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Saskatoon, Saskatchewan, Canada

Canada

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Y. T. John Kwong
Environmental Sciences Division
National Hydrology Research Institute
Saskatoon, Saskatchewan

and

W. G. Whitley
Water Resources Division
Northern Affairs Program
Indian and Northern Affairs Canada
Whitehorse, Yukon
Y1A 3V1

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ASSESSMENT OF THE IMPACT OF ACID ROCK DRAINAGE ON THE WATER QUALITY OF THE SOUTH MACMILLAN RIVER, YUKON TERRITORY

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ABSTRACT

Carbonaceous and siliceous marine strata of the Devono-Mississippian Earn Group host several important lead zinc prospects in the Macmillan Pass area of east-central Yukon Territory. The abundance of pyrite-rich shale units occurring in the rock assemblages, however, renders acid rock drainage a major environmental concern for future mining development in the area. A detailed field investigation and sampling program conducted in August of 1990 has shown that natural weathering of sulphide-rich rocks is a major contributor of acidity and zinc to the South Macmillan River. There is a general relationship between geology and water chemistry along the course of the river. In fact, for tributaries with flows generally less than 0.5 m^3/sec, the water chemistry is predominately controlled by the local lithology. As yet, the South Macmillan River appears to be able to absorb the loadings of acid rock drainage products from its tributaries such that the water quality in the main body shows only minor changes in the last decade. Data presented and reviewed in this report could serve as a reference set for identifying any future contaminant input to the river.

INTRODUCTION

In the vicinity of Macmillan Pass in east-central Yukon (Figure 1), several lead zinc prospects occur in carbonaceous and silica-rich marine strata of the Devono-Mississippian Earn Group (Abbot and Turner, 1990). The more important ones include the Tom property (Goodfellow and Rhodes, 1990) and the Jason deposit (Turner, 1990). Because of the abundance of pyrite-bearing shale units occurring in the rock assemblages, acid rock drainage is a major environmental concern in the Macmillan Pass District. The major water body that would be affected by development of prominent prospects in the area is the South Macmillan River. The South Macmillan River is tributary to the Pelly and Yukon Rivers and, downstream of the study area, contains arctic grayling, chinook salmon, whitefish and slimy sculpin. The Canol Road connects Macmillan Pass to Ross River and Whitehorse providing summer access to prospectors, tourists and hunters.

Since the mid-1970's, several water quality studies have been conducted by various groups (Brown, 1982; Monenco Consultants Ltd., 1982; Pearson and Associates, 1981; Soroka and Jack, 1983; Jack and Osler, 1983; and various internal reports, Department of Indian and Northern Affairs). In August, 1990, personnel from the Water Resources Branch, Department of Indian and Northern Affairs, Whitehorse and National Hydrology Research Institute, Saskatoon, revisited the area and conducted an investigation on the extent and impact of acidic drainage occurrences. This report documents some of the data collected in these investigations, compares water quality data with previous data sets and presents a brief assessment of the impact of acidic drainage (both naturally occurring and induced by human activity) on the water chemistry of the upper reaches of the South Macmillan River.

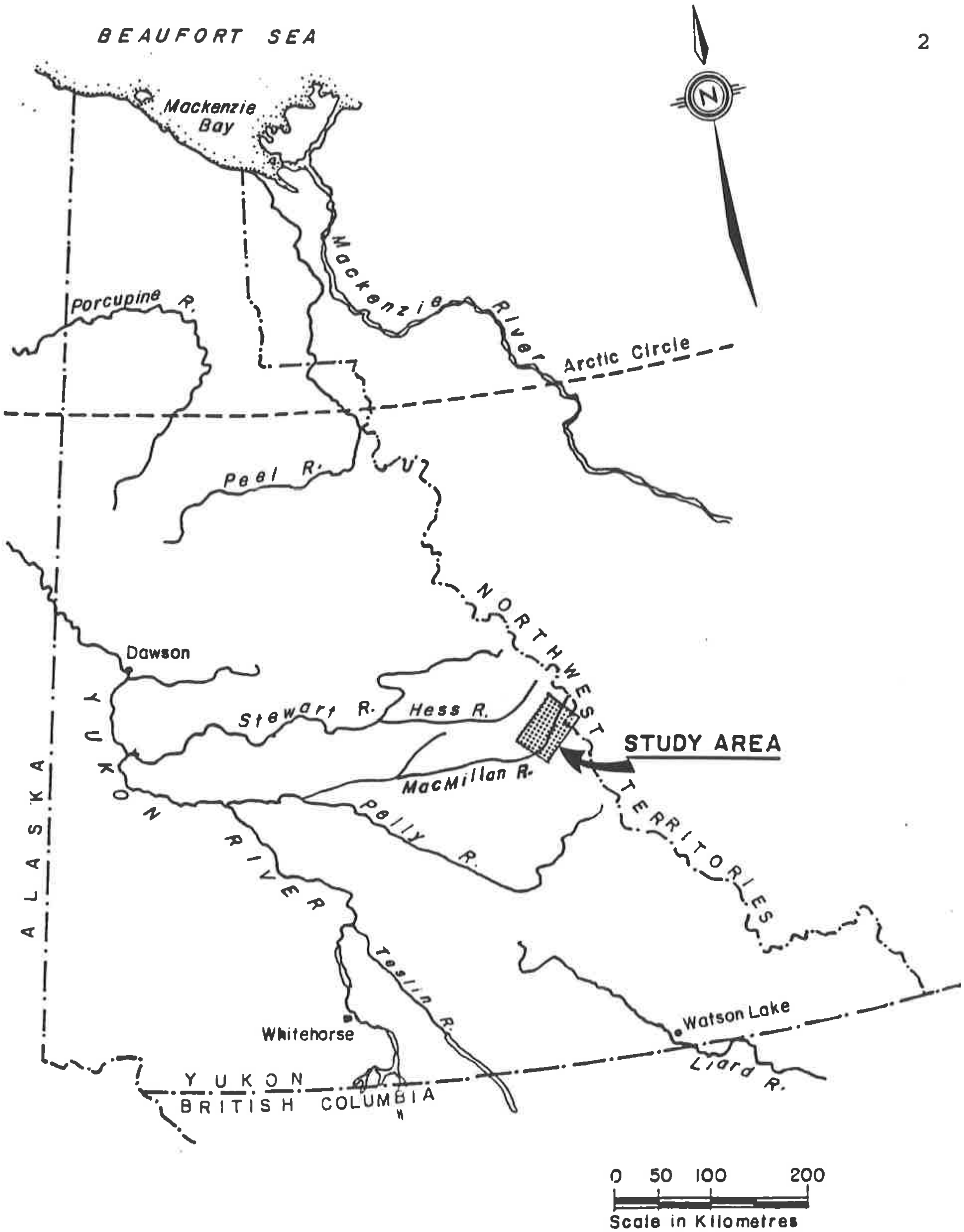

Figure 1. Location of the Macmillan Pass study area.

GENERAL SETTING

As recorded in the weather station of Environment Canada at Tsichu River in the Northwest Territories, Macmillan Pass has a mean annual temperature of about -8°C and an annual precipitation of approximately 50 cm. The extreme temperatures recorded in the 1975-1981 period are -51.1°C and 27.2°C, respectively. The study area lies in the Itsi Range ecoregion of Oswald and Senyk (1977). The terrain is dominantly mountainous and lies above 1000 m a.s.l. With widespread occurrences of discontinuous permafrost, most valley bottoms contain peat plateau, palsas, collapse scars and peat hummocks. Lower slopes usually have hummocky surfaces while the upper slopes are often covered with talus or scree material. The corresponding vegetation types are patterned fen and bog communities in the valleys; sedge tussocks with willows and ericaceous shrubs on the mid to lower slopes; lichens, moss, sphagnum, willows, ericaceous shrubs and some forbs on subdued alpine areas; and, little or no vegetation on the talus or scree slopes.

SAMPLING AND ANALYTICAL METHODS

Water samples were collected from fast flowing water near the centre of most sampled streams except the South Macmillan River which was sampled near the bank. Samples for routine water quality parameters, metals and sediments were collected and analyzed following the methods of Laboratory Services, Pacific and Yukon Region, Environment Canada. Samples for dissolved metals were passed through a 0.45 µm filter prior to preservation with nitric acid. Acidity and alkalinity were determined in the field by titration to the phenolpthalien or bromcresol green endpoints and the results expressed in mg/L as calcium carbonate.

Stream flow was measured by wading with a current meter. These flow measurements were used to calculate the loadings of selected parameters tabulated in Appendix I. In addition, miscellaneous streamflow measurements for Macintosh Creek, Sekie Creek #1, Sekie Creek #2 and various locations on the upper South Macmillan River are available in the Yukon Water Resources Hydrometric Program Historical Summary 1975-1986 (Indian and Northern Affairs Canada, 1988). A Water Survey of Canada flow monitoring station is located on the South Macmillan River at Kilometre 407 of Canol Road (Station 12 of this study) and has provided flow records since 1974. These additional sources of flow information allow a comparison of seasonal flow regimes when required.

RESULTS AND INTERPRETATION

I. South Macmillan River

Twelve water quality stations were established on the South Macmillan River (Figure 2). Table 1 shows the selected water chemistry at these stations. Compared with previous measurements, filterable residues, sulphate, calcium, and magnesium have increased while alkalinity has decreased at all the stations.

Station 1 has the highest acidity of the river stations and similar chemistry to Station 2. The river apparently drains a large area of sulphide-rich shales along the Yukon - Northwest Territories border which provide for the acid drainage. However, there is a significant change in chemistry at Station 3 where pH increases to 7.1 coincident with higher calcium and magnesium concentrations and lower iron and manganese concentrations. This indicates a source of alkalinity between Stations 2 and 3.

Between Stations 3 and 4, sulphate increases from 70 to 75 mg/L (corresponding to a loading of 107 and 379 g/sec, respectively, Appendix I) and extractable zinc from 0.22 to 0.34 mg/L (or 0.33 to

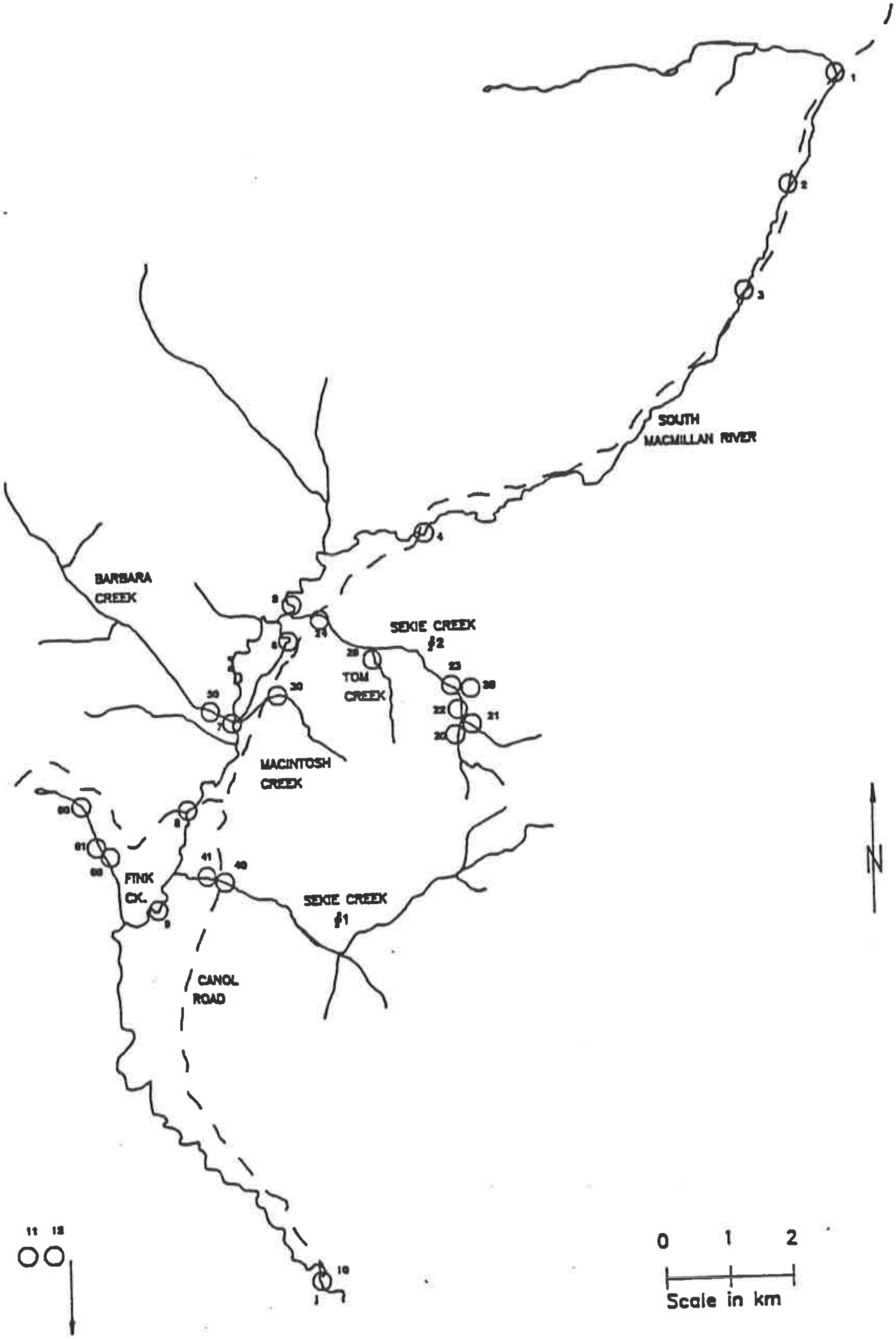

Figure 2. Location of sampling stations along the South Macmillan River.

Table 1. Water quality of the Macmillan river near Macmillan Pass, Yukon

Station		pH units	SO4 mg/l	ext. Zn mg/l	filterable Residues mg/l	Acidity mg/l	Alkalinity mg/l	Na mg/l	Ca mg/l	Mg mg/l	Fe mg/l	Mn mg/l
1	this study	3.8	74.7	0.438	130	45	<1	0.2	10.1	2.5	0.619	0.256
	prev. mean	3.9(1)	73(1)	0.4(1)	103(1)	ND	ND	0.5	7.1	1.4	ND	ND
2	this study	4.2	63.7	0.392	120	33	<1	0.2	12.4	2.8	0.417	0.33
	prev. mean	6.4(4)	62(1)	0.4(1)	88(1)	6(3)	30(3)	0.3(4)	9.8(1)	9.8(1)	0.2(3)	ND
	prev. range	4.6–8.1				4–8	26–32	.2–.5			0–.2	
3	this study	7.1	69.6	0.217	130	3	12	0.2	19.2	6.8	0.074	0.119
4	this study	5.0(3)	75.4(3)	0.342(3)	116(3)	6.3(4)	<1(3)	0.3(3)	19.8(3)	7.1(3)	0.36(3)	0.199(3)
	prev. mean	6.3(3)	51(3)	0.3(1)	89(3)	ND	5(3)	0.4(3)	13.4(3)	4.1(3)	0.6(1)	ND
	prev. range	5.8–7.3	38–70		71–102		3–6	.2–.5	2.3–15.2	3.7–4.7		
5	this study	7.2	77.1	0.283	150	2	17	0.2	26.4	8.9	0.175	0.172
	prev. mean	7.1(4)	54(3)	0.267(3)	116(4)	ND	28(2)	0.4(4)	14.8(2)	4.6(2)	0.7(1)	ND
	prev. range	6.1–7.5	44–62	.1–.5	101–143		23–32	.2–.7	2.3–17.3	3.7–5.4		
6	this study	6.9	80.7	0.419	150	3	8	0.2	23.6	8.1	0.703	0.173
	prev. mean	6.1(6)	52(3)	0.25(2)	121(3)	5(3)	19(6)	0.28(6)	14.1(2)	4.3(2)	1.1(1)	ND
	prev. range	5.4–6.8	36–73	.2–.3	99–149	2–6	12–28	.2–.5	1.4–16.7	3.3–5.3		
7	this study	6.8	82.5	0.448	140	3	7	0.3	24.3	8.4	0.726	0.183
	prev. mean	7.0(2)	58(2)	0.3(2)	119(2)	ND	19(2)	0.5(2)	18.8(2)	5.8(2)	ND	ND
	prev. range	7.0–7.0	58–58	.3–.3	119–119		19–19	0.5	8.8–18.8	5.8–5.8		
8	this study	6.7	80.8	0.43	150	3	8	0.3	25	8.4	0.753	0.18
	prev. mean	6.6(1)	24(1)	0.4(1)	136(1)	ND	19(1)	0.5(1)	22.6(1)	7.2(1)	ND	ND
	prev. range											
9	prev. mean	6.2(3)	ND	ND	ND	6(3)	24(3)	ND	ND	5.9(1)	1.3(1)	ND
	prev. range	5.9–6.4				4–6	22–26					
10	this study	7	61.7	0.356	110	3	10	0.4	21.2	6.4	0.255	0.121
	prev. mean	6.8(5)	53(2)	0.3(2)	108(2)	5(3)	25(5)	0.48(5)	16.4(1)	5.3(2)	0.9(3)	ND
	prev. range	6.2–7.4	44–61	.2–.4	95–121	4–6	14–36	.2–.5		4.7–5.9	0.9–0.9	
11	this study	6.9	46	0.209	90	3	8	0.6	16	4.4	0.06	0.081
	prev. mean	6.4(3)	ND	ND	21(3)	5(3)	ND	0.6(3)	ND	ND	0.4(3)	ND
	prev. range	6.0–6.6			18–24	4–6		.5–.7			0.4–0.4	
12	this study	6.9	38	0.157	80	3	8	0.7	14.8	3.8	0.053	0.057

Note: Sample size for the mean calculation is in bracket;
ND = not determined.

1.72 g/sec in terms of loading). The pH decreases to 5.0 at station 4 with lower alkalinity. There is less variation observed in Stations 5 to 8. The pH remains near 7. Small increases in sulphate and dissolved iron are apparent in the downstream direction while the other variables show little variation in concentration. The river in this reach receives the flows of Sekie Creek #2 (Station 24) and Macintosh Creek (Station 30).

Further downstream at Station 10 the measured sulphate concentration of 61.7 mg/L translates into a loading of 745 g/sec and the extractable zinc of 0.36 mg/L corresponds to a loading of 4.30 g/sec (Appendix I). These loadings represent the cumulative input of acid rock drainage products from the sampled area. However, from Stations 10 to 12 the decreasing concentrations of sulphate, extractable zinc, filterable residues, calcium, magnesium, dissolved iron and manganese indicate increased dilution with negligible new input from the tributary streams.

Two patterns emerge from the data presented in Table 1. First, the drainage shows an overall increase in sulphate, filterable residues, calcium and magnesium concentrations and a decrease in alkalinity compared with previous studies at all stations. This suggests that the natural and man-induced acid mine drainage have increased. Second, the changes at Stations 10, 11, and 12 are small. This suggests that the South Macmillan River below the Macmillan Pass area is presently able to absorb the changes.

II. Sekie Creek #2 and the Tom Property

Table 2 shows the selected water chemistry of streams around the Tom Property. Compared with previous measurements, all sampling locations close to the mine workings (Stations 20 through 23) show a slight decrease in pH and prominent increase in sulphate, filterable residue, total iron and dissolved calcium. Extractable zinc and dissolved magnesium also increase in most of the sampling

TABLE 2. Aqueous Geochemistry of Streams around the Tom Property

Station	Data	pH	SO4	ext. Zn	f.Res	Acidity	Alkal.	dis. Na	dis. Ca	dis. Mg	tot. Fe	dis. Fe	dis. Mn	tot. Mn
20	this study	3.4	99.2	0.754	200	84	<1	0.6	7.1	1.5	9.86	8.11	0.169	0.188
	prev. mean	3.6(3)	33(2)	0.2(3)	67(3)	-	1(1)	0.3(3)	2.6(3)	0.7(3)	3.3(1)			
	prev. range	3.6-3.6	27-41	0.1-0.3	36-90	-	1	0.2-0.5	2.1-3.3	0.4-1.2	3.3			
21	this study	3.5	70.6	0.366	130	56	<1	0.9	4.2	1.4	3.38	2.96	0.169	0.164
	prev. mean	3.8(3)	33(2)	0.2(3)	71(3)	-	1(1)	0.3(3)	1.9(3)	1(3)	1.2(1)			
	prev. range	3.4-4.0	27-42	0.1-0.2	60-83	-	<1-1	0.2-0.5	1.5-2.3	0.5-2.0	1.2			
22	this study	3.3	102	1.45	190	84	<1	0.7	6.5	1.8	8.71	7.53	0.205	0.213
	prev. mean	3.5(1)	53(1)	1.6(1)	94(1)	-	-	0.5(1)	3.2(1)	0.7(1)	-			
	prev. range	3.5	53	1.6	94	-	-	0.5	3.2	0.7	-			
23	this study	3.3	107	2.18	220	84	<1	0.5	9.7	3.2	10.1	8.86	0.373	0.363
	prev. mean	3.5(2)	52(2)	1.6(2)	113(2)	-	1(1)	0.3(2)	5.0(2)	1.3(2)	5.1(1)			
	prev. range	3.4-3.5	43-60	1.2-2	103-122	-	1	0.1-0.5	4.5-5.3	1.1-1.4	5.1			
24	this study	3.2	156	2.29	280	116	<1	0.4	8.6	3.1	20.3	16.6	0.331	0.322
	prev. mean	3.3(7)	153(4)	2.2(4)	248(4)	145(3)	-	0.4(7)	10.1(4)	3.6(4)	22.8(3)			
	prev. range	3.1-3.4	78-251	1.1-3.3	152-358	108-214	-	0.2-0.8	4.6-15.4	1.9-6.1	3.5-48.8			
28	this study	4	248	6.05	430	27	<1	0.3	54.4	16.2	27.4	22	2.27	2.33
	prev. mean	6.0(3)	168(3)	3.0(3)	336(3)	-	18(3)	0.9(3)	52.8(3)	12.3(3)	25.1(1)			
	prev. range	4.3-7.5	155-179	1.1-5.2	324-349	-	1-37	0.3-1.9	47.3-63.5	10-13.8	25.1			
29	this study	3.8	28.4	0.327	60	79	<1	0.3	0.8	0.3	1.55	1.34	0.029	0.032
	prev. mean	4.2(1)	9(1)	<.05(1)	54(1)	-	-	0.5(1)	0.2(1)	0.1(1)	-			
	prev. range	4.2	9	<.05	54	-	-	0.5	0.2	0.1	-			

Note: Sample size is in bracket.

stations. Water flowing from the adit (Station 28) similarly shows a decrease in pH, increase in sulphate, filterable residue, extractable zinc, dissolved magnesium and, less prominently, dissolved calcium and total iron concentrations. Furthermore, measurable alkalinity previously reported appears to have been depleted. Water from a tributary stream of Sekie Creek #2 (Station 29), which runs through a less disturbed valley, also shows a decreased pH and increased sulphate and extractable zinc. However, the concentrations of sulphate and zinc are significantly less than those associated with the mine workings.

Data from Station 24 near the confluence of Sekie Creek #2 with the South Macmillan River is not significantly different from previous values. The relatively high acidity measured in all stations except that of the adit is also a noteworthy observation.

From the data presented in Table 2, it is apparent that recent weathering of sulphides in rocks around Sekie Creek #2 has contributed to the observed decrease in pH and increase in other parameters noted above. Exploration activities might have enhanced the weathering process by exposing more sulphide-containing material to oxidation. However, probably due to dilution, the net effect on water chemistry farther downstream than Station 24 appears to be minimal. The relative high acidity measured in the stations, except the adit, reflects the paucity in buffering capacity of the rocks in the vicinity. Thus, the potential for acid mine drainage is high in the area.

III. Macintosh Creek

Table 3 shows the water chemistry of a naturally occurring acidic stream south of Sekie Creek #2 (Figure 3), the stream is referred to as Macintosh Creek here. The only evidence of human disturbance is small-scale soil sampling. The correspondence of measured acidity with sulphate content at all stations strongly suggests that acid is derived from weathering of sulphides in rocks with negligible neutralization potential. The extent of contamination along the stream is comparable to or even exceeds that of Sekie Creek #2, especially at a couple of ground water discharge points (Stations B and G). Sulphide oxidation in rocks in the vicinity of the stream is enhanced by the creation of permeable zones resulting from acid leaching of minerals and dissolution of oxidation products. However, because of the small volume of water flow and possibly other attenuation effects in the delta area prior to entering South Macmillan River, loadings from Macintosh Creek appear to have little effect on the water quality of the River. A detailed discussion of the data shown in Table 4 is presented elsewhere (Kwong and Whitley, in preparation).

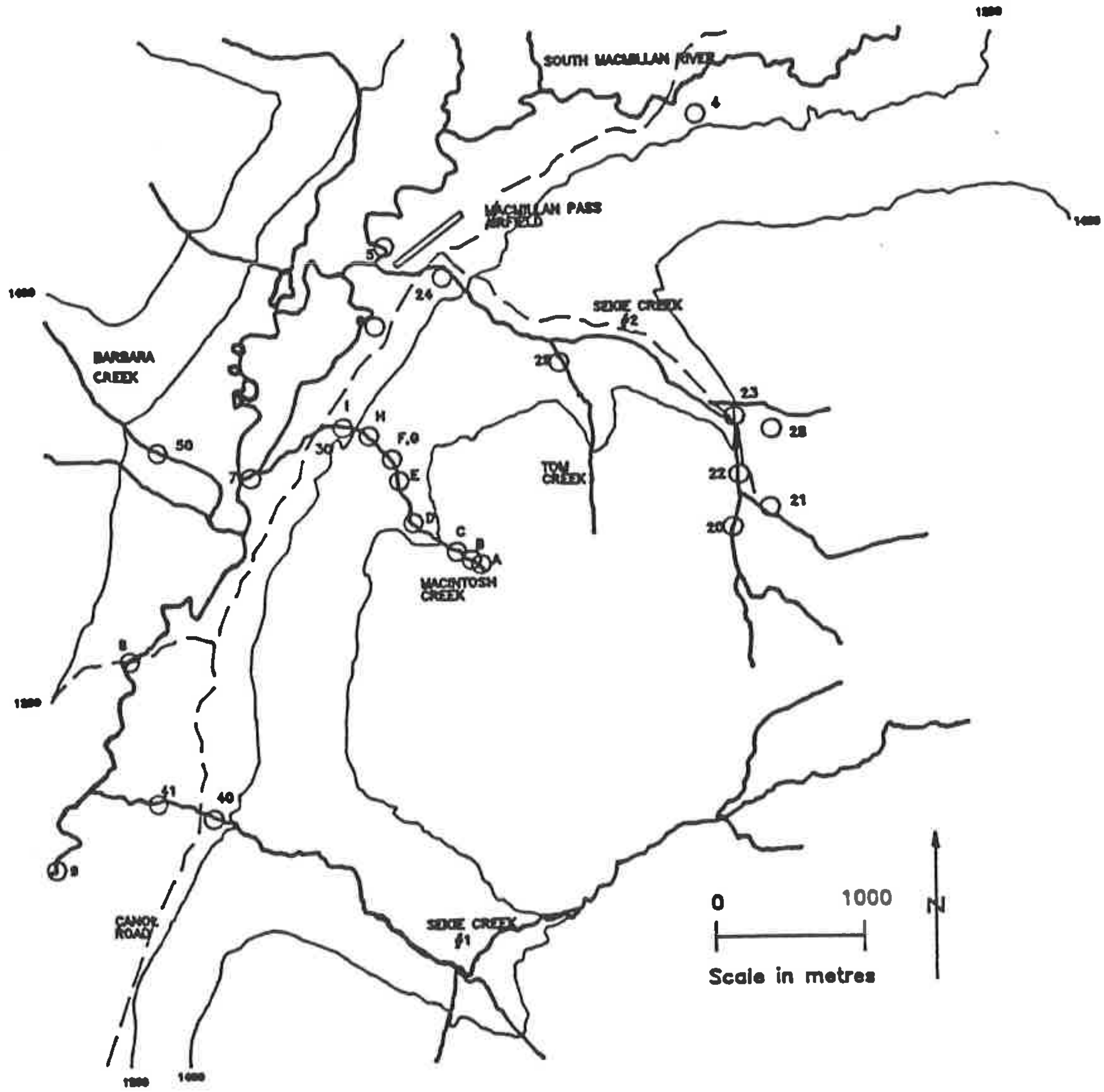

Figure 3. Sampling stations along Sekie Creek #2 and Macintosh Creek.

TABLE 3. Aqueous Geochemistry of MacIntosh Creek, MacMillan Pass Area, Yukon Territory.

Sample #	A	B	C	D	E	F	G	H	I	J(blank)
Ca(mg/L)	1.40	18.6	2.66	4.38	4.33	4.66	13.7	6.87	6.80	0.06
Mg	0.97	30.0	4.78	7.11	6.66	7.24	21.6	10.6	10.6	0.02
Na	0.25	0.62	0.33	0.45	0.40	0.42	0.63	0.45	0.45	<.01
K	0.40	12.4	1.27	0.59	0.53	0.75	8.51	2.57	2.63	<.01
Al	5.4	156	26.4	38.5	35.8	37.8	95.3	54.9	58.2	<.3
Si	6.0	18.1	7.2	9.8	9.4	9.8	18.1	11.7	11.3	<.4
Fe	0.11	298	29.3	15.3	11.7	16.7	206	64.3	63.5	<.03
Mn	0.04	1.12	0.18	0.27	0.24	0.27	0.71	0.39	0.40	<.01
Zn	0.12	5.00	0.88	1.46	1.35	1.45	4.80	2.30	2.35	0.015
Cd	0.009	0.132	0.027	0.036	0.032	0.036	0.096	0.046	0.05	<.005
Co	0.03	0.25	0.04	0.07	0.07	0.07	0.16	0.07	0.07	<.015
Ni	0.08	2.52	0.41	0.61	0.59	0.61	1.62	0.88	0.88	<.02
Cu	0.02	0.69	0.19	0.36	0.32	0.32	0.03	0.23	0.23	0.03
Pb	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02
As(µg/L)	<0.4	32.9	9.3	1.3	<0.4	1.3	8.65	1.82	1.87	<0.4
SO_4(mg/L)	12.6	1610	221	316	284	310	983	505	540	<3
Acidity (mg/L as Cc)	40	1609	220	324	302	329	1124	502	515	-
pH(rel.U)	3.80	3.30	3.30	2.98	2.98	3.03	3.36	3.10	3.16	-
Eh (mV)	330	336	461	515	549	493	293	454	454	-
T (deg.C)	4.8	5.9	7.3	5.0	6.9	7.8	6.8	8.0	10.1	-
Conduct. (µS/cm)	91	765	411	546	530	580	576	728	725	-

IV. Other Stations

Station 30, (same as Station I above) where Macintosh Creek crosses the Canol road, has been previously sampled (Jack and Osler, 1983; Soroka and Jack, 1983) and shows some changes. Sulphate, extractable zinc, filterable residues, calcium and magnesium concentrations are all higher compared with the previous data while pH and sodium remain similar. Although this stream has the lowest pH of all the sampling stations and an acidity comparable to Station 1 on the South Macmillan River, the acid loading is significantly less than that of Station 1 because of the small flow volume.

Sekie Creek #1 (Stations 40 and 41) shows some differences between the previous data and those of this study. These include a slight

Table 4. Water quality of other streams in the Macmillan Pass area.

Station		pH units	SO4 mg/l	ext. Zn mg/l	filterable Residue mg/l	Acidity mg/l	Alkal. mg/l	Na mg/l	Ca mg/l	Mg mg/l	Fe mg/l	Mn mg/l
30	this study	2.9	417	2.2	830	42.4	<1	0.4	8.6	9.1	52.3	0.354
	prev. mean	2.9(1)	162(1)	1.8(1)	607(1)	ND	ND	0.5(1)	6.9(1)	5.8(1)	ND	ND
40	this study	6.5	15.1	0.041	10	3	3	0.5	5.2	0.8	0.026	0.019
	prev. mean	5.5(2)	15(2)	0.05(2)	33(2)	5(2)	7.2(2)	0.4(2)	4.2(2)	0.7(2)	ND	ND
	prev. range	4.2–6.7	14–16	0–.1	30–35	2–10	2–14	.3–.5	3.7–4.7	.6–.8		
41	this study	6.5	15.2	0.039	<10	3	2	0.5	5	0.8	0.016	0.019
	prev. mean	5.9(1)	13(1)	(0)	29(1)	ND	2(1)	0.5(1)	3.83(1)	0.7(1)	ND	ND
50	prev. mean	7.9(1)	19(1)	0(1)	86(1)	ND	46(1)	0.5(1)	17.6(1)	4.6(1)	ND	ND
60	this study	7.8	14.4	0.016	<10	2	66	0.3	26	4.6	0.42	0.049
	prev. mean	7.7(1)	14(1)	0(1)	93(1)	ND	52(1)	0.5(1)	22.1(1)	3.9(1)	ND	ND
61	prev. mean	8.1(1)	16(1)	0.1(1)	112(1)	ND	71(1)	0.5(1)	22.5(1)	5.5(1)	ND	ND
76	this study	6.7	20.9	1.49	100	40	24	0.4	10.8	3.7	7.84	0.345

Note: Sample size is in bracket; ND = not determined increase in pH and a moderate decrease in filterable residues. The other variables has however remained very similar.

The chemistry of Fink Creek (Stations 60) on the west side of the valley shows little change compared with previous data. The high pH and alkalinity at Station 60 are similar to many streams in the southern Yukon (Jack et al., 1983) and very different from the other streams discussed above. Stations 50 and 61, also located on the west side of the valley and sampled previously (Jack and Osler, 1983), are again characterized by water with alkaline pH. Apparently, differences in lithology across the valley are responsible for the observed differences in water chemistry. Station 76 renders groundwater discharged from a drill hole in the vicinity of Station 61. Though pH remains near neutral, the water is relatively enriched in iron, sulphate and acidity. The drill hole probably penetrates sulphide-rich material enclosed by rocks with appreciable buffering capacity and the water chemistry reflects the results of partial neutralization in situ.

DISCUSSION

1.) Assessment of the Acid Rock Drainage Problem

This study, coupled with previous investigations, has identified three major sources of acidic drainage in the area. These are i) acidic drainage of yet unidentified source at the NWT-Yukon border (Station 1); ii) Sekie Creek #2 which drains through the Tom mineral prospect; and, iii) Macintosh Creek. Of the three sources, only the acid production in Sekie Creek #2 could have been enhanced by human activity; the remaining two appear to have resulted from natural weathering of sulphide-rich rocks. Furthermore, comparing the acidity loadings at the Stations 1 and 24 (24.4 and 37.6 g/L, respectively), natural acid production is similar to that resulted from intense exploration activity at Sekie Creek #2. As yet, the

South Macmillan River appears to be able to absorb the acid production and loadings of acid rock drainage products from its tributaries such that the water quality in the main body shows only minor changes in the last decade and that there is little evidence of acid rock drainage contamination below Station 10. Nevertheless, data presented here confirm the high acid rock drainage potential of the study area. Mining development in the district should be closely monitored for acid mine drainage problems. The current data set could serve as a reference set to identify any future contaminant input to the River.

2.) Lithological Control of Acid Rock Drainage Occurrences

Whereas the majority of the sampling stations are located in the east side of the South Macmillan River, it is evident, particularly when combined with data from previous studies, that most drainage input from the west side of the valley is neutral to slightly alkaline in character. A brief review of the geology of the study area suggests that local lithology is a main factor controlling the occurrences of acid rock drainage. Whereas sulphide-rich rocks also abound on the west side of the river (e.g. Abbot, 1982, 1983; Turner, 1990), the occurrence of limestone and calcareous shale units of the Road River Group (Abbot, 1983) effectively neutralizes the acid produced by the oxidation of sulphides. Sekie Creek #1 on the east side of the river is characterized by good quality water because it drains mostly through a non-sulphide-bearing intrusion (Abbot, 1983) in contrast to sulphide-bearing, carbonaceous and siliceous strata underlying Sekie Creek #2 and Macintosh Creek. In fact, for the size of most tributary streams to South Macmillan River in the study area (with flow generally less than 0.5 cubic metres per second), it appears that the stream water chemistry is predominately controlled by the local lithology. This may have important implications for future mining development in the area, particularly with respect to the prevention and control of acid mine drainage.

3.) Recommended Future Work

This study encompasses only cursory field investigation and careful field sampling and measurements completed within a week. Though subsequent laboratory analyses and comparison with previous data have provided a broad picture of the acid rock drainage situation in the study area, much work remains to be done to effect a detailed impact assessment. More information is required in the following areas:

i) The source of acidic drainage in the upper reaches of South Macmillan River near the NWT-Yukon border is yet unidentified. It is desirable to locate the source and assess the extent of the occurrence and its impact.

ii) Limited by time, streams on the west side of the river have not been examined and adequately sampled in this study. Though the presence of calcareous rocks may have neutralized small amounts of acid produced in-situ, other products of acid rock drainage like sulphate and zinc generally behave conservatively under the prevalent pH conditions, a detailed impact assessment has to take these and similar loadings into account. In addition, the buffering capacity of the lithologies on the west side of the river should be determined to assess its potential use as an acid neutralizing agent.

iii) Despite continuous loadings from acidic tributaries, the main body of the South Macmillan River still does not appear to change much in water quality. Processes and mechanisms of metal (particularly zinc) transport and attenuation especially at confluences with the South Macmillan River should be studied in detail so as to shed light on possible threshold loadings which would start to adversely affect the water quality of the river.

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APPENDIX I. Flow measurements and loadings of selected species.

Station		1	2	3	4	10	20	21	22	23	24	28	29	30	40
Flow (m^3/sec)		0.543	0.768	1.537	5.020	12.608	0.099	0.083	0.149	0.199	0.342	0.006	0.032	0.020	1.686
Acidity	(g/sec)	24.44	25.34	4.61	15.06	37.82	8.32	4.65	12.52	16.72	39.67	0.17	2.53	8.48	5.06
Alkalin.	(g/sec)	0.54	0.77	18.44	5.02	126.08	0.10	0.08	0.15	0.20	0.34	0.01	0.03	0.02	5.06
Ca	(g/sec)	5.48	9.52	43.80	96.38	267.29	0.70	0.35	0.97	1.93	2.94	0.35	0.03	0.17	8.77
Cd	(g/sec)	0.01	0.01	0.02	0.07	0.06	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Co	(g/sec)	0.01	0.01	0.02	0.10	0.10	0.00	0.00	0.01	0.01	0.03	0.00	0.00	0.00	0.01
Cu	(g/sec)	0.02	0.03	0.01	0.10	0.06	0.01	0.01	0.03	0.03	0.03	0.00	0.00	0.00	0.01
Mg	(g/sec)	1.36	2.15	10.45	34.64	80.69	0.15	0.12	0.27	0.64	1.06	0.10	0.01	0.18	1.35
Ni	(g/sec)	0.08	0.11	0.12	0.55	0.88	0.02	0.01	0.02	0.03	0.09	0.00	0.00	0.01	0.03
Zn	(g/sec)	0.24	0.32	0.32	1.67	2.98	0.06	0.03	0.20	0.43	0.76	0.03	0.01	0.03	0.05
T.Hardnes	(g/sec)	32.31	48.38	153.55	409.13	1012.42	7.44	3.58	10.97	18.25	41.04	1.75	0.54	6.80	28.16
f.solids	(g/sec)	70.59	92.16	199.81	587.34	1386.88	19.80	10.79	28.31	43.78	95.76	2.76	1.92	16.60	67.44
Sulfate	(g/sec)	40.56	48.92	106.98	364.95	777.91	9.82	5.86	15.20	21.29	53.35	1.59	9.09	8.34	25.46