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**BULK DEPOSITION OF IONS IN THE  
TURKEY LAKES WATERSHED**

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#### **MANAGEMENT PERSPECTIVE**

Implications of the level of atmospheric deposition of airborne pollutants at the Turkey Lakes Watershed (TLW) must be taken in context to the objectives of the larger NWRI mass balance study at this site, e.g., to define to the process of basin acidification. These results show that the sparcely located sampling stations of the national air and precipitation monitoring network may substantially under-estimate the amount of atmospheric deposition occurring at a given location; the discrepancy arises from the influence of specific local factors such as elevation in the TLW. The winter-time importance of nitric acid in the precipitation (approximately equal to sulphuric acid) may have implications with respect to imposition of stricter auto emission standards in Canada.

## PERSPECTIVE-GESTION

Il y a lieu d'analyser les conséquences de la quantité de dépôts de polluants atmosphériques dans le bassin versant de Turkey Lakes (BVTL) à la lumière des objectifs de l'étude plus étendue de l'équilibre des masses qu'a réalisée l'INRE à cet endroit, c'est-à-dire qu'il faut définir le processus d'acidification d'un bassin. Les résultats démontrent que les stations de prélèvement du réseau national de surveillance de l'atmosphère et des précipitations, dispersées sur un vaste territoire, peuvent conduire à sous-estimer considérablement la quantité de dépôts atmosphériques à un lieu donné; cette inexactitude est due à l'influence de facteurs locaux spécifiques, notamment l'élévation du bassin versant de Turkey Lakes (BVTL). La concentration élevée d'acide nitrique dans les précipitations au cours de l'hiver (qui équivaut approximativement à celle de l'acide sulfurique) peut avoir comme conséquence l'imposition de normes d'auto-émission plus sévères au Canada.

Dépôt de masses d'ions dans le bassin versant de Turkey Lakes  
R. G. Semkin et D. S. Jeffries

## EXECUTIVE SUMMARY

Samples of weekly total rainfall and/or snowfall have been collected in a continuously-open collector at the Turkey Lakes Watershed (TLW) near Sault Ste. Marie, Ontario. Results and interpretation reported here cover the period September 1981 to June 1984. Total precipitation quantity for this period was 1212 mm/yr of which the greater part (70%) occurred as rain. There is a significantly greater amount of precipitation occurring at the higher elevation portions of the watershed.

The chemical composition of the precipitation is dominated by the chemical species (ions) composing sulphuric acid, e.g., hydrogen ion and sulphate; however, other chemical species such as ammonium and nitrate ions (from various natural and man-made nitrogen sources) and calcium (from soil dust) are also present. Some of the species (sulphate, ammonium, and calcium) exhibited higher concentrations in summer than in winter. In contrast, the acidity of precipitation (hydrogen ion concentration) was lower in the summer compared to winter. This seasonal variation means that sulphuric acid is the predominant "acid" in precipitation, particularly during the warm season of the year. In winter, however, nitric acid is just as important as sulphuric acid in contribution to the overall snow acidity. The concentrations of acids in the precipitation at the TLW are lower than those occurring in south-central Ontario, southern Quebec, and much of the northeastern USA, but higher than those occurring in northwestern Ontario, Newfoundland, and Labrador.

The ecological importance of the precipitation acidity lies not with its concentration, but with the total amount deposited. In this regard, the deposition of acids at the TLW are comparable to that occurring in south-central Ontario, southern Quebec, etc., due to the greater amount of precipitation experienced at the former site.

## RÉSUMÉ ADMINISTRATIF

Des échantillons des précipitations mensuelles totales de pluie ou de neige ont été prélevés dans un collecteur ouvert en permanence installé dans le bassin versant de Turkey Lakes (BVTL), près de Sault-Sainte-Marie (Ontario). Les résultats et les interprétations qui figurent dans ce rapport traitent de la période de septembre 1981 à juin 1984. La quantité totale de précipitations au cours de cette période s'élevait à 1 212 mm par année, dont la plus grande partie (70 p. 100) tombait sous forme de pluie. On a remarqué que les précipitations étaient beaucoup plus abondantes dans les parties les plus élevées du bassin versant.

Les principaux composants chimiques des précipitations sont les substances (ions) qui forment l'acide sulfurique, c'est-à-dire les ions d'hydrogène et les sulfates. On a toutefois décelé d'autres composants, notamment des ions d'ammonium et de nitrate (provenant de diverses sources d'azote naturelles et anthropiques) et du calcium (provenant de la poussière du sol). Certaines substances chimiques (sulfate, ammonium et calcium) étaient plus concentrées au cours de l'été que l'hiver. Par contre, l'acidité des précipitations (concentration des ions hydrogène) était plus faible en été qu'en hiver. Cette variation saisonnière signifie que l'acide sulfurique est le principal agent d'acidité des précipitations, surtout au cours de la saison estivale. En hiver cependant, l'acide nitrique contribue autant que l'acide sulfurique à l'acidité globale de la neige. La concentration d'acides dans les précipitations du BVTL est plus faible que dans les précipitations du centre sud de l'Ontario, du sud du Québec et de la plus grande partie du nord-est des États-Unis, mais plus élevée par contre que celles du nord-ouest de l'Ontario, de Terre-Neuve et du Labrador.

Ce n'est pas tellement la concentration d'acides qui joue sur l'environnement, mais plutôt la quantité totale qui se dépose. À cet égard, les dépôts d'acides dans le BVTL sont comparables à ceux qui caractérisent le centre sud de l'Ontario, le sud du Québec, etc., et ceci, parce que les précipitations y sont plus abondantes.

## ABSTRACT

Bulk deposition has been collected at the Turkey Lakes Watershed (near Sault Ste. Marie, Ontario) on a weekly basis since September 1981. Average precipitation quantity was 1212 mm over four years with rainfall accounting for approximately 70% of the total. The chemistry of bulk deposition is dominated by hydrogen and sulphate ions. Seasonal variations in chemistry were observed with summer concentrations of  $\text{SO}_4$ ,  $\text{NH}_4$ , and Ca exceeding winter values by about 40%. The hydrogen ion content of bulk deposition is lower in the summer months while the  $\text{SO}_4:\text{NO}_3$  equivalent ratio is at a maximum. Sulphate,  $\text{NO}_3$ ,  $\text{NH}_4$  and H ion concentrations are significantly correlated ( $p<.001$ ). A greater proportion of  $\text{NO}_3$  appears to be associated with  $\text{HNO}_3$  than  $\text{SO}_4$  with its strong acid counterpart, e.g. sulphate is better correlated with  $\text{NH}_4$  and Ca than H. Annual deposition to the watershed is comparable to other areas experiencing more acidic precipitation due to the relatively high precipitation rate in this location.

## RÉSUMÉ

Depuis 1981, on a recueilli, à l'aide d'un collecteur, les précipitations hebdomadaires dans le bassin versant des lacs Turkey (près de Sault-Sainte-Marie, en Ontario). L'accumulation moyenne des précipitations au cours de la période de quatre ans a été de 1 212 mm, dont 70 p. 100 sous forme de pluie. Les principaux ions que l'on a trouvés en solution sont ceux d'hydrogène et de sulfate. Des variations saisonnières de la chimie des précipitations ont été observées. Ainsi, les concentrations estivales de  $\text{SO}_4$ ,  $\text{NH}_4$ , et Ca se sont révélées environ 40 p. 100 plus élevées qu'en hiver. La teneur en ions d'hydrogène était à la baisse au cours des mois d'été tandis que le ratio équivalent de  $\text{SO}_4 : \text{NO}_3$  atteignait sa valeur maximale. Il existe une corrélation significative entre les concentrations d'ions de  $\text{NO}_3$ ,  $\text{NH}_4$ , et H ( $p < 0,001$ ). Il semble que la corrélation entre les concentrations de  $\text{NO}_3$  et de  $\text{HNO}_3$ , soit plus forte que celle entre les concentrations de  $\text{SO}_4$  et de  $\text{H}_2\text{SO}_4$ . En effet, la corrélation des ions de sulfate avec le  $\text{NH}_4$  et le Ca semble plus marquée que celle avec les ions d'hydrogène. Étant donné l'intensité des précipitations cumulatives qui s'abattent dans le bassin versant précité, celles-ci ont des répercussions semblables à celles de précipitations plus acides dans d'autres régions.

ACCUMULATION GLOBALE DES IONS DANS LE BASSIN VERSANT DES LACS TURKEY  
R.G. Semkin et Dean S. Jeffries

## I. INTRODUCTION

The chemistry of bulk deposition was determined as a means of calculating the atmospheric input to the Turkey Lakes Watershed. Terrestrial basins located in the Precambrian Shield generally act as a sink for nutrients and hydrogen ion transported from external sources (Scheider et al., 1979). Although sulphate has been primarily implicated in the long-term acidification of poorly buffered watersheds (Harvey et al., 1981), the role of nitrate in atmospheric deposition has received increased attention, particularly during periods of elevated runoff such as occur at spring melt or after heavy rainfalls. Marked depressions in pH and alkalinity concentrations in stream and lake waters have been reported during such events and are coincident with increasing nitrate levels (Galloway and Dillon, 1983; Semkin et al., 1984). High acidity in atmospheric deposition may significantly affect a catchment as manifested by the increased weathering of geological materials and the subsequent export of base cations, the reduction of the buffering capacity of surface waters (by replacing bicarbonate with sulphate), and mobilization of metals such as Al from the soils into the aquatic regime.

In an evaluation of precipitation chemistry over North America, Munger and Eisenreich (1983) separated the ionic components into three main groups:

- i) Ca, Mg, K - derived from the erosion of soil and bedrock;

- ii) Na, Cl - derived from coastal sea salts;
- iii) SO<sub>4</sub>, NO<sub>3</sub>, NH<sub>4</sub> - derived from gaseous precursors SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub> emitted to the atmosphere.

The chemistry of bulk deposition will therefore have a geographical flavour and reflect the relative source strength of each of these groups. This factor plus reactions occurring during transport, especially the reactions of strong mineral acidity (H<sub>2</sub>SO<sub>4</sub> and HNO<sub>3</sub>) with neutralizing agents such as calcareous dust and ammonia, will define the net composition of the deposition at various sites.

## II. STUDY AREA

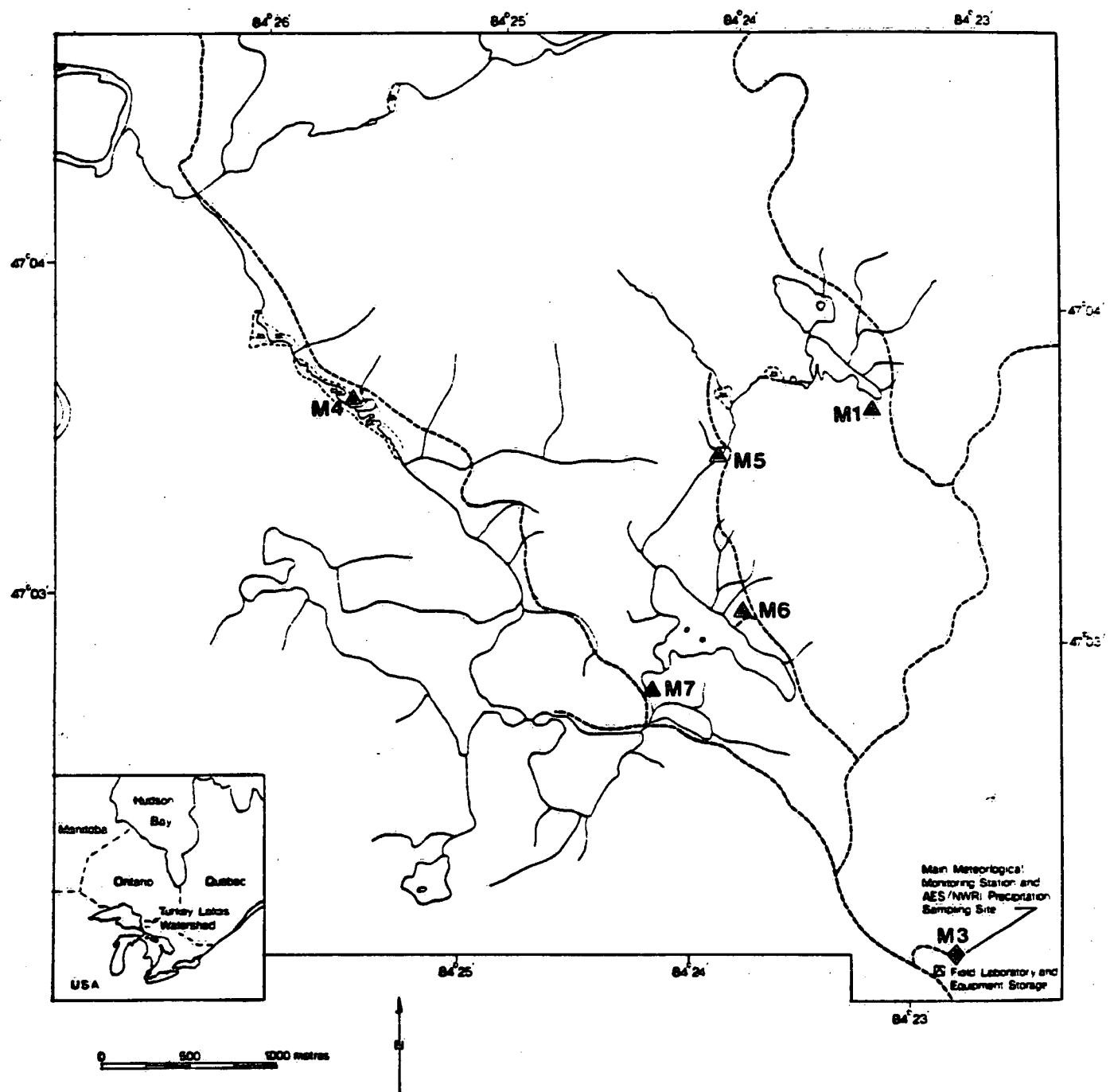
The Turkey Lakes Watershed is an undisturbed, forested basin located approximately 50 km north of Sault Ste. Marie, Ontario. The physical and biological characteristics of the watershed have been previously outlined (Jeffries and Semkin 1982; Semkin and Jeffries, 1983).

A main meteorological station (M3) has been established at a site just south of the watershed (Figure 1). In addition to measurements of bulk deposition, various air and precipitation monitoring networks are operative at this location (Jeffries and Semkin, 1982).

## III. METHODS

### Precipitation Quantity

Precipitation quantity at the main meteorological station is recorded by means of a standard rain gauge and Nipher snow gauge.



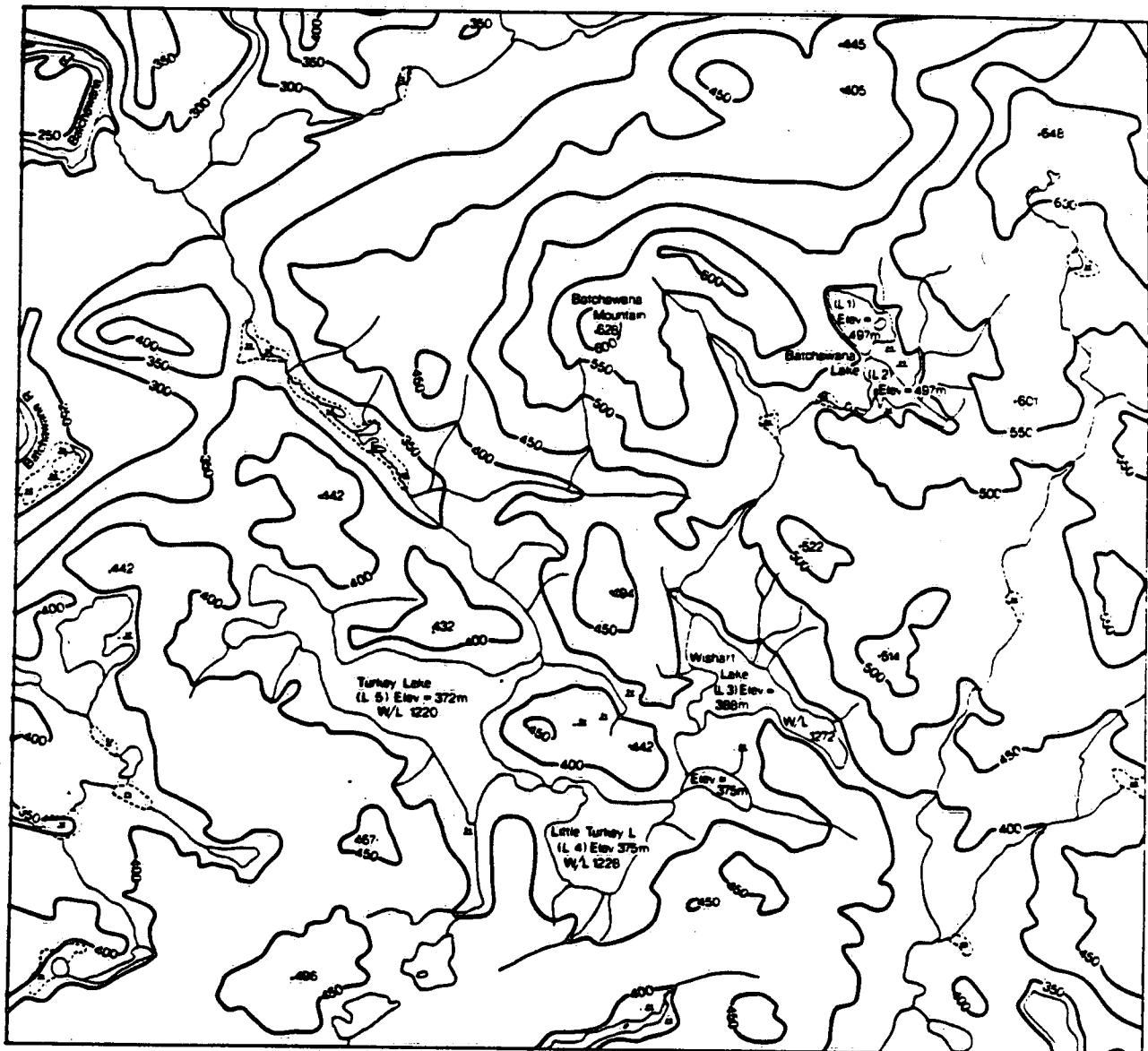
**Figure 1 Sampling Locations for Precipitation and Bulk Deposition**

Continuous measurements of precipitation are obtained by using a Belmont-model weighing-bucket recorder. Relief in the Turkey Lakes Watershed is about 300 m (Figure 2), so that orographic factors do affect the distribution of precipitation in the basin. To account for this variation, standard rain and Nipher snow gauges are deployed at different elevations in the study site as is shown in Figure 1.

#### Bulk Deposition Chemistry

Bulk deposition was collected at the main site (M3) with a Teflon-coated, stainless steel funnel  $0.25\text{ m}^2$  in area. Samples were channeled into a glass bottle for rain or a polyethylene bucket for snow. The collector bottle/bucket was housed in a light-proof box which was mounted on a wooden deck approximately 1 m above ground surface. Samples were taken on a weekly basis beginning on September 1, 1981.

All samples were analyzed for pH and specific conductivity immediately after collection. Subsamples were processed and submitted for analysis of major ions, nutrients and trace elements in accord with methods defined by the Department of the Environment (1979). Starting in June 1982, measurement of the major anions - sulphate, nitrate and chloride, was accomplished by employing a Dionex model 2010i ion chromatograph.



Topographic Map of the Turkey Lakes Watershed

0 500 1000 METRES



Contour Interval 50 metres  
-36 Elevation (metres AMSL)  
-Bog or swamp

Figure 2.

## "V. RESULTS AND DISCUSSION

### Precipitation Quantity

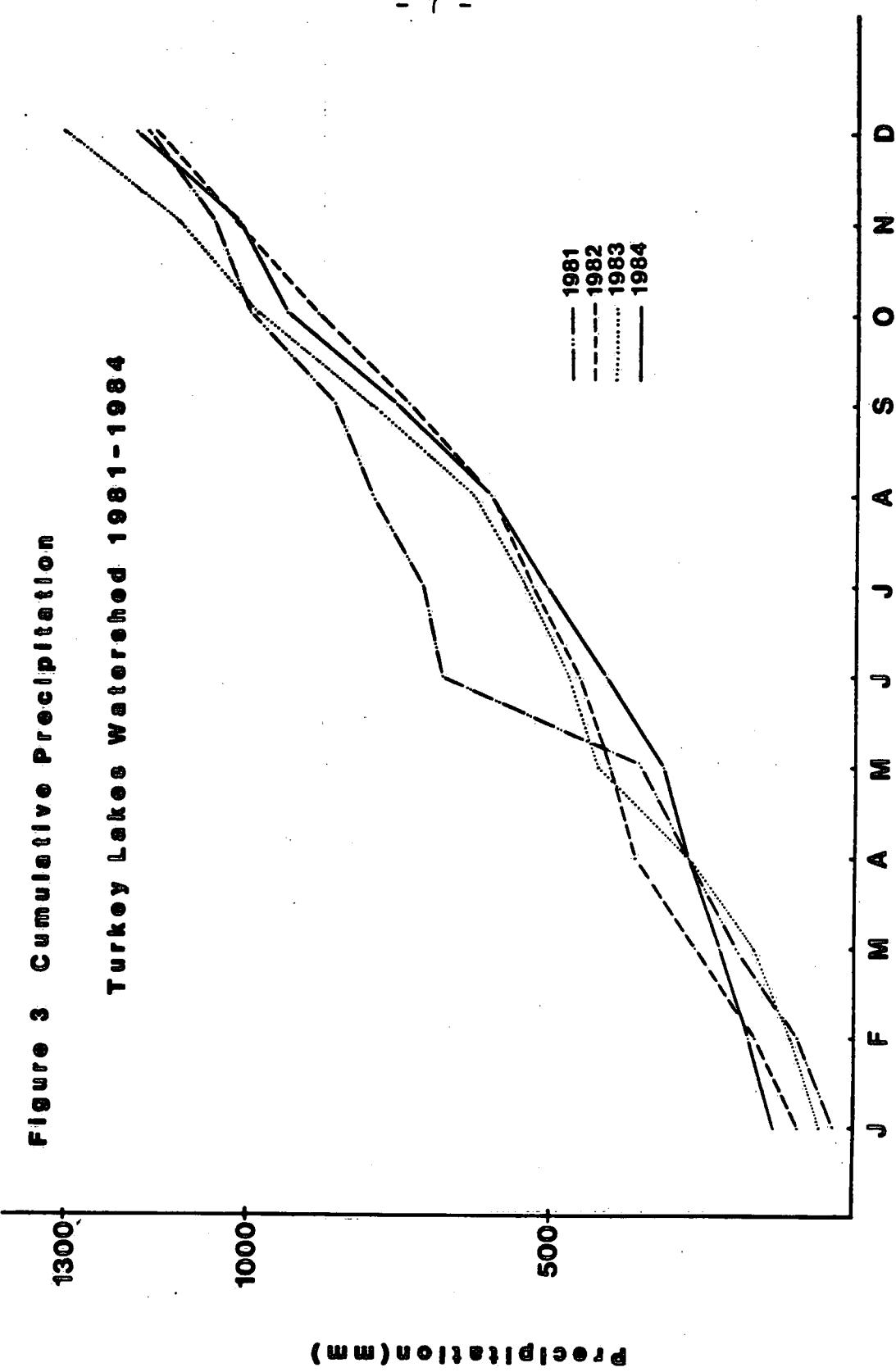
Cumulative precipitation for the years 1981 to 1983 as recorded at the main meteorological station is illustrated in Figure 3. The mean annual precipitation for the four years was 1212 mm. Rain was the predominant form of wet deposition averaging 70% of the total precipitation incident upon the watershed.

Deviations from the quantity of precipitation measured at the main site are reported in Table 1. The effect of increasing elevation at the various gauging locations is evident from the data with upstream portions of the basin recording up to 15% more precipitation than at the main facility.

Table 1. Variation in Annual Precipitation at Selected Sites Within the Turkey Lakes Watershed

Site*	Elevation a.s.l.(m)	Precipitation (mm)		
		1982	1983	1984
M3 (Main Site)	396	1313	1161	1195
M1	498	1421	1304	1249
M5	457	-	1340	1266
M4	347	1281	1247	1260

\*Refer to Figure 1 for location of monitoring site.



### Chemistry of Bulk Deposition

#### Results

A summary of bulk deposition chemistry at the Turkey Lakes watershed is presented in Table 2. Results for individual samples collected on a weekly basis are given in the Appendix. Deposition quality can be influenced by the duration and intensity of precipitation events so that the concentration of a given ionic constituent can best be represented by a volume-weighted mean value (Table 2). For comparative purposes, data from other North American and European monitoring sites are shown in Table 3. In terms of volume-weighted values, ion concentrations at Turkey Lakes are generally lower than those observed in regions closer to major sources of atmospheric emissions and greater than those at a background area in Ontario (e.g. ELA).

Over the period of study, the order of importance of ionic constituents in bulk deposition was as follows:



On an equivalent basis, sulphate accounted for approximately 29% and hydrogen ion 28% of the ionic makeup of bulk deposition. From Figure 4, it is apparent that  $\text{H}^+$ ,  $\text{NH}_4^+$  and  $\text{Ca}^{2+}$  are the major cations present, accounting for some 88% of the cationic pool. Sulphate and nitrate are the significant anions contributing 95% of the total. These five ions generally regulate the chemical composition of deposition in continental areas, particularly where anthropogenic emissions are substantial (Table 3).

Table 2. Statistical Summary of Bulk Deposition Chemistry<sup>1</sup> in the  
Turkey Lakes Watershed September 1, 1981 - July 10, 1984

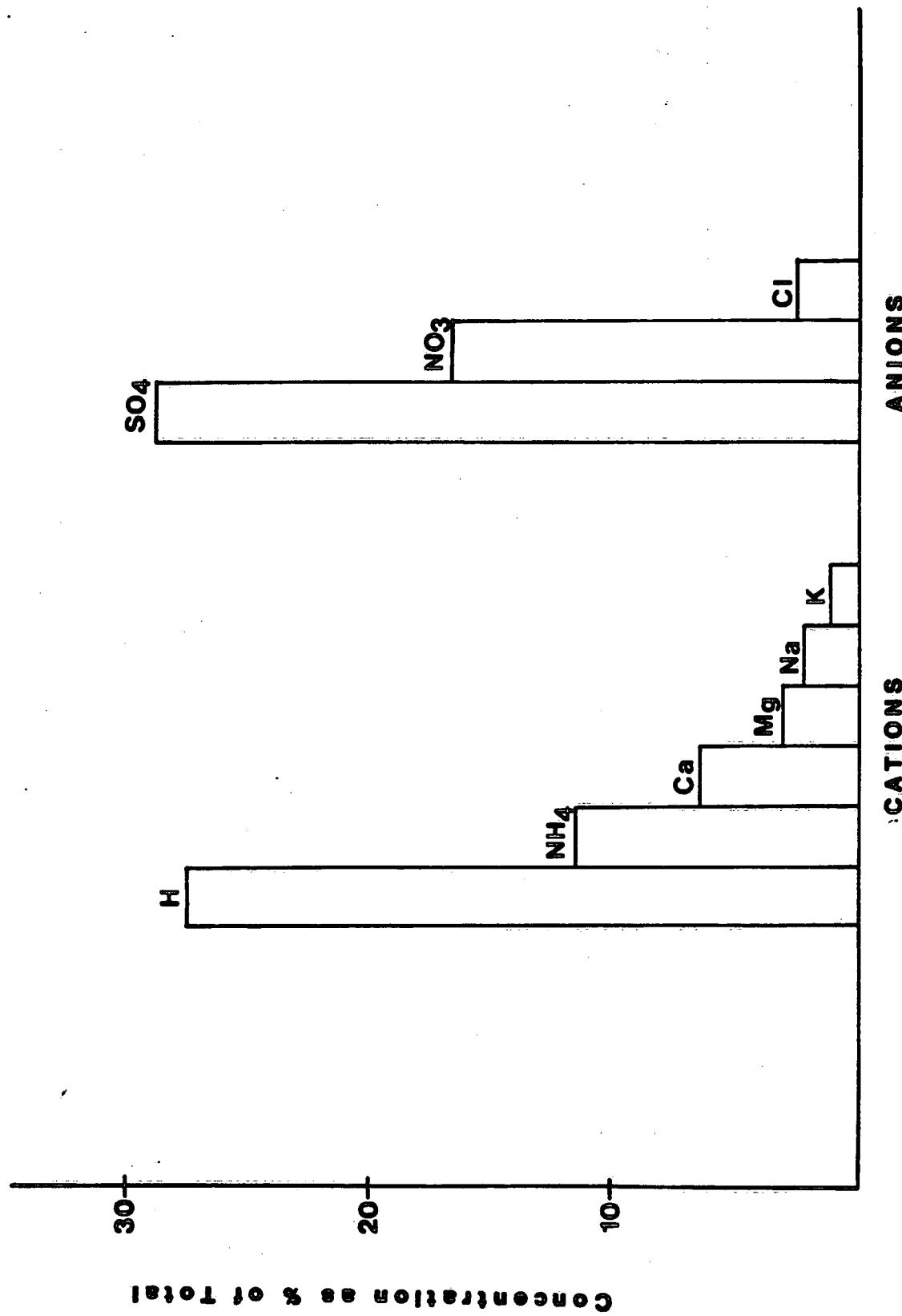
	Samples	Arithmetic	Standard	Range	Volume-
		Mean	Deviation		Weighted Mean
H <sup>+</sup>	141	54.9 (pH 4.26)	46.5	0.1-218.8	50.0 (pH 4.30)
NH <sub>4</sub> <sup>+</sup>	131	28.3	25.3	2.0-118.7	21.0
Ca <sup>2+</sup>	138	18.7	20.9	0.5- 99.8	11.7
Mg <sup>2+</sup>	137	7.7	6.7	0.8- 34.6	5.4
Na <sup>+</sup>	133	5.7	5.1	0.4- 24.4	4.0
K <sup>+</sup>	136	3.8	5.8	0.2- 44.5	2.4
SO <sub>4</sub> <sup>2-</sup>	134	68.5	54.8	4.2-326.9	52.4
NO <sub>3</sub> <sup>-</sup>	136	41.1	42.8	1.1-375.5	30.4
Cl <sup>-</sup>	138	5.7	4.0	0.1- 19.7	4.6

<sup>1</sup>All concentrations in  $\mu\text{eqL}^{-1}$  unless otherwise specified.

**Table 3 Volume-Weighted Chemistry ( $\mu\text{eq L}^{-1}$ ) of Bulk Deposition at Various Study Sites**

Site	H	pH	$\text{NH}_4$	Ca	Mg	Na	K	$\text{SO}_4$	$\text{NO}_3$	Cl	Reference
Turkey Lakes, Ontario 1981-1984	50.0	4.30	21.0	11.7	5.4	4.0	2.4	52.4	30.4	4.6	This study.
Rhubarb Brook, USA 1963-1982	69.3	4.16	10.6	6.5	3.0	4.8	1.5	54.0	23.5	11.2	Likens <i>et al.</i> , 1984
Tillingbourne, SE England 1977-1981	70.8	4.15	40.9					80.5	36.2	97.4	Skeffington, 1984
Pitlochry, Scotland 1976-1979	49.0	4.31	23.3					98.2	34.5	70.1	Harriman as reported in Skeffington, 1984
Birkenes, Norway 1972-1980	57	4.24	38.	9.	13	56	4	74	38	58	Christophersen and Wright, 1980.
Storgama, Norway 1973-1978	54	4.27	27	7	4	15	2	59	31	18	Dyrme and Christophersen, 1980
Solling, W. Germany 1969-1979	77.6	4.11	94.2					161	65.2	46.0	Matzner <i>et al.</i> as reported in Skeffington, 1984
Muskoka-Haliburton, Ont. 1976-1978	74.5	4.13	35.0	42.0	10.0	23.0	5.0	83.0	38.5	10.5	Scheider <i>et al.</i> , 1979
Sudbury, Ontario 1977-1979	72.7	4.14	41.7	29.2	6.9	30.3	3.4	85.3	59.3	10.9	Jeffries, 1984
Average of 3 sites											
ELA, Renora, Ontario 1970-1973	10.9	4.96	20.9	22.4	9.4	8.3	3.3	45.0	18.5	10.0	Schindler <i>et al.</i> , 1976

Figure 4 Percentage Ionic Composition of Bulk Deposition



Seasonal fluctuations in bulk deposition chemistry are illustrated in Table 4 which compares summer concentrations (rain) with winter (snow and freezing rain) values. Based on volume-weighted concentrations, bulk deposition in the summer months is enriched in  $\text{SO}_4$ ,  $\text{NH}_4$ , and  $\text{Ca}$  by about 40% compared to winter concentrations. However, the hydrogen ion concentration in summer precipitation is 25% lower than that occurring in snow and freezing rain (pH 4.37 compared to pH 4.25). In spite of the relative abundance of sulphate during the summer months, the reduced acidity of deposition at this time may be indicative of:

- i) elevated summer concentrations of calcareous materials and ammonia which would tend to neutralize the acidity; or
- ii) a higher percentage of  $\text{SO}_4$  in summer is associated with  $\text{NH}_4$  in aerosols;

Conversely, higher concentrations of  $\text{HNO}_3$  during winter may account for the higher acidity observed during this season.

Concentrations of sulphate and nitrate can provide an estimate of the contribution of  $\text{H}_2\text{SO}_4$  and  $\text{HNO}_3$  to the acidity of deposition. Galloway and Likens (1981) reported that 1979 levels of  $\text{H}_2\text{SO}_4$  at Hubbard Brook could account for 73% and 61% of the summer and winter acidity respectively, whereas the  $\text{HNO}_3$  content could explain 31% and 59% of the summer and winter strong acidity. Equivalent ratios of  $\text{SO}_4/\text{NO}_3$  at Sudbury were observed to vary from winter lows of 1:1 to summer highs of 3:1 (Jeffries, 1984). Plots of the bulk  $\text{SO}_4/\text{NO}_3$

Table 4. Seasonal Fluctuations in Bulk Deposition Chemistry<sup>1</sup> at the Turkey Lakes Watershed

Parameter	n	$\bar{x}$	s	Summer			Winter			Volume Weighted Mean	Summer <sup>2</sup> /Winter
				Range	Volume-Weighted Mean	n	$\bar{x}$	s	Range		
SO <sub>4</sub>	64	85.8	64.2	10.4-326.9	62.5	70	52.8	38.9	4.2-180.7	43.6	1.43
NO <sub>3</sub>	62	38.2	36.3	1.1-255.6	27.6	74	43.6	46.4	7.4-315.5	32.9	0.83
H	67	42.9	43.7	0.1-204.2	42.5	74	65.7	46.6	7.2-218.8	56.4	0.75
NH <sub>4</sub>	58	36.1	29.2	2.3-118.7	24.1	73	22.2	19.8	2.0-86.9	18.1	1.33
Ca	65	25.7	24.9	1.0-89.8	14.0	73	12.4	13.9	0.5-99.8	9.8	1.43

1. All concentrations in  $\mu\text{eqL}^{-1}$  represent mean values of weekly bulk deposition samples.
2. Ratio of summer volume-weighted mean/winter volume-weighted mean.
3. n = number of samples;  $\bar{x}$  = arithmetic mean; s = standard deviation.

equivalent ratio at the Turkey Lakes watershed (Figure 5) also show a predominant summer contribution of  $H_2SO_4$  to the strong acidity of deposition and fairly equal amounts of  $H_2SO_4$  and  $HNO_3$  during the winter months. The sulphate to nitrate equivalent ratio averaged over three years was 0.85 for the month of January and 2.74 for August.

The co-variation of major ions in bulk deposition has been discussed by numerous researchers. Skeffington (1984) employed a variety of statistical procedures to investigate the chemistry of bulk deposition in southeast England. His summary results indicated that  $SO_4$ ,  $NO_3$ , and  $NH_4$  were strongly correlated suggesting that their variation had a common source and that H correlated better with  $NO_3$  than with  $SO_4$ . In an analysis of precipitation data from the United States NADP network, Gorham et al. (1984) reported that H was more closely correlated with  $SO_4$  ( $r^2 = 0.85$ ) than with  $NO_3$  ( $r^2 = 0.63$ ) and attributed the relationship between H and  $NO_3$  to their strong mutual correlation with  $SO_4$ .

The correlations between precipitation depth and concentrations of major constituents at the Turkey Lakes are presented in Table 5. All the ions in deposition except hydrogen are inversely correlated with the amount of precipitation falling at the study site. Hydrogen ion appears to be more strongly correlated with nitrate ( $r = 0.73$ ) than with sulphate ( $r = 0.55$ ); however, the significant interaction between  $NO_3$  and  $SO_4$  ( $r = 0.63$ ) masks any direct linkage between H and either anion.

Figure 5  
Seasonal Variation  $\text{SO}_4:\text{NO}_3$  Equivalent Ratio For Bulk Deposition

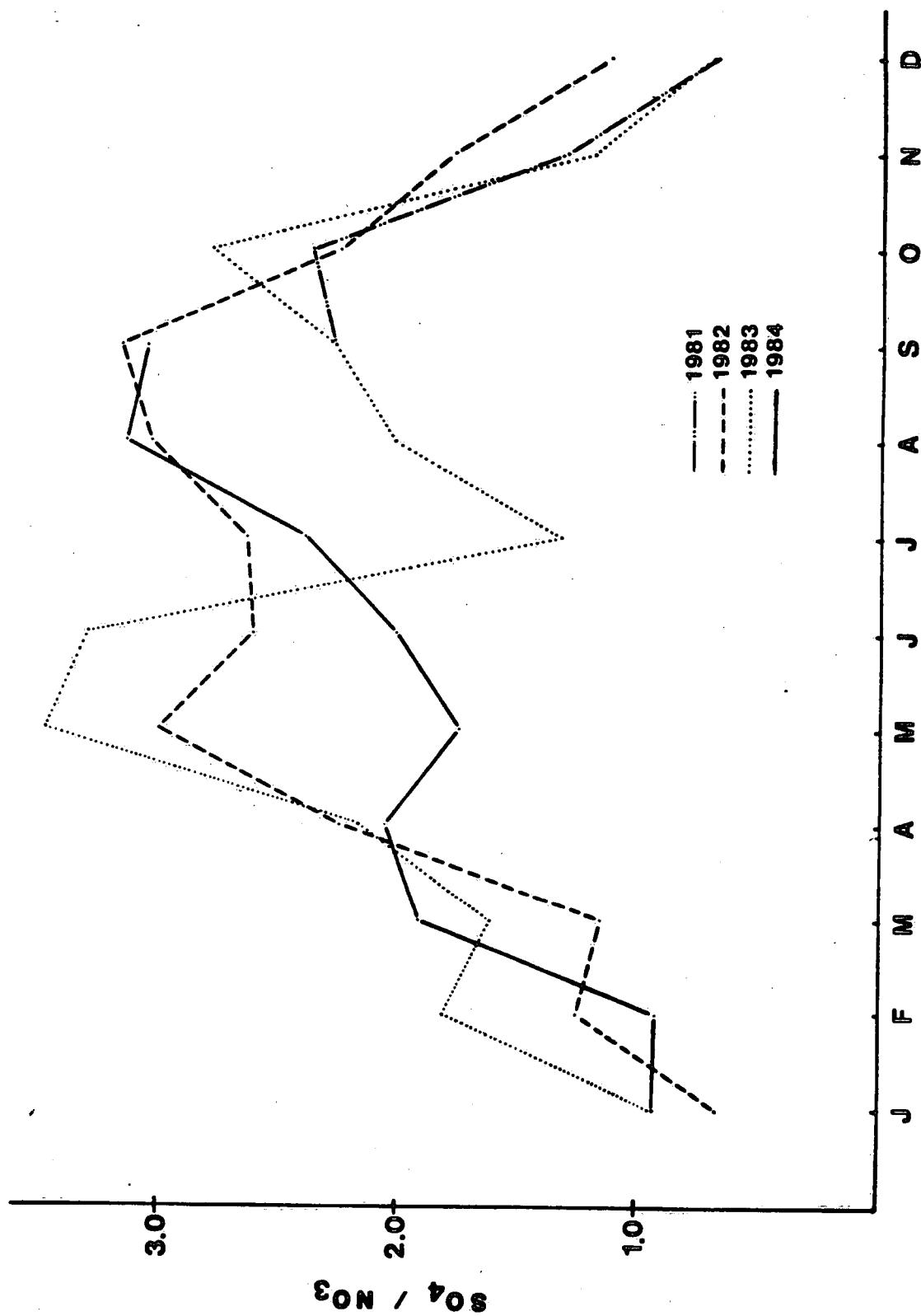


Table 5. Pearson Correlation Coefficients<sup>1</sup> Between  
Ions and Precipitation Depths

Depth	H <sup>+</sup>	NH <sub>4</sub> <sup>+</sup>	Ca <sup>2+</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>	
Depth	1.00					
H <sup>+</sup>	-0.14	1.00				
NH <sub>4</sub> <sup>+</sup>	-0.41*	0.33*	1.00			
Ca <sup>2+</sup>	-0.45*	0.09	0.42*	1.00		
SO <sub>4</sub> <sup>2-</sup>	-0.40*	0.55*	0.70*	0.63*	1.00	
NO <sub>3</sub> <sup>-</sup>	-0.35*	0.73*	0.46*	0.55*	0.63*	1.00

\*Significant at p < .001

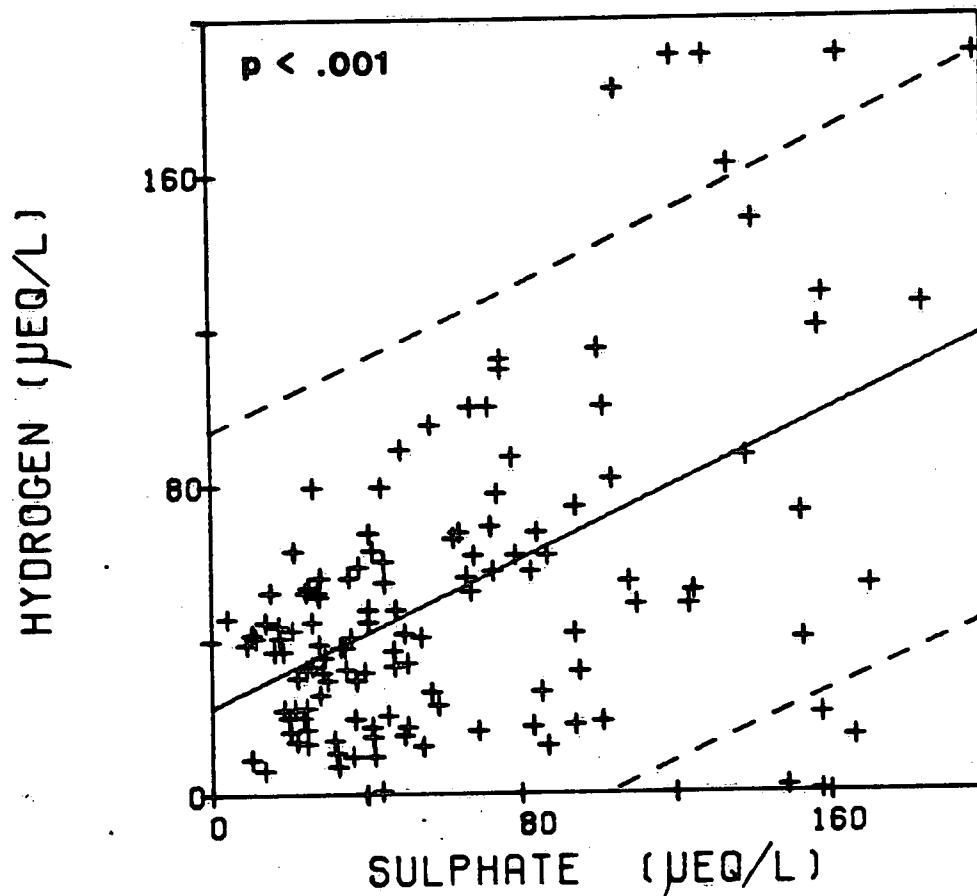
1. Number of samples between 125 and 141.

Using Turkey Lakes data, regressions of H on SO<sub>4</sub> and NO<sub>3</sub> were calculated and are presented in Figures 6 and 7. As with Skeffington's results (1984), the relative slopes of the regression lines suggest that a greater proportion of the NO<sub>3</sub> is associated with HNO<sub>3</sub> (79%) than SO<sub>4</sub> with H<sub>2</sub>SO<sub>4</sub> (47%) in bulk deposition. The high correlation between SO<sub>4</sub> and NH<sub>4</sub> ( $r = 0.70$ ) further supports the contention that a sizeable portion of the measured sulphate may not be contributing to the overall precipitation acidity. It should be noted, however, that NH<sub>4</sub> deposited to a watershed is a net acidifying substance if it is retained within the basin, while NO<sub>3</sub> is a net alkalizing substance under the same conditions (Harvey et al., 1981). Ammonium ion is strongly retained in terrestrial sub-basins within the Turkey Lakes Watershed (Nicolson, 1983).

Atmospheric deposition in meq m<sup>-2</sup>yr<sup>-1</sup> was computed for the two complete years of measurement, i.e., 1982 and 1983, and is summarized in Table 6. Material loadings for other experimental sites accompany the Turkey Lakes data and illustrate the significance of precipitation depth in determining deposition. The ionic content of deposition at the watershed is less concentrated than in areas more directly affected by airborne contaminants, e.g., Sudbury, south-central Ontario; however, the greater precipitation quantity recorded at the study basin results in comparable rates of material deposition.

Figure 6

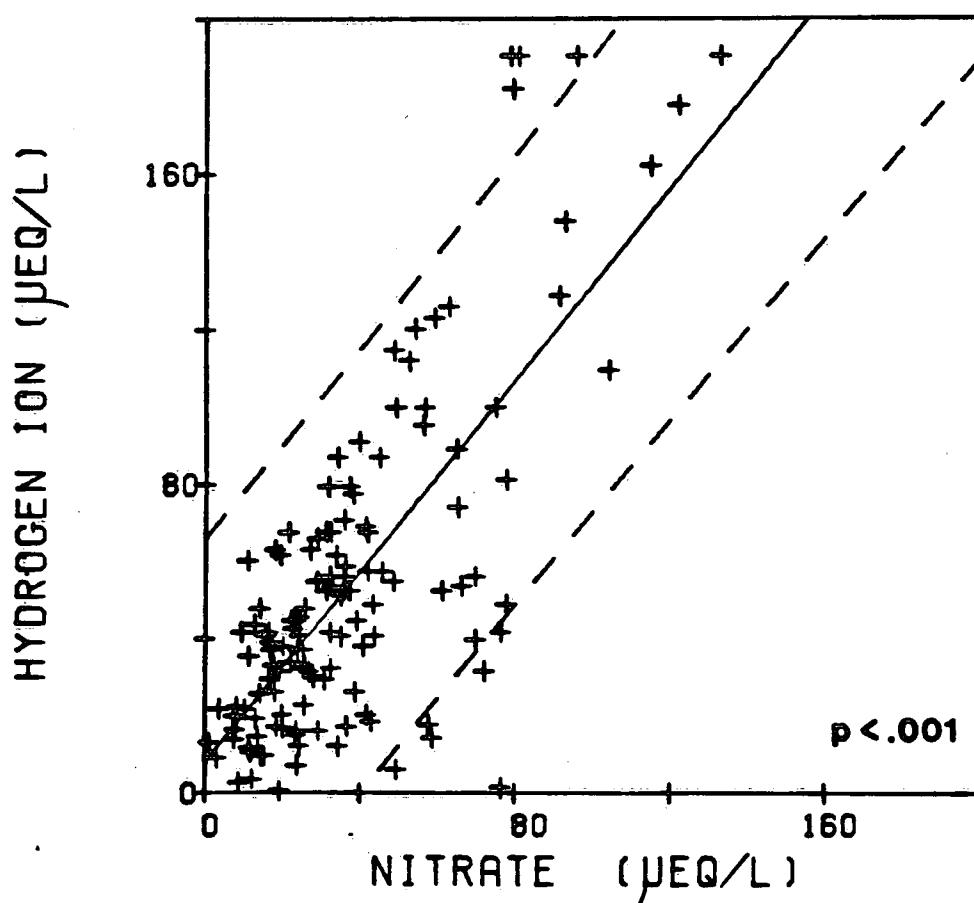
HYDROGEN ION VS SULPHATE



$$(\text{H}) = 0.47(\text{SO}_4) + 22.95 \quad r = 0.55$$

Figure 7

HYDROGEN ION VS NITRATE



$$(H) = 0.79(\text{NO}_3^-) + 23.72 \quad r = 0.73$$

**Table 6 Atmospheric Loadings (meq m<sup>-2</sup>yr<sup>-1</sup>) As Calculated From Bulk Depositon Chemistry at the Turkey Lakes and Elsewhere.**

Site	H	NH <sub>4</sub>	Ca	Mg	Na	K	SO <sub>4</sub>	NO <sub>3</sub>	Cl	Annual Precipitation (mm)	Reference
Turkey Lakes, Ontario 1982	65.1	28.0	13.7	7.2	4.2	3.3	77.9	40.4	3.5	1313	This study
	65.5	22.2	11.0	5.2	4.8	2.7	57.9	33.7	6.7	1161	
Muskoka-Haliburton, Ont. 1976-1978	56.4	26.4	31.4	7.52	17.3	3.49	62.9	29.3	7.66	758	Scheider <u>et al.</u> 1979
Sudbury, Ontario June 77-May 78 (average of 3 sites)	71.3	28.3	31.4	7.75	42.5	4.31	82.2	40.2	11.79	903	Jeffries, 1984
Tillingbourne, SE Eng. 1977-1981	74.7	43.6					85.8	38.7	106	1067	Sheffington, 1984
Pitlochry, Scotland 1976-1979	40.6	20.7					82.9	30.7	62.3	890	Harriman as reported in Sheffington, 1984
Solling, W. Germany 1969-1979	61.7	85.0					148	57.1	48.2	900	Matzner <u>et al.</u> , 1982 as reported in Sheffington, 1984
Birknes, Norway 1972-1978	80.0	53.3	12.6	18.2	78.6	5.6	103.8	53.3	81.4	1403	Christophersen and Wright, 1980
Storgata, Norway 1973-1978	51.5	25.7	6.7	3.8	14.3	1.9	56.2	29.5	17.2	953	Dyabe and Christophersen, 1980
Hubbard Brook, USA 1963-1974	96.9	16.1	10.8	4.8	6.9	2.3	79.9	31.7	19.8	1313	Likens <u>et al.</u> , 1977

## V. SUMMARY

Bulk deposition at the Turkey Lakes Watershed has been collected on a weekly basis since September 1, 1981. The mean annual precipitation for 1981 through 1984 was 1212mm. Five ions dominate the chemistry of bulk deposition -  $\text{SO}_4$ , H,  $\text{NO}_3$ ,  $\text{NH}_4$ , Ca. Seasonal variations in the ionic constituents were observed with concentrations of  $\text{SO}_4$ ,  $\text{NH}_4$ , and Ca being 40% greater in the summer months compared to winter. However, the acidity of bulk deposition in the summer samples was less than that measured over the winter months (pH 4.37 vs pH 4.25). Sulphate/nitrate equivalent ratios were approximately 1 during the cold season and increased to around 3 in the summer.

Sulphate, nitrate and hydrogen ions were significantly correlated suggesting that these ions had a common source. With the exception of H, the major ions in bulk deposition were inversely correlated with the depth of precipitation. A greater proportion of  $\text{NO}_3$  appeared to be associated with  $\text{HNO}_3$  than  $\text{SO}_4$  with  $\text{H}_2\text{SO}_4$ .

Material loadings calculated for the Turkey Lakes Watershed were similar to those in areas receiving deposition of a higher ionic strength. This reflected the greater precipitation depth recorded at the study site.

## VI. ACKNOWLEDGEMENTS

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**APPENDIX**

## TURKEY LAKES WATERSHED PROJECT

## --- MAJOR ION CONCENTRATIONS -----

## NWRI BULK PRECIPITATION - H3

FROM YR	DATE MO	TO DY	DEPTH MM	PH	CA MG/L	MG MG/L	NA MG/L	K MG/L	NH4 MG/L	SO4 MG/L	CL MG/L	NO3 MG/L	COND US/CN 25 C
81 9 1	81 9 12	81 9 19	2.69	6.16	1.16	.228	.198	.168	.273	2.11	.314	.268	12.3
81 9 15	81 9 26	81 9 26	1.79	6.49	1.72	.149	.118	.108	.515	3.31	.247	.488	19.2
81 9 19	81 9 29	81 9 17	1.56	4.49	1.52	.249	.020	.188	.676	7.35	.378	.978	42.9
81 9 23	81 10 12	81 10 24	1.47	4.47	1.47	.268	.059	.059	.354	2.43	.271	.311	42.9
81 9 27	81 10 16	81 10 28	1.46	4.46	1.46	.260	.018	.020	.661	2.43	.289	.164	42.9
81 10 1	81 10 21	81 10 30	1.46	4.46	1.46	.260	.018	.020	.173	1.14	.297	.272	42.9
81 10 5	81 10 25	81 10 34	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.086	.368	22.3
81 10 9	81 10 29	81 10 38	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	34.7
81 10 13	81 10 33	81 10 41	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 17	81 10 37	81 10 45	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 21	81 10 41	81 10 49	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 25	81 10 45	81 10 53	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 29	81 10 49	81 10 57	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 33	81 10 47	81 10 55	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 37	81 10 51	81 10 59	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 41	81 10 55	81 10 63	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 45	81 10 59	81 10 67	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 49	81 10 63	81 10 71	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 53	81 10 67	81 10 75	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 57	81 10 71	81 10 79	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 61	81 10 75	81 10 83	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 65	81 10 79	81 10 87	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 69	81 10 83	81 10 91	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 73	81 10 87	81 10 95	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 77	81 10 91	81 10 99	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 81	81 10 95	81 10 103	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 85	81 10 99	81 10 107	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 89	81 10 103	81 10 111	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 93	81 10 107	81 10 115	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 97	81 10 111	81 10 119	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 101	81 10 115	81 10 123	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 105	81 10 119	81 10 127	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 109	81 10 123	81 10 131	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 113	81 10 127	81 10 135	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 117	81 10 131	81 10 139	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 121	81 10 135	81 10 143	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 125	81 10 139	81 10 147	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 129	81 10 143	81 10 151	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 133	81 10 147	81 10 155	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 137	81 10 151	81 10 159	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 141	81 10 155	81 10 163	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 145	81 10 159	81 10 167	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 149	81 10 163	81 10 171	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 153	81 10 167	81 10 175	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 157	81 10 171	81 10 179	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 161	81 10 175	81 10 183	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 165	81 10 179	81 10 187	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 169	81 10 183	81 10 191	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 173	81 10 187	81 10 195	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 177	81 10 191	81 10 199	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 181	81 10 195	81 10 203	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 185	81 10 199	81 10 207	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 189	81 10 203	81 10 209	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 193	81 10 207	81 10 211	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 197	81 10 211	81 10 215	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 201	81 10 215	81 10 219	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 205	81 10 219	81 10 223	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 209	81 10 223	81 10 227	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 213	81 10 227	81 10 231	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 217	81 10 231	81 10 235	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 221	81 10 235	81 10 239	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 225	81 10 239	81 10 243	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 229	81 10 243	81 10 247	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 233	81 10 247	81 10 251	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 237	81 10 251	81 10 255	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 241	81 10 255	81 10 259	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 245	81 10 259	81 10 263	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 249	81 10 263	81 10 267	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 253	81 10 267	81 10 271	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 257	81 10 271	81 10 275	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 261	81 10 275	81 10 279	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 265	81 10 279	81 10 283	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 269	81 10 283	81 10 287	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 273	81 10 287	81 10 291	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 277	81 10 291	81 10 295	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 281	81 10 295	81 10 299	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 285	81 10 299	81 10 303	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6
81 10 289	81 10 303	81 10 307	1.38	3.58	1.38	.239	.048	.048	.378	1.25	.143	.158	18.6

TURKEY LAKES WATERSHED PROJECT

## MAJOR ION CONCENTRATIONS

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## TURKEY LAKES WATERSHED PROJECT

## ----- MAJOR ION CONCENTRATIONS -----

## NWRI BULK PRECIPITATION - M3

FROM YR MO DY	DATE TO YR MO DY	PRECIP DEPTH MM	pH	Ca MG/L	Mg MG/L	Na MG/L	K MG/L	NH4 MG/L N	SO4 MG/L	Cl MG/L	NO3 MG/L N	COND US/CN 25 C
84 3 13	84 3 29	1.53	4.96	.20	.030	.230	<	.040	.500	3.74	.359	.478
84 3 28	84 4 17	2.89	4.26	.10	.060	.440	<	.020	.215	2.15	.172	.484
84 3 27	84 4 17	4.43	4.21	.44	.110	.130	.530	.095	3.26	.276	.473	.34.9
84 4 17	84 4 24	5.01	4.59	.79	.140	.070	.220	.111	.39	.298	.330	.71.4
84 4 24	84 5 1	4.99	4.62	.39	.140	.140	.560	.370	.563	3.47	.760	.579
84 5 1	84 5 15	2.21	4.16	1.80	.060	.270	.320	.633	.93	.369	.1.898	.39.4
84 5 10	84 5 15	4.31	4.28	1.06	.140	.270	.320	.520	.527	.527	.856	.43.4
84 5 15	84 5 22	4.49	4.28	1.92	.220	.080	.430	.430	.599	.248	.809	.46.9
84 5 22	84 5 29	4.75	4.75	1.57	.340	.260	.260	.501	.51	.581	.1.870	.29.9
84 5 29	84 6 5	5.81	6.25	1.58	.141	.110	.130	.240	.528	.7.15	.164	.357
84 6 5	84 6 12	3.28	4.64	3.28	.41	.39	.050	.150	.465	.2.60	.142	.498
84 6 12	84 6 19	6.19	4.89	4.39	.39	.070	.060	.090	.496	.2.19	.067	.278
84 6 19	84 6 26	6.26	4.69	4.12	.060	.070	.060	.030	.158	.1.83	.142	.19.6
84 6 26	84 7 3	7.3	2.47	4.66	.12	.020	.020	.130	.261	1.55	.165	.165
84 7 3	84 7 10	1.51	4.97	.24	.050	.050	<	.050	.130	.1.55	.165	.14.9