SNOWPACK CHEMISTRY IN SOUTH CENTRAL BRITISH COLUMBIA

by
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INTRODUCTION

Precipitation during the winter in British Columbia falls as snow at upper elevations in the coastal area and at all levels throughout the interior. Snowflakes collect a variety of impurities by scavenging as they descend through the atmosphere. During deposition and between snow storms, dry atmospheric fallout as well as local sources of contamination add to the impurities contained in and on the snowpack. This study of the chemistry of snowpacks will quantify the impurities present in the sample, and provide some idea of the ambient chemical background.

It is assumed that there has always been some variation in the chemical makeup of snow however it seems evident that contamination may occur as a result of human activity. In order to establish a historical perspective it is necessary to monitor the chemistry over time and space. This program covers a sizeable area of British Columbia but is only able to provide a brief insight into the subject. Many chemical compounds were investigated, but sulphates and nitrates were of primary interest.

HISTORICAL REVIEW

To date, there appears to be little published information relating to the chemistry of snow in British Columbia. An early investigator (summer, 1973), collected data from 1969 and reported that the sulphate concentration of his snow samples contained less than 0.5 mg/l.

Recently, in two programs initiated by Canada's Atmospheric Environment Service (AES), snowpacks were sampled for chemical analysis. The first investigation on Vancouver Island (S&B Research, 1982) and the second in southwestern British Columbia (Mclaren, 1982) are summarized in Table 1.

TABLE 1
ATMOSPHERIC ENVIRONMENT SERVICES
Acid Snow Sampling 1981 to 1983

LOCATION	ELEVATION meters	MEAN pH	SO_4 mg/l	NO_3 mg/l
Vancouver Island	1 000+	5.4	.25	.21
Vancouver Island	750	5.14	.2	.25
Southwestern B.C.	1 450+	5.1	.2	.27
Mt. Seymour	945	4.91	.4	.48

The data shows that SO_4 and NO_3 ion concentration generally increases as the pH declines. The horizontal variability of the pH within a 100 meter circle is $\pm$ 0.2 pH units.

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In 1981 the British Columbia Ministry of Environment began its snow chemistry monitoring program in the south central interior. At that time the Hat Creek coal fired power plant was planned for the area, though subsequently cancelled. The program has continued to the present as a means of estimating ambient acid snow conditions for this region. The deposition pattern of cations and anions in snowpack samples is used as a means of assessing the "completeness" of the analysis.

SAMPLING EQUIPMENT

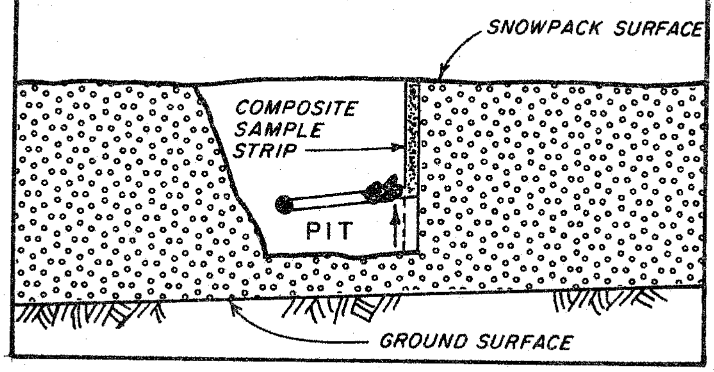
The snow sampling kits are prepared by the Ministry of Environmental Laboratory in Vancouver, B.C. Each kit contains a freezer grade polyethylene bag, a plastic scoop (cannister) and a 200 ml plastic bottle. An extensive decontamination process was completed for each kit prior to distribution to the field observers. This process included a nitric acid bath for the polyethylene bag, scoop and sample bottle, followed by 16 deionized water rinses. Following this process the pieces are dried and sealed. The field observer supplies a shovel for the snow pit which must be cleaned just prior to excavation.

SAMPLING METHOD

Sampling for chemical analysis must be carefully controlled as to location, methodology, handling and testing, particularly to control individual observers and their varying abilities. In order to produce comparable results over time, it was decided that sampling sites should be representative and easily identifiable. Since the Ministry operates the provincial snow survey program, it was decided to use well established snow courses for this purpose. The snow surveyors could be easily instructed to carry out the additional task, with the likelihood that they would remain on the job in future years.

FIGURE I

SNOW CHEMISTRY SAMPLING PIT



Using a clean metal shovel the pit is dug at the sampling site to within a few centimeters of the ground (Figure 2). There should be no contamination sources such as helicopter exhaust. With the sharp edge of the scoop, a composite snow sample is taken along the vertical axis from the bottom to the top of the pit. The sample, which is transferred to the polyethylene bag, should provide a minimum of 200 ml of melt water. The bag is sealed by tying for transport away from the snow course. The snow is allowed to melt at room temperature, then transferred to the sample bottle and shipped to the Environment Laboratory in Vancouver by the observer.

TESTING

The chemical analysis is performed according to the procedure, "Collection and Analysis of Acid Precipitation", published by the Environmental Laboratory in 1981(2). Upon arrival the 200 ml of snow water is processed as follows:

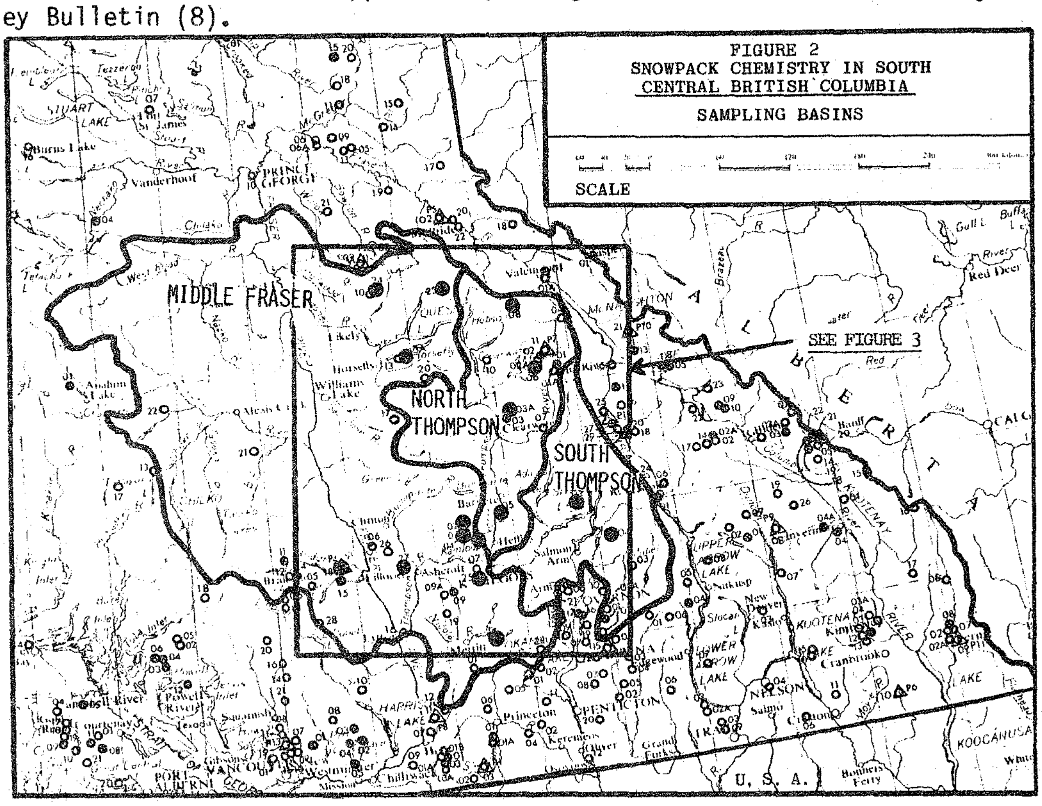
1. pH is measured on the unfiltered sample.
2. Acidity is measured on filtered samples.
3. Chemical analysis to determine concentration of the following ions: SO_4^{2-}, NO_3^-, NH_4^+, C_1^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, PO_4^{3-}, Al^{3+}, F^-.

The acidity is determined by Gram's plot titration procedure using microlitre additions of standard sodium hydroxide. Testing for the above ions is performed in a decreasing order of priority to ensure that the most important tests are done first. In the event of sample loss, the consequence is minimized.

The sulphate ion concentration in samples collected in the winter of 1981 and 1982 was determined by the turbidimetric method. The sulphate detection limit by this method is 0.5 mg/L. The SO_4 in 1983 and 1984 samples was determined by using Dionex ion chromatography which has a detection limit of 0.05 mg/l. According to the LRTAP-InterLab comparison, the turbidimetric method gives 25 to 65% higher results than the ion chromatographic method. For this reason, in assessing the SO_4 ion concentrations only 1983 and 1984 results have been used. Furthermore, with the aid of Dionex ion chromatographic method the anions; Cl^-, NO_3^-, and cations Na^+, K^+ and NH_4^+ were also analyzed for winter samples taken in 1983 and 1984.

SAMPLING LOCATIONS

This program was conducted in three major river basins, the middle Fraser, and the North and South Thompson (Figure 2). In the winter of 1981, seven Middle Fraser, three North and two South Thompson snow courses were sampled. In the winter of 1982, as well as subsequent years this network was extended to include 16 snow courses: 10 in the Middle Fraser, 4 in the North Thompson and 2 in the South Thompson. The coordinates of stations in the study area are included in Appendix 1, along with concurrent snow survey data from the Snow Survey Bulletin (8).



METEOROLOGY - 1980 TO 1984

Temperature is a significant factor with respect to snowpack since it indicates whether the snowpack has undergone freeze-thaw cycles or not. During freeze-thaw, pollutants are eluted from the snow and are segregated in the liquid water moving through the snow (Johanessen, et al, 1978). This would introduce within the snowpack a variation of pH as well as chemistry. Sampling was conducted on April 1st to pre-empt spring melt, yet be near the maximum seasonal snowpack. Results of snow surveys at selected sites are shown as a percent of average in Table 2.

In the study region the snowpack sampling sites are located at elevations from 870 meters to 2 000 meters. Since surface temperature data were not available to assess the temperature effect on snowpack at higher elevations, upper air temperatures at Prince George Airport were used. The daily radiosonde temperatures are measured at 4 a.m. and 4 p.m. at

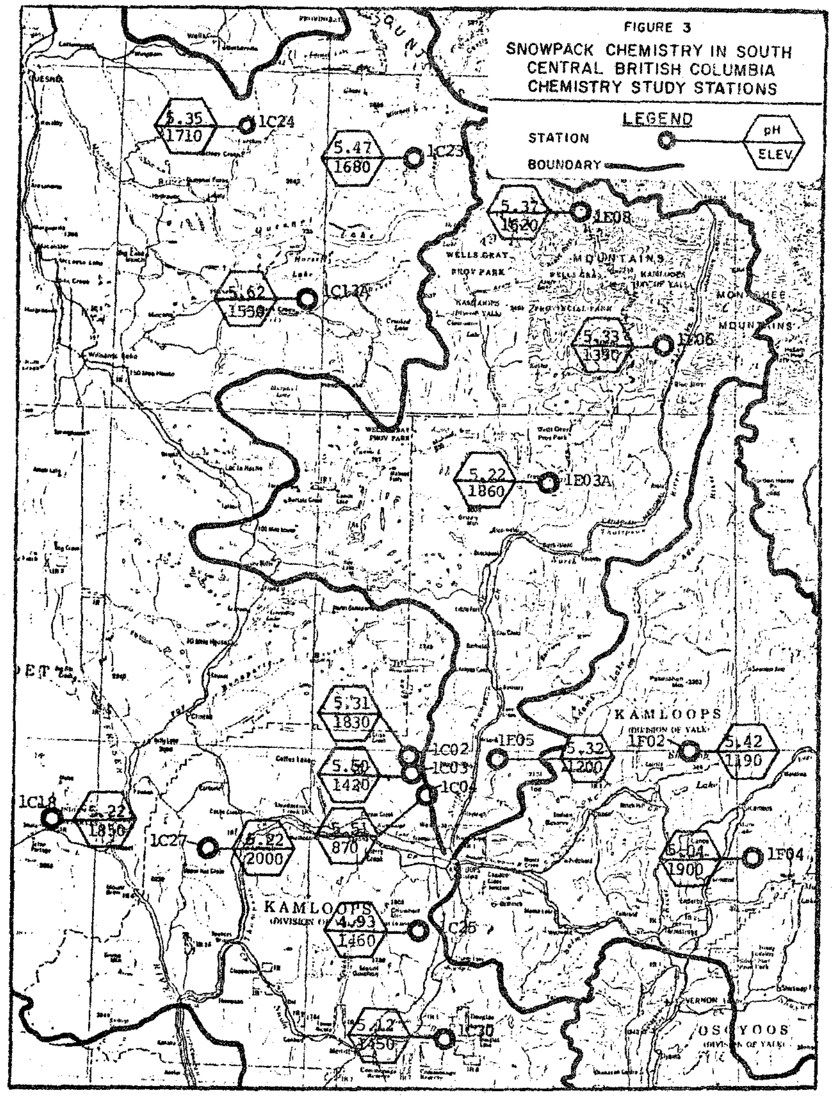


TABLE 2
SNOWPACK CONDITIONS AT SELECTED SNOW COURSES

BASIN AND SNOW COURSE NUMBER	NAME	AVERAGE TO 1984	YEARS ON RECORD	APRIL 1st % OF AVERAGE DEPTH/SWE 1981	1982	1983	1984
Middle Fraser							
1C02	Porcupine Ridge	147	23	67	102		116
		445		55	104		115
1C18	Mission Ridge	166	17	70	95	69	57
		605		62	97	69	51
1C25	Lac Le Jeune	45	12	47	149	118	102
		127		50	145	121	107
North Thompson							
1E04	Knouff Lake	56	27	41	121	91	86
		163		49	122	101	87
1E06	Cook Forks	250	22	78	100	98	87
		947		79	97	101	91
South Thompson							
1F02	Anglemont	106	27	63	115	92	77
		374		66	120	103	88
1F04	Enderby	281	21	80	120	102	97
		1 004		88	129	111	102

TABLE 3

UPPER AIR TEMPERATURES ABOVE 0°C AND WATER EQUIVALENT OF RELATED SNOW COURSES

Winter Period	Number of Days upper-air temperatures were measured (At Prince George Airport)	Number of observations above 0°C made at 4 P.M	Number of observations above 0°C made at 4 A.M	Water equivalents for selected snow courses in Middle Fraser mm	Water equivalents for selected snow courses in N. and S. Thompson mm
Dec 80 to March 81	114	49 (43%)	35 (31%)	140	160
Dec 81 to March 82	120	9 (7.5%)	7 (6%)	290	820
Dec 82 to March 83	121	22 (18%)	19 (16%)	200	750
Dec 83 to March 84	122	33 (27%)	28 (23%)	200	710

850 mb level (1 500($\pm$) meters MSL) for the winter periods from 1981 to 1984. The number of occasions the temperature has been above 0° during each winter period are summarized in Table 3.

From this temperature summary, it is seen that the winter of 1981 was the warmest, 1982 the coldest and the winters of 1983 and 1984 were between the two extremes. The measured snow course water equivalent data, presented in Appendix 1, coincidentally follow an inverse temperature trend in which the greater snowpacks occur at the lowest temperatures.

RESULTS

All data collected is included in Appendix 2 and compared with other observations in Appendix 3. Mean pH of snow samples collected in the Middle Fraser, North and South Thompson snow courses in the winter of 1981 to 1984 are shown in Figure 3. These pH values represent the 4 year average at the site, and are coupled with the site elevation.

a) pH - The chemical analysis of snowpack samples were done for four years and each year's raw data have been presented in Appendix 2. Preliminary analysis of data suggests that the pH of snowpack samples range from 5 to 5.5 with the exception of a few samples. Normal background pH away from the coast is approximately 5.6. Samples with higher pH had higher concentration of calcium as in 1982 Horsefly Mountain sample or sodium as in 1983 Tranquille Lake sample. Low pH such as 4.9 was noted when low concentrations of metals such as Ca, Mg or Na were present in snow melt water. Although not conclusive, there is some indication that the samples with low pH were associated with shallow snowpacks of 21 to 67 cm compared to other sites in the area which had snow depths between 100 to 260 cm. Low pH values were regularly observed at Lac Le Jeune while less often at such sites as Mission Ridge, Spahomin and Enderby.

b) Ionic Concentration - Average ionic concentrations in snowpack samples taken in the Middle Fraser, North Thompson and South Thompson are listed in Appendix 3. Data collected elsewhere is also presented to compare the study values to a neutral reference.

On the basis of chemical equivalence for the snow melt water the following relationship should hold:

$$\sum \text{Cations} = \sum \text{Anions}$$

In fact for 1981 and 1982 $\sum$ Cations > $\sum$ Anions

and for 1983 and 1984 $\sum$ Cations < $\sum$ Anions

The difference in the first two years of data are due to overestimation of SO_4 concentrations by using the turbidimetric method and for the next two years the difference could be due to error or incomplete anion analysis, such as excluding bicarbonate ion (HCO_3).

c) Sulphate - The sulphate ion in micro-equivalences per liter (μ eq/l) from the snowpack samples were determined by the following methods (See Table 4):

- Turbidimetric - sulphate concentration varied from 16 to 37 μ eq/l, where 37 was observed in the South Thompson in 1980. This compares with 18 μ eq/l observed by Logan et al (1982) in the Cascade Mountains in Washington.

- Ion Chromatographic - sulphate concentration for 1983 and 1984 range from 4 to 9.5 μ eq/l in the study area. This compares with 4 μ eq/l on Vancouver Island and 5 for Moore Creek in the Skeena Region. The background sulphate content in snow samples from remote places like Greenland or Antarctic was about 1.5 μ eq/l.

TABLE 4
MEAN SULPHATION VALUES OF SNOW CORE SAMPLES DETERMINED BY TURBIDIMETRIC AND ION-CHROMATOGRAPHIC METHODS
(Values in μ equivalences per liter)

	MIDDLE FRASER				NORTH THOMPSON				SOUTH THOMPSON			
ANALYTICAL METHOD	1982	1982	1983	1984	1981	1982	1983	1984	1981	1982	1983	1984
Turbidmetric	21.98	23.67			16.64	22.36			37.44	15.89		
Ion-Chromatographic			9.57	4.77			4.47	3.80			5.62	4.30
Total Mean Ion-Chromatographic Values Lower Than Total Mean Turbidimetric Values	68.6%				78.8%				81.4%			

When comparing the results it is noted that the total mean sulphate concentrations obtained by the ion-chromatographic method appear to be consistently less than those determined by the turbidimetric method. However, this cannot be stated with certainty because the sulphate results compared by the two methods, although from the same sites, are from different years.

d) Nitrate - In addition to sulphate ion, the nitrate ion concentration in the snowpack is also a quantitative indicator of acid deposition. The mean nitrate concentration in the snowpack samples collected in the study region for the winter of 1981 to 1984 range from 4.5 to 10 μ eq/L (Appendix 3).

e) SO_4:NO_3 Ratio - In the study region ranged from 0.7 to 1.3. When less than 1 the nitrate concentration is more than sulphate in the snowpack and vice versa. In the winters of 1983 and 1984 the nitrate concentration was greater than the sulphate. The general trend in pristine areas is for the NO_3 concentration to exceed that for SO_4 (see Appendix 3).

f) Ca:SO_4 Ratio - When the Ca:SO_4 ratio is greater than one, the resulting pH tends to be higher than normally observed due to an excess amount of calcium (buffering capacity) in meltwater and vice versa. This can be seen in the 1984 data from the Middle Fraser and North Thompson (see Appendix 3).

ELEVATION EFFECT ON SNOWPACK CHEMISTRY

In designing the snowpack chemistry study, Porcupine Ridge, Tranquille Lake and Pass Lake snow course locations in the Middle Fraser were chosen to determine the effect, if any, of elevation in snowpack chemistry. The elevation of these snow course stations are 1830, 1420 and 870 meters, (MSL) respectively. The analysis of the samples taken in April, 1982 and 1984 had insufficient variation to indicate elevation significance. There is no correlation between pH and elevation data.

SUMMARY

For the four winters from 1981 to 1984, snowpack chemistry data were collected in the Middle Fraser, North and South Thompson basins. The data was analysed and following are the general conclusions:

1. The mean pH values of snowpack meltwater in the Middle Fraser ranged from 4.93 to 5.62, in the North Thompson from 5.22 to 5.37 and the South Thompson from 5.04 to 5.42. Values less than pH 5 were observed consistently during the study period at Lac Le Jeune and occasionally at Mission Ridge in the Middle Fraser and at Spahomin and Enderby in the South Thompson.

2. Sulphate concentrations in snow water samples determined by ion chromatographic method were lower than sulphate concentrations determined by the turbidimetric method. This is consistent with the findings of other investigators.

3. The ratio of $\sum$ cations/$\sum$ anions should theoretically be equal to one. However, in the 1983 and 1984 study samples where sulphate concentrations were determined by the ion chromatographic method, the cation and anion ratios ranged from 1.23 and 1.58. In contrast, in the 1981 and 1982 samples where sulphate concentrations were determined by the turbidimetric method, the cation and anion ratios ranged from 0.52 to 0.74.

4. The SO_4^{2-}/NO_3^- ratio in snow samples collected in 1983 and 1984 ranged from 0.7 to 1.3, with a mean ratio of 0.88. This ratio in the Middle Fraser is higher than that observed either in the North or in the South Thompson.

5. No clear effect of elevation on snowpack chemistry was noted in South Central B.C. during the study period.

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APPENDIX I

SUMMARY OF SNOW DEPTH AND WATER EQUIVALENT AT SNOW SAMPLING STATIONS FOR 1981, 1982, 1983 AND 1984 COMPARED TO PERIOD OF RECORD AVERAGE+ UP TO 1980

DRAINAGE BASIN AND SNOW COURSE STATION NO.	NAME OF SNOW COURSE	ELEVATION (meters)	LATITUDE DEG MIN	LONGITUDE DEG MIN	AVERAGE UP TO 1984 DEPTH (cm) / SWE (mm)	YEARS OF DATA	APRIL 1 SNOW DEPTHS (cm)/ SNOW WATER EQUIVALENT (mm) 1981	1982	1983	1984
MIDDLE FRASER										
1C02	Porcupine Ridge	1 830	50° 58'	120 33'	147	23	98	150	N/M	170
					445		243	462	N/M	511
1C03	Tranquille Lake	1 420	50° 56'	120° 33'	87	34	43	97	80	102
					246		116	274	220	274
1C04	Pass Lake	870	50° 51'	120° 30'	21	34	No Snow	42	No Snow	7
					69			115		17
1C13A	Horsefly Mountain	1 550	52° 20'	121° 02'	134	14	94	164	89	128
					426		306	612	324	420
1C18	Mission Ridge	1 850	50° 46'	122° 12'	166	17	116	158	114	94
					605		377	587	418	310
1C23	Penfold Creek	1 680	52° 45'	120° 34'	267	12	N/M	282	N/M	252
					987			959		913
1C24	Yanks Peak	1 710	52° 51'	121° 25'	208	12	186	222	165	206
					725		486A	800	561	707
1C25	Lac Le Jeune (Upper)	1 460	50° 27'	120° 30'	45	12	21	67	53	46
					127		63	184A	154	136
1C27	Cornwall Hills	2 000	50° 42'	121° 27'	87	7	85	102	N/M	N/M
					209		212A	260		
1C30	Spahomin	1 450	50° 68'	120° 22'	–	–	12	51	29	13
					–		32	130	78	34
NORTH THOMPSON										
1E03A	Trophy Mountain No. 2	1 860	51° 49'	119° 57'	162	11	120	177	135	161
					515		428	602	426	514
1E05	Knouff Lake	1 200	50° 59'	120° 08'	56	27	23	68	51	48
					163		80	199	164	141
1E06	Cooks Forks	1 390	52° 10'	119° 19'	250	22	194	250	244	218
					947		746	919	956	864
1E08	Azure River	1 620	52° 37'	119° 43'	283	14	254	315	258	285
					1 046		882	1 009	915	1 092
SOUTH THOMPSON										
1F02	Anglemont	1 190	51° 00'	119° 11'	106	27	67	122	97	82
					374		245	448	386	329
1F04	Enderby	1 900	50° 39'	118° 55'	281	21	225	337	286	272
					1 004		883	1 293	1 110	1 015

+ Annual Historical Summary 1935-1984, Internal Ministry of Environment document

A Estimated Water Equivalent

APPENDIX 2A
SNOWPACK CHEMISTRY DATA SUMMARY FOR THE WINTER OF 1980/81
(in mg/l)

STATION:

Sample Number	STATION	pH	Acidity Strong eq/l	Acidity Total eq/l	Phosphate (PO_4^{---}) mg/l	Fluoride (F^-) mg/l	Sulphate ($SO_4^=$) mg/l	Nitrate (NO_3^-) mg/l	Chloride (Cl^-) mg/l	Ammonium (NH_4^+) mg/l	Sodium (Na+) mg/l	Potasssium (K^+) mg/l	Magnesium (M_g^{++}) mg/l	Calcium (Ca^{++}) mg/l	Aluminum (Al^{+++}) mg/l
1	Middle Fraser Porcupine Ridge	5.03	<15	32	0.015		0.5	0.53	<0.5	0.105	0.1	<0.1	<0.02	0.06	0.07
2	Tranquille Lake	5.06	<15	39	0.034		2.5	0.27	<0.5	0.021	0.1	0.1	0.02	0.07	0.06
3	Pass Lake	-	-	-	-		-	-	-	-	-	-	-	-	-
4	Horsefly Mountain	5.20	<15	54	0.009		0.5	0.22	<0.5	0.039	0.1	0.1	<0.02	<0.02	<0.02
5	Mission Ridge	5.18	<15	40	0.034		1.7	0.4	<0.5	0.215	0.2	0.3	<0.02	<0.02	<0.02
6	Penfold Creek	5.99	<15	32	0.009		<0.5	0.35	<0.5	0.038	0.2	<0.1	<0.02	0.29	0.06
7	Yanks Peak	5.22	<15	30	0.009		0.6	0.27	<0.5	0.025	0.3	<0.1	<0.02	<0.02	0.03
8	Lac Le Jeune(Upper)	-	-	-	-		-	-	-	-	-	-	-	-	-
9	Cornwall Hills	5.13	<15	25	0.043		1.1	0.35	<0.5	0.092	0.1	0.2	<0.02	<0.02	<0.02
10	North Thompson Trophy Mountain No. 2	5.18	<15	32	0.015		1.3	0.31	<0.5	0.044	0.1	0.1	<0.02	0.02	0.02
11	Knouff Lake	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	Cooks Forks	5.02	<15	34	0.012		<0.5	0.40	<0.5	0.051	0.1	0.1	<0.02	<0.02	<0.02
13	Azure River	5.33	<15	22	<0.009		0.6	0.31	<0.5	0.034	0.2	<0.1	<0.02	0.02	0.02
14	South Thompson Anglemont	5.58	<15	29	<0.009		1.4	0.49	1.3	0.051	0.9	<0.1	<0.02	0.03	<0.02
15	Enderby	4.71	23	54	0.018		2.2	0.44	<0.5	0.23	0.1	<0.1	0.03	0.14	<0.02
15	Spahomin														

APPENDIX 2B
SNOWPACK CHEMISTRY DATA SUMMARY FOR THE WINTER OF 1981/82
(in mg/l)

STATION:

Sample Number	STATION	pH	Acidity Strong µeq/l	Acidity Total µeq/l	Phosphate (PO_4^{---}) mg/l	Fluoride (F^-) mg/l	Sulphate ($SO_4^=$) mg/l	Nitrate (NO_3^-) mg/l	Chloride (Cl^-) mg/l	Ammonium (NH_4^+) mg/l	Sodium (Na+) mg/l	Potasssium (K^+) mg/l	Magnesium (M_g^{++}) mg/l	Calcium (Ca^{++}) mg/l	Aluminum (Al^{+++}) mg/l
1	Middle Fraser Porcupine Ridge	5.3	<15	24	<0.009	-	0.5	0.49	<0.5	0.035	0.2	<0.1	<0.02	0.02	<0.02
2	Tranquille Lake	5.36	<15	<15	<0.009	-	0.5	0.62	<0.5	0.044	0.1	0.1	0.04	0.11	<0.02
3	Pass Lake	5.44	<15	<15	<0.009	<0.04	(1.5)	0.53	<0.05	0.047	0.1	<0.1	0.05	0.06	0.04
4	Horsefly Mountain	6.51	<15	23	0.015	<0.04	1.5	0.49	<0.5	0.049	0.3	<0.1	0.11	0.66	0.04
5	Mission Ridge	5.23	<15	23	<0.009	<0.04	(2.1)	0.35	<0.5	0.016	0.2	<0.1	<0.02	0.06	<0.02
6	Penfold Creek	5.33	<15	17	<0.009		0.8	0.49	<0.5	0.037	0.3	0.1	0.05	0.09	0.05
7	Yanks Peak	-	-	-	-		-	-	-	-	-	-	-	-	-
8	Lac Le Jeune(Upper)	4.97	<15	47	0.013	<0.04	(1.5)	0.67	<0.5	0.075	0.2	<0.1	<0.02	0.06	<0.02
9	Cornwall Hills	5.23	<15	28	0.012	-	0.7	0.35	<0.5	0.049	0.2	<0.1	<0.02	0.03	<0.02
10	North Thompson Trophy Mountain No. 2	5.08	<15	67	0.037	<0.04	(1.5)	0.58	<0.5	0.059	0.3	0.1	0.02	0.13	<0.02
11	Knouff Lake	5.26	<15	26	<0.009	-	0.6	0.75	<0.5	0.062	0.2	<0.1	0.08	0.03	0.02
12	Cooks Forks	5.54	<15	28	0.012	<0.04	(1.7)	0.75	<0.5	0.072	0.1	0.1	0.05	0.11	0.03
13	Azure River	5.36	<15	28	<0.009	-	<0.5	0.40	<0.5	0.031	0.3	0.1	<0.02	0.06	0.02
14	South Thompson Anglemont	5.31	<15	<15	<0.009	-	<0.5	0.49	<0.5	0.052	0.2	<0.1	0.04	0.16	<0.02
15	Enderby	5.12	<15	39	0.009	-	0.9	0.53	<0.5	0.13	0.2	<0.1	0.03	0.06	<0.02
16	Spahomin	4.94	<15	42	0.015	-	0.9	0.22	<0.5	0.083	0.2	0.1	<0.02	0.04	<0.02

NOTE: Sulphate values presented within ( ) are of suspect value.

APPENDIX 2C
SNOWPACK CHEMISTRY DATA SUMMARY FOR THE WINTER OF 1982/83
(In mg/l)

STATION:

Sample Number	STATION	pH	Acidity Strong (μeq/l)	Acidity Total (μeq/l)	Phosphate (PO_4^{---}) mg/l	Fluoride (F^-) mg/l	Sulphate ($SO_4^{=}$) mg/l	Nitrate (NO_3^-) mg/l	Chloride (Cl^-) mg/l	Ammonium (NH_4^+) mg/l	Sodium (Na+) mg/l	Potassium (K^+) mg/l	Magnesium (M_g^{++}) mg/l	Calcium (Ca^{++}) mg/l	Aluminum (Al^{+++}) mg/l
1	Middle Fraser Porcupine Ridge	→ NO DATA ←													
2	Tranquille Lake	6.25		69	0.018	<0.04	1.7	0.49	0.43	0.081	1.23	0.2	0.02	0.19	<0.02
3	Pass Lake	5.45		50	0.018	<0.04	0.2	0.53	0.29	0.082	0.28	0.06	0.03	0.07	<0.02
4	Horsefly Mountain	5.3		59	<0.009	<0.04	0.23	0.31	0.28	0.029	0.42	<0.02	0.02	0.03	<0.02
5	Mission Ridge	4.96		51	0.012	<0.04	0.21	1.37	<0.1	0.046	0.10	<0.02	<0.02	0.02	<0.02
6	Penfold Creek	5.25		39	<0.009	<0.04	0.19	0.58	0.06	0.04	0.01	<0.02	0.02	0.02	<0.02
7	Yanks Peak	5.2		76	0.015	<0.04	0.62	0.89	0.15	0.046	0.42	0.04	0.04	0.06	0.09
8	Lac Le Jeune(Upper)	4.95		56	0.009	<0.02	0.15	0.44	0.21	0.075	0.07	<0.02	<0.02	<0.02	<0.02
9	Cornwall Hills	5.41		39	0.046	<0.04	0.38	0.40	0.14	0.05	0.10	0.0	0.04	0.33	0.12
10	North Thompson Trophy Mountain No. 2	5.33		65	0.025	<0.04	0.30	0.49	0.19	0.07	0.16	0.0	0.0	0.04	<0.02
11	Knouff Lake	5.1		78	<0.009	<0.04	0.09	0.35	0.1	0.12	0.04	<0.02	<0.02	<0.02	<0.02
12	Cooks Forks	5.43		54	<0.009	<0.04	0.13	0.40	0.1	0.033	0.11	<0.02	0.02	0.02	<0.02
13	Azure River	5.0		91	0.009		0.34	0.58	0.12	0.034	0.12	<0.02	0.03	0.05	0.07
14	South Thompson Anglemont	5.29		66	<0.009	<0.04	0.24	0.44	0.12	0.06	0.17	<0.02	<0.02	0.07	<0.02
15	Enderby	→ NO DATA ←													
16	Spahomin	5.21		55	0.018	<0.04	0.3	0.53	0.15	0.053	0.13	<0.02	0.05	0.14	<0.02

APPENDIX 2D
SNOWPACK CHEMISTRY DATA SUMMARY FOR THE WINTER OF 1983/84
(mg/l)

STATION:

Sample Number	STATION	pH	Acidity Strong (μeq/l)	Acidity Total (μeq/l)	Phosphate (PO_4^{---}) mg/l	Fluoride (F^-) mg/l	Sulphate ($SO_4^{=}$) mg/l	Nitrate (NO_3^-) mg/l	Chloride (Cl^-) mg/l	Ammonium (NH_4^+) mg/l	Sodium (Na+) mg/l	Potassium (K^+) mg/l	Magnesium (M_g^{++}) mg/l	Calcium (Ca^{++}) mg/l	Aluminum (Al^{+++}) mg/l
1	Middle Fraser Porcupine Ridge	5.61	2.5	41	.012		.29	.35	.18	.06	.16	.15	.09	.15	.05
2	Tranquille Lake	5.45	3.6	25	.012		.21	.31	.09	.05	.08	.07	.06	.12	.05
3	Pass Lake	5.65	2.2	24	.009		.06	.22	.06	.04	.03	.03	.05	.08	<.02
4	Horsefly Mountain	5.57	2.7	38	.04		0.25	0.31	0.07	0.04	0.06	0.04	0.02	0.18	0.02
5	Mission Ridge	5.51	3.1	49	.022		.28	.18	.09	0	.10	.15	.07	.19	<.02
6	Penfold Creek	5.32	4.8	39	.012		.39	.31	.32	.05	.24	.18	.04	.22	.11
7	Yanks Peak	5.63	2.4	45	.022		.14	.22	.46	.04	.45	.41	0	.12	<0.02
8	Lac Le Jeune(Upper)	4.87	13.6	45	.009		.18	.58	.07	.04	.08	.02	.05	.23	.05
9	Cornwall Hills	5.14	7.3	29.7	.009		.27	.49	.08	.06	.07	.02	.04	.09	.05
10	North Thompson Trophy Mountain No. 2	5.32	4.8	45	<.009		.29	.40	.21	.05	.16	.06	.03	.08	.02
11	Knouff Lake	5.62	2.4	40	.009		.10	.22	.07	.10	.06	.03	.05	.02	.04
12	Cooks Forks														
13	Azure River	5.83	1.5	66	.052		.16	.22	.22	.03	.17	.28	.07	.19	.11
14	South Thompson Anglemont	5.52	3.0	62	.022		.19	.31	.14	.11	.07	.05	.03	.08	.06
15	Enderby	5.32	4.8	26	<.009		.20	.31	.06	.04	.04	.02	0	.05	.03
16	Spahomin	5.22	6.1	65	.043		.22	.27	.10	0	.06	.16	.03	.09	<.02

APPENDIX 3
SUMMARY OF AVERAGE SNOWPACK CHEMISTRY DATA
(In µ equivalents per litre - except pH)

Location	MIDDLE FRASER				NORTH THOMPSON				SOUTH THOMPSON				Cascade Mts[8] Washington	Greenland[7]	Antarctic[7]	Vancouver[9] Island McBride	Snow Pack Moore Cree Skeena Reg
Period	1981	1982	1983	1984	1981	1982	1983	1984	1981	1982	1983	1984	81			1981/82	82/83
pH Range	5.06/5.99	4.97/6.51	4.95/6.25	4.87/5.65	5.02/5.33	5.08/5.54	5.00/5.43	5.3 to 5.8	4.71/5.88	4.94/5.31	5.21/5.29	5.22/5.52	4.71 - 4.84				
Median pH	5.25	5.41	5.33	5.4	5.18	5.31	5.21	5.58	5.13	5.12	5.25	5.35	4.77			5.48	6.11
Cations H^+	5.62	3.89	4.68	4.69	6.61	4.9	6.17	2.9	7.41	7.59	5.62	4.6	16.98			3.31	0.8
NH_4	4.23	2.44	3.10	2.21	2.38	3.10	3.55	3.3	7.76	4.88	3.16	2.8	4.36			0.61	2.9
Na^+	6.83	8.7	14.27	6.14	5.78	9.79	4.70	5.7	21.75	8.7	6.53	2.4	8.86			8.7	11.7
Ca^{2+}	3.54	2.0	4.49	7.67	1.0	2.15	1.65	4.8	4.24	1.50	5.24	3.7	5.62			1.5	13.5
Mg^{2+}	1.65	3.29	2.14	4.31	1.65	3.54	1.65	4.1	2.06	2.47	2.88	1.7	1.39			0.49	0.0
K^+	3.66	2.56	1.28	3.09	2.56	2.56	0.384	3.2	2.56	2.56	0.512	2.0	2.07			5.12	0.0
SUM	25.53	22.88	29.96	33.51	19.98	26.04	18.10	24	45.78	27.7	23.94	17.2	39.28			19.73	28.9
Anions	T	T	I.C.	I.C.	T	T	I.C.	I.C.	T	T	I.C.	I.C.					
SO_4^{2-}	21.98	23.67	9.57	4.77	16.64	22.36	4.47	3.8	37.44	15.89	5.62	4.3	17.61	1.66	1.48	4.16	5.4
NO_3^-	5.49	5.47	7.49	5.32	8.03	9.98	6.60	4.5	8.92	7.33	7.81	4.8	10.62			0.64	4.3
SO_4/NO_3	-	-	1.3	0.9	-	-	0.7	0.8	-	-	.7	.9	1.7			6.5	1.3
Alkalinity	-	-	-	6.63	-	-	-	6.3	-	-	-	1.3					
Cl^-	14.1	14.1	5.87	4.46	14.1	14.1	3.61	4.7	25.38	14.1	3.81	2.8	10.10			5.64	3.4
SUM	41.59	43.24	22.93	21.18	38.77	46.44	14.68	19.3	71.74	37.32	17.24	13.2	38.33			10.44	13.1
Cation / Anion	0.61	0.53	1.31	1.58	0.52	0.56	1.23	1.26	0.64	0.74	1.39	1.3	1.02			1.89	2.21
Ca/SO_4	-	-	0.47	1.61	-	-	0.37	1.26	-	-	0.9	0.86	0.32				2.5

NOTE: I.C. = Ion Chromatograph T = Turbidimetric