 cm). Determination of the volume of water in this zone is achieved using soil porosity values presented in section 4.1.2; the calculation of change in N content considers N concentration at times of maximum water table fluctuation.

The data presented in Tables 24 and 25 illustrate a flux of N (NO_3^--N and NH_4^+-N) into (+) and from (-) the saturated zone in association with fluctuation of the water table elevation. Given this data, a question arises as to the relative contribution of N from snowmelt and that which results from soil sources. Using the values of N content in the saturated area and the N content of snowmelt occurring during the corresponding time interval the following section provides an indication of the enrichment of snowmelt water during infiltration.

	DWT (cm)	SA (cm)	l	NO_3^--N[1] Conc. (mg/l)	NH_4^+-N[2] Conc. (mg/l)	NO_3^--N Mass m^2 (mg)	NH_4^+-N Mass m^2 (mg)	^WT (cm)	+/- NO_3^--N Mass m^2 (mg)	+/- NH_4^+-N Mass m^2 (mg)
Dec. 16	70	35	123	10.8	0.17	1330	3.5	NA	NA	NA
Dec. 21	52	53	186	7.9	0.21	1470	39.1	+18	+140	+34.4
Jan. 3	83	22	77	7.5	0.23	576	17.7	-31	-894	-21.4
Jan. 10	96	9	32	6.3	0.32	202	10.2	-13	-374	- 7.5
Jan. 16	104	1	4	4.4	0.34	20	1.4	- 8	-182	- 8.8
Jan. 21	77	28	98	13.2	0.30	1290	29.4	+27	+1270	+28.0
Jan. 30	101	4	14	11.6	0.39	160	5.5	-24	-1130	-23.9
Feb. 1	67	38	133	11.8	0.35	1570	46.5	+34	+1410	+41.0
Feb. 13	92	13	46	8.2	0.13	380	5.9	-25	-1190	-40.6
Feb. 16	85	20	70	10.8	0.16	760	11.2	+ 7	+ 380	+ 5.3
Feb. 23	92	13	46	11.1	0.25	510	11.5	- 7	- 250	+ 0.3
Feb. 29	88	17	60	12.7	0.26	760	15.6	+ 4	+ 250	+ 4.1
Mar. 2	101	4	14	8.3	0.26	120	3.6	-13	- 640	-12.0
Mar. 12	83	22	77	20.6	0.35	1590	26.9	+18	+1470	+23.3
Mar. 16	93	12	42	13.9	0.29	580	12.2	-10	-1010	-14.7
Mar. 18	86	19	67	16.9	0.27	1132	18.1	+ 7	+ 552	+ 5.9
Mar. 20	89	16	56	23.8	0.30	1332	16.8	- 3	+ 200	- 1.3
Mar. 26	56	49	172	13.7	0.29	2356	49.9	+33	+1024	+33.1
Mar. 28	71	34	119	NA	NA	NA	NA	-15	NA	NA

Table 24: Site 1 - Change in Mass of N in the Shallow Saturated Zone

DWT Depth to water table (cm below ground surface)
SA Saturated Area above well base (cm)
l Volume of water (l) per m^2 of saturated area - based on porosity = 35%
[1] Mean concentration of NO_3^--N - excluding wells S1D7, S1D9, S1D10
[2] Mean concentration of NH_4^+-N
^WT Change in elevation of water table (cm)
Mass m^2 Mass (mg) of N in solution in saturated area above well bottom
+/- Change in mass (mg) of N in solution in measured saturated area

	DWT (cm)	SA (cm)	l	NO_3^--N[1] Conc. (mg/l)	NH_4^+-N[2] Conc. (mg/l)	NO_3^--N Mass m^2 (mg)	NH_4^+-N Mass m^2 (mg)	^WT (cm)	+/- NO_3^--N Mass m^2 (mg)	+/- NH_4^+-N Mass m^2 (mg)
Dec. 21	50	55	193	5.1	0.25	98	4.8	NA	NA	NA
Jan. 3	83	22	77	9.4	0.18	724	13.9	-33	+626	+9.1
Jan. 10	98	7	25	8.4	0.29	210	7.3	-15	-514	-6.6
Jan. 16	98	7	25	3.8	0.23	95	5.8	NA	-115	-1.5
Jan. 21	103	2	7	11.1	0.17	78	1.2	-5	-17	-4.6
Jan. 30	102	3	11	6.7	0.39	74	4.3	+1	-4	+3.1
Feb. 1	66	39	137	10.1	0.22	1384	30.1	+36	+1310	+25.8
Feb. 13	84	21	74	11.1	0.13	821	9.6	-18	-563	-20.5
Feb. 16	87	18	63	12.4	0.13	781	8.2	-3	-40	-0.4
Feb. 23	83	22	77	9.2	0.20	708	15.4	+4	-73	+7.2
Feb. 29	89	16	56	12.7	0.22	711	12.3	-6	+2	-3.1
Mar. 2	93	12	42	12.9	0.23	542	9.7	-4	-169	-2.6
Mar. 12	67	38	133	17.7	0.22	2354	29.3	+26	+1812	+19.6
Mar. 16	85	20	70	18.8	0.19	1316	13.3	-18	-1038	-16.0
Mar. 18	81	24	84	15.4	0.21	1294	17.6	+4	-22	+4.3
Mar. 20	86	29	102	28.5	0.22	2907	22.4	+5	+1613	+4.8
Mar. 26	51	54	189	13.1	0.21	2476	39.7	+15	-431	+17.3
Mar. 28	57	48	168	NA	0.13	NA	NA	-6	NA	NA

Table 25. Site 2 - Change in Mass of N in the Shallow Saturated Zone

DWT Depth to water table (cm below ground surface)
SA Saturated Area above well base (cm)
l Volume of water (l) per m^2 of saturated area - based on porosity = 35%
[1] Mean concentration of NO_3^--N
[2] Mean concentration of NH_4^+-N
^WT Change in elevation of water table (cm)
Mass m^2 Mass of N in solution in saturated area above well bottom
+/- Change in mass (mg) of N in solution in measured saturated area

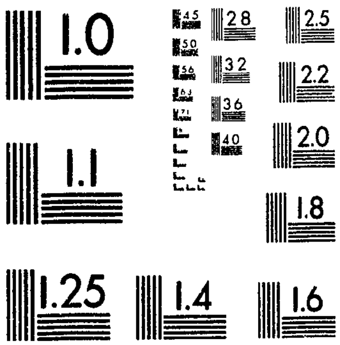
4.4.3 *Comparison of* N *content in meltwater and groundwater*

As reported in section 4.1.3 not all available melt water infiltrates the ground surface during a melt event. Calculation of N input to groundwater from the snowpack is therefore problematic. However, assuming 100% infiltration, when N in snowmelt and groundwater is compared on an event basis, the data indicate that N input in melt water generally accounts for only a small fraction of the total present in the saturated zone (Table 26).

	Site 1			
	Potential Melt Water Input (m^2)		Change in Mass of N (mg/m^2) in Saturated Zone	
	NO_3^--N (mg)	NH_4^+-N (mg)	NO_3^--N (mg)	NH_4^+-N (mg)
Dec. 16 - Dec 21	21.8	7.8	+140	+34.4
Dec. 21 - Jan 3	7.2	11.2	-894	-21.4
Jan. 3 - Jan 10	8.3	7.8	-374	-7.5
Jan. 16 - Jan 21	30.3	15.1	+1270	+28.0
Jan. 30 - Feb 2	10.0	10.4	+1410	+41.0
Feb. 13 - Feb 16	20.9	26.6	+380	+5.3
Feb. 22 - Feb 29	16.6	17.3	+250	+4.1
Mar. 2 - Mar 12	30.9	42.2	+1470	+23.3
Mar. 15 - Mar 26	27.4	27.9	+1767	+37.7

Table 26: Comparison of Potential Input of N from Meltwater and Observed Changes in N Content of the Shallow Saturated Zone

2 OF/DE 2



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With the exception of the period December 21 to January 10 an increase in NO_3^--N content is observed in the saturated zone during melt events. Moreover, the loss calculated between December 21 and January 10 may not be representative of actual change as the data for this period is limited. In all other cases the increase in NO_3^--N content is well in excess of the potential snowmelt contribution. Smaller than average increases between February 13 and February 29 reflect the reduction in infiltration of melt water (Table 26) and reduced leaching and translocation of N ions during this period.

The change in NH_4^+-N content follows a similar trend as change in NO_3^--N content the exception being the period March 2 to March 12. In most cases the increase in NH_4^+-N content is well in excess of the potential snowmelt contribution. Consistent with change in NO_3^--N content a smaller than average increase in NH_4^+-N content is observed between February 13 and February 29 when infiltration was limited. Soil sources clearly account for most of the increase in groundwater N content during melt events. This is further indicative that most water contributing to the rise in water table is pre-event which is displaced from the unsaturated zone and capillary fringe area.

4.4.4 *N Enrichment of Soil Percolate Water*

Comparison of N content in water samples obtained from 'shallow' and 'deep' wells further demonstrates N enrichment of meltwater during percolation (see Figures 3 and 4 for well locations). Observations at shallow wells are limited to times at which the upper 30 cm of the soil was saturated: these numbering 10 and 12 occasions at Site 1 and Site

2 respectively (Appendix G). At both sites the NO_3^--N content of melt water generally increases during percolation (Table 27); the available data indicating that NO_3^--N enrichment of melt water occurs throughout the depth sampled.

In contrast the NH_4^+-N concentration of snowmelt is generally greater than the concentration observed in soil water (Table 27) suggesting nitrification to NO_3 and/or gaseous loss. Furthermore, a difference in the pattern of change is observed between site 1 and site 2. At site 1 NH_4^+-N concentration generally decreases with depth while at site 2 an increase is usually observed. As previously reported, under favourable conditions NH_4^+-N is rapidly transformed to NO_3^--N however fixation of NH_4^+-N may account for some of the loss observed at site 2 (Stevenson, 1986). Transformation of NH_4^+ to NO_3^- would contribute to any initial increase in NO_3^- concentration resulting from the removal of NO_3^--N ions during percolation, but would not provide a sufficient quantity to result in the enrichment observed at either site.

	NO_3^--N (mg/l)			NH_4^+-N (mg/l)		
Site 1	Snowmelt	S	D[1]	Snowmelt	S	D
Dec. 21	0.46	2.3	7.9	0.36	0.15	0.21
Jan. 18	0.49	13.5	28.1	0.39	0.63	0.14
Jan. 19		9.9	16.2		0.71	0.38
Jan. 20	1.16	5.5	13.2	0.90	1.40	
Jan. 21		4.9			0.72	
Jan 31	2.57	6.1	15.8	2.00	0.65	0.22
Feb. 1	0.53	7.2	11.8	0.41	0.61	0.35
Feb. 2	1.15	6.8	10.6	0.90	0.35	0.29
Mar. 10		3.2		1.43		
Mar. 11		4.8			0.88	0.58
Mar. 12	3.39	11.8	20.7	1.51	0.88	0.35
Mar. 15	NA	NA	19.2	2.16	NA	0.28
Mar. 24		6.7	13.0	2.00	0.54	0.27
Mar. 25	1.71	3.9	12.7	1.23	0.64	0.30
Mar. 26	0.80	2.3	13.7	0.41	0.48	0.29

	NO_3^--N[2]		NH_4^+-N[2]	
Site 2	S	D	S	D
Dec. 21	2.7	5.1	0.14	0.25
Jan. 20	11.1	6.4	0.09	0.10
Jan. 22	NA	11.1	NA	0.13
Jan. 30	9.3	6.7	0.11	0.30
Feb. 1	9.3	10.1	0.09	0.17
Feb. 2	12.9	12.7	0.10	0.21
Feb. 3	NA	11.3	NA	0.14
Mar. 9	9.3	12.1	0.16	0.21
Mar. 10	7.1	10.8	0.19	0.21
Mar. 11	8.0	11.8	0.22	0.17
Mar. 12	9.6	17.7	0.21	0.17
Mar. 15	NA	20.6	NA	0.21
Mar. 24	12.4	14.0	0.19	NA
Mar. 25	9.0	11.5	0.22	0.16
Mar. 26	5.2	13.1	0.14	0.16

Table 27. Comparison of N concentration in Deep and Shallow Wells

1 Mean value excluding wells S1D7, S1D9 and S1D10
2 Mean excluding well S2D7

4.5 Conclusion

The intention of this research was to study the change in mineral N content in soil and percolate water during winter months, as related to snowmelt infiltration. The study also examined atmospheric N contribution to determine whether this source provided a significant contribution to N concentrations in the shallow saturated soil zone.

During the months December, 1987 to March, 1988 snowcover displayed considerable spatial and temporal variability. Prominent peaks in the elevation of the groundwater table commonly followed snowmelt events; the combination of above average temperatures, rain events and a relatively thin depth of frost resulting in infiltration of most melt water during thaw events.

Changes in the mass of soluble N (NO_3^--N and NH_4^+-N) in the vadose and shallow saturated zones were related to variations in the rate and volume of infiltration. The rate of infiltration in turn depended upon surface conditions and was controlled by precipitation and snowcover accumulation, and temperature.

Periods of reduced infiltration following snowmelt events were generally characterized by the accumulation of mineral N in the soil profile. Measured changes in soil NO_3^--N and exchangeable NH_4^+-N are the net result of a variety of N-processes acting simultaneously, including mineralization, nitrification, defixation of NH_4^+-N, leaching and denitrification. Periods of drying and wetting, and freezing and thawing of the soil resulted in the increased availability of mineral N. Losses resulting from leaching, indicated by changes in the N content of soil N, are further reflected in increases in the N content of groundwater samples. While NO_3^- is transported downward in percolate water it can simultaneously be lost by denitrification; and it has been suggested that a large proportion of the loss occurred via this process (Stevenson, 1986).

Overwinter transformation of organic N in the vadose zone resulted in a significant increase in the N content of soils in early spring (March 28). NO_3^--N content increased in the 0-30, 30-60 and 60-90cm depths by 12.5, 13.5 and ~5 g/m^2 at site 1 and 5.3, 3.3, and 2.9 g/m^2 at site 2. Changes in NH_4^+-N content were not consistent, those changes observed were generally small and deemed not to be significant. The increase in NO_3^--N content at site 1 was subsequently reduced by leaching associated with spring rainfall so that by late spring (April 26) the N content of the soil was not significantly different from that observed at the time of early winter sampling (January 9). At site 2, additional increases in NO_3^--N were observed between March 28 and April 26 so that at the time of final sampling N content was significantly greater than recorded January 9. Once again NH_4^+-N content did not vary significantly.

Although it is not possible to absolutely quantify the loss of N during the winter months this study demonstrates that considerable movement of N can be associated with snowmelt events; the degree to which N transformations and leaching occur during winter being related to the timing and rate of infiltration. The flux of N from the vadose and capillary fringe areas is seen to be a function of soil moisture conditions prior to a melt event, the length of time between infiltration events, the drainage volume of an event and of the soil N content. Finally, comparison of NO_3^--N and NH_4^+-N concentrations in winter precipitation and shallow groundwater indicated that the contribution of precipitation N to groundwater is a small fraction in comparison to that derived from soil sources.

In order to reduce the N content of drainage water, management practices must aim to reduce the N concentration in soil water as it is difficult to control the volume of subsurface drainage. Annual crops usually leave a considerable amount of inorganic N in the soil at harvest. In addition to this fraction, mineralization of organic N produces a further pool of N which is susceptible to leaching. Therefore, to reduce N export to surface waters, management practices which result in large inorganic and organic N residues in the upper soil zones after cropping should be avoided. While N losses from soil cannot be completely eliminated, conservation tillage, maintenance of cover crops, more efficient rates and timing of fertilizer application and waste disposal, can act to reduce the post harvest N content of soil thereby reducing the likelihood of water quality degradation. Continued efforts are required to determine N inputs needed to decrease N loss while maintaining or even increasing crop yields through efficient fertilizer use. For this reason factors influencing over-winter N transformations and N loss continues to provide an interesting area for research.

4.6 Recommendations for improved sampling strategy

This study supports previous research suggesting that considerable loss of soluble inorganic N occurs during winter months. The purpose of this section is to make suggestions for future work in the area of over-winter change in inorganic N content. These suggestions include recommendations for an improved sampling strategy which should be considered in order to provide a more detailed analysis of the over winter loss of N during snowmelt events.

In order to account for the total loss of N between fall harvesting and spring sowing, the following recommendations should be considered when developing a sampling strategy:

1) Sampling should be conducted throughout the fall, winter and spring seasons to asses the full impact of seasonal variations in temperature and precipitation:

2) The number of recording devices implemented for the measurement of precipitation and snowmelt should be increased;

3) The determination of Total N, and fixed ammonium content would greatly enhance the understanding of the changes observed in Nitrate and Ammonium content.

4) Soil samples should be obtained more frequently and from greater depth in order to facilitate a detailed examination of the relationship between soil moisture and soil N content. Increased soil moisture readings could be achieved through the installation of access tubes for a soil moisture probe;

5) A detailed and more accurate assessment of the flux of N from the vadose zone to the phreatic zone should be made. This could be achieved through the use of soil percolate lysimeters and continuous recording of changing water table elevation and N concentrations in deeper groundwater wells. In addition, soil permeability should be measured in situ by means of a slug test or similar procedure;

6) Differences in soil type, topography and thaw patterns contribute to different hydrological response in soils. These differences may significantly alter N transformations occurring within the soil and therefore different soil and land use types must be examined and the concentration of N in shallow ground water during snowmelt evaluated;

7) In conjunction with the recommendations listed above the fate of N exported from the vadose zone should be examined. In part this would be achieved by obtaining samples from greater depth. In addition, the examination of N dynamics of drainage water, produced by subsurface tile drainage and surface runoff, would provide a measure of the N contribution to surface waters from agricultural land during periodic snowmelt events.

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APPENDIX A. Extensive snow survey, January 15, 1988.

APPENDIX A Extended Snow Survey, Feb. 5 Site 1

DENSITY		DEPTH (cm)		WEQ (cm)	
Stubble	Open	Stubble	Open	Stubble	Open
0.13	0.06	12.00	12.00	1.56	0.72
0.12	0.11	12.70	12.50	1.52	1.38
0.13	0.11	12.00	12.00	1.56	1.32
0.11	0.12	10.30	9.70	1.13	1.16
0.12	0.10	14.00	12.00	1.68	1.20
0.12	0.13	12.70	10.30	1.52	1.34
0.15	0.08	15.30	13.00	2.29	1.04
0.10	0.12	14.00	12.70	1.40	1.52
0.08	0.11	17.70	11.00	1.42	1.21
0.12	0.11	10.00	11.00	1.20	1.21
0.11	0.13	10.00	10.00	1.10	1.30
0.12	0.14	12.70	11.00	1.52	1.54
0.13	0.13	10.60	12.30	1.38	1.60
0.13	0.12	9.30	9.60	1.21	1.15
0.17	0.13	10.00	12.30	1.70	1.60
0.14	0.12	8.60	12.30	1.20	1.48
0.17	0.16	9.60	9.60	1.63	1.54
			Mean	1.47	1.31
			Max	2.29	1.60
			Min	1.10	0.72
			Stdev	0.29	0.22

APPENDIX A Extended Snow Survey, Feb. 5 Site 2

DENSITY	DEPTH (cm)		WEQ (cm)	
	Furrow	Ridge	Furrow	Ridge
0.12	11.67	9.50	1.40	1.14
0.08	14.00	4.67	1.12	0.37
0.10	10.33	3.33	0.98	0.32
0.09	11.33	7.33	0.97	0.63
0.08	7.33	6.00	0.59	0.48
0.12	17.67	8.00	2.12	0.96
0.10	14.67	5.00	1.47	0.50
0.12	10.67	8.33	1.28	1.00
0.13	15.67	4.33	2.04	0.56
0.13	11.00	8.33	1.43	1.08
0.12	9.00	4.33	1.08	0.52
0.12	9.33	4.67	1.12	0.56
0.16	9.00	6.00	1.44	0.96
0.12	9.67	1.00	1.16	0.12
0.11	10.00	5.67	1.10	0.62
0.11	10.33	6.00	1.14	0.66
0.11	11.33	10.67	1.25	1.17
0.09	11.00	6.00	0.99	0.54
0.09	8.33	6.33	0.75	0.57
0.10	8.33	8.00	0.83	0.80
0.12	9.33	8.00	1.12	0.96
0.10	11.67	6.33	1.17	0.63
0.07	7.00	9.00	0.49	0.63
0.10	11.33	7.00	1.13	0.70
0.10	12.00	5.67	1.20	0.57
0.09	11.33	4.67	1.02	0.42
		Mean	1.17	0.67
		Max	2.12	1.17
		Min	0.49	0.12
		Stdev	0.35	0.26

APPENDIX B. Precipitation data.

Appendix B: Precipitation Data

Date	P1 (ml)	P2 (ml)	Mean (ml)	WEQ (cm)	R/S	NO_3^--N (mg/l)	NH_4^+-N (mg/l)	NO_3^--N (mg/m^2)	NH_4^+-N (mg/m^2)
Dec 19	810	825	818	1.81	M	0.46	0.30	8.32	5.43
Jan 3 *	101	111	106	0.23	M	2.21	1.40	5.08	3.22
Jan 7	46	49	48	0.11	S	1.62	1.53	1.78	1.68
Jan 9				TR	S	NA	NA	NA	NA
Jan 13				TR	S	NA	NA	NA	NA
Jan 15 **				0.22	S	0.64	5.87	1.41	12.91
Jan 17	110	120	115	0.25	R	2.27	3.03	5.67	7.58
Jan 18	484	492	488	1.08	R	0.91	0.73	9.83	7.88
Jan 20	193	196	195	0.43	R	0.86	0.93	3.70	3.99
Jan 21				TR	S	NA	NA	NA	NA
Jan 22 **				0.20	S	NA	NA	NA	NA
Jan 23	19	20	20	0.04	S	NA	2.11	NA	0.84
Jan 24 **				0.15	S	NA	NA	NA	NA
Jan 25	72	67	70	0.15	S	1.59	1.67	2.39	2.50
Jan 27	9	10	10	0.02	S	NA	3.10	NA	0.62
Feb 1	460	465	463	1.02	M	0.55	0.98	5.61	9.99
Feb 2 **				0.69	S	0.06	0.11	0.41	0.76
Feb 4 **				0.64	S	0.15	0.44	0.96	2.82
Feb 8	91	97	94	0.21	S	1.96	4.97	4.12	10.44
Feb 11	45	32	39	0.09	S	2.05	2.18	1.85	1.96
Feb 12				TR	S	NA	NA	NA	NA
Feb 13	222	202	212	0.47	S	1.25	0.79	5.88	3.71
Feb 17 *	200	260	230	0.51	M	1.31	1.25	6.68	6.38
Feb 23 **				1.60	M	0.61	0.87	9.76	13.92
Feb 25	12	10	11	0.02	S	0.54	5.00	0.11	1.00
Feb 27 **				TR	S	NA	NA	NA	NA
Mar 9	41	42	42	0.09	R	9.79	10.50	8.81	9.45
Mar 15 *	279	273	276	0.61	M	2.26	1.40	13.79	8.54
Mar 16 **				0.10	S	NA	NA	NA	NA
Mar 20	62	68	65	0.14	S	2.73	1.84	3.82	2.58
Mar 23 **				0.48	S	NA	NA	NA	NA
Mar 24	180	177	179	0.39	R	3.19	4.20	12.44	16.38
Mar 25 ***				0.05	R	NA	NA	NA	NA
Mar 26	456	455	456	1.01	R	0.56	0.85	5.66	8.53

	WEQ (cm)	NO_3^--N mg/m^2	NH_4^+-N mg/m^2
Total	12.8	118.1	149.2

1 Sampling Date (Precipitation event occurs in prior 24 hours)
WEQ Water equivalence (cm)
R/S Precipitation Type (M - Mixture rain and snow)
TR Trace precipitation not measurable
NA No Data Available
* Composite since previous sampling date
** Field observation made when gauge empty
*** Value obtained from measurement of lysimeter catch

APPENDIX C. Snowpack water equivalence and N content.

Snowpack Water Equivalence (cm) and Nitrogen Content (mg/l)

SITE 1

		WEQ cm
DEC 19	SS1.1	7.03
	SS1.2	ND
	SS1.3	3.92
	SS1.4	ND
	SS1.5	4.10
	SS1.6	ND
	SS1.7	5.27
	SS1.8	5.46
	SS1.9	5.78
	SS1.10	6.54
	SS1.11	5.51
	SS1.12	5.81
	MEAN	5.49
		0.33

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
JAN 7	SS1.1	2.15	0.77	0.33	16.55	7.02
	SS1.2	2.43	0.74	0.33	17.98	8.05
	SS1.3	2.16	1.02	0.69	22.03	14.82
	SS1.4	2.35	0.40	0.83	9.40	19.52
	SS1.5	2.55	0.99	1.43	25.24	36.41
	SS1.6	3.66	0.94	0.60	63.54	40.56
	SS1.7	3.66	1.33	0.29	89.90	19.60
	SS1.8	3.27	1.13	0.27	36.95	8.70
	SS1.9	1.66	0.88	0.24	14.61	4.03
	SS1.10	1.46	0.68	0.25	9.93	3.61
	SS1.11	1.90	1.22	0.45	23.18	9.51
	SS1.12	1.93	1.00	0.28	19.30	5.31
	MEAN	2.43	0.92	0.50	29.05	14.68
		0.22	0.07	0.10	2.87	4.46

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
JAN 15	SS1.1	1.76	0.38	0.24	6.69	4.22
	SS1.2	1.73	0.35	0.25	6.05	4.33
	SS1.3	1.50	0.34	0.38	5.10	5.70
	SS1.4	1.38	0.38	0.22	5.24	3.04
	SS1.5	4.70	0.72	0.40	33.34	18.80
	SS1.6	2.21	0.97	0.35	21.44	7.73
	SS1.8	1.97	1.15	0.45	22.66	3.37
	SS1.9	1.27	0.59	0.31	7.49	3.94
	SS1.10	1.62	0.63	0.34	10.21	5.51
	SS1.11	1.48	0.61	0.47	9.03	6.96
	SS1.12	2.05	0.49	0.55	10.04	11.27
	MEAN	1.97	0.60	0.36	12.53	7.21
		0.27	0.08	0.13	2.88	[illegible]

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
FEB 2	SS1.1	0.63	0.06	0.10	0.38	0.62
	SS1.2	0.72	0.08	0.11	0.58	0.77
	SS1.3	0.70	0.05	0.12	0.35	0.84
	SS1.4	0.77	0.07	0.10	0.54	0.79
	SS1.5	0.63	0.02	0.11	0.13	0.71
	SS1.6	0.63	0.05	0.11	0.32	0.72
	MEAN	0.68	0.06	0.11	0.38	0.74
		0.02	0.01	0.00	0.06	0.02

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
FEB 5	SS1.1	1.14	0.15	0.45	1.71	5.11
	SS1.2	1.45	0.12	0.45	1.74	6.51
	SS1.3	1.44	0.13	0.48	1.87	6.91
	SS1.4	1.15	0.14	0.51	1.61	5.86
	SS1.5	1.48	0.11	0.28	1.63	4.11
	SS1.6	1.43	0.14	0.46	2.00	6.59
	SS1.7	1.67	0.16	0.25	2.67	4.14
	SS1.8	1.20	0.21	0.49	2.52	5.87
	SS1.9	1.20	0.15	0.35	1.80	4.17
	SS1.10	1.53	0.19	0.55	2.91	8.47
	SS1.11	1.49	0.16	0.49	2.38	7.25
	SS1.12	1.18	0.16	0.58	1.89	6.84
	SS1.13	1.65	0.15	0.40	2.47	6.62
	MEAN	1.39	0.15	0.44	2.09	6.03
		0.05	0.01	0.02	0.12	0.35

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
FEB 16	SS1.1	2.10	0.48	0.41	10.08	8.62
	SS1.2	2.36	0.80	0.45	18.88	10.57
	SS1.3	3.08	0.78	0.84	24.02	26.02
	SS1.4	1.36	0.54	0.31	7.34	4.19
	SS1.5	3.86	0.65	0.41	25.09	15.85
	SS1.8	4.58	0.71	0.31	32.52	14.32
	SS1.9	1.32	1.06	1.02	13.99	13.43
	SS1.10	4.44	0.62	0.77	27.53	34.40
	SS1.12	2.52	0.49	0.43	12.35	10.94
	MEAN	2.85	0.68	0.55	19.09	15.37
		0.44	0.06	0.08	3.17	3.13

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
FEB 23	SS1.1	3.64	0.20	0.33	7.28	11.98
	SS1.2	6.86	0.54	0.74	37.04	50.90
	SS1.3	4.75	0.58	1.24	27.55	58.85
	SS1.4	7.64	0.62	0.65	47.37	49.74
	SS1.5	7.49	0.49	0.69	36.70	51.91
	SS1.6	5.34	0.73	0.71	38.98	37.75
	SS1.7	4.45	0.35	0.52	15.58	23.05
	SS1.8	6.86	0.86	0.96	59.00	65.79
	SS1.9	7.36	0.23	0.50	16.93	37.09
	SS1.10	5.81	0.49	0.46	28.47	26.84
	SS1.11	4.98	0.39	0.59	19.42	29.28
	SS1.12	5.75	0.28	0.55	16.10	31.80
	MEAN	5.91	0.48	0.66	29.20	39.58
		0.47	0.05	0.07	5.02	5.09

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
FEB 29	SS1.1	6.60	0.62	0.67	40.92	44.22
	SS1.2	3.83	1.31	1.40	50.17	53.80
	SS1.3	4.42	0.61	0.64	26.96	28.26
	SS1.4	5.44	0.32	0.52	17.41	28.43
	SS1.5	6.58	0.88	0.85	57.90	55.89
	SS1.6	5.75	0.43	0.69	24.72	39.71
	SS1.7	5.35	0.78	0.83	41.73	44.19
	SS1.8	5.26	0.87	1.16	45.76	61.01
	SS1.9	6.90	0.27	0.39	18.63	26.73
	SS1.10	4.50	0.43	0.69	19.35	30.37
	SS1.11	3.17	0.70	1.22	22.19	38.76
	SS1.12	5.34	0.50	0.83	26.70	44.11
	MEAN	5.20	0.64	0.82	32.95	41.33
		0.33	0.08	0.08	3.98	3.31

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
MAR 8	SS1.1	6.00	0.36	4.45	21.60	267.12
	SS1.2	0.00	0.00	0.00	0.00	0.00
	SS1.3	4.10	0.64	0.78	26.24	31.86
	SS1.4	5.80	0.67	0.82	38.96	47.50
	SS1.5	3.20	0.67	0.85	21.44	27.10
	SS1.6	4.95	0.59	0.77	29.20	38.12
	SS1.7	0.00	0.00	0.00	0.00	0.00
	SS1.8	2.10	0.46	0.65	9.66	13.67
	SS1.9	5.96	0.52	0.67	30.99	40.05
	SS1.10	0.00	0.00	0.00	0.00	0.00
	SS1.11	6.80	0.86	1.27	58.48	86.16
	SS1.12	7.10	1.33	1.67	94.43	113.29
	MEAN	3.83	0.51	0.99	27.58	55.32
		0.75	0.25	0.33	8.54	23.21

APPENDIX C

Snowpack Water Equivalence (cm) and Nitrogen Content (mg/l).

SITE 2		WEQ cm
DEC 19	SS2.1	5.82
	SS2.2	5.32
	SS2.3	5.10
	SS2.4	4.51
	SS2.5	8.60
	SS2.6	4.58
	MEAN	5.66
		0.57

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
JAN 7	SS2.1	1.97	0.74	0.67	14.57	13.24
	SS2.2	2.36	0.94	0.66	22.24	15.64
	SS2.3	3.28	0.49	0.60	16.17	19.59
	SS2.4	1.97	0.32	0.74	6.28	14.53
	SS2.5	1.97	0.74	0.43	14.57	8.46
	SS2.6	1.37	0.30	0.36	4.17	4.99
	SS2.7	1.23	ND	ND	NA	NA
	SS2.8	2.25	ND	ND	NA	NA
	SS2.9	2.08	ND	ND	NA	NA
	SS2.10	2.57	ND	ND	NA	NA
	MEAN	2.11	0.59	0.58	13.00	12.74
		0.17	0.10	0.06	2.49	1.95

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
JAN 15	SS2.1	1.49	ND	ND	NA	NA
	SS2.2	1.43	ND	ND	NA	NA
	SS2.3	1.52	0.15	0.07	2.29	1.12
	SS2.4	1.58	0.29	0.43	4.58	6.78
	SS2.5	1.49	0.24	0.15	3.58	2.23
	SS2.6	1.45	0.21	0.27	3.04	3.96
	SS2.7	1.94	0.12	0.21	2.33	4.07
	SS2.8	1.58	0.25	0.21	3.95	3.32
	SS2.9	1.63	0.20	0.12	3.26	1.98
	SS2.10	1.76	0.13	0.36	2.29	6.41
	MEAN	1.59	0.20	0.23	3.16	3.72
		0.05	0.02	0.04	0.30	0.72

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
FEB 5	SS2.1	1.26	0.15	0.22	1.95	2.74
	SS2.2	0.98	0.12	0.15	1.18	1.50
	SS2.3	1.36	0.21	0.15	2.83	2.06
	SS2.4	1.38	0.28	0.43	3.30	5.96
	SS2.5	1.74	0.17	0.18	2.94	3.17
	SS2.6	1.10	0.19	0.28	2.07	3.12
	SS2.7	1.30	0.19	0.22	2.51	2.83
	SS2.8	1.12	0.17	0.23	1.89	2.55
	SS2.9	0.80	0.12	0.13	0.93	1.01
	SS2.10	1.15	0.18	0.21	2.11	2.37
	MEAN	1.22	0.18	0.22	2.22	2.73
		0.08	0.01	0.03	0.25	0.40

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
FEB 16	SS2.1	2.28	0.49	0.25	11.24	5.75
	SS2.2	2.44	0.83	0.32	20.17	7.74
	SS2.3	2.31	1.06	0.30	24.45	6.90
	SS2.4	1.66	0.78	0.33	13.00	5.42
	SS2.5	3.25	0.94	0.38	30.63	12.44
	SS2.6	1.95	0.59	0.27	11.59	5.19
	SS2.7	3.30	0.73	0.37	23.93	12.32
	SS2.8	2.36	1.16	0.43	27.38	10.24
	SS2.9	0.00	ND	ND	0.00	0.00
	SS2.10	2.47	0.70	0.38	17.29	9.39
	MEAN	2.20	0.80	0.34	17.97	7.54
		0.28	0.07	0.02	2.92	1.19

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
FEB 23	SS2.1	6.50	0.80	0.47	52.63	30.35
	SS2.2	6.36	0.73	0.48	46.11	30.27
	SS2.3	6.19	0.59	0.32	36.30	19.50
	SS2.4	3.56	0.49	0.42	17.55	14.95
	SS2.5	5.70	0.30	0.36	17.36	20.75
	SS2.6	7.92	0.36	0.36	28.71	28.83
	SS2.7	6.65	0.39	0.27	26.03	17.69
	SS2.8	7.00	0.41	0.41	28.42	28.91
	SS2.9	5.29	0.49	0.41	25.70	21.48
	SS2.10	7.72	0.57	0.46	43.66	35.10
	SS2.11	0.00	ND	ND	0.00	0.00
	SS2.12	2.14	0.42	0.29	8.99	6.21
	MEAN	5.43	0.50	0.39	27.66	21.22
		0.66	0.05	0.02	4.23	2.91

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
FEB 29	SS2.1	5.68	0.43	0.43	24.71	24.65
	SS2.2	4.42	0.39	0.43	17.30	19.18
	SS2.3	4.60	0.46	0.50	21.34	22.97
	SS2.4	2.23	0.55	0.44	12.29	9.89
	SS2.5	3.02	1.23	0.27	37.22	8.03
	SS2.6	4.49	0.38	0.39	16.93	17.60
	SS2.7	4.28	0.75	0.52	32.06	22.17
	SS2.8	4.46	0.43	0.49	19.19	22.06
	SS2.9	4.42	0.55	0.27	24.14	11.96
	SS2.10	3.81	0.59	0.51	22.65	19.47
	SS2.11	3.33	1.67	0.98	55.53	32.63
	SS2.12	3.43	0.87	0.43	29.84	14.89
	MEAN	4.01	0.69	0.47	26.10	18.79
		0.25	0.11	0.05	3.20	1.91

		WEQ cm	NO3-N mg/l	NH4+N mg/l	NO3-N mg/m2	NH4+N mg/m2
MAR 8	SS2.1	3.00	0.26	0.64	7.83	19.07
	SS2.2	3.00	0.36	0.39	10.66	11.76
	SS2.3	3.00	0.26	0.39	7.83	11.55
	SS2.4	3.00	0.36	0.48	10.66	14.28
	SS2.5	3.00	0.42	0.35	12.62	10.50
	SS2.6	3.00	0.28	0.27	8.48	7.98
	SS2.7	3.00	0.22	0.27	6.53	8.19
	SS2.8	3.00	0.36	0.26	10.66	7.77
	SS2.9	3.00	0.25	0.41	7.40	12.39
	MEAN	3.00	0.31	0.38	9.18	11.50
		0.00	0.02	0.04	0.64	1.13

APPENDIX C: Mean Snowpack Water Equivalence and Nitrogen Load

	Weq (cm)		NO_3^--N[1] (mg/m^2)		NH_4^+-N[1] (mg/m^2)	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Dec 19	5.5 (0.3)	5.7 (0.6)	ND ND	ND ND	ND ND	ND ND
Jan 7	2.4 (0.2)	2.1 (0.2)	29.1 (2.9)	13.0 (2.5)	14.7 (4.5)	12.7 (2.0)
Jan 15	2.0 (0.3)	1.6 (0.1)	12.5 (2.7)	3.2 (0.5)	7.3 (1.3)	3.7 (0.7)
Feb 2	0.7 (0.0)	ND ND	0.4 (0.1)	ND ND	0.7 (0.0)	ND ND
Feb 5	1.4 (0.1)	1.2 (0.1)	2.1 (0.1)	2.2 (0.3)	6.0 (0.4)	2.7 (0.4)
Feb 16	2.8 (0.4)	2.2 (0.3)	19.1 (3.2)	17.9 (2.9)	15.4 (3.2)	7.5 (1.2)
Feb 23	5.9 (0.5)	5.4 (0.7)	29.2 (5.0)	27.6 (4.3)	39.6 (5.1)	21.2 (2.9)
Feb 29	5.2 (0.3)	4.0 (0.3)	32.9 (4.0)	26.1 (3.2)	41.3 (3.3)	18.9 (1.9)
Mar 8	3.8 (0.8)	3.0 (0.0)*	27.6 (9.5)	9.2 (0.6)	55.8(33.2)	11.5 (1.1)

Weq Water equivalence

APPENDIX D. Snow lysimeter data.

Appendix D: Lysimeter Data

Date[1]	Volume (ml)	WEQ (cm)	NO_3^--N (mg/l)	NH_4^+-N (mg/l)	NO_3^--N (mg/m_2)	NH_4^+-N (mg/m^2)
Dec 19	225	0.03	0.41	1.85	0.12	0.56
Dec 20	21200	2.61	0.78	0.21	20.36	5.48
Dec 21	3260	0.40	0.40	0.36	1.60	1.44
Dec 23	280	0.03	0.00	NA	0.00	NA
Jan 3*	16200	1.99	0.28	0.49	5.57	9.75
Jan 13	3000	0.37	2.25	2.11	8.33	7.81
Jan 16	3000	0.37	2.64	2.72	9.77	10.06
Jan 17	3000	0.37	1.38	1.34	5.11	4.96
Jan 18**	10200	1.25	0.86	0.39	10.75	4.86
Jan 20	3840	0.47	1.02	0.90	4.79	4.23
Jan 25	316	0.04	4.06	3.85	1.62	1.54
Jan 30**	1660	0.20	1.80	2.00	3.60	4.00
Feb 1	8640	1.06	0.31	0.41	3.25	4.35
Feb 2	1890	0.23	1.36	0.90	3.13	2.07
Feb 16	13000	1.60	1.25	0.70	20.00	11.20
Feb 19	329	0.04	2.44	2.02	0.98	0.81
Feb 23	13500	1.66	0.99	1.01	16.43	16.77
Feb 25	30	0.00	0.90	0.91	NA	NA
Feb 27	80	0.01	1.84	4.79	0.18	0.48
Mar 3	4000	0.49	2.20	2.97	10.78	14.55
Mar 6	330	0.04	6.02	6.55	2.41	2.62
Mar 7	2700	0.33	1.57	2.39	5.18	7.89
Mar 8	7700	0.95	0.95	1.41	9.03	13.39
Mar 9	2000	0.25	1.39	1.51	3.48	3.78
Mar 15*	2000	0.25	3.39	2.16	8.48	5.40
Mar 20	2100	0.26	0.42	1.29	1.09	3.35
Mar 24	5680	0.70	1.71	2.00	11.97	14.00
Mar 25**	415	0.05	0.80	1.23	0.40	0.61
Mar 26	9000	1.11	0.49	0.41	5.44	4.55

	WEQ (cm)	NO_3^--N mg/m^2	NH_4^+-N mg/m^2
Total	17.8	174.2	160.5

1 Sampling Date (Precipitation event occurs in prior 24 hours)

NA No Data Available

WEQ Water equivalence (cm)

* Composite Since Previous Sampling Date

** Lysimeter completely empty

APPENDIX E. Soil moisture content.

APPENDIX E: Moisture Content[1] in Soils Jan.9 - Apr. 26

		Site 1			Site 2		
Depth (cm)		0-30	30-60	60-90	0-30	30-60	60-90
Jan 09	Mean	27.8	19.0	NA	24.6	19.1	14.2
	Max.	35.7	36.5	NA	27.7	21.8	17.2
	Min.	18.2	12.5	NA	21.9	16.9	12.4
	$\sigma/\sqrt{N}$	1.3	1.8	NA	1.0	1.0	0.9
	No. Obs.	13	11	NA	5	4	4
Jan 29	Mean	31.5	19.1	17.6	33.9	19.4	18.0
	Max.	40.2	30.2	21.3	37.1	23.4	20.5
	Min.	22.4	8.7	11.8	30.0	17.1	16.2
	$\sigma/\sqrt{N}$	1.5	1.4	0.4	0.9	0.7	1.0
	No. Obs.	13	12	8	8	7	3
Feb 10	Mean	31.3	18.7	18.1	33.5	19.6	NA
	Max.	38.2	26.5	27.0	37.0	22.1	NA
	Min.	22.4	11.2	12.9	29.2	16.2	NA
	$\sigma/\sqrt{N}$	1.4	1.2	1.3	0.9	0.7	NA
	No. Obs.	13	13	11	9	9	NA
Mar 06	Mean	NA	19.8	18.7	41.2	20.3	16.8
	Max.	NA	25.6	26.4	47.3	25.1	31.0
	Min.	NA	15.1	13.9	36.9	16.1	8.9
	$\sigma/\sqrt{N}$	NA	0.7	1.3	1.2	1.1	2.0
	No. Obs.	NA	11	8	9	9	8
Mar 28	Mean	28.9	22.1	21.0	29.6	20.4	19.0
	Max.	39.6	45.5	33.1	38.3	28.8	25.3
	Min.	18.9	12.4	12.7	24.5	16.7	12.2
	$\sigma/\sqrt{N}$	1.4	2.2	1.5	1.4	1.1	1.4
	No. Obs.	13	13	12	9	9	9
Apr 26	Mean	21.9	16.7	16.5	20.2	17.4	17.8
	Max.	25.6	20.8	20.9	23.2	19.8	22.7
	Min.	16.8	11.2	11.4	17.6	14.0	10.9
	$\sigma/\sqrt{N}$	0.7	0.8	0.3	0.6	0.7	1.3
	No. Obs.	13	13	11	9	9	7

[1] expressed as percentage of dry mass

APPENDIX E Soil Moisture Content (% Dry Weight) Site 1

	LOCATION	JAN9	JAN29	FEB10	MAR6	MAR28	APR26
0-30 cm	1.1	21.6	23.7	24.1		25.1	20.8
	2.1	33.9	32.9	29.0		39.6	25.4
	3.1	32.5	29.4	29.5		23.9	20.9
	4.1	22.8	29.5	35.6		29.3	16.8
	5.1	25.3	40.2	37.8		31.9	21.0
	6.1	25.6	33.0	31.6		28.5	22.1
	7.1	18.2	38.9	37.1		31.1	22.1
	8.1	35.7				26.5	25.6
	9.1	28.9	25.6	26.4		18.9	16.8
	10.1	26.0	22.4	30.4		28.8	21.7
	11.1	33.5	33.9	31.9		32.4	25.6
	12.1	25.2	35.6	38.2		33.0	23.7
	13.1	31.9	35.9	32.9			
	14.1	27.9	28.2	22.4		27.0	22.3
30-60 cm	1.2	21.0	22.1	22.8	19.8	25.1	20.8
	2.2		16.8	16.3		17.9	15.1
	3.2	12.5	19.3	14.1	18.3	18.8	16.5
	4.2	15.7	12.8	11.2	18.7	23.1	14.2
	5.2		22.4	19.5	17.6	16.8	11.4
	6.2	22.0		23.3		13.2	18.3
	7.2	14.6	19.2	19.0	24.1	23.8	18.0
	8.2	13.1				23.5	16.2
	9.2	15.6	8.7	13.1	25.6	12.4	11.2
	10.2	19.6	18.8	18.5		24.6	18.3
	11.2	19.9	21.8	19.3	15.1	20.6	19.0
	12.2	36.5	30.2	26.5	19.4	45.5	20.0
	13.2	19.2	18.0	20.5	20.8		
	14.2	18.7	18.5	19.3	18.2	22.2	16.5
60-90 cm	1.3		20.1	19.4	15.6	22.3	19.0
	2.3		11.8	12.9	26.4	15.6	12.9
	3.3		20.9	20.0	13.9	15.4	
	4.3					23.7	13.7
	5.3		17.9	13.7	19.1	12.7	11.4
	6.3			14.9			14.8
	7.3				16.9	19.3	14.5
	8.3					26.9	17.8
	9.3					18.9	
	10.3		11.8	21.5		22.4	19.2
	11.3		18.1	16.1		20.8	18.7
	12.3			27.0	15.7	33.1	20.9
	13.3		21.3	18.9	21.9		
	14.3		19.2	17.0	20.2	20.6	18.3

APPENDIX E Soil Moisture Content (% Dry Weight) Site 2

	LOCATION	JAN9	JAN29	FEB10	MAR6	MAR28	APR26
0-30 cm	1.1	23.3	37.1	36.8	37.2	24.5	20.8
	2.1	27.1	36.9	32.7	47.3	32.1	19.2
	3.1	21.9	30.0	37.0	36.9	38.3	21.3
	4.1		30.5	36.2	40.3	28.9	23.2
	5.1	27.7	30.5	33.3	43.4	26.3	21.1
	6.1		36.4	30.0	37.4	34.9	18.2
	7.1		35.5	33.5	46.1	27.5	22.3
	8.1		33.9	32.5	41.0	26.7	17.6
	9.1	23.1		29.2	41.3	26.9	18.0
30-60 cm	1.2	21.8	19.4	22.1	16.1	21.9	19.8
	2.2	20.9	17.1	20.2	20.4	17.0	14.2
	3.2	18.6	23.4	16.4	17.3	16.7	17.6
	4.2		17.7	16.2	16.9	28.8	19.6
	5.2	17.1	18.4	20.7	25.0	21.1	14.0
	6.2			21.1	25.1	18.7	18.2
	7.2		20.5	21.3	21.0	19.9	17.8
	8.2		19.4	21.2	18.4	19.7	18.8
	9.2	16.9		16.9	22.2	19.7	16.6
60-90 cm	1.3	14.2	17.2		8.9	25.3	21.6
	2.3	17.2	16.2		16.7	17.3	13.2
	3.3	13.1			14.4	15.0	17.6
	4.3				18.5	19.8	17.1
	5.3	12.4				14.8	10.9
	6.3				16.4	12.3	
	7.3		20.5		10.9	23.8	22.0
	8.3				17.4	20.3	22.7
	9.3				31.0	13.7	17.5

APPENDIX F. Groundwater table elevation.

APPENDIX F Depth to Groundwater Table (cm) Site 1

DATE	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	MEAN
DEC20/87	-103	-76	-58	-102	-25	-56	-63	-35	-102	-20	-64
DEC21	-99	-53	-62	-95	-22	-28	-35	-7	-82	-36	-51.9
JAN3/88	-95	-100	-87	-96	-74	-61	-78	-69	-82	-90	-83.2
JAN10	-103	-107	-96		-91	-99	-84	-102	-90	-96	-96.4
JAN12								-103	-100		-101.5
JAN14			-106		-102	-107	-103	-103	-96	-102	-102.7
JAN16			-106	-104		-105			-103	-102	-104
JAN18	-105		-75			-42	-105		-104	-103	-89
JAN19	-101		-78	-105	-99	-57	-73		-104	-103	-90
JAN20	-105		-82			-59	-72		-100	-99	-86.2
JAN21	-98		-67		-65	-53	-58	-94	-85	-99	-77.4
JAN22	-105	-108	-82	-104	-91	-62	-68	-105	-85	-99	-90.9
JAN23	-103	-110	-85	-103	-94	-63	-74	-103	-86	-94	-91.5
JAN25	-101	-109	-90	-104	-95	-70	-79	-102	-89	-95	-93.4
JAN27	-105	-110	-110	-104	-98	-89	-83	-105	-92	-98	-99.4
JAN29			-108		-97	-104	-94	-105	-97	-100	-100.7
JAN30	-105	-100	-104			-104	-94	-105	-96	-99	-100.9
JAN31	-108	-109	-52		-98	-54	-102	-104	-101	-100	-92
FEB1/88	-101	-82	-70		-45	-39	-53	-39	-82	-89	-66.7
FEB2	-102	-105	-84	-102	-63	-49	-58	-52	-88	-85	-78.8
FEB3	-105	-109	-86		-80	-62	-73	-64	-84	-86	-83.2
FEB4	-106	-110	-86		-87	-66	-73	-76	-82	-78	-84.9
FEB5	-106	-110	-86		-89	-89	-74	-103	-85	-91	-92.6
FEB8	-105	-110	-86	-101	-92	-63	-77	-101	-94	-92	-92.1
FEB10	-105	-110	-89	-106	-89	-67	-78	-104	-95	-93	-93.6
FEB11	-106	-110	-89	-103	-87	-67	-78	-103	-96	-98	-93.7
FEB13	-105	-110	-90		-86	-69	-79	-102	-97	-94	-92.4
FEB16			-90		-93	-65	-75		-91	-97	-85.2
FEB18	-104	-109	-95	-103	-92	-68	-78	-103	-94	-98	-94.4
FEB19	-104	-109	-101	-104	-96	-67	-78	-103	-98	-98	-95.8
FEB23	-103	-109	-90	-102	-85	-68	-80	-101	-88	-97	-92.3
FEB25			-101		-96	-69	-78		-87	-96	-87.8
FEB27			-99	-103	-96	-70	-79		-90	-96	-90.4
FEB29			-103		-98	-87	-83		-95	-98	-94
MAR2			-103		-96	-111	-83	-103	-100	-99	-99.3
MAR4			-105			-105	-87		-98	-96	-98.2
MAR7			-104			-101	-84	-104	-92	-95	-96.7
MAR8			-106			-106	-95	-104	-96	-96	-100.5
MAR9			-104			-105	-76		-94	-89	-93.6
MAR10			-104			-102	-74		-93	-89	-92.4
MAR11	-105		-103	-104	-96	-98	-71		-88	-85	-93.8
MAR12	-76		-81		-98	-60	-71	-104	-88	-85	-82.9
MAR15	-93		-86		-94	-67	-78	-103	-84	-92	-87.1
MAR16	-103		-96		-96	-68	-78	-102	-93	-95	-91.4
MAR18	-102		-74	-104	-95	-65	-75		-86	-92	-86.6
MAR20	-100		-83		-93	-68	-78	-103	-86	-94	-88.1
MAR21	-100		-86		-92	-70	-78	-104	-86	-95	-88.9
MAR23			-90		-91	-68	-78		-87	-95	-84.8
MAR24	-88	-108	-75	-104	-91	-42	-68		-77	-97	-83.3
MAR25	-84	-103	-74	-104	-81	-46	-60	-104	-71	-76	-80.3
MAR26	-90	-74	-71	-99	-40	-37	-51	-24	-41	-36	-56.3
MAR28	-93	-89	-82	-92	-59	-55	-65	-50	-64	-65	-71.4

Number of observations indicates times water available

APPENDIX F Depth to Groundwater Table (cm) Site 2

DATE	D1	D2	D3	D4	D5	D6	D7	D8	MEAN
DEC20/87			-63	-24	-86	-48	-26	-25	-45.3
DEC21	-99	-78	-45	-30	-49	-35	-24	-40	-50
JAN3/88	-77	-73	-83	-89	-78	-93	-85	-86	-83
JAN10	-91	-92	-101	-104	-97	-98	-99	-99	-97.6
JAN14	-105	-99							-102
JAN16	-100	-96							-98
JAN18		-49							-49
JAN19		-101							-101
JAN20	-104	-96		-103		-96			-99.8
JAN21		-101	-105						-103
JAN22	-103		-103						-103
JAN27	-101	-97	-96						-98
JAN29	-104	-100							-102
JAN30	-101	-99							-100
JAN31	-105	-119						-34	-86
FEB1	-32	-97	-65	-74	-90			-39	-66.2
FEB2	-48	-98	-71	-77	-81			-78	-75.5
FEB3	-58	-98	-76	-82	-84			-86	-80.7
FEB4	-103	-98	-77	-83	-85			-87	-88.8
FEB8	-99	-84	-76	-84	-85			-87	-85.3
FEB11	-96	-79	-78	-84	-86			-88	-85.2
FEB13	-94	-74	-81	-85	-86			-86	-84.3
FEB16	-99	-79	-78	-88	-88			-88	-86.7
FEB18	-101	-78	-82	-89	-90			-90	-88.3
FEB19	-104	-79	-82	-90	-88			-88	-88.5
FEB23	-94	-75	-74	-87	-86			-85	-83.5
FEB25	-100	-78	-78	-85	-86			-85	-85.3
FEB27	-99	-78	-79	-86	-89			-88	-86.5
FEB29	-99	-78	-82	-91	-91			-91	-88.7
MAR2	-101	-81	-88	-97	-96			-94	-92.8
MAR4	-101	-86	-88	-103	-94			-90	-93.7
MAR7	-46	-85	-77	-102	-85			-91	-81
MAR8	-21	-78	-65	-104	-80			-88	-72.7
MAR9	-1	-67	-37	-94	-63			-78	-56.7
MAR10	-15	-56	-60	-84	-65			-79	-59.8
MAR11	-24	-56	-64	-79	-72			-81	-62.7
MAR12	-51	-59	-64	-74	-73			-78	-66.5
MAR15	-76	-71	-73	-79	-77	-99	-95	-79	-81.1
MAR16	-100	-73	-76	-82	-85		-99	-81	-85.1
MAR18	-96	-69	-72	-78	-80		-98	-77	-81.4
MAR21	-94	-74	-78	-81	-82	-98	-96	-82	-85.6
MAR23	-89	-71	-77	-80	-81		-98	-77	-81.9
MAR24	-29	-35	-45	-61	-58	-98	-92	-63	-60.1
MAR25	-44	-42	-50	-47	-57	-90	-50	-26	-50.8
MAR26	-27	-24	-32	-25	-38	-32	-27	-19	-28
MAR28	-55	-59	-65	-54	-61	-54	-50	-59	-57.1

Number of observations indicates times water available

APPENDIX G. Groundwater N Content.

APPENDIX 6 Nitrate Concentration (mg/l) in Groundwater at Site I (Deep wells)

DATE	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	NO.OBS.	MEAN	MAX	MIN	
DEC16			15.72	13.40	11.94	6.41	32.32	6.60			6.00	14.40	32.32	6.41	3.56
DEC17		40.48	14.37	8.15	16.40	18.35					5.00	19.55	40.48	8.15	4.92
DEC21		16.02	13.98	7.47	6.70	2.43	29.99	1.16	82.99	87.36	9.00	27.57	87.36	1.16	10.62
JAN3			13.40	11.07	4.08	4.08	22.71	4.95	52.71	38.80	8.00	18.98	52.71	4.08	5.97
JAN10	4.59	10.77	10.48		3.47	3.42	23.59	5.32	60.28	40.19	9.00	18.01	60.28	3.42	6.27
JAN14							18.64		59.40		2.00	39.02	59.40	18.64	14.41
JAN16			7.28			1.46			58.24	6.21	4.00	18.30	58.24	1.46	11.59
JAN18			29.70			26.40					2.00	28.05	29.70	26.40	1.17
JAN19	11.65		25.14			11.75	44.46		88.52		5.00	36.30	88.52	11.65	12.85
JAN20			18.64			7.86	37.18		89.69		4.00	38.34	89.69	7.86	15.73
JAN21	16.60		20.68		9.32	9.61	31.45	9.61	92.02		7.00	27.04	92.02	9.32	10.42
JAN22		25.92	22.71		6.60	7.86	26.79		90.85	48.34	7.00	32.73	90.85	6.60	10.21
JAN23			19.22		6.99	5.24	26.21		81.54	41.06	6.00	30.04	81.54	5.24	10.60
JAN25	10.92		18.35		6.99	7.57	30.87	5.34	86.20	45.02	8.00	26.41	86.20	5.34	9.20
JAN27			17.47		7.47	7.57	30.28		83.87	47.76	6.00	32.40	83.87	7.47	10.39
JAN31			19.51			12.23	27.96		82.70	53.00	5.00	39.08	82.70	12.23	11.53
FEB1	18.64	12.23	15.43		5.82	8.74	36.11	10.00	80.37	48.05	9.00	26.15	80.37	5.82	7.75
FEB2	9.90	14.37	14.75	9.61	6.70	8.64	35.53	10.19	97.26	63.48	10.00	27.04	97.26	6.70	9.09
FEB3	9.90	16.60	15.72		6.70	6.70	33.49	8.06	88.33	54.94	9.00	26.71	88.33	6.70	8.82
FEB4			15.14		6.41	6.41	48.05	6.79	91.00	52.42	7.00	32.32	91.00	6.41	11.42
FEB5			16.70		7.86	7.86	50.23	8.44	91.00	59.99	7.00	34.58	91.00	7.86	11.52
FEB8			18.64	10.48	9.61	10.68	38.44	6.70	62.51	62.51	8.00	27.45	62.51	6.70	7.88
FEB11			20.38	12.81							2.00	16.60	20.38	12.81	2.68
FEB13			15.43		6.41	7.57	34.94	3.59	71.34	50.18	7.00	27.07	71.34	3.59	9.09
FEB16			16.11		6.89	9.03	39.60		77.75	50.18	6.00	33.26	77.75	6.89	10.39
FEB18			15.72	10.19	7.28	10.00	39.02		78.62	49.03	7.00	29.98	78.62	7.28	9.39
FEB23		14.27	14.27	9.61	15.14		37.86	2.62	76.88	47.30	8.00	27.24	76.88	2.62	8.27
FEB25			14.56		6.41	8.74	39.02		76.00	46.72	6.00	31.91	76.00	6.41	10.14
FEB27			14.85	8.06	6.99	8.74	38.44		76.00	46.14	7.00	28.46	76.00	6.99	9.17
FEB29			15.92			9.61	41.93		80.37	46.72	5.00	38.91	80.37	9.61	11.27
MAR2			15.72		6.12	9.12	38.05	2.33	77.17	44.22	7.00	27.53	77.17	2.33	9.50
MAR4							37.86		77.75	44.41	3.00	53.34	77.75	37.86	10.09
MAR7			14.07			2.91	25.63	0.87	58.53	31.72	6.00	22.29	58.53	0.87	8.02
MAR8						9.61	35.53		76.00	44.41	4.00	41.39	76.00	9.61	11.86
MAR9			18.93			10.19	35.53		73.38	51.91	5.00	37.99	73.38	10.19	10.17
MAR10			13.10			8.15	33.20		66.39	51.91	5.00	34.55	66.39	8.15	9.94
MAR11			18.73		7.47	10.48	33.78		71.64	57.87	6.00	33.33	71.64	7.47	9.82
MAR12	23.30		21.84			16.89	39.60		76.00	64.02	6.00	40.28	76.00	16.89	9.15
MAR15	20.87		21.55		15.92	18.35	50.09		92.89	129.78	7.00	49.92	129.78	15.32	15.67
MAR16	16.11		19.12		12.23	14.95	60.38	7.57	93.18	77.10	8.00	37.58	93.18	7.57	11.20
MAR18	17.18		20.58	16.31	13.01	17.28	45.23		81.54	56.33	8.00	33.43	81.54	13.01	8.27
MAR21	25.63		19.51		30.38	25.14	62.90	18.35	79.50	55.37	8.00	39.60	79.50	18.35	7.63
MAR23	17.11		16.89			12.23					3.00	15.41	17.11	12.23	1.29
MAR24	14.17	14.56	17.76	11.36	7.86	12.42	44.26		89.11	69.79	9.00	31.26	89.11	7.86	9.33
MAR25	13.40	16.31	18.05		6.21	9.71	38.44		80.08	51.34	8.00	29.19	80.08	6.21	8.49
MAR26	14.66	23.39	16.31	13.69	9.32	9.32	39.41	8.93	67.27	51.34	10.00	25.36	67.27	8.93	6.12
NO.OBS	16.00	11.00	43.00	13.00	31.00	42.00	41.00	19.00	41.00	37.00					
MEAN	15.29	18.63	17.27	10.94	9.05	10.04	36.95	6.71	78.46	53.16					
MAX	25.63	40.48	29.70	16.31	30.38	26.40	62.90	18.35	97.26	129.78					
MIN	4.59	10.77	7.28	7.47	3.47	1.46	18.64	0.87	52.71	6.21					

Number of observations indicates times water available
Values represent the average of three replicates

APPENDIX 8 Ammonium Concentration (mg/l) in Groundwater at Site 1 [Deep wells]

DATE	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	NO.OBS	MEAN	MAX	MIN	
DEC16		0.23	0.15	0.16	0.12	0.19	0.15				6.00	0.17	0.23	0.12	0.01
DEC21			0.23	0.63	0.24	0.16	0.22	0.22		0.18	7.00	0.27	0.63	0.16	0.06
JAN3			0.37	0.40	0.37	0.21	0.16	0.16	0.15	0.17	8.00	0.25	0.40	0.15	0.04
JAN10	0.12	0.32	0.50		0.32	0.47	0.39	0.24	0.26	0.29	9.00	0.32	0.50	0.12	0.04
JAN14							0.29		0.33		2.00	0.31	0.33	0.29	0.01
JAN16			0.32			0.44			0.35	0.24	4.00	0.34	0.44	0.24	0.04
JAN18			0.14			0.14					2.00	0.14	0.14	0.14	0.00
JAN19	0.46		0.22			0.19	0.53		0.31		5.00	0.34	0.53	0.19	0.06
JAN20			0.17			0.21	0.35		0.24		4.00	0.24	0.35	0.17	0.02
JAN21	0.36		0.20		0.20	0.20	0.60		0.24		6.00	0.30	0.60	0.20	0.06
JAN22			0.16		0.16	0.17	0.26		0.22	0.17	6.00	0.19	0.26	0.16	0.02
JAN25	0.45		0.24		0.20	0.23	0.37	0.41	0.32	0.24	8.00	0.31	0.45	0.20	0.03
JAN27			0.25		0.17	0.25	0.28		0.35	0.27	6.00	0.26	0.35	0.17	0.02
JAN30			0.34			0.41	0.35		0.46	0.39	5.00	0.39	0.46	0.34	0.02
JAN31			0.20			0.18	0.29			0.21	4.00	0.22	0.29	0.18	0.02
FEB1	0.35	0.33	0.22		0.30	0.23	0.30	0.36	0.37	0.36	9.00	0.31	0.37	0.22	0.02
FEB2	0.34	0.31	0.21	0.69	0.27	0.20	0.29	0.25	0.32	0.30	10.00	0.32	0.69	0.20	0.04
FEB3		0.31	0.22		0.17	0.18	0.23	0.21	0.27	0.21	8.00	0.23	0.31	0.17	0.01
FEB4			0.18		0.17	0.18	0.24	0.21	0.25	0.31	7.00	0.22	0.31	0.17	0.02
FEB5			0.17		0.16	0.16	0.27	0.19	0.27	0.28	7.00	0.21	0.28	0.16	0.02
FEB8			0.16	1.01	0.10	0.13	0.23	0.21	0.23	0.20	8.00	0.28	1.01	0.10	0.09
FEB11			0.14	0.94							2.00	0.54	0.94	0.14	0.28
FEB13			0.11		0.06	0.06	0.16	0.18	0.17	0.14	7.00	0.12	0.18	0.06	0.02
FEB16			0.14		0.11	0.13	0.20		0.21	0.18	6.00	0.16	0.21	0.11	0.02
FEB18			0.14	0.87	0.09	0.12	0.20		0.18	0.18	7.00	0.25	0.87	0.09	0.09
FEB23			0.21	1.10	0.19		0.24	0.33	0.28	0.26	7.00	0.37	1.10	0.19	0.11
FEB25			0.21		0.17	0.21	0.28		0.25	0.28	6.00	0.23	0.28	0.17	0.02
FEB27			0.19	0.85	0.15	0.19	0.23		0.22	0.20	7.00	0.29	0.85	0.15	0.09
FEB29			0.22			0.21	0.29		0.33	0.28	5.00	0.26	0.33	0.21	0.02
MAR2			0.22		0.18	0.22	0.29	0.34	0.29	0.28	7.00	0.26	0.34	0.18	0.02
MAR4							0.28		0.32	0.30	3.00	0.30	0.32	0.28	0.01
MAR7			0.24			0.20	0.28	0.37	0.33	0.31	6.00	0.29	0.37	0.20	0.02
MAR8							0.24		0.31	0.33	3.00	0.29	0.33	0.24	0.02
MAR9			0.25			0.34	0.32		0.34	0.33	5.00	0.32	0.34	0.25	0.31
MAR10			0.26			0.25	0.32		0.41	0.37	5.00	0.32	0.41	0.25	0.02
MAR11			0.24		0.22	0.25	0.30		0.33	0.35	6.00	0.28	0.35	0.22	0.02
MAR12	0.47		0.28			0.28	0.33		0.37	0.40	6.00	0.35	0.47	0.28	0.03
MAR15	0.36		0.28		0.20	0.22	0.28		0.30	0.33	7.00	0.28	0.36	0.20	0.02
MAR16	0.38		0.28		0.22	0.22	0.29	0.39	0.25	0.29	8.00	0.29	0.39	0.22	0.02
MAR18	0.36		0.19	0.95	0.20	0.21	0.26		0.35	0.31	8.00	0.35	0.95	0.19	0.08
MAR21	0.40		0.23		0.25	0.24	0.25	0.37	0.33	0.37	8.00	0.30	0.40	0.23	0.02
MAR23	0.26		0.17			0.16					3.00	0.20	0.26	0.16	0.02
MAR24	0.32	0.43	0.21	0.75	0.24	0.21	0.23		0.27	0.26	9.00	0.32	0.75	0.21	0.05
MAR25	0.33	0.42	0.22		0.27	0.22	0.26		0.31	0.38	8.00	0.30	0.42	0.22	0.02
MAR26	0.26	0.36	0.24	0.41	0.26	0.22	0.28	0.33	0.30	0.37	10.00	0.30	0.41	0.22	0.02
MAR28	0.17	0.17	0.11	0.24	0.15	0.14	0.17	0.18	0.17	0.22	10.00	0.17	0.24	0.11	0.01
NO. OBS	16.00	9.00	43.00	13.00	30.00	41.00	42.00	18.00	40.00	38.00					
MEAN	0.34	0.32	0.22	0.69	0.20	0.22	0.28	0.28	0.29	0.28					
MAX	0.47	0.43	0.50	1.10	0.37	0.47	0.60	0.41	0.46	0.40					
MIN	0.12	0.17	0.11	0.16	0.06	0.06	0.15	0.16	0.15	0.14					

Values represent the average of three replicates
Number of observations reflect the times water available

APPENDIX 6 Nitrate Concentration (mg/l) in Groundwater at Site 2 (Deep wells)

DATE	D1	D2	D3	D4	D5	D6	D7	D8	NO.OBS	MEAN	MAX	MIN	
DEC21	5.05	3.40	6.89	2.91	8.44	4.08	26.50	4.95	8.00	7.78	26.50	2.91	2.57
JAN3	11.16	6.50	9.90	6.12	9.03	8.25	29.02	15.14	8.00	11.89	29.02	6.12	2.48
JAN10	6.79	3.40	8.25	5.73	10.09	6.70	19.51	17.76	8.00	9.78	19.51	3.40	1.92
JAN16	2.62	4.95							2.00	3.79	4.95	2.62	0.82
JAN18		9.03							1.00	9.03	9.03	9.03	0.00
JAN20	6.21	9.32		4.66		5.53			4.00	6.43	9.32	4.66	0.88
JAN22	11.07		11.07						2.00	11.07	11.07	11.07	0.00
JAN27	11.26	5.24	9.90						3.00	8.80	11.26	5.24	1.49
JAN30	7.57	5.82							2.00	6.70	7.57	5.82	0.62
FEB1	9.90	7.28	11.94	8.44	13.98			9.32	6.00	10.14	13.98	7.28	0.91
FEB2	10.77	9.03	14.27	10.48	17.57			13.98	6.00	12.68	17.57	9.03	1.18
FEB3	9.71	8.35	13.10	9.71	16.02			11.07	6.00	11.32	16.02	8.35	1.05
FEB4	13.98	7.28	12.81	8.44	15.72			10.77	6.00	11.50	15.72	7.28	1.22
FEB5	10.48	9.22	13.69	10.19	16.31			11.65	6.00	11.92	16.31	9.22	0.98
FEB8	14.56	13.30	18.35	14.56	21.35			16.31	6.00	16.40	21.35	13.30	1.11
FEB13	10.19	9.12	12.52	9.12	15.43			10.48	6.00	11.15	15.43	9.12	0.91
FEB16	11.26	10.87	13.40	9.90	16.79			12.33	6.00	12.42	16.79	9.90	0.91
FEB18	11.36	10.87	14.27	10.19	16.60			12.13	6.00	12.57	16.60	10.19	0.30
FEB23	8.25	9.61	12.23	8.15	6.21	8.15		11.65	7.00	9.18	12.23	6.21	0.75
FEB25	9.61	9.32	12.81	8.15	15.43			10.77	6.00	11.02	15.43	8.15	0.99
FEB27	10.39	9.61	12.81	8.74	15.72			12.42	6.00	11.62	15.72	8.74	0.96
FEB29	11.07	10.87	13.69	9.61	17.18			13.98	6.00	12.73	17.18	9.61	1.02
MAR2	11.65	10.48	12.72	11.36	16.60			14.56	6.00	12.89	16.60	10.48	0.85
MAR4	9.90	9.80	12.52	8.93	15.72			14.46	6.00	11.89	15.72	8.93	1.04
MAR7	5.82	4.08	7.09	2.62	12.62			8.06	6.00	6.71	12.62	2.62	1.30
MAR8	12.52	10.39	13.40	9.32	16.02			13.98	6.00	12.60	16.02	9.32	0.91
MAR9	11.07	10.19	12.81	9.71	13.69			15.14	6.00	12.10	15.14	9.71	0.79
MAR10	7.57	8.74	13.20	7.86	13.10			14.27	6.00	10.79	14.27	7.57	1.14
MAR11	9.32	10.48	11.07	9.12	15.34			15.43	6.00	11.79	15.43	9.12	1.07
MAR12	16.02	16.50	16.70	14.75	20.48			21.84	6.00	17.71	21.84	14.75	1.04
MAR15	18.05	19.32	21.26	22.71	31.16	11.75	43.68	20.00	8.00	23.49	43.68	11.75	3.24
MAR16	16.11	15.14	17.37	16.40	22.03		45.72	25.63	7.00	22.63	45.72	15.14	3.79
MAR18	11.94	11.84	16.50	15.53	21.35		36.40	14.95	7.00	18.36	36.40	11.84	3.00
MAR21	9.71	9.51	48.02	35.52	57.68	7.57	60.32	32.03	8.00	32.54	60.32	7.57	7.21
MAR24	11.65	11.94	13.69	11.07	17.76	11.26	71.63	20.48	8.00	21.18	71.63	11.07	6.84
MAR25	7.57	9.61	11.26	8.83	16.70	11.55	60.56	14.75	8.00	17.60	60.56	7.57	5.83
MAR26	7.86	31.45	11.65	8.74	15.14	10.77	74.54	6.50	8.00	20.83	74.54	6.50	7.64
NO.OBS	36.00	36.00	33.00	32.00	31.00	10.00	10.00	31.00					
MEAN	10.28	10.05	13.97	10.55	17.33	8.56	46.79	14.41					
MAX	18.05	31.45	48.02	35.52	57.68	11.75	74.54	32.03					
MIN	2.62	3.40	6.89	2.62	6.21	4.08	19.51	4.95					

Values represent the average of three replicates
Number of values indicative of times water available

APPENDIX G Ammonium Concentration (mg/l) in Groundwater at Site 2 [Deep wells]

DATE	D1	D2	D3	D4	D5	D6	D7	D8	NO.OBS	MEAN	MAX	MIN	
DEC21	0.10	0.13		0.18	0.13	0.14	0.16	0.18	7.00	0.15	0.18	0.10	0.01
JAN3	0.13	0.15	0.15	0.14	0.11	0.14	0.15	0.15	8.00	0.14	0.15	0.11	0.00
JAN10	0.16	0.18	0.21	0.18	0.20	0.26	0.32	0.28	8.00	0.22	0.32	0.16	0.02
JAN16	0.17	0.18							2.00	0.18	0.18	0.17	0.00
JAN18		0.06							1.00	0.06	0.06	0.06	0.00
JAN20	0.14	0.07		0.12		0.07			4.00	0.10	0.14	0.07	0.02
JAN22	0.13		0.14						2.00	0.13	0.14	0.13	0.01
JAN27	0.14	0.17	0.22						3.00	0.18	0.22	0.14	0.02
JAN30	0.29	0.32							2.00	0.30	0.32	0.29	0.01
FEB1	0.10	0.23	0.21	0.14	0.26			0.10	6.00	0.17	0.26	0.10	0.02
FEB2	0.16	0.26	0.26	0.19	0.22			0.14	6.00	0.21	0.26	0.14	0.02
FEB3	0.13	0.15	0.16	0.11	0.17			0.09	6.00	0.14	0.17	0.09	0.01
FEB4	0.16	0.15	0.17	0.13	0.16			0.12	6.00	0.15	0.17	0.12	0.01
FEB5	0.12	0.15	0.17	0.12	0.13			0.11	6.00	0.13	0.17	0.11	0.01
FEB8	0.13	0.16	0.14	0.09	0.10			0.09	6.00	0.12	0.16	0.09	0.01
FEB13	0.08	0.10	0.14	0.10	0.12			0.08	6.00	0.10	0.14	0.08	0.01
FEB16	0.08	0.11	0.14	0.10	0.09			0.09	6.00	0.10	0.14	0.08	0.01
FEB18	0.10	0.14	0.13	0.10	0.11			0.10	6.00	0.11	0.14	0.10	0.01
FEB23	0.15	0.16	0.20	0.14	0.18	0.18		0.13	7.00	0.16	0.20	0.13	0.01
FEB25	0.14	0.15	0.20	0.15	0.14			0.16	6.00	0.16	0.20	0.14	0.01
FEB27	0.13	0.17	0.17	0.14	0.16			0.15	6.00	0.15	0.17	0.13	0.01
FEB29	0.15	0.19	0.18	0.15	0.20			0.17	6.00	0.17	0.20	0.15	0.01
MAR2	0.16	0.20	0.21	0.16	0.17			0.17	6.00	0.18	0.21	0.16	0.01
MAR4	0.14	0.18	0.20	0.18	0.28			0.27	6.00	0.21	0.28	0.14	0.02
MAR7	0.16	0.19	0.20	0.23	0.19			0.16	6.00	0.19	0.23	0.16	0.01
MAR8	0.15	0.18	0.23	0.20	0.16			0.15	6.00	0.18	0.23	0.15	0.01
MAR9	0.23	0.21	0.25	0.21	0.17			0.19	6.00	0.21	0.25	0.17	0.01
MAR10	0.18	0.23	0.22	0.20	0.23			0.21	6.00	0.21	0.23	0.18	0.01
MAR11	0.14	0.21	0.15	0.17	0.21			0.16	6.00	0.17	0.21	0.14	0.01
MAR12	0.17	0.20	0.17	0.17	0.16			0.16	6.00	0.17	0.20	0.16	0.00
MAR15	0.14	0.21	0.21	0.16	0.19	0.31	0.43	0.21	8.00	0.23	0.43	0.14	0.03
MAR16	0.14	0.16	0.12	0.14	0.14		0.36	0.17	7.00	0.18	0.36	0.12	0.03
MAR18	0.13	0.19	0.15	0.17	0.14		0.29	0.17	7.00	0.18	0.29	0.13	0.02
MAR21	0.12	0.18	0.16	0.20	0.17	0.19	0.38	0.18	8.00	0.20	0.38	0.12	0.02
MAR25	0.11	0.18	0.14	0.16	0.16	0.16	0.28	0.23	8.00	0.18	0.28	0.11	0.02
MAR26	0.14	0.17	0.19	0.20	0.13	0.15	0.27	0.16	8.00	0.17	0.27	0.13	0.01
MAR28	0.09	0.13	0.11	0.06	0.12	0.10	0.20	0.08	8.00	0.11	0.20	0.06	0.01
NO.OBS	36.00	36.00	32.00	32.00	31.00	10.00	10.00	31.00					
MEAN	0.14	0.17	0.18	0.15	0.16	0.17	0.28	0.16					
MAX	0.29	0.32	0.26	0.23	0.28	0.31	0.43	0.28					
MIN	0.08	0.06	0.11	0.06	0.09	0.07	0.15	0.08					

Values represent the average of three replicates
Number of observations indicates the times water available

APPENDIX 6 N Concentration (mg/l) Shallow Wells
SITE 1

NO3-N Concentration (mg/l)

DATE	S1S1	S1S2	S1S3	S1S4	S1S5	S1S6	S1S7	S1S8	S1S9	S1S10
DEC21						2.33				
JAN10						4.08				
JAN18			20.09				11.94		8.44	
JAN19						11.65	9.90		8.15	
JAN20	5.53									
JAN21	5.53									4.37
JAN31						8.44	5.82	6.12	5.24	4.66
FEB1		6.99		7.86	6.99	6.99	7.86	7.86	6.41	6.41
FEB2					5.97			9.32		5.10
MAR9								4.37	2.77	
MAR10									3.20	
MAR11									4.80	
MAR12				11.65					12.52	11.21
MAR24				7.28	7.28		4.37	8.30	8.30	4.95
MAR25				5.53	3.64		2.33	7.57	3.20	1.46
MAR26		2.91		4.08	1.46	1.46				1.75
NO.OBS	2.00	2.00	1.00	5.00	5.00	6.00	6.00	6.00	10.00	8.00
MEAN	5.53	4.95	20.09	7.28	5.07	5.82	7.04	7.26	6.30	4.99
MAX	5.53	6.99	20.09	11.65	7.28	11.65	11.94	9.32	12.52	11.21
MIN	5.53	2.91	20.09	4.08	1.46	1.46	2.33	4.37	2.77	1.46

NH4+N Concentration (mg/l)

DATE	S1S1	S1S2	S1S3	S1S4	S1S5	S1S6	S1S7	S1S8	S1S9	S1S10
DEC21			0.03			0.26		0.19		0.11
JAN10						0.25				
JAN18			0.62	0.63			0.81		0.48	
JAN19						0.25	1.29		0.60	
JAN20	1.40									
JAN21	0.29									1.15
JAN31					0.28	0.84		0.71	0.42	0.98
FEB1		1.14		0.42	0.34	0.51	0.41	0.52	0.54	0.98
FEB2					0.13			0.26		0.66
MAR9								3.20	1.39	
MAR10									1.43	
MAR11									0.88	
MAR12				0.72					1.30	0.64
MAR24				0.37	0.47		0.34	0.61	0.64	0.79
MAR25				0.75	0.55		0.46	0.73	0.74	0.62
MAR26		0.46		0.67	0.46	0.20				0.63
NO.OBS	2.00	2.00	2.00	6.00	6.00	6.00	5.00	7.00	10.00	9.00
MEAN	0.84	0.80	0.32	0.59	0.37	0.39	0.66	0.89	0.84	0.73
MAX	1.40	1.14	0.62	0.75	0.55	0.84	1.29	3.20	1.43	1.15
MIN	0.29	0.46	0.03	0.37	0.13	0.20	0.34	0.19	0.42	0.11

Appendix 6 N Concentration (mg/l) Shallow Wells
SITE 2

NO3-N Concentration (mg/l)

DATE	S2S1	S2S2	S2S3	S2S4	S2S5	S2S6	S2S7	S2S8	S2S9	S2S10
DEC22					1.75	0.87		5.53		
JAN21	10.48				8.74				14.27	
JAN31	10.34	9.90	9.90							6.99
FEB1	9.76		11.21	9.17	9.76	6.41	7.86	9.90	10.77	9.03
FEB2		14.85	14.85	12.38	13.40		11.21	12.52	13.98	9.90
FEB16			13.40							
FEB18									11.36	
FEB23							6.12	8.44		
MAR7			9.76							
MAR8			4.95		10.05					
MAR9				12.23	9.90		5.82			
MAR10	6.41		3.79	11.79	9.03		4.80			
MAR11	8.74		5.39	13.40	6.99				5.97	
MAR12			12.23	11.94	6.55				8.15	
MAR24	17.47		13.98	9.17	10.19	12.08	11.36	11.21	11.36	14.85
MAR25			7.28	6.12	9.32	11.94	7.57	11.21	7.86	11.36
MAR26		8.88	2.91	3.79	4.66	5.82	4.37	6.70	3.79	6.70
NO.OBS	6.00	3.00	12.00	9.00	12.00	5.00	8.00	7.00	9.00	6.00
MEAN	10.53	11.21	9.14	10.00	8.36	7.43	7.39	9.36	9.72	9.80
MAX	17.47	14.85	14.85	13.40	13.40	12.08	11.36	12.52	14.27	14.85
MIN	6.41	8.88	2.91	3.79	1.75	0.87	4.37	5.53	3.79	6.70

NH4+N Concentration (mg/l)

DATE	S2S1	S2S2	S2S3	S2S4	S2S5	S2S6	S2S7	S2S8	S2S9	S2S10
DEC22					0.17	0.12	0.09	0.14	0.16	0.18
JAN21	0.06				0.08				0.14	
JAN31	0.08	0.16	0.07							0.13
FEB1	0.11		0.07	0.12	0.08	0.14	0.08	0.08	0.11	0.09
FEB2		0.13	0.07	0.10	0.08		0.07	0.07	0.19	0.11
FEB16			0.13							
FEB18									0.26	
FEB23							0.09	0.27		
MAR7			0.42							
MAR8			0.50		0.21					
MAR9				0.20	0.17		0.12			
MAR10	0.17		0.27	0.18	0.19		0.11			
MAR11	0.18		0.18	0.20	0.20				0.33	
MAR12	0.21		0.19	0.19	0.15				0.31	
MAR24			0.13	0.12	0.22	0.15	0.14	0.16	0.39	0.17
MAR25			0.26	0.18	0.32	0.13	0.31	0.18	0.24	0.17
MAR26		0.20	0.06	0.11	0.06	0.12	0.29	0.13	0.18	0.14
NO.OBS	6.00	3.00	12.00	9.00	12.00	5.00	9.00	7.00	10.00	7.00
MEAN	0.13	0.16	0.20	0.15	0.16	0.13	0.14	0.15	0.23	0.14
MAX	0.21	0.20	0.50	0.20	0.32	0.15	0.31	0.27	0.39	0.18
MIN	0.06	0.13	0.06	0.10	0.06	0.12	0.07	0.07	0.11	0.09

APPENDIX H. Soil N content.

APPENDIX H: Soil NO_3^--N Content (μg/g)

		Site 1			Site 2		
Depth (cm)		0-30	30-60	60-90	0-30	30-60	60-90
Jan 09	Mean	30.7	28.4	NA	23.9	12.5	6.3
	Max.	42.2	55.8	NA	34.1	16.0	6.6
	Min.	21.1	12.1	NA	18.1	6.9	6.0
	$\sigma/\sqrt{N}$	1.6	5.3	NA	2.6	1.8	0.2
	No. Obs.	13	11	NA	5	4	4
Jan 29	Mean	40.3	38.8	27.9	23.3	16.1	6.6
	Max.	66.4	62.4	58.8	36.2	33.2	6.0
	Min.	23.2	24.1	11.2	13.0	6.0	0.0
	$\sigma/\sqrt{N}$	4.0	3.2	4.8	2.5	2.9	5.4
	No. Obs.	13	12	8	8	7	3
Feb 10	Mean	65.9	27.8	27.2	29.2	20.4	NA
	Max.	114.6	38.3	43.1	39.2	26.2	NA
	Min.	20.2	15.1	18.1	18.1	11.2	NA
	$\sigma/\sqrt{N}$	7.9	1.4	2.1	2.0	1.5	NA
	No. Obs.	13	13	11	9	9	NA
Mar 06	Mean	NA	45.8	56.5	59.7	41.8	33.4
	Max.	NA	76.3	100.4	84.4	56.4	42.2
	Min.	NA	30.2	30.2	42.2	31.1	30.2
	$\sigma/\sqrt{N}$	NA	3.7	8.3	4.6	3.2	1.4
	No. Obs.	NA	11	8	9	9	8
Mar 28	Mean	58.6	54.4	34.2	35.8	19.1	11.6
	Max.	117.6	166.8	57.3	51.3	66.4	27.1
	Min.	33.2	17.2	16.0	12.1	12.1	6.0
	$\sigma/\sqrt{N}$	6.1	11.7	3.7	4.2	5.6	1.9
	No. Obs.	13	13	12	9	9	9
Apr 26	Mean	32.2	18.3	16.2	38.0	35.2	44.4
	Max.	63.3	35.3	34.1	52.8	78.4	69.4
	Min.	15.1	9.0	9.0	27.1	24.1	27.1
	$\sigma/\sqrt{N}$	3.2	2.1	2.2	2.5	5.3	4.6
	No. Obs.	13	13	11	9	9	7

APPENDIX H Soil Nitrate Content (μg/g) SITE 1

	LOCATION	JAN9	JAN29	FEB10	MAR6	MAR28	APR26
0-30 cm	1.10	31.06	60.32	27.14		57.30	33.18
	2.10		28.65	103.45		45.24	43.13
	3.10	28.65	66.35	21.11		43.13	32.27
	4.10	33.18	23.22	114.61		69.37	29.26
	5.10	36.19	48.86	84.45		117.62	63.34
	6.10	42.22	53.38	75.40		85.35	40.11
	7.10	33.18	59.42	90.48		69.37	22.02
	8.10	37.10				57.30	27.14
	9.10	28.65	28.65	78.42		33.18	27.14
	10.10	28.65	27.75	20.21		51.27	36.19
	11.10	21.11	30.16	59.42		51.27	26.24
	12.10	30.16	37.10	59.42		39.21	15.08
	13.10	28.05	30.16	61.22			
	14.10	21.11	30.16	61.22		42.22	24.13
30-60 cm	1.20	55.80	46.75	31.06	76.30	42.22	21.11
	2.20		37.70	27.14	45.24	45.24	26.24
	3.20	18.10	28.65	27.14	46.14	23.22	20.21
	4.20	18.10	24.13	24.13	38.30	42.22	21.11
	5.20		52.18	27.14	49.16	166.78	35.29
	6.20	32.27		30.16		42.22	17.19
	7.20		62.43	38.30	51.27	42.22	11.16
	8.20	14.18				45.24	9.05
	9.20	18.10	28.65	30.16	53.38	17.19	12.06
	10.20	12.06	37.70	24.13		42.22	25.03
	11.20	55.80	43.13	31.06	32.27	132.70	9.05
	12.20	55.80	27.14	27.14	30.16	42.22	12.06
	13.20	18.10	45.24	15.08	34.08		
	14.20	14.18	32.27	29.26	47.35	23.22	18.10
60-90 cm	1.30		33.18	33.18	100.43	29.26	34.08
	2.30		11.16	24.13	55.19	30.16	19.30
	3.30		20.21	29.26	73.29	17.19	
	4.30					42.22	26.24
	5.30		31.97	30.16	45.24	53.38	9.05
	6.30			24.13			18.10
	7.30				78.42	42.22	12.97
	8.30			24.13		57.30	12.06
	9.30					24.13	
	10.30		19.60	25.03		42.22	14.18
	11.30		27.14	43.13		33.18	11.16
	12.30		21.11	30.16	30.16	23.22	12.06
	13.30			18.10	36.19		
	14.30		58.31	18.10	33.19	15.98	9.05

APPENDIX H Soil Nitrate Content (µg/g) SITE 2

	LOCATION	JAN9	JAN29	FEB10	MAR6	MAR 28	APR26
0-30 cm	1.10	20.21	36.19	27.14	55.80	51.27	52.78
	2.10	20.21	20.21	39.21	55.80	48.26	30.16
	3.10	34.08	12.97	18.10	68.46	24.13	42.22
	4.10		20.21	33.18	65.45	45.24	27.14
	5.10	27.14	27.14	26.24	42.22	27.14	42.22
	6.10		24.13	37.10	75.40	47.35	39.21
	7.10		18.10	27.14	84.45	30.16	30.16
	8.10		27.14	27.14	44.34	12.06	42.22
	9.10	18.10		27.14	45.24	36.19	36.19
30-60 cm	1.20	6.94	12.06	26.24	34.38	66.35	30.16
	2.20	15.08	6.03	19.00	47.35	12.06	30.16
	3.20	15.98	15.08	11.16	31.06	12.06	42.22
	4.20		15.08	15.08	31.06	21.11	27.14
	5.20	12.06	15.98	21.11	52.18	12.06	27.14
	6.20			20.21	41.32	12.06	30.16
	7.20		15.08	23.22	51.27	12.06	24.13
	8.20		33.18	24.13	31.06	12.06	78.42
	9.20			23.22	56.40	12.06	27.14
60-90 cm	1.30	6.03	0.00		31.06	27.14	27.14
	2.30	6.03	0.00		42.22	12.06	42.22
	3.30	6.94			30.16	12.06	
	4.30				30.16	9.95	51.27
	5.30	6.03				6.03	36.19
	6.30				33.18	9.95	
	7.30				31.06	9.05	42.22
	8.30		19.31		37.10	6.03	59.37
	9.30				32.27	12.06	42.22

APPENDIX H: Soil NH_4^+-N Content (μg/g)

		Site 1			Site 2		
Depth (cm)		0-30	30-60	60-90	0-30	30-60	60-90
Jan 09	Mean	9.4	4.5	NA	6.6	6.5	3.5
	Max.	11.7	9.2	NA	7.0	7.6	4.2
	Min.	6.5	2.5	NA	6.2	3.6	4.2
	$\sigma/\sqrt{N}$	0.5	0.6	NA	0.1	0.7	0.2
	No. Obs.	13	11	NA	5	5	4
Jan 29	Mean	12.6	4.9	2.9	12.3	6.0	6.0
	Max.	20.7	7.2	5.8	15.3	7.6	9.0
	Min.	8.5	3.5	1.6	9.2	4.0	3.8
	$\sigma/\sqrt{N}$	0.9	0.3	0.5	0.7	0.5	1.3
	No. Obs.	13	12	8	8	7	3
Feb 10	Mean	13.6	4.5	3.7	3.7	9.6	NA
	Max.	25.3	6.9	5.7	4.9	14.0	NA
	Min.	9.2	2.5	2.6	2.1	7.8	NA
	$\sigma/\sqrt{N}$	1.1	0.4	0.3	0.3	0.6	NA
	No. Obs.	13	13	10	9	9	NA
Mar 06	Mean	NA	4.2	3.8	6.1	4.1	3.3
	Max.	NA	6.4	7.8	8.5	7.0	5.0
	Min.	NA	2.7	1.4	4.9	2.1	2.1
	$\sigma/\sqrt{N}$	NA	0.4	0.6	0.4	0.4	0.3
	No. Obs.	NA	11	8	9	9	8
Mar 28	Mean	6.3	4.6	3.8	7.2	5.4	4.6
	Max.	7.2	7.6	5.3	9.7	12.8	11.8
	Min.	4.6	2.3	2.0	6.2	3.2	2.8
	$\sigma/\sqrt{N}$	0.2	0.4	0.4	0.3	0.9	0.9
	No. Obs.	13	13	12	9	9	9
Apr 26	Mean	4.4	2.9	2.8	6.7	3.9	2.7
	Max.	5.0	4.1	4.0	9.7	6.9	7.0
	Min.	3.7	1.6	1.8	4.9	1.7	1.8
	$\sigma/\sqrt{N}$	0.1	0.2	0.2	0.5	0.5	0.7
	No. Obs.	13	13	11	9	9	7

APPENDIX H Exchangeable Soil Ammonium Content (µg/g) SITE 1

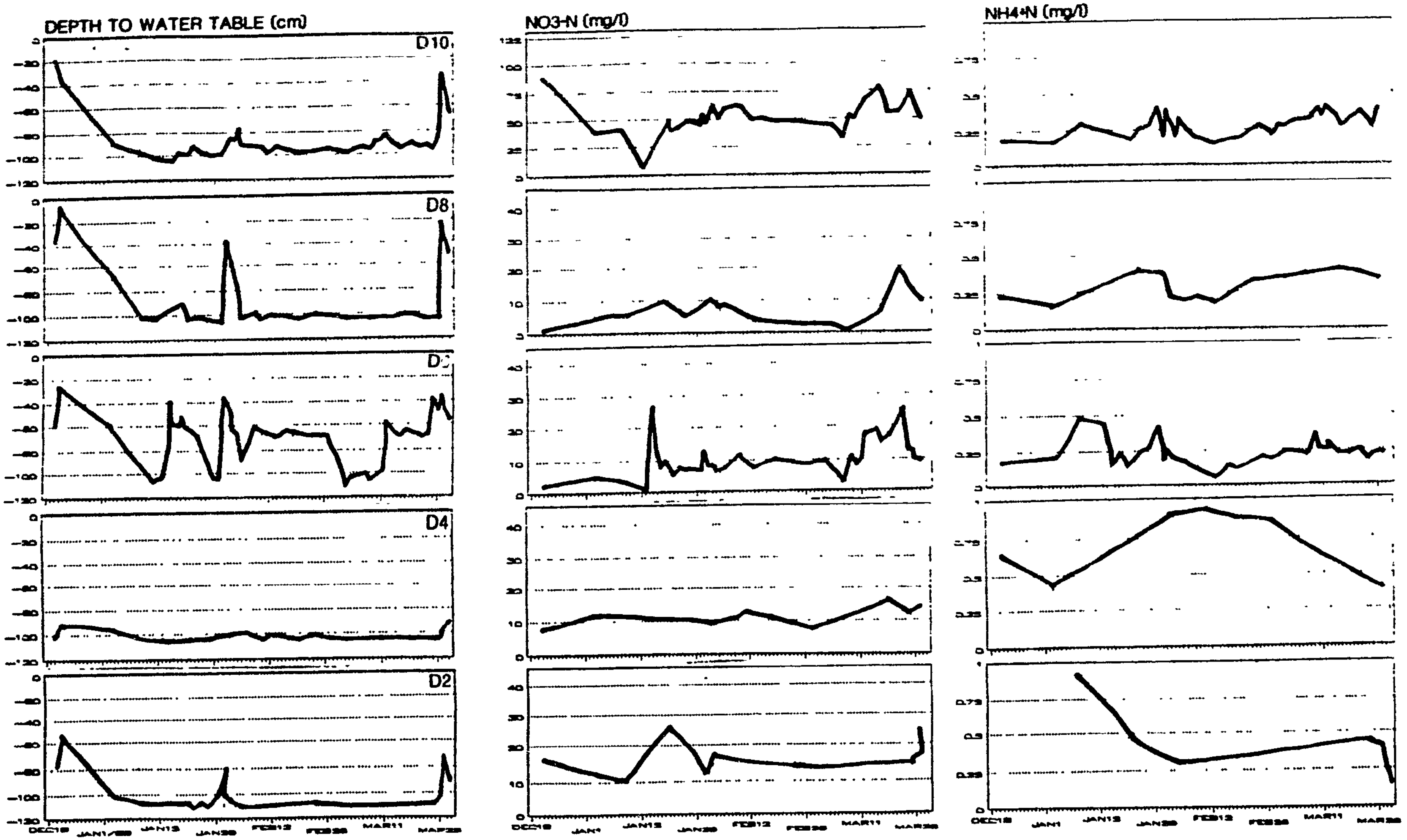
	LOCATION	JAN9	JAN29	FEB10	MAR6	MAR28	APR26
0-30 cm	1.10	7.14	13.51	12.32		5.12	4.76
	2.10		18.80	14.07		6.52	4.20
	3.10	10.50	9.38	15.12		5.54	4.42
	4.10	7.08	11.00	12.11		6.16	3.72
	5.10	6.48	12.08	11.27		7.21	4.62
	6.10	8.26	8.48	9.24		6.52	4.76
	7.10	7.42	11.66	11.41		6.52	4.28
	8.10	10.86				6.72	4.00
	9.10	10.58	11.00	12.39		4.62	4.62
	10.10	11.38	11.24	13.37		6.86	4.38
	11.10	9.84	12.04	11.06		6.44	4.98
	12.10	10.54	9.74	25.27		7.14	4.42
	13.10	10.44	13.58	15.26			
	14.10	11.66	20.72	14.35		5.96	4.34
30-60 cm	1.20	6.23	7.21	6.79	4.83	4.94	4.14
	2.20		4.42	3.44	2.94	4.52	3.12
	3.20	2.80	3.86	2.70	6.44	3.16	2.52
	4.20	2.46	4.48	2.46	3.92	3.22	2.28
	5.20		4.10	4.66	3.99	3.02	1.62
	6.20	3.08		5.81		3.22	3.68
	7.20		5.25	4.24	6.30	6.10	3.72
	8.20	2.66				6.23	2.98
	9.20	3.08	3.50	4.28	4.06	2.32	2.28
	10.20	4.98	4.80	4.06		5.96	3.30
	11.20	5.04	4.98	3.92	2.88	4.98	2.38
	12.20	9.24	4.28	6.93	2.70	7.56	3.30
	13.20	3.86	7.14	4.06	3.16		
	14.20	5.82	4.55	4.84	4.76	4.24	2.66
60-90 cm	1.30		5.81	4.94	3.18	4.62	2.36
	2.30		2.28	2.98	3.60	3.44	2.38
	3.30		2.10	3.22	7.80	2.00	
	4.30					3.22	2.28
	5.30		2.60	3.58	3.39	2.38	1.82
	6.30			3.50			2.64
	7.30				4.41	4.30	2.34
	8.30					5.26	3.08
	9.30					3.82	
	10.30		2.10	4.24		4.38	3.22
	11.30		2.60	3.22		2.38	2.24
	12.30		1.62	5.67	2.56	4.90	2.60
	13.30			2.56	1.40		
	13.40		3.92	2.84	3.50	3.12	2.52

APPENDIX H Exchangeable Soil Ammonium Content (μg/g) SITE 2

	LOCATION	JAN9	JAN29	FEB10	MAR6	MAR26	APR28
0-30 cm	1.10	6.20	11.55	4.42	6.30	9.66	9.66
	2.10	6.52	11.42	2.10	8.47	7.28	6.10
	3.10	7.04	14.42	3.50	6.79	7.28	4.90
	4.10		15.26	3.12	4.94	6.24	5.92
	5.10	7.00	9.24	3.92	4.90	6.38	5.08
	6.10		13.20	4.66	5.32	6.94	7.28
	7.10		13.16	3.96	6.02	6.44	6.16
	8.10		10.50	4.90	5.54	7.74	8.82
	9.10	6.40		3.02	6.51	7.08	6.72
30-60 cm	1.20	7.56	7.36	10.43	2.14	12.78	6.86
	2.20	7.56	4.66	10.99	4.84	3.16	2.18
	3.20	6.86	6.44	7.84	3.08	4.56	3.72
	4.20		5.32	7.91	3.30	5.78	3.64
	5.20	3.57	6.79	7.91	4.52	3.30	1.68
	6.20			9.73	4.10	4.98	4.06
	7.20		3.96	14.00	4.52	4.00	3.50
	8.20		7.56	9.59	3.50	5.50	5.32
	9.20	7.00		7.98	7.04	4.62	3.99
60-90 cm	1.30	3.92	8.96		2.10	11.80	7.04
	2.30	2.24	5.32		3.12	2.80	1.82
	3.30	3.78			2.52	3.72	
	4.30				3.82	4.80	3.02
	5.30	4.20				3.78	2.42
	6.30				3.44	3.50	
	7.30				3.54	3.30	2.74
	8.30		3.82		2.84	4.34	5.32
	9.30				5.04	3.54	3.32

APPENDIX I. Groundwater elevation and N content.

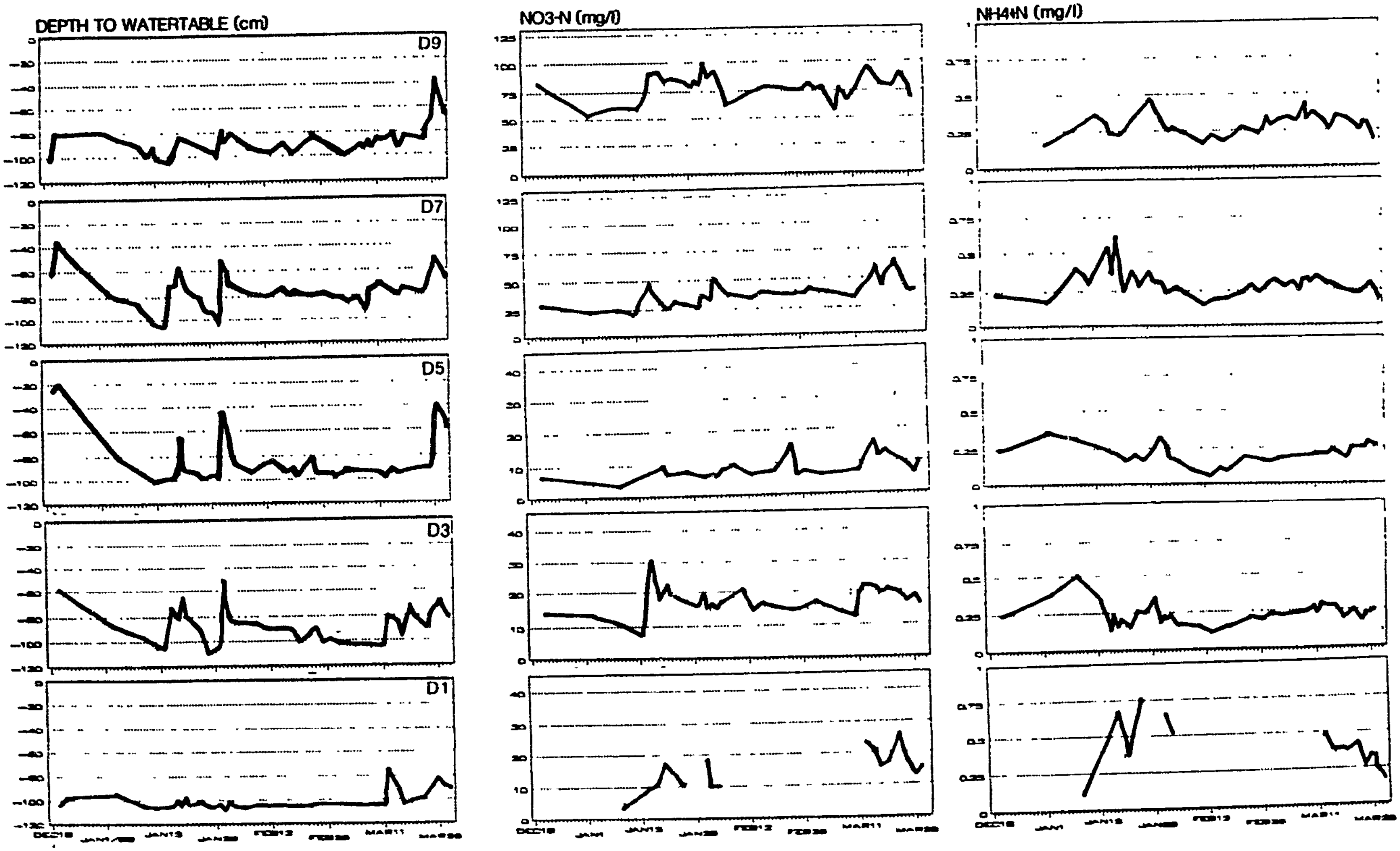
SITE 1


DEPTH TO WATER TABLE (cm)

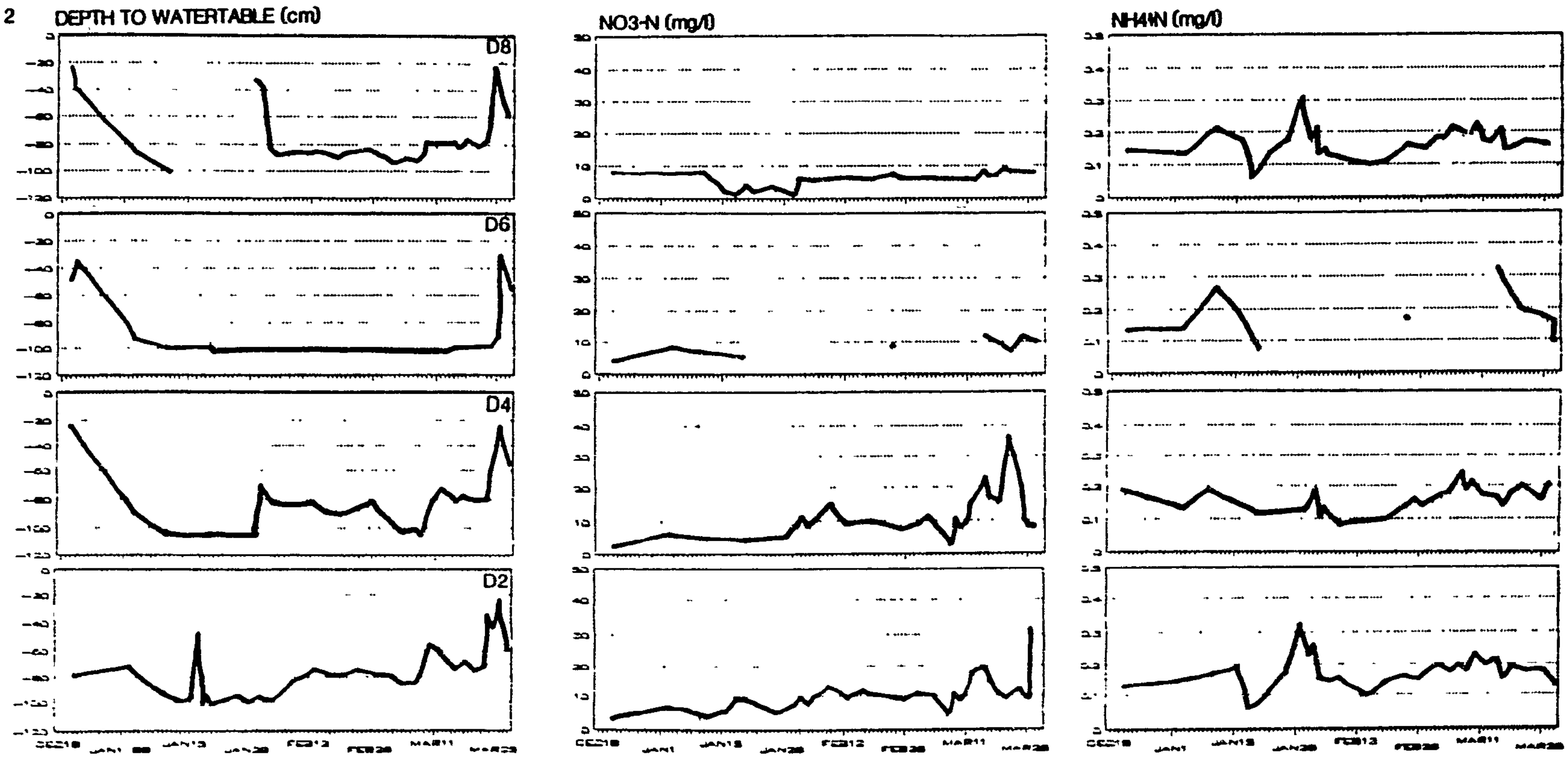
NO3-N (mg/l)

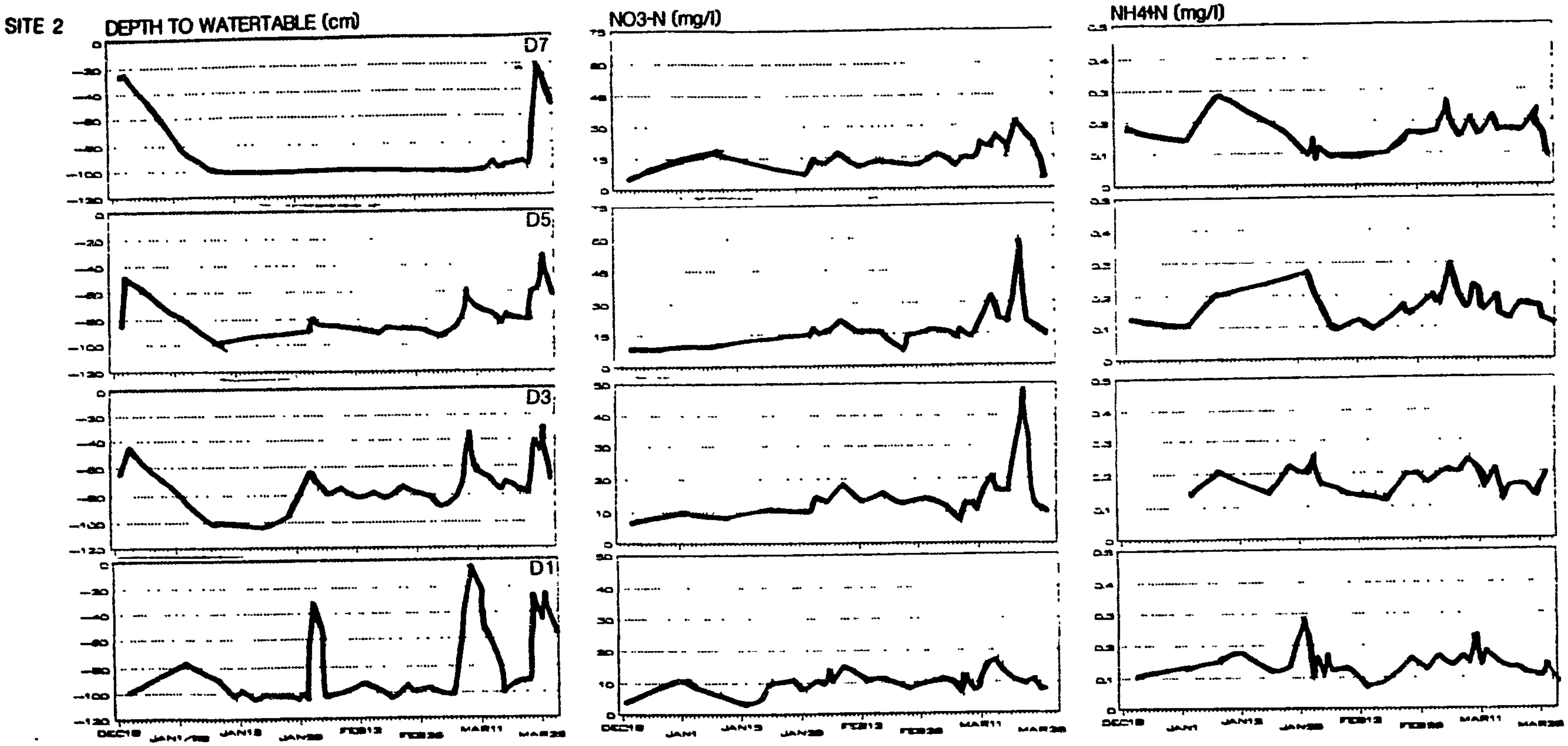
NH4-N (mg/l)

SITE 1


DEPTH TO WATERTABLE (cm)
NO3-N (mg/l)
NH4-N (mg/l)
D9
D7
D5
D3
D1
0
-20
-40
-60
-80
-100
-120
125
100
75
50
25
40
30
20
10
1
0.75
0.5
0.25
DEC18
JAN1/88
JAN13
JAN28
FEB12
FEB28
MAR11
MAR28

SITE 2


DEPTH TO WATERTABLE (cm)
NO3-N (mg/l)
NH4-N (mg/l)
D8
D6
D4
D2
0
-20
-40
-60
-80
-100
-120
0
10
20
30
40
50
0
0.1
0.2
0.3
0.4
0.5
DEC18
JAN1
JAN15
JAN29
FEB12
FEB26
MAR11
MAR25


SITE 2
DEPTH TO WATERTABLE (cm)
NO3-N (mg/l)
NH4N (mg/l)
D7
D5
D3
D1
0
-20
-40
-60
-80
-100
-120
75
60
45
30
15
50
40
20
10
0.5
0.4
0.3
0.2
0.1
DEC18
JAN1/88
JAN1
JAN13
JAN28
FEB13
FEB28
MAR11
MAR28