ASSESSMENT AND CHARACTERIZATION OF EFFLUENT ORIGINATING FROM THE TOM MINING PROPERTY (SEKIE CREEK #2) MAC PASS, YUKON

Prepared for

ROSS RIVER DENA COUNCIL

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Preface

This report was prepared for the Ross River Dena Council (RRDC) and the Department of Indian and Northern Affairs (DIAND) in response to concerns raised with respect to effluent originating from a mineral exploration adit in the headwaters of the South Macmillan River. We are grateful for the assistance by George Smith (RRDC), Norman Barichello, Vic Enns (EPS), Gerry Whitley (DIAND), Pat Roach (DIAND) and Mark Palmer (DIAND) in the administration and support of this project. Norwest Laboratories of Surrey, B.C., performed sediment and water quality analyses.

Executive Summary

Can-nic-a-nick Environmental and Laberge Environmental Services were requested by the Ross River Dena Council, under the auspices of the Federal Department of Indian and Northern Affairs, to investigate the effluent originating from a mineral exploration adit (1981) within the Macmillan Pass area of the Yukon Territory. The primary objective of this study was to characterize water quality originating from the Tom Creek property underground workings (Sekie Creek #2 drainage) and compare to Federal and Provincial water quality guidelines. In addition a site specific water quality objective for zinc was derived utilizing data from previous baseline studies and toxicological information pertaining to the biota of the region. Zinc is the most common contaminant found in these headwaters and is in high concentrations in the adit flow.

The headwaters of the Macmillan River, specifically within Macmillan pass area have high acid rock drainage potential and low buffering capacity. Water quality is generally poor in the region but does meet many of the drinking water guidelines. While fish have not been reported in the upper reaches, aquatic life can be found where physical and chemical conditions permit. Any large landscape disturbance in this area could have a potential to negatively influence the water quality of the South Macmillan River.

As previously reported, the surface waters of Sekie Creek #2 continue to have the poorest water quality within the region. The drainage has been severely impacted by human activity, with many physical alterations and surface disturbances. The adit located on the TOM property is a major contributor of acid rock drainage. Water quality of the adit flow has declined since 1991, becoming more acidic and containing higher levels of zinc. Sekie Creek #2 at its confluence with the South Macmillan River, does not meet derived water quality objectives or guidelines for drinking water or the protection of aquatic life.

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1.0 Introduction

Can-nic-a-nick Environmental and Laberge Environmental Services were contracted by the Ross River Dena Council, under the direction of the Federal Department of Indian and Northern Affairs to investigate the effluent originating from a mineral exploration adit within the Macmillan Pass area of the Yukon Territory. The drainage is located near the Yukon/NWT border at the headwaters of the South Macmillan River and is within the Ross River Dena Traditional Territory. It was one of a number of drainages in the area that received a significant amount of exploration activity during the early eighties. The original owner of the property was Hudson Bay Mining and Smelting Company. As part of the exploration, underground workings were constructed of which effluent now contributes a significant portion of the flow to Sekie Creek # 2 and ultimately the South Macmillan River. There is currently no water license or monitoring regime associated with this discharge. There is potential for this water source to be utilized by the public who use the area for a variety of recreational, cultural and economic activities. The watershed is utilized by a variety of wildlife endemic to the area.

2.0 Study Area

The Macmillan Pass is located in east central Yukon, near the Northwest Territory border and approximately 210 kilometers north east of the community of Ross River, Yukon. Sekie Creek #2 whose drainage is encompassed by the TOM property forms part of the headwater drainage of the South Macmillan River within the Macmillan Pass in the Selwyn Mountain Range. The pass and associated TOM property is accessed by a seasonal road that was originally built in the early 1940's (North Canol) and upgraded in 1969. A few kilometers downstream from the property the creek skirts an airstrip before entering the South Macmillan River. The elevation of the study area is between 1180 m to 1465 m above sea level.

The area lies within the Arctic Cordillera ecozone, specifically the Selwyn Mountain ecoregion. The rugged mountainous terrain forms part of the northern extension of the Rocky Mountains. Climatic conditions vary with elevation. The mean annual temperature for the ecoregion is approximately –4.5°C with a summer mean of

9.5°C and a winter mean of -19.5°C (DOE, 1997). Mean annual precipitation is highly variable ranging from 600 mm at lower elevation up to 750 mm at high elevations. The valley that encompasses the pass is relatively narrow and situated in a northwesterly aspect. Permafrost is extensive with bare rock outcrops; talus slopes and rubble are common. Alpine tundra is prevalent at higher elevations with subalpine open woodland vegetation at lower elevations. Alpine vegetation consists of crustose lichens, mountain avens, dwarf willow, and ericaceous shrubs. Subalpine vegetation consists of discontinuous open stands of stunted white spruce, and occasional alpine fir and lodgepole pine, in a matrix of willow, dwarf birch, and northern labrador tea with a ground cover of moss and lichen. Sedge, cottongrass, and mosses occur in wet sites. Characteristic wildlife includes caribou, grizzly and black bear, Dall sheep, moose, beaver, fox, wolf, hare, pica, raven, rock and willow ptarmigan, bald and golden eagle. Climate and resources provide opportunities for hunting and trapping of wildlife, ecotourism, and mineral exploration. The area is currently being negotiated in the Yukon Land Claim process.

The Selwyn Mountains are composed of Palaeozoic and Proterozoic strata intruded by granitic stocks, which have been extensively glaciated (DOE, 1977). The geology of the area is described in detail by Abbot (1982), Abbot and Turner (1990) and Turner (1990).

Previous assessments (Kwong and Whitley, 1991; Davies and Shepard, 1982) and baseline surveys (Jack and Osler; 1983; Monenco, 1982; Pearson and Associates, 1981 and Soroka and Jack, 1983) provide descriptions of water quality, sediment and aquatic resource characteristics of drainages within the Macmillan Pass area.

3.0 Methods

The primary objective of this project was to characterize the water and sediment from several key sites and relate results to existing guidelines, previous databases (physical, biological and toxicological information) and derived water quality objectives. The fieldwork was conducted September 11, 1998.

3.1 Water Quality

Water quality samples were collected and preserved on September 11, 1998, from each of the sites as described in Table 1 and presented in Figure 1. In-situ conductivity and temperature measurements were determined at each site using an Orion conductivity meter model 126. In-situ pH measurements were taken with an Accumet Portable AP5 pH meter. Norwest Labs of Surrey, BC supplied brand new plastic sample bottles. Samples to be analyzed for acidity, alkalinity, sulfate and total suspended solids were collected in one litre plastic bottles. Samples to be analyzed for total metals and hardness were collected in 250-ml plastic bottles and preserved with nitric acid. All sample bottles were partially filled and rinsed three times prior to collecting sample waters. The methods for parameter determination by Norwest Labs are based on *Standard Methods for the Examination of Water and Wastewater,* 19th Edition, published by the American Public Health Association.

3.2 Water Quantity

Instantaneous discharge was measured at three sites. An area with a uniform cross section was chosen and the velocity and depth were measured using a Price Minimeter. Up to ten readings were taken across the profile of the stream. Total discharge was calculated as the sum of these individual discharges (area x velocity).

3.3 Stream Sediments

Single stream sediment samples were collected from areas of deposition along the stream bank, generally characterized by the finest grain size evident at the site. A teflon trowel was used to collect the sediment that was placed into ziplock bags. The samples were kept cool prior to shipment with the water samples to Norwest Labs. At the lab the samples were dried, passed through a 100 mesh (0.15 mm) stainless steel sieve, and then run through an ICP analysis to determine total metals levels, using methods found in *Test Methods for Evaluating Solid Waste, Physical /Chemical Method, SW846*, 3rd Edition.

3.4 Data Comparisons to Guidelines

All available water quality, quantity, sediment and biological data gleaned from reports pertaining to the Macmillan Pass were compiled for comparisons. Reports and raw data were obtained from Federal and Territorial Government libraries and office files. Parameters of concern (i.e. zinc, pH) from historic sampling sites were assembled chronologically for trend through time comparisons. While zinc assaying methods differed slightly between studies, it was assumed extractable and total values were comparable because of the low suspended solids in the surface waters of the region. Comparisons of the water quality were also evaluated against the following guidelines:

1. *Canadian Drinking Water Guidelines* (Health Canada, 1996)
2. *Protection and Management of Aquatic Sediment Quality* (Ontario Ministry of Environment, 1993)
3. *Water Quality Guidelines for the Protection of Aquatic Life* (CCME, 1991)

3.5 Derivation of Water Quality Objectives for Zinc

Zinc is a metal of concern within the headwaters of the Macmillan River because of high background levels that characterize the water of the region and the high concentrations that originate from the adit flow within Sekie Creek #2. Adit discharge and overall water quality within the Sekie Creek #2 drainage was evaluated against regional background levels using methodology described in *Methods for Deriving Site-Specific Water Quality Objectives in British Columbia and Yukon* (BC Environment, 1997). The methodology utilizes area specific physical, biological and toxicological data to rationally develop objectives for waste discharges into the environment. Current and historic data from undisturbed drainages specific to the headwaters of the Macmillan River were used for this purpose. Derivation of a site-adapted water quality objective for zinc was made using the recalculation procedure as described in the manual.

4.0 Results

All waters tested were slightly acidic to acidic with the exception of South MacMillan River at bridge No. 4 (upstream of Sekie Creek #2 confluence), which was

Table 1 Site descriptions and sampling protocols for water quality sites within the headwaters of the South Macmillan River, summer 1998.

Site Description	Sample Type
North Canol Road, South Macmillan River Bridge No. 6 (63°14'N 130°01'W)	IS, WC
North Canol Road, South Macmillan River Bridge No. 5 South (63°14'N 130°02'W)	IS
North Canol Road, South Macmillan River Bridge No. 4 (63°13'N 130°04'W)	IS, WC, SS
North Canol Road, South Macmillan River Bridge No. 3 (63°11'N 130°10'W)	IS, WC, SS
Sekie Creek #2 10 meters above the confluence with the adit flow (63°10'N 130°10'W)	IS, WC, SS, F
Flow from adit which discharges into Sekie Creek #2, 50 meters downstream of adit entrance (63°10'N 130°10'W)	IS, WC, SS, F
North Canol Road ,Sekie Creek #2, 25 meters upstream of culvert (63°11'N 130°12'W)	IS, WC, SS, F
North Canol Road, South Macmillan River Bridge No. 2 (63°06'N 130°12'W)	IS,WC,SS
North Canol Road, South Macmillan River Bridge No. 1	IS, WC

IS = in-situ measurements
WC = water chemistry
SS = stream sediment chemistry
F = flow measurement

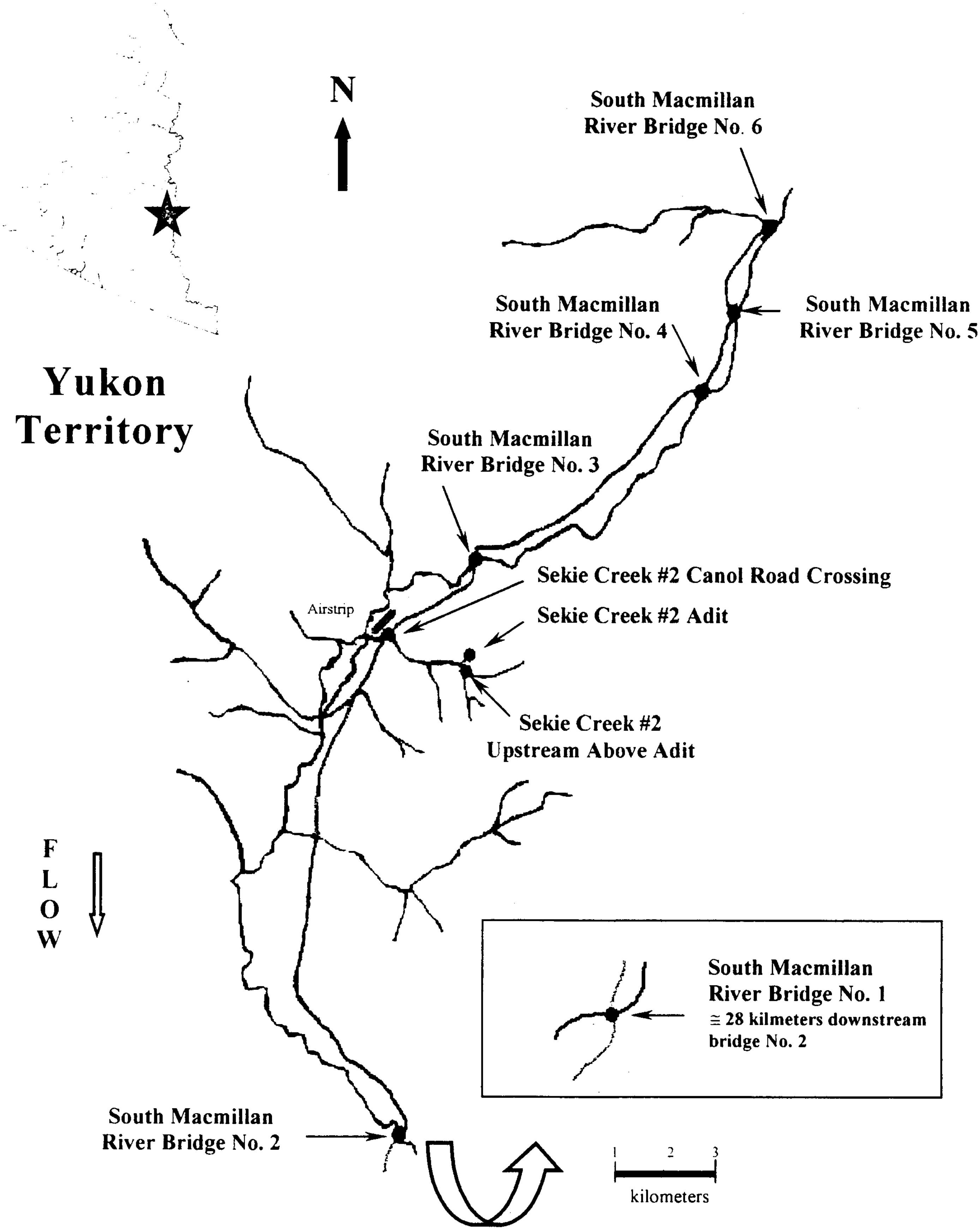

Figure 1 Upper Macmillan River study area (NTS 105 O/1) and location of sampling sites.

neutral in pH. This site also had some measurable alkalinity that was not exhibited at any other sampled location, an indication of poor buffering capacity of surface waters in the region. Waters ranged from soft (60.3 mg/L) within the South MacMillan River at bridge No. 6 to hard (258 mg/L) at the Sekie Creek #2 adit flow.

Zinc concentrations varied throughout ranging from a low of 0.296 mg/L within the South Macmillan River at bridge No.4 to a high of 11.8 mg/L within the adit flow. Other metals were found in varying concentrations, however the sampling sites within the Sekie Creek #2 drainage were consistently above those values derived at other sites within the South Macmillan River. All water quality data are included in Appendix I.

Sediment data suggest the headwaters of the South MacMillan River appear to be of a relatively similar chemistry. With the exception of arsenic and lead, sediment metal concentrations were the highest within the locations sampled in the South Macmillan River, with the highest concentrations at bridge No. 4. The sediment associated with the adit flow within Sekie Creek #2, while having the lowest concentrations of the majority of elements, the highest concentrations of arsenic, iron, sulphur and thallium were found here. The sediment associated with the adit flow was a yellow/orange fine-grained material. Detailed sediment analyses for all sites are presented in Appendix II. Of the 33 elements analyzed, the following five were below detection in all samples: antimony, bismuth, selenium, silver and uranium.

5.0 Discussion

5.1 Background

Mineral staking within the Macmillan Pass area first began in 1951. Specifically the TOM claims which included the Sekie Creek # 2 drainage received extensive exploration between 1951 and 1953 that included geological mapping, soil sampling, trenching and an extensive drilling program amounting to 39 drill holes for a total of 5,436 meters (Freberg, 1976). The property lay idle until 1966 when the property and associated drainage was resurveyed. In 1967 an advanced drilling program was initiated within a newly discovered mineralized zone within the boundaries of the TOM property. The mineralized area was discovered utilizing more intensive geological mapping, soil and geophysical surveys. In 1968 an additional 4,946 meters of drilling was completed

(Carne, 1979). In 1969 the Canol Road and associated airstrip was upgraded. Staking activity and interest escalated within other areas of the Macmillan Pass during the 1970's. During the 1981-1982 season the Hudson Bay Mining and Smelting Company operated a 30 to 50 person camp on the upper reach of Sekie Creek #2. Underground workings under a water authorization issued by DIAND resulted in the construction of 1,800 meters of tunneling. In March 1982 bad ground and excess water forced termination of the underground development 100 m short of target (Soroka and Jack, 1983).

Seepage from the adit was initially utilized for the mining operations and excess water was lime treated in a settling pond located in the mine, before being pumped and discharged into Sekie Creek #2. Water characterization in 1981at the discharge point after treatment resulted in pH neutralization (6.8 to 8.8) and a decrease in zinc concentration. Upon termination of the project, pumping and water treatment ceased. Lower drifts within the adit were allowed to fill and flow from the adit was anticipated to stabilize at 9 to 13.5 L/sec (Soroka and Jack, 1983). Measurements of flow during the winter of 1981-82 estimated a discharge of 17.25 L/sec (Soroka and Jack, 1983). Subsequent measurements since 1982 have ranged from 12 to 16 L/sec. Sporadic measurements of flow from the adit since 1982 have averaged 14 L/sec. Chemical composition of the adit flow since construction suggest a trend to more acidic conditions and increasing zinc content, typical of acid mine drainages (Table 2, Figure 2 and3).

Biological baseline information within the Sekie Creek #2 drainage was collected only after considerable physical alteration occurred within the drainage (Figure 3 and 4). Impacts from early drilling programs, road and airport upgrading, gravel extraction, camp development, underground workings and other surface disturbances such as trenching are all contributing factors. Much of the riparian vegetation was removed that resulted in large amounts of suspended solids and debris entering the creek (Monenco, 1982). Impacts on the aquatic environment were compounded by release of treated and untreated flows from the adit. Soroka and Jack (1983) found low numbers and diversity of benthic organisms within Sekie Creek #2. No fish have ever been reported within this drainage. While no pre-adit baseline data could be found, it can be concluded that exploration activities have negatively affected the water quality within Sekie Creek #2.

Figure 2 Discharge of adit, September 1998.

Figure 3 Flow 30 meters below adit, September 1998.

Figure 4 Active erosion and sediment of Rust (Sekie Creek #2) due to upstream road construction (Monenco, 1982).

Figure 5 Lower reach of Sekie Creek #2 showing absence of riparian vegetation in September, 1998.

Table 2 Comparisons of water quality data collected during moderate flows (late summer) between 1981 and 1998 within Sekie Creek #2 drainage, a headwater tributary of the South Macmillan River.

Site	Year	Date	pH	Hardness	Zinc	Flow (L/sec)	Sampler
Sekie Cr #2 u/s Adit	1998	Sept 11	2.8	86.8	4.820	26.7	Current Study
	1990	July	3.3	73.6	1.450		Kwong & Whitley
	1981	July 7	4.0	10.7	1.550	80.0	Soroka & Jack
	1981	Sept 22	3.3	10.0	0.433		DIAND
		mean	3.3	45.3	2.063		
Adit Flow	1998	Sept 11	3.2	258.0	11.800	16.1	Current study
	1991	July	3.4	307.0	6.580		Kwong & Whitley
	1990	August	4.0	272.0	5.900		Kwong & Whitley
	1987	July 7	5.9	270.0	5.380	12.0	DIAND
	1981	July 7	6.8	200.0	1.060		Soroka & Jack
	1981	Sept 23	8.8	210.0	0.188		DIAND
		mean	5.3	252.8	5.151		
Sekie Cr #2 @ rd-xing	1998	Sept 11	2.9	129.0	9.220	71.2	Current study
	1991	July	3.0	204.0	3.670		Kwong & Whitley
	1990	August	3.2	120.0	2.230		Kwong & Whitley
	1987	July 7				318.0	DIAND
	1981	July7	3.6	50.8	2.290	400*	Soroka & Jack
	1981	August	3.1	84.0	2.400		Pan Ocean (Monenco)
	1981	Sept	2.9	51.0	3.360		Pan Ocean (Monenco)
		mean	3.1	106.5	3.862		

* estimated

While the headwaters within the South Macmillan River are also generally of poor water quality, conditions are not as extreme as those found in Sekie Creek #2. This is reflected in the occurrence of several aquatic ecological components known to inhabit the area. Previous studies (Monenco, 1982; Soroka and Jack, 1983; Jack and Osler, 1983) have identified several aquatic organisms found within some of the smaller tributaries and mainstem portions of the South Macmillan, within the vicinity of Macmillan Pass (Table 3). Benthic communities have generally been described as low in diversity and density throughout the Macmillan Pass headwaters, generally lower than those reported for other alpine streams (Archibald and Burns, 1981). Habitat utilization by arctic grayling within the South Macmillan River extends to just upstream of Bridge #2 on the Canol Road (Monenco, 1982; Davies and Shepard, 1981). This site is located approximately 11 kilometers downstream of the confluence with Sekie Creek #2. Arctic grayling and round whitefish are considered to be the only species likely to be found in the headwaters of the South Macmillan River (Elson, 1974).

Previous researchers have speculated many causes for the low diversity and abundance of benthos in the Macmillan Pass drainages. The low hardness and conductivity of these waters combined with the cold climate have been linked to low productivity (Jack and Osler, 1983). Monenco (1981) concluded that low densities of periphyton (algae) and benthos were attributed to low temperatures, low nutrients, poor habitat and presence of toxins or other metabolic inhibitors. Soroka and Jack (1983) attribute the low capability to support bottom fauna as a function of low pH, cold climate, low hardness and conductivity.

5.2 Canadian Drinking Water Guidelines

Within the region and those drainages that encompass Macmillan Pass, one of the primary objectives in water management is the provision for clean water for drinking water supplies and to protect wildlife who share the resource. The Government of Canada established national guidelines that established levels of chemical and physical parameters to be considered safe in drinking water in April 1996.

Table 3 Known aquatic life contained within the headwaters of the South Macmillan River, Yukon.

Stream	Aquatic Life
Sekie Creek #2	Chrysophyta (golden-brown algae)
	Cyanophyta (blue-green algae)
	Diptera (flies)
	Plecoptera (stoneflies)
South Macmillan River	Chlorophyta (green algae)
(including tributaries)	Chrysophyta (golden-brown algae)
	Bacillariophyta (diatoms)
	Oligochaeta (aquatic worms)
	Plecoptera (stoneflies)
	Tricoptera (caddisflies)
	Diptera (flies)
	Ephemeroptera (mayflies)
	Salmonidae (arctic grayling*)

* the farthest upstream report was a group of arctic grayling juveniles 300 meters north of the Macmillan River at Bridge No. 2 during August, 1981.

Table 4 Comparisons of water quality of the headwaters of the South Macmillan River to *Canadian Drinking Water Guidelines* (Health Canada, 1996) and *Water Quality Guidelines for the Protection of Aquatic Life* (CCME, 1991). Water quality samples were obtained on September 11, 1998.

Parameter	South Macmillan (Upstream of Sekie Creek # 2 Confluence)			Sekie Creek #2			South Macmillan (Downstream of Sekie Creek #2 Confluence)		Guidelines	
	Bridge No. 6	Bridge No. 4	Bridge No. 3	Adit Flow	Upstream above adit	Canol Road Crossing	Bridge No. 2	Bridge No. 1	Drinking Water	Protection of Aquatic Life
Hardness (mg/L)	60	142	132	258	86.8	129	127	81.5		
In-situ pH	3.14	7.06	4.79	3.22	2.84	2.85	5.03	6.30	6.5 to 8.5	6.5 to 9.0
Arsenic (mg/L)	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	0.025 (IMAC)	0.005
Cadmium (mg/L)	0.011	0.004	0.018	0.043	0.094	0.204	0.013	0.004	0.005 (MAC)	.0002 to .0018*
Copper (mg/L)	0.068	0.017	0.030	0.027	1.030	0.362	0.021	0.007	< 1.0	0.002 – 0.004*
Iron (mg/L)	0.56	0.12	2.87	89.00	69.80	113.00	5.40	1.23	< 0.3 (AO)	0.30
Lead (mg/L)	<0.0003	<0.0003	<0.0003	0.1050	0.0170	0.0437	0.0012	<0.0003	0.01 (MAC)	0.001 – 0.007*
Zinc (mg/L)	0.909	0.296	0.898	11.80	4.82	9.22	.827	.357	< 5.0 (AO)	0.03

AO – aesthetic objective
MAC – maximum acceptable concentration
IMAC – interim maximum acceptable concentration
*objective value dependant on water hardness

Table 4 summarizes data for selected parameters with comparisons to the Health Canada (1991) guidelines for drinking water. The water sampled at the South Macmillan River at bridge No. 2 was the only site that met the aesthetic guideline for pH from the current survey. Extremely low pH values (2.84 to 3.22) were found throughout the Sekie Creek #2 drainage.

With respect to metals, water quality within the Sekie Creek #2 drainage fair poorest to drinking water guidelines. The flow from the adit exceeded maximum drinking water levels for arsenic, cadmium, iron, lead and zinc. With the exception of arsenic, these parameters in addition to copper were also exceeded downstream at the Canol road crossing. This suggests the current discharge from the adit influences downstream water quality within the Sekie Creek #2 drainage.

All South Macmillan River sites met the drinking water guideline for arsenic, copper, lead and zinc. Cadmium levels exceeded the drinking water guidelines at South Macmillan River sampling locations associated with bridges No.'s 2, 3 and 6.

All surveyed sites were above the aesthetic objective for iron with the exception of Macmillan River Bridge No. 4. The greatest iron content was measured within the flow of Sekie Creek #2 at the Canol road crossing (113 mg/L).

5.3 Ontario Aquatic Sediment Guidelines

For comparative purposes Ontario aquatic sediment guidelines were used to evaluate stream sediment assays. Having no established guidelines specific to the Yukon, the values contained in the guideline are simply useful as an evaluation tool. Comparisons of five elements (As, Cd, Cu, Pb and Zn) to the guidelines are presented in Table 5.

Generally the surface waters throughout the Macmillan Pass region are acidic (pH ranged for 2.85 to 5.03) which would tend to dissolve metals from sediments and retain them in solution. This attribute is evidenced in sediments of the South Macmillan River at bridge No. 4, where a neutral surface pH (7.06) corresponded to generally higher metal concentrations in the sediments. All of the sampled locations exceeded the severe effect level for arsenic. The stream sediments at the adit contained the highest arsenic concentration of 326 mg/L. All locations exceeded the low effect level for cadmium and

Table 5 Comparisons of stream sediment metal concentrations of the headwaters of the South Macmillan River to the *Protection and Management of Aquatic Sediment Quality* (Ontario Ministry of Environment, 1993). Sediment samples were obtained on September 11, 1998.

Parameter	South Macmillan (Upstream of Sekie Creek # 2 Confluence)		Sekie Creek #2			South Macmillan (Downstream of Sekie Creek #2 Confluence)	Guidelines	
	Bridge No. 4	Bridge No. 3	Adit Flow	Upstream above adit	Canol Road Crossing	Bridge No. 2	Low Effect Level	Severe Effect Level
Arsenic (mg/L)	51	46	326	67	85	52	6	33
Copper (mg/L)	137	28	6	28	38	96	16	110
Cadmium (mg/L)	5.0	2.2	2.8	0.9	1.6	3.1	0.6	10.0
Lead (mg/L)	23	22	19	150	347	33	31	250
Zinc (mg/L)	481	332	86	113	316	438	120	820

zinc, but were less than those concentrations that have a severe effect on aquatic life. At bridge No. 4 on the South Macmillan River sediment values for copper exceeded the severe effect level, while surprisingly the sediment associated with the adit flow was the only site below the low effect level. The severe effect level of lead was exceeded at Sekie Creek #2 at the Canol road crossing and was the greatest in sediments upstream of the adit confluence. All other locations were near or below the low effect level for lead.

Stream sediment samples were collected from some of the same locations as in 1981 and have been tabulated in Table 6 for comparison. Data from 1981 represent averages of three separate grab samples. Data showed similarity in copper and cadmium concentrations between sampling years at all sites. There were significant elevated levels in 1981 of lead and especially zinc, in the Sekie Creek #2 drainage. This is probably related to the high level of surface disturbances during the early 1980's causing mobilization and leaching of metals, especially from the adit. The concentrations of all parameters within the sampled locations of the South Macmillan River drainage appear relatively consistent over time. However , the high metal content in both sediment and surface waters of Sekie Creek #2 may be reflected in stream sediments directly below its confluence with the South Macmillan River.

5.4 Canadian Water Quality Guidelines for Protection of Aquatic Life

The naturally soft and acidic waters found in the region drain mineralized areas. This results in the dissolving and retention of metals in the water column. Metal values are consequently high and none of the sites in the current study area met the protection of aquatic life guidelines for cadmium, copper, and zinc (Table 4). Iron guidelines were exceeded at all locations except at bridge No.4 within the South Macmillan River. Lead exceeded the guidelines at all sites in the Sekie Creek #2 drainage and all South Macmillan River sites except for the most downstream location at Bridge No.1. Arsenic exceeded the guidelines only in the adit flow. Zinc was the most common contaminant that characterized all surface waters of the area, exceeding aquatic protection guidelines by 10 times at the South Macmillan bridge No.4 and by 375 times at the adit flow.

Table 6 Comparisons of metals in sediment collected during the summer season in 1981 to 1998 within Sekie Creek #2 drainage and two sites within the South Macmillan River.

Site	Year	Arsenic	Copper	Cadmium	Lead	Zinc	Sampler
South Macmillan River Bridge No.3	1998	46	95	2.2	22	332	Current survey
	1981	65	126	1.02	29	392	Soroka & Jack
Sekie Creek #2 u/s Adit	1998	67	28	0.9	150	113	Current survey
	1981	50	20	0.7	200	254	Soroka & Jack
Sekie Creek #2 Canol Road xing	1998	85	38	1.6	347	316	Current survey
	1981	154	36	3.6	530	1297	Soroka & Jack
South Macmillan River Bridge No.2	1998	52	96	3.1	33	438	Current survey
	1981	42	93	3.9	46	625	Jack & Osler
	1981	51	79	6	51	501	Monenco

5.5 Derivation of Water Quality Objectives for Zinc

In the South Macmillan River the protection of fish and other aquatic organisms has been identified as a water management goal. In addition, wildlife is an integral part of the ecosystem in this area and it is important to protect wildlife species that utilize the river as a drinking source.

Current guidelines for the protection of aquatic life stipulate waste discharges containing zinc should not exceed a maximum of .03 mg/L. This is a fixed guideline value and not dependent on the ambient water hardness in the receiving waters as is the case for cadmium, copper and lead values. For these metals softer water increases the potential for harmful effects. Within the headwaters of the South Macmillan River water hardness is variable but generally considered low (soft) from previously collected data at moderate flows. Ambient water hardness characteristics during low and high flows remains unknown as all previous data collections have occurred post peak flows in early to mid June and pre low flow periods of October to May.

Toxicological data specific to zinc suggest a number of factors have the potential to influence toxicity (Nagpal, 1997). Factors include water hardness, calcium, magnesium, salinity, pH, temperature, and the presence of other metals. Of these, water hardness was found to be the most important factor, with toxicity decreasing with increasing hardness. Zinc was also found to be most toxic at near neutral pH and at elevated temperatures. Insufficient information was located to adjust the current guidelines based on the concentrations of other metals, pH, or water temperature. Using the ambient water hardness in the receiving water system zinc levels that would be predicted to protect aquatic life were calculated using the equation:

$$WQG\ (mg/L) = (7 + 0.755 \bullet (hardness - 90))/1000$$ (Nagpal, 1997)

The results suggests a more conservative objective should be considered of .018 mg/L, reflecting the lack of buffering capacity (i.e. soft waters) of surface waters in the region. (Table 7).

While mineral exploration have occurred throughout the area, the impact of these activities on water quality in the South Macmillan River upstream of Sekie Creek #2 is assumed minimal and that current concentrations of zinc within these waters are close to

Table 7 Summary of water hardness and preliminary water quality objectives for dissolved zinc in the headwaters of the South Macmillan River, Yukon.

Location	Water Hardness (mg/L)*	WQOs for Zinc (mg/L)**
South Macmillan Bridge No. 6	49	.007
South Macmillan Bridge No. 5	48	.007
South Macmillan Bridge No. 4	104	.018
South Macmillan Bridge No. 3	72	.007

*moderate flow data only (July to Sept)
** calculated using: WQG (mg/L) = (7 + 0.755 • (hardness – 90))/1000 from Nagpal 1997

Table 8 Summary of average zinc concentrations compiled from data collected from 1981 to 1998 studies within undisturbed and disturbed portions of the headwaters of the Macmillan River.

Location	Level of Disturbance	Average Zinc Concentration (mg/L)*
South Macmillan Bridge No. 6	Low	.557 (4)
South Macmillan Bridge No. 5	Low	.385 (3)
South Macmillan Bridge No. 4	Low	.245 (3)
South Macmillan Bridge No. 3	Low	.399 (6)
Sekie Creek #2 Adit	High	5.151 (6)
Sekie Creek #2 u/s Adit	High	2.063 (4)
Sekie Cr #2 @ Canol rd-xing	High	3.862 (6)

*numbers in parenthesis indicate sample size to derive average background levels. Data compiled from current and previous studies from sampling locations within the South Macmillan River upstream of Sekie Creek #2 suggest background concentrations of zinc have averaged from .245 mg/L to .557 mg/L (Table 8). Conversely, Sekie Creek #2 zinc concentrations have averaged from 2.063 mg/L to 5.151 mg/L within the adit flow. Toxicological information (Appendix III) on similar groups of organisms as those found in the waters of Macmillan Pass suggest that the first toxic effects of zinc on algae occur around .002 to .040 mg/L. Severe effects on these organisms ranged from .1 to 4 mg/L. Growth and emergence of mayflies fed algae with concentrations of 2 mg/L significantly affected growth and emergence of mayflies. This information as well as the metal sediment data suggests no aquatic life could survive within the headwaters of the South Macmillan River. While currently the situation within Sekie Creek #2, previous studies have documented aquatic organisms in these headwaters of the South Macmillan River, albeit low in diversity and abundance. Therefore other characteristics in the water chemistry must influence the toxicity or bioavailability of zinc. Further, it could also be concluded that organisms contained in the Macmillan Pass region might be less sensitive to zinc as those represented in the data set.

In conclusion it would be reasonable to suggest a refinement of the current water quality objectives to reflect background levels. Specifically, discharges from Sekie Creek #2 into the Macmillan River should not exceed .4 mg/L (rounding off .399 mg/L) of zinc, reflecting the average background concentrations just above its confluence with the South Macmillan River. It is believed that zinc concentrations below this level would achieve an ecological non-degradation objective while meeting other less stringent water uses (i.e., wildlife and raw water for drinking water supply). This value may need to be revised dependant on low flow hardness characteristics or when any additional background data becomes available. Currently water quality at all sampling locations within the Sekie Creek #2 drainage do not meet this objective.

5.5 Conclusion

Sekie Creek #2 is indicative of a stream exhibiting acid rock drainage. It has inherent value as an impacted watershed for study and serves for effective comparisons to other drainages throughout the Territory displaying similar characteristics. However acid rock drainage is not limited to Sekie Creek #2. There exists natural acid rock drainage in the headwaters of the South Macmillan River, as evidenced in the water quality of the South Macmillan River at Bridge No.'s 3, 4, 5 and 6. Acid rock drainage is the product formed by the atmospheric oxidation of the relatively common iron-sulphur minerals pyrite (FeS2) and pyrrhotite (FeS) in the presence of bacteria (*Thiobacillus ferrooxidans*). Sulphide minerals are ubiquitous in the geological environment, usually found in rock that lies beneath a mantle of soil and often beneath the water table. Consequently there is normally minimal contact with oxygen, and acid generation proceeds at a slow rate as to be negligible or not detectable. Untreated (not neutralized) acid rock drainage creates two quite distinct environmental problems - the acidity from sulphuric acid and the heavy metal solubilization.

Alkaline minerals naturally found in the environment can neutralize acidic waters. Examples of acid neutralizing minerals are calcite (CaCO3) and dolomite (Ca, MgCO3). Calcium-based carbonate in the rock neutralizes acid but as acid generation continues, the calcium-based carbonate is consumed and the pH of the water decreases. At some point in the future, decades or even centuries, depending on the geology of the area, the acid generation rate will slow as the more reactive sulphide becomes completely oxidized. Current water chemistry data suggests the lack of calcium-based rock in the upper South Macmillan River as indicated by the soft waters encountered in this region.

As concluded with this and other previous studies (Kwong and Whitley, 1991), the headwaters of the Macmillan River specifically within Macmillan pass have high acid rock drainage potential and low buffering capacity. Any future mineral exploration activity approaching those levels that previously occurred on Sekie Creek #2 have the potential to negatively influence the water quality of the South Macmillan River. Zinc is the most prevalent contaminant in the surface waters of Sekie Creek #2 and currently does not meet the derived objective for the protection of aquatic life or aesthetic drinking water standard. While zinc alone is not the sole contributor to the overall poor water quality of Sekie Creek #2, any remediation of this metal within the Sekie Creek #2 drainage will by default address other associated metal contaminants.

6.0 Recommendations

1. The adit flow within the Sekie Creek #2 drainage is a significant source of acid mine drainage that affects the water quality within the South Macmillan River. Remedial action should be taken to improve the water quality and/or reduce the flow at the source.

2. Other sources of anthropogenic induced acid rock drainage within the upper reaches of Sekie Creek #2 drainage should be identified and mitigated if logistically possible.

3. A target objective of .4 mg/L of total zinc should be considered at a point of compliance in the waters of Sekie Creek #2 at its confluence with the South Macmillan River.

4. Water quality within the headwaters of the South Macmillan River should be characterized during low flow periods (October to May).

5. Surface waters of Sekie Creek #2 are not suitable for drinking water supplies at the Canol Road or mine road access points and should be posted (currently there is no such sign).

7.0 References

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APPENDIX I DETAILED WATER CHEMISTRY DATA

Site	Temp (°C)	PH	Conductivity (uS/cm)	Flow (L/s)	Hardness (CaC03)	NFR (mg/L)	Alkalinity (CaC03)	Acidity (CaC03)	Sulphate (SO4) (mg/L)	Aluminum T-Al (mg/L)	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium T-Be (mg/L)	Bismuth (mg/L)	Boron (mg/L)	Cadmium T-Cd (mg/L)	Calcium T-Ca (mg/L)	Chromium T-Cr (mg/L)
Macmillan Bridge No. 6	3.6	3.14	307		60.3					10.3	<0.005	<0.01	0.0258	0.00071	0.0017	<0.002	0.0107	17.4	0.00177
Macmillan Bridge No. 5	4.5	4.76	183.6																
MacMillan Bridge No. 4	3.8	7.06	266		142	8	31	<5	110	2.54	<0.005	<0.01	0.0659	0.00019	0.0022	<0.002	0.00417	40.1	0.00113
MacMillian Bridge No. 3	4.4	4.79	300		132	8	<5	167	160	6.22	<0.005	<0.01	0.0349	0.00037	0.0026	0.003	0.0176	29.9	0.00256
Sekie Cr #2 u/s Adit	3.4	2.84	947	26.7	86.8	13	<5	307	630	58.6	0.007	<0.01	0.0318	0.0019	0.0031	0.074	0.0942	21.6	0.0759
Sekie Cr #2 Adit flow	2.4	3.22	879	16.1	258	97	<5	300	540	18.7	0.005	0.05	0.0141	0.00177	0.0043	0.085	0.0426	62.6	0.00656
Adit flow - Duplicate										18.3	0.007	0.05	0.0102	0.00171	0.0041	0.085	0.0414	62.5	0.00618
Sekie Cr #2 @ rd x-ing	4.8	2.85	1160	71.2	129	7	<5	450	810	70.3	0.006	<0.01	0.0145	0.00209	0.0046	0.111	0.204	27.6	0.0646
Macmillan Bridge No. 2	5.8	5.03	270		127	21	<5	30	135	5.39	<0.005	<0.01	0.502	0.00024	0.0024	0.007	0.0132	31.5	0.00322
MacMillan Bridge No. 1	7.1	6.30	169.8		81.5	8	<5	<5	78	1.7	<0.005	<0.01	0.0558	0.00011	0.002	0.004	0.0044	21.6	0.00122
Maximum	7.1	7.06	1160	71.2	258	97	31	450	810	70.3	0.007	0.05	0.502	0.00209	0.0046	0.111	0.204	62.6	0.0759
Minimum	2.4	2.84	169.8	16.1	60.3	7	0	0	78	1.7	0	0	0.0102	0.00011	0.0017	0	0.00417	17.4	0.00113

APPENDIX I DETAILED WATER CHEMISTRY DATA

Site	Cobalt (mg/L)	Copper (mg/L)	Iron (mg/L)	Lead (mg/L)	Lithium (mg/L)	Magnesium T-Mg (mg/L)	Manganese T-Mn (mg/L)	Molybdenum (mg/L)	Nickel (mg/L)	Phosphorus (mg/L)
Macmillan Bridge No. 6	0.0415	0.0678	0.562	<.0003	0.028	4.1	0.452	0.00011	0.287	<0.03
Macmillan Bridge No. 5										
Macmillan Bridge No. 4	0.013	0.0169	0.116	<.0003	0.013	10.2	0.164	0.00127	0.107	<0.03
Macmillian Bridge No. 3	0.0324	0.0298	2.87	<.0003	0.019	14	0.47	0.00047	0.255	<0.03
Sekie Cr #2 u/s Adit	0.115	1.03	69.8	0.017	0.023	7.99	0.755	0.00164	1.13	1.08
Sekie Cr #2 Adit flow	0.13	0.0267	89	0.105	0.031	24.8	4.73	0.0004	0.677	0.05
Adit flow - Duplicate	0.126	0.0248	88.1	0.101	0.032	24.8	4.59	0.00038	0.652	0.04
Sekie Cr #2 @ rd x-ing	0.161	0.362	113	0.0437	0.033	14.6	1.59	0.00066	1.38	0.71
Macmillan Bridge No. 2	0.0193	0.0211	5.4	0.0012	0.01	11.8	0.259	0.00077	0.185	0.04
Macmillan Bridge No. 1	0.00959	0.00743	1.23	<.0003	0.008	6.7	0.147	0.00044	0.0844	<0.03
Maximum	0.161	1.03	113	0.105	0.033	24.8	4.73	0.00164	1.38	1.08
Minimum	0.00959	0.00743	0.116	0	0.008	4.1	0.147	0.00011	0.0844	0

Site	Potassium (mg/L)	Selenium T-Se (mg/L)	Silicon (mg/L)	Silver (mg/L)	Sodium (mg/L)	Strontium (mg/L)	Sulphur (mg/L)	Thallium (mg/L)	Titanium (mg/L)	Vanadium T-V (mg/L)	Zinc (mg/L)
Macmillan Bridge No. 6	<0.4	0.008	3.96	0.00053	<0.4	0.0943	42.3	0.002	<.00002	0.00061	0.909
Macmillan Bridge No. 5											
Macmillan Bridge No. 4	<0.4	0.006	2.77	0.00067	<0.4	0.117	36.7	0.003	<.00002	0.00059	0.296
Macmillian Bridge No. 3	0.7	<0.004	3.7	0.00062	<0.4	0.115	51	0.003	0.00011	0.00281	0.898
Sekie Cr #2 u/s Adit	3.6	<0.004	7.98	0.0004	<0.4	0.0835	187	<0.001	0.00042	0.297	4.82
Sekie Cr #2 Adit flow	3	<0.004	4.37	0.00083	<0.4	0.23	161	0.002	0.0001	0.024	11.8
Adit flow - Duplicate	3	<0.004	4.4	0.00088	<0.4	0.224	166	0.003	<.00002	0.0219	11.3
Sekie Cr #2 @ rd x-ing	3.4	<0.004	8.85	0.00028	<0.4	0.104	261	<0.001	0.00149	0.217	9.22
Macmillan Bridge No. 2	0.6	<0.004	3.94	0.00057	0.5	0.109	47	0.003	0.00056	0.0082	0.827
Macmillan Bridge No. 1	0.4	<0.004	3.2	0.00062	0.9	0.0813	26.3	0.003	0.00208	0.00213	0.357
Maximum	3.6	0.008	8.85	0.00088	0.9	0.23	261	0.003	0.00208	0.297	11.8
Minimum	0	0	2.77	0.00028	0	0.0813	26.3	0	0	0.00059	0.296

APPENDIX II DETAILED SEDIMENT CHEMISTRY DATA

Site	Lab Reference Number	Al ug/g	Sb ug/g	As ug/g	Ba ug/g	Be ug/g	Bi ug/g	Cd ug/g	Ca ug/g	Cr ug/g	Co ug/g	Cu ug/g	Fe ug/g	Pb ug/g	Li ug/g	Mg ug/g	Mn ug/g	Mo ug/g
Macmillan Bridge No. 4	38437-1	27300	<2	51	1400	1.6	<5	5	4750	39.7	33.4	137	35000	23	22.1	2730	474	12
MacMillian Bridge No. 3	38437-2	24500	<2	46	1120	1	<5	2.2	2390	31.3	18.3	95.1	51000	22	15.8	1610	361	12
Sekie Cr #2 u/s Adit	38437-3	17900	<2	67	2640	0.8	<5	0.9	334	49.4	0.3	27.7	65000	150	9.2	1270	19.8	22
Sekie Cr #2 Adit flow	38437-4	1060	<2	326	58.2	<0.1	<5	2.8	230	7.6	<0.1	6.3	430000	19	<0.5	<1	3.8	10
Adit flow – Duplicate	38437-5	937	<2	335	43.7	<0.1	<5	2.6	224	7.8	<0.1	6.2	430000	28	<0.5	<1	3.8	12
Sekie Cr #2 @ rd x-ing	38437-6	16700	<2	85	2590	0.2	<5	1.6	218	40.7	<0.1	38	94000	347	7.5	832	15.9	13
MacMillan River No. 2	38437-7	27500	<2	52	1300	1.2	<5	3.1	3760	35.6	15.5	95.5	55000	33	15.8	1550	248	15
Maximum		27500	0	335	2640	1.6	0	5	4750	49.4	33.4	137	430000	347	22.1	2730	474	22
Minimum		937	0	46	43.7	0	0	0.9	218	7.6	0	6.2	35000	19	0	0	3.8	10

APPENDIX II DETAILED SEDIMENT CHEMISTRY DATA

Site	Lab Reference Number	Ni ug/g	P ug/g	K ug/g	Se ug/g	Si ug/g	Ag ug/g	Na ug/g	Sr ug/g	S ug/g	Th ug/g	Sn ug/g	Ti ug/g	U ug/g	V ug/g	Zn ug/g	Zr ug/g
MacMillan Bridge No. 4	38437-1	125	2350	10600	<2	758	<0.5	270	46	910	8	3	282	<5	200	481	35.5
MacMillian Bridge No. 3	38437-2	64.5	1930	5600	<2	629	<0.5	256	32	2790	8	2	169	<5	160	332	22.3
Sekie Cr #2 u/s Adit	38437-3	8.9	2210	5900	<2	566	<0.5	471	37	6200	13	2	234	<5	800	113	20.3
Sekie Cr #2 Adit flow	38437-4	2.8	222	<20	<2	232	<0.5	<5	<1	53000	110	<1	5.7	<5	69	86.4	<0.1
Adit flow – Duplicate	38437-5	3.5	203	<20	<2	77	<0.5	<5	<1	52000	120	<1	3.7	<5	68	86.4	<0.1
Sekie Cr #2 @ rd x-ing	38437-6	6.4	1450	5700	<2	891	<0.5	194	27	7900	11	<1	154	<5	570	316	16.4
MacMillan Bridge No. 2	38437-7	70.9	2640	6000	<2	709	<0.5	226	44	2560	10	2	205	<5	220	438	23.7
Maximum		125	2640	10600	0	891	0	471	46	53000	120	3	282	0	800	481	35.5
Minimum		2.8	203	0	0	77	0	0	0	910	8	0	3.7	0	68	86.4	0

APPENDIX III SUMMARY OF AQUATIC TOXICITY DATA FOR ZINC THAT ARE APPLICABLE TO THE HEADWATERS OF THE SOUTH MACMILLAN RIVER

Species	Life Stage	Data type	Form	pH	D.O. (mg/l)	Temp. (°C)	Alkal-inity (mg/L)	Hard-ness (mg/L as$CaCO_3$)	Conc. (mg/L)	Effect	Reference
Chironomus riparius (diptera, chironomidae)	larvae	S,M,2	.	7.3-7.7	-	20	-	-	0.1	Significant delay in development for all instars	Timmermans *et al.* 1992
Epeorus latifolium (mayfly)	larvae	F,M,1	$ZnSO_4$	7.9-8.0	-	15.5	-	83 µg/L	0.1-0.3	Growth inhibition- 2 weeks; all dead before emergence	Hatakeyama 1989
Epeorus latifolium (mayfly)	larvae	F,M,1	$ZnSO_4$	7.9-8.0	-	15.5	-	83 µg/L	Fed algae with 940 µg/g	No decrease in growth rate	Hatakeyama 1989
Epeorus latifolium (mayfly)	larvae	F,M,1	$ZnSO_4$	7.9-8.0	-	15.5	-	83 µg/L	Fed algae with 1380 µg/g	Wk 1: growth rate 55% of control; Wk 2: restoration of normal growth rate	Hatakeyama 1989
Epeorus latifolium (mayfly)	larvae	F,M,1	$ZnSO_4$	7.9-8.0	-	15.5	-	83 µg/L	Fed algae with 2000 µg/g	Growth and emergence significantly affected	Hatakeyama 1989
Insect Community	30 d of colonization on trays in Clinch River	F,M,1	.	8.93	8.9	22.4	59	85	0.015	Macroinvertebr ate abundance reduced by 57% within 4 days	Clements *et al.* 1988

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Species	Life Stage	Data type	Form	pH	D.O. (mg/l)	Temp (°C)	Alkalinity (mg/L)	Hardness (mg/L as$CaCO_3$)	Conc. (mg/L)	Effect	Reference
Tanytarsus dissimilis (chironomidae): insect	Embryogenesis hatching	S,M,2	$ZnCl_2$	7.5	8.7	22	43.9	46.8	.0368	LC50-10 d	Anderson *et al.* 1980
Tanytarsus dissimilis (chironomidae): insect	Embryogenesis hatching & larval development	S,M,2	$ZnCl_2$	7.5	8.7	22	43.9	46.8	0.08-0.100	10% larval survival	Anderson *et al.* 1980
Cladophora glomerata (green alga)	Growth of similar size, age and condition were selected	F,M,1 river simulation velocity	$ZnSO_4$	-	-	-	-	-	.4	First toxic signs, 2 of 4 samples showed cytoplasmic abnormalities	Mchardy & George 1990
Cladophora glomerata (green alga)	Growth of similar size, age and condition were selected	F,M,1 river simulation velocity	$ZnSO_4$	-	-	-	-	-	1	3 samples had damaged filaments	Mchardy & George 1990
Cladophora glomerata (green alga)	Growth of similar size, age and condition were selected	F,M,1 river simulation velocity	$ZnSO_4$	-	-	-	-	-	1.75	All 4 samples displayed evidence of toxicity	Mchardy & George 1990
Cladophora glomerata (green alga)	Growth of similar size, age and condition were selected	F,M,1 river simulation velocity	$ZnSO_4$	-	-	-	-	-	4	2 of 4 samples had 99% of their filaments completely colourless and dead	Mchardy & George 1990

APPENDIX III SUMMARY OF AQUATIC TOXICITY DATA FOR ZINC THAT ARE APPLICABLE TO THE HEADWATERS OF THE SOUTH MACMILLAN RIVER

Species	Life Stage	Data type	Form	pH	D.O. (mg/l)	Temp. (°C)	Alkal-inity (mg/L)	Hard-ness (mg/L as$CaCO_3$)	Conc. (mg/L)	Effect	Reference
Scenedesmus quadricauda (green algae)	-	S,M,2	$ZnSO_4$	8	-	constant	-	-	0.25	EC50-4hr (photosynthesis)	Starodub *et al.* 1987
Scenedesmus quadricauda (green algae)	-	S,M,2	$ZnSO_4$	4.5	-	20	-	-	.1	Growth rate–15 days=0.100 (sig. Different from control)	Starodub *et al.* 1987
Scenedesmus quadricauda (green algae)	-	S,M,2	$ZnSO_4$	6.5	-	20	-	-	.1	Growth rate–15 days=0.101	Starodub *et al.* 1987
Scenedesmus quadricauda (green algae)	-	S,M,2	$ZnSO_4$	8.5	-	20	-	-	.1	Growth rate–15 days=0.122	Starodub *et al.* 1987
Scenedesmus quadricauda (green algae)	-	S,M,2	$ZnSO_4$	4.5	-	20	-	-	.225	Growth rate–15 days=0.040 (sig. Different from control)	Starodub *et al.* 1987
Scenedesmus quadricauda (green algae)	-	S,M,2	$ZnSO_4$	6.5	-	20	-	-	.225	Growth rate–15 days=0.042 (sig. Different from control)	Starodub *et al.* 1987
Scenedesmus quadricauda (green algae)	-	S,M,2	$ZnSO_4$	8.5	-	20	-	-	.225	Growth rate–15 days=0.131	Starodub *et al,* 1987

APPENDIX III SUMMARY OF AQUATIC TOXICITY DATA FOR ZINC THAT ARE APPLICABLE TO THE HEADWATERS OF THE SOUTH MACMILLAN RIVER

Species	Life Stage	Data type	Form	pH	D.O. (mg/l)	Temp. (°C)	Alkalinity (mg/L)	Hardness (mg/L as$CaCO_3$)	Conc. (mg/L)	Effect	Reference
Scenedesmus quadricauda (green algae)	-	S,M,2	$ZnSO_4$	4.5	-	20	-	-	.5	Growth rate–15 days=0.000 (sig. Different from control)	Starodub *et al.* 1987
Scenedesmus quadricauda (green algae)	-	S,M,2	$ZnSO_4$	6.5	-	20	-	-	.5	Growth rate–15 days=0.026 (sig. Different from control)	Starodub *et al.* 1987
Scenedesmus quadricauda (green algae)	-	S,M,2	$ZnSO_4$	8.5	-	20	-	-	.5	Growth rate–15 days=0.109 (sig. Different from control)	Starodub *et al.* 1987
Scenedesmus quadricauda (green algae)	-	-	-	-	-	-	-	-	.002	First deleterious effect	Matulova 1978
Selanastrum capricornutum (green alga)	-	na	-	-	-	-	-	-	.03	Some growth inhibition-7d	EPA 1980
Selanastrum capricornutum (green alga)	-	na	-	-	-	-	-	-	0.040-0.068	95% growth inhibition-14d	EPA 1980
Selanastrum capricornutum (green alga)	-	na	-	-	-	-	-	-	.1	100% growth inhibition-7d	EPA 1980

APPENDIX III SUMMARY OF AQUATIC TOXICITY DATA FOR ZINC THAT ARE APPLICABLE TO THE HEADWATERS OF THE SOUTH MACMILLAN RIVER

Species	Life Stage	Data type	Form	pH	D.O. (mg/l)	Temp. (°C)	Alkal-inity (mg/L)	Hard-ness (mg/L as$CaCO_3$)	Conc. (mg/L)	Effect	Reference
Selanastrum capricornutum (green alga)	-	S,M,2 AAPBT medium	$ZnCl_2$	6.8-7.2	-	24	8.2	14.9	0.03	Initiation of growth rate inhibition	Bartlett *et al.* 1974
Selanastrum capricornutum (green alga)	-	S,M,2 AAPBT medium	$ZnCl_2$	6.8-7.2	-	24	8.2	14.9	0.12	Complete inhibition of growth rate	Bartlett *et al.* 1974
Selanastrum capricornutum (green alga)	-	S,M,2 AAPBT medium	$ZnCl_2$	6.8-7.2	-	24	8.2	14.9	0.12	Complete inhibition of growth rate algicidal	Bartlett *et al.* 1974
Selanastrum capricornutum (green alga)	-	S,N,2	$ZnSO_4$	6.0-6.3	-	24	-	-	0.0041	7-d EC50	Chiaudani & Vighi, 1978