A PRELIMINARY ASSESSMENT OF SUBAQUEOUS TAILINGS DISPOSAL IN BENSON LAKE, BRITISH COLUMBIA

MEND Project 2.11.1a-b

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A Preliminary Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia

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EXECUTIVE SUMMARY

The Benson Lake Coast Copper Mine operated from 1962–1973, during which 3.6 million tonnes of high grade copper ore was mined. A copper concentrate mill and, a magnetite recovery plant which operated from 1963–1970, discharged tailings under permit into Benson Lake. Over the period of operations, the tailings were discharged into progressively deeper waters to combat a continuing problem with lake turbidity caused by colloidal suspension of tailing fines. A flocculating agent was also added at the tailings pond to assist settlement.

Benson Lake is a reasonably small, deep, soft watered, and oligotrophic coastal lake. It is characterized by isothermal conditions during the winter, establishment of a thermocline over the summer, and a fall turnover. Field studies by the Environmental Protection Service in 1967 and 1973 found the entire lake bottom was covered by tailings and devoid of benthic life. In 1967, even the outlet river had a layer of fines on the bottom, and was populated by turbid–water benthic invertebrates. A bathymetry map prepared in 1970 showed the depth profile had not been significantly changed by tailings deposition.

The lake supports rainbow (*Oncorhynchus mykiss*) and cutthroat (*O. clarki*) trout, Dolly Varden char (*Salvelinus alpinus*) and sculpin (*Cottus asper*). Even after the mine was shut down, the fish concentrated their feeding on drift organisms carried into the lake by inlet streams. The resident fish were found in 1967 and 1973 to have high levels of zinc in their tissues, but equally high concentrations were found in a nearby control lake (Maynard Lake).

This study constitutes the initial stage of a field assessment of the lake's recovery from tailings disposal. The 1989–90 work included mapping the lake's bathymetry, and establishing staff and crest gauges and discharge sites on inlet and outlet streams. Inlet streams include Raging River, Benson River and Craft Creek, while the outlet is through the lower Benson River. Bathymetry mapping provided a series of limnological morphometric parameters. Stream profiles were prepared for discharge site cross–sections.

Benson Lake is 2.1 km long, with a maximum depth of 54 m (mean depth = 25.5 m), and a surface area of 7.73 x 10^5 m^2. The relative depth (5.4%) and shoreline development factor (1.7) describe a small and deep elliptical lake with relatively high stability and only moderate potential for littoral zone development. Comparisons between present bathymetry and the depth profile from 1970 suggest the deeper portions of the lake (>50 m) have been partly filled.

Insufficient data are available to define hydrographic rating curves for each of the inlet and outlet streams. A comparison of the net inflow (9.5 m^3/s) and outflow (8.5 m^3/s) for November 3, 1989 suggested gauge and discharge sites with more laminar flows should be selected. Sites were checked and re–established as required on March 4, 1990.

SOMMAIRE

La mine Benson Lake Coast Copper Mine a été en service de 1962 à 1973, période pendant laquelle 3,6 millions de tonnes de minerai de cuivre à forte teneur ont été extraites. Une usine d'enrichissement du cuivre ainsi qu'une usine de récupération de magnétite (en service de 1963 à 1970) ont déversé des résidus dans le lac Benson, un permis les y autorisant. Avec le temps, les résidus ont été déversés dans des eaux de plus en plus profondes afin de combattre un problème persistant de turbidité des eaux du lac par suite de la mise en suspension colloïdale des particules fines comprises dans les résidus. Un floculant a aussi été ajouté dans la lagune à résidus pour faciliter la décantation.

Le lac Benson est situé sur la côte et il est plutôt petit, assez profond et ses eaux douces sont oligotrophes. Il se caractérise par des conditions isothermes pendant l'hiver, l'établissement d'un métalimnion en été et un brassage en automne. Des études effectuées sur place par le Service de protection de l'environnement en 1967 et en 1973 ont permis de constater que le fond du lac était complètement recouvert de résidus et dépourvu de vie benthique. En 1967, même le fond de l'émissaire était recouvert d'une couche de particules fines et était peuplé d'invertébrés benthiques vivant en eaux turbides. Une carte bathymétrique préparée en 1970 montrait que le profil des profondeurs n'avait pas été tellement affecté par le dépôt des résidus.

Le lac soutient des populations de truite arc-en-ciel (*Oncorhynchus mykiss*) et de truite fardée (*O. clarki*), d'omble chevalier (*Salvelinus alpinus*) et de chabot piquant (*Cottus asper*). Même après la fermeture de la mine, les poissons ont concentré leur alimentation sur les organismes à la dérive transportés dans le lac par les affluents. En 1967 et 1973, on a constaté que les tissus des poissons résidents renfermaient de fortes concentrations de zinc, mais des concentrations tout aussi fortes ont été constatées dans un lac témoin des environs (le lac Maynard).

La présente étude constitue le premier stade d'une évaluation sur place du rétablissement du lac à partir du moment où l'élimination des résidus y a cessé. Les travaux effectués en 1989–1990 ont consisté notamment à cartographier la bathymétrie du lac, à installer des échelles limnimétriques et de crête, de même qu'à aménager des lieux de mesure de débit tant sur les affluents que sur les émissaires. Les affluents sont entre autres les suivants : la rivière Raging, la rivière Benson et le ruisseau Craft, tandis que c'est le cours inférieur de la rivière Benson qui sert d'émissaire. La Cartographie bathymétrique a fourni une série de paramètres morphométriques. Des profils fluviaux ont été préparés afin d'obtenir ensuite des profils en travers des lieux de mesure de débit.

Le lac Benson a une longueur de 2,1 km, sa profondeur maximale est de 54 m (profondeur moyenne = 25,5 m) et sa superficie est de 7,73 x 10^5 m^2. La profondeur relative (5,4 %) et le coefficient d'évolution des rives (1.7) décrivent un lac elliptique, à la fois petit et profond, dont la stabilité est relativement élevée et dont le potentiel de formation d'une zone littorale est plutôt modéré. Les comparaisons effectuées à partir de 1970 entre la bathymétrie contemporaine et le profil de profondeur permettent de penser que les parties plus profondes du lac (> 50 m) ont été partiellement comblées.

Les données existantes sont insuffisantes pour définir des courbes de débits jaugés pour chacun des affluents et des émissaires. Une comparaison des débits nets d'admission (9.5 m^3/s) et de sortie (8.5 m^3/s) enregistrés le 3 novembre 1988 a incité à choisir des lieux de limnimétrie et de mesure de débit où les écoulements seraient plus laminaires. Les lieux en question ont été trouvés, vérifiés et aménagés comme voulu le 4 mars 1990.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 - Introduction

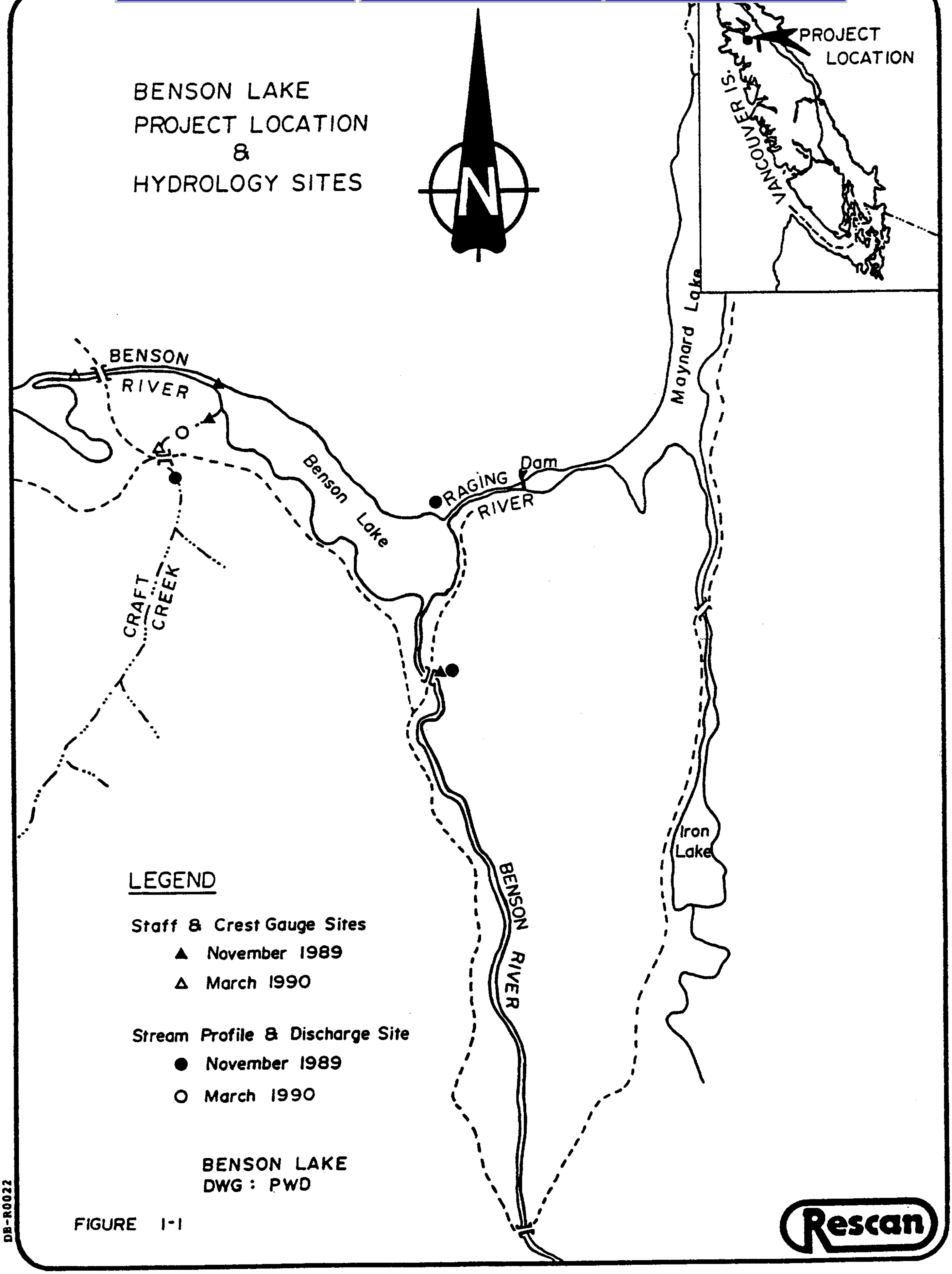
1.0 INTRODUCTION

The Benson Lake watershed is part of the Marble River drainage and is located in northern Vancouver Island, about 15 km east of the town of Port Alice (Figure 1-1). The drainage is primarily surrounded by a coastal western hemlock biogeoclimatic zone. MacMillan Bloedel Limited currently logs the Benson River and Raging River drainages out of their Port McNeil division. Access to the area is therefore excellent along active logging roads.

The area is characterized by limestone karst formations, and has historically been the location of a number of mining operations. The Benson Lake Coast Copper Mine, owned by Cominco Ltd., commenced operations in August 1962 and operated until January 1973. Over the operating period, a total of 3.6 million tons of ore were mined. The underground operation and adjoining concentrator processed 750 to 850 tpd, and discharged the tailings under permit into Benson Lake.

Throughout the operation of the mine, the company experienced problems with lake turbidity caused by suspension of the finer colloidal fractions of the tailings (Hallam et al. 1974). During mine operations, benthic organisms in Benson Lake were eliminated by tailings deposition (Kussat et al. 1972), and tailings fines were found in the outlet Benson River. As a result, resident fish in the lake were observed to preferentially feed on aquatic and terrestrial invertebrates found in drift entering the system from inlet streams. High zinc concentrations in both water and fish flesh were observed although the metal concentrations in fish from Maynard Lake, a control lake, were found to be similar to those found in Benson Lake fish. Maynard Lake flows into Benson lake over a power dam and via the Raging River (Figure 1-1). A study carried out 10 months after operations ceased found an improvement in lake water clarity, although metal concentrations in the water and fish tissue had not changed (Hallam et al. 1974). Hallam et al. concluded improvements in productivity and benthic invertebrate recolonization could be expected.

The present study constitutes the initial stage of a field assessment of the lake's recovery from subaqueous disposal of reactive mine wastes. The study is part of CANMET's Mine Environmental Neutral Drainage (MEND) program. The 1989-90 work included mapping the bathymetry of the lake, and establishing staff/crest gauge and discharge


BENSON LAKE
PROJECT LOCATION
&
HYDROLOGY SITES
N
PROJECT LOCATION
VANCOUVER IS.
BENSON RIVER
Benson Lake
RAGING RIVER
Dam
Maynard Lake
CRAFT CREEK
BENSON RIVER
Iron Lake
LEGEND
Staff & Crest Gauge Sites
▲ November 1989
△ March 1990
Stream Profile & Discharge Site
● November 1989
○ March 1990
BENSON LAKE
DWG : PWD
FIGURE 1-1
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sites on inlet streams including the Raging River, Benson River and Craft Creek and the outlet stream (the Benson River).

1.1 Background Review

Cominco's Coast Copper mine mined two underground deposits - Benson Lake and Coast Copper. The mine operated between August 1962 to January 1973 when it closed down because of unfavourable economics conditions. Although rates at 750 tpd, the mill often processed up to 850 tpd. Copper concentrate was produced from high grade ore (mean grade 2.02% Cu); later, a magnetite recovery plant began operation in March 1963 producing iron concentrate (64-65% Fe) from iron plant feed assaying 29% Fe. The iron plant was shut down in September 1970 because sulphur content in the concentrations exceeded specifications.

The mill discharged tailings under permit into Benson Lake, because terrain constraints pre-empted land tailings disposal into a conventional impoundment. A bathymetric map of Benson Lake from a March 1970 survey includes the location of the three Secchi disk stations and the initial tailings discharge site (Figure 1-2, Kussat et al. 1972). From the estimated mineral composition of the tailings (Table 1-1) the sulphur content was estimated at approximated 1% (Rescan 1989).

Excessive turbidity in Benson Lake was an immediate and lingering problem throughout the mine's operation (Cominco's Benson Lake pH, clarity, Secchi and turbidity monitoring data for 1961-68, Hallam et al. 1974, Kussat et al. 1972). The tailings contained a poorly settling colloidal fraction that the Cominco and government reports did not identify. Comparisons of the analyses of Benson River solids with magnetic plant tailings indicate they were quite similar (Table 1-2).

Cominco attempted unsuccessfully to mitigate the problem through testing and use of various flocculants. At the request of the Fisheries Service, Cominco twice moved the tailings outfall to deeper portions of the lake. After 1970, tailings were discharged into a tailings float and the flocculating agent Alchem D176 was added to the mixture at the float site (Kussat et al. 1972). Tailings were discharged at a depth of 30.5 m, with a settling clearance of approximately 14 m.

Despite these measures, the turbidity problem remained, particularly during the winter months when the lake was isothermal. Hallam et al. (1974) suggested this resulted from

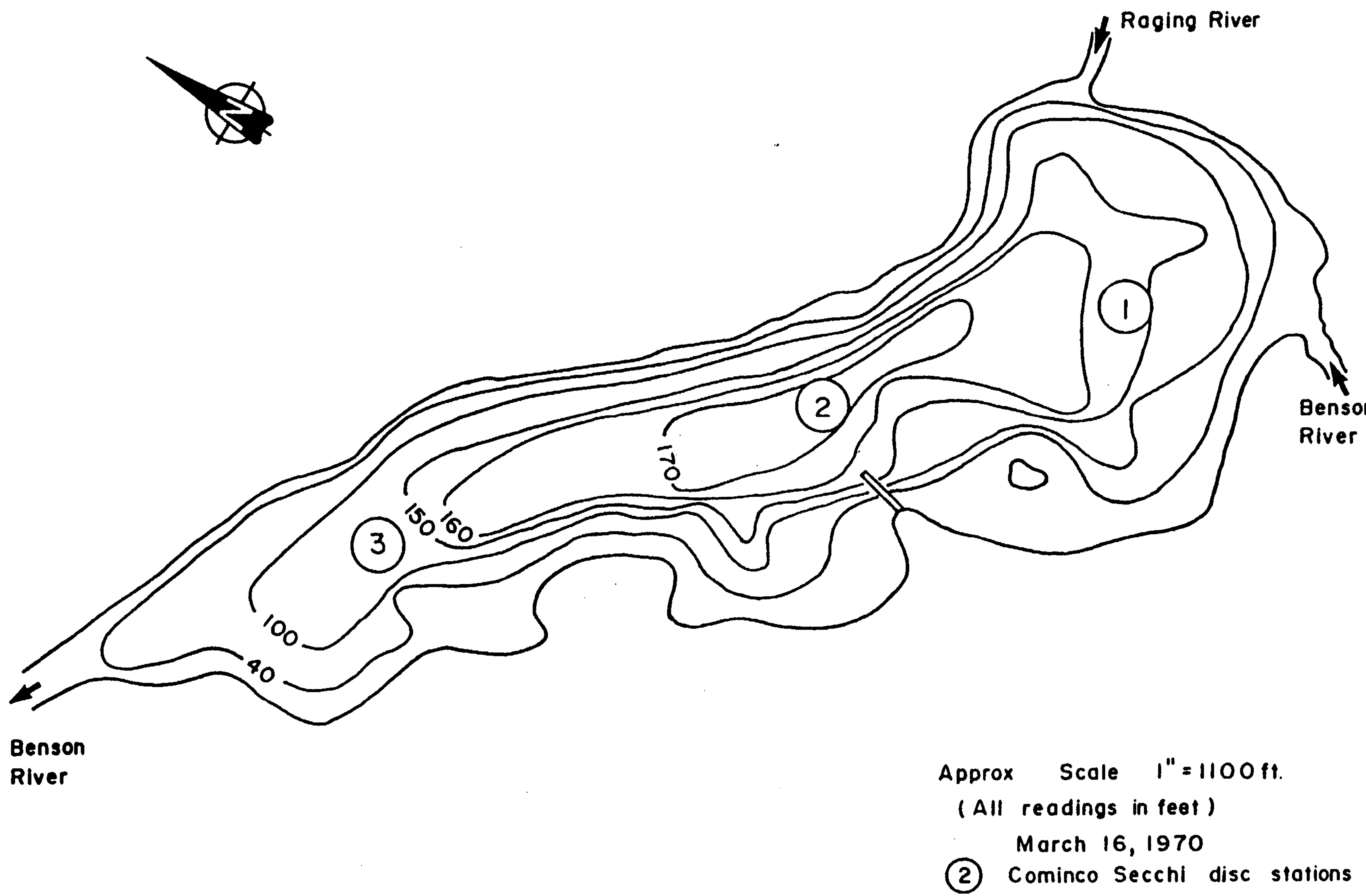

Figure 1-2 Benson Lake Showing Contours, Secchi Disc Stations, and Discharge Location

Rescan

Table 1-1

Estimated Mineral Composition for Coast Copper Mine Tailings[1]

Mineral	Estimated Percentage in the Tailings
Garnet	32.00
Epidote	27.00
Calcite	3.00
Feldspar	4.00
Diopside	0.50
Actinolite	0.50
Chlorite	0.50
Quartz	0.30
Sericite	0.30
Magnetite	28.80
Chalcopyrite	.11
Bornite	.10
Pyrrhotite	1.00
Pyrite	1.00
Unidentified	.89
Total	**100.00**

[1] 1960 Cominco internal memo.

Table 1-2

Spectrographic Values for Benson Lake Magnetic Plant Tailings (XRD 5200) and Benson River Solids (XRD 5201)[1]

Semi-Quantitative Spectrographic Analysis (in approximate%)				
	Benson River Solids at Kathleen Lake Outlet		Tailings	Benson River Solids
	+325 Mesh	-325 Mesh	XRD 5200	XRD 5201
Al	3	3	7	5
Ba	<0.01	<0.01	<0.01	<0.01
Ca	3	3	10	3
Cr	<0.01	<0.01	<0.01	<0.01
Co	<0.01	<0.01	0.01	0.01
Cu	0.05	0.01	0.05	0.2
Ga	<0.01	<0.01	<0.01	<0.01
In	-	-	<0.003	<0.003
Fe	7	7	5	5
Mg	1	1	1	1
Mn	0.1	0.1	0.2	0.1
Mo	-	-	<0.01	<0.01
Ni	<0.01	<0.1	<0.01	<0.01
Pb	0.01	0.01	-	0.01
K	0.1	0.1	0.1	0.1
Si	30	30	25	20
Ag	<0.003	<0.003	<0.003	<0.003
Na	1	1	5	3
Sr	<0.01	<0.01	0.3	0.02
Ti	0.1	0.1	0.5	0.5
V	0.01	0.01	0.05	0.05
Zn	2	2	<0.01	0.03
Zr	-	-	0.01	0.01

[1] 1967 Cominco Internal memo.

stratification in the lake during summer, creating a thermocline that acted as a density differential barrier preventing the colloidal tailings in the hypolimnion from entering the upper epilimnion. At the fall turnover, the colloidal tailings were dispersed throughout the water column (Kussat et al. 1972). Seasonal changes in thermal stratification in the lake are shown in Figures 1-3 to 1-5. A summary of Cominco's major mitigation efforts are presented in Table 1-3.

Table 1-3

Mitigation Efforts at Benson Lake

Tailings Outfall Location	Dates	Ore Treated Short Tons	Lake Depth m	Downpipe Length m
Initial	Aug./62 - Sept./64	550,000	42.7	30.5
First move; 305m down lake plus raft	Sept./64 - Nov./70	1,800,000	45.0	30.5
Second move; a further 305m down lake	Nov./70 - Jan./73 (mine closed)	900,000	48.8	45

[1]1967 Cominco internal memo.

Field studies in 1967, five years after the mine started up, found the entire lake bottom was overlain by tailings and there was no benthic invertebrate life (Kussat et al. 1970). Even the outlet Benson River had a layer of tailings fines on the bottom, and most of the benthic invertebrates present were turbid water species (*Ephemerella* spp.). By comparison, mayflys, especially *Baetis* spp., were more common in the inlet Raging River. Gillnetting in 1968 caught rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*O. clarki*), Dolly Varden char (*Salvalinus alpinus*) and sculpin (*Cottus asper*). These fish were feeding on a variety of aquatic and terrestrial insects.

No differences were noted in heavy metal content between cutthroat trout fish samples from Benson and Maynard Lakes (Table 1-4). However, the small sample size (2 trout per lake) make the comparative results inconclusive. Benson Lake water analyses from about the same time are also included in Table 1-4. Relatively high zinc levels in both

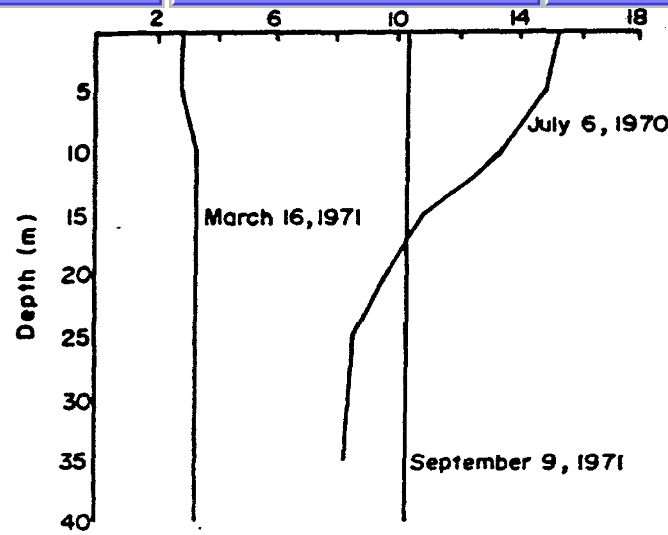

Figure 1-3 Benson Lake Thermal Stratification, Station 1 Temperature °C

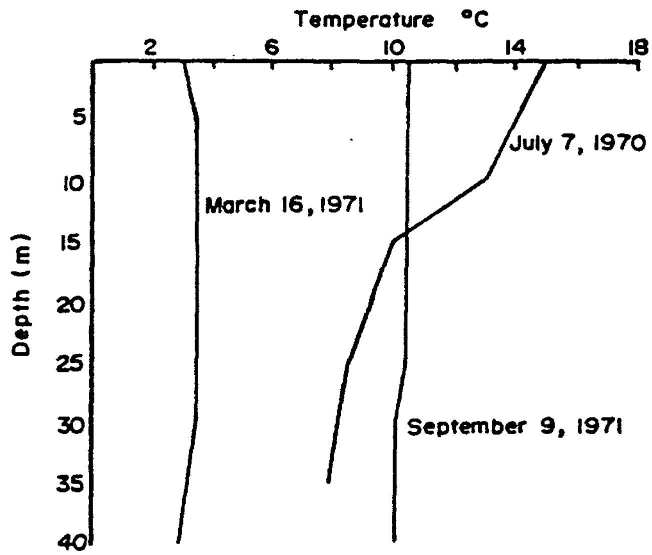

Figure 1-4 Benson Lake Thermal Stratification, Station 2 Temperature °C

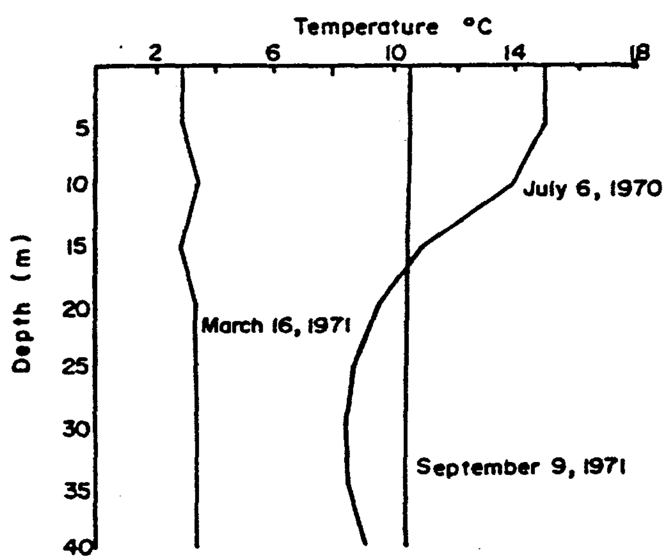

Figure 1-5 Benson Lake Thermal Stratification, Station 3 Temperature °C

Table 1-4

Mean Concentrations of Some Heavy Metals in Trout and Water from Benson and Maynard Lakes[1]

Specimen	Benson Lake Metals	Benson Lake Water (ppm)	Benson Lake Fish (ppm)	Maynard Lake Fish (ppm)
Cutthroat Trout (*Salmo clarki*)	Hg	<0.00005	0.1	0.1
	Cu	<0.005	0.2	0.3
	Zn	0.06	6.5	8.5
	Pb	<0.01	0.1	0.1
	Cd		0.1	0.1

1 Fish samples taken March 16, 1971; water sample taken February 2, 1971; heavy metal analyses by Cominco's Trail laboratory. Data from Kussat et al., 1972.

the fish tissue and lake water were noted. Benson Lake water was classified as soft watered and oligotrophic, and high zinc was reported earlier in Benson River water. Soft water enhances the potential for heavy metal toxicity to aquatic organisms.

Lake soundings were completed in March 1970 to determine bathymetry in the region of the outfall (Figure 1-2, Kussat et al. 1972). Relative to 1962 Cominco readings, the lake depth had not been significantly altered.

Extensive turbidity surveys in 1970 and 1971 were done in an attempt to understand the role of temperature stratification in lake water turbidity. The temperature regimes at Stations 1, 2 and 3 indicate that in July 1970 that the lake was stratified Figures 1-3 to 1-5; a thermocline was found in between the depths of the 7.5 and 20 m. Subsequent surveys measured isothermal conditions on March 16, 1971 and again on September 9, 1971, suggesting an early fall turnover. On these dates, suspended tailings solids were found to be present throughout the water column to a depth of 50 m at Station 2. This finding was confirmed at two additional stations. It was suggested that turbidity in the lake during the winter was due to material entering from the inflow streams. Monthly Secchi disk results are plotted for 1968 and 1970 (Figures 1-6 and 1-7).

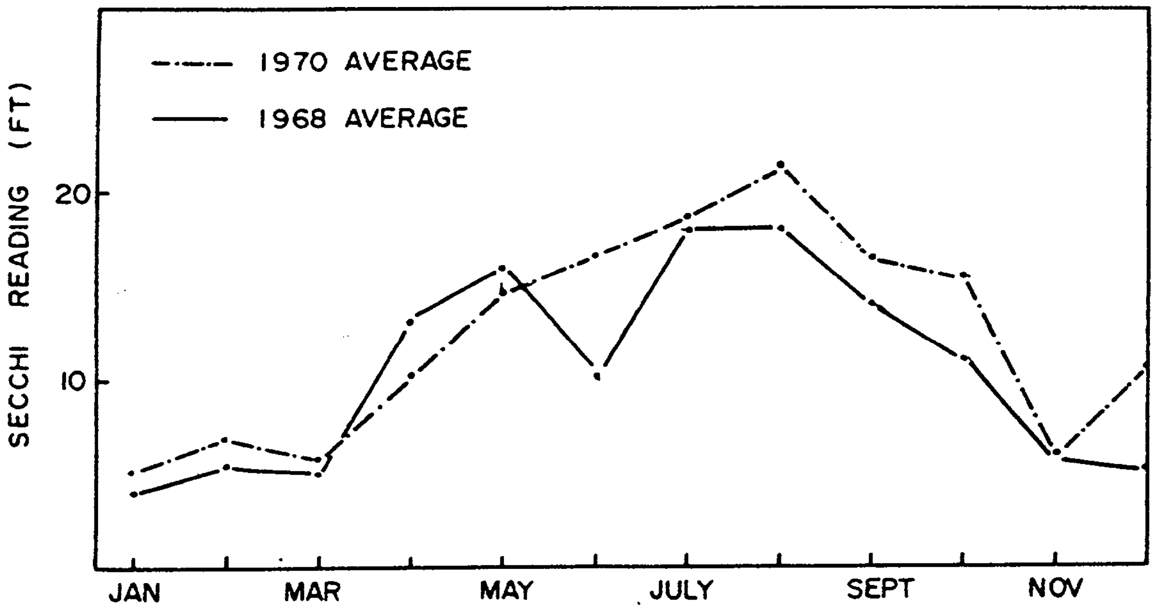

Figure 1-6 1968 and 1970 Average Secchi Disc Values, Benson Lake Station 2

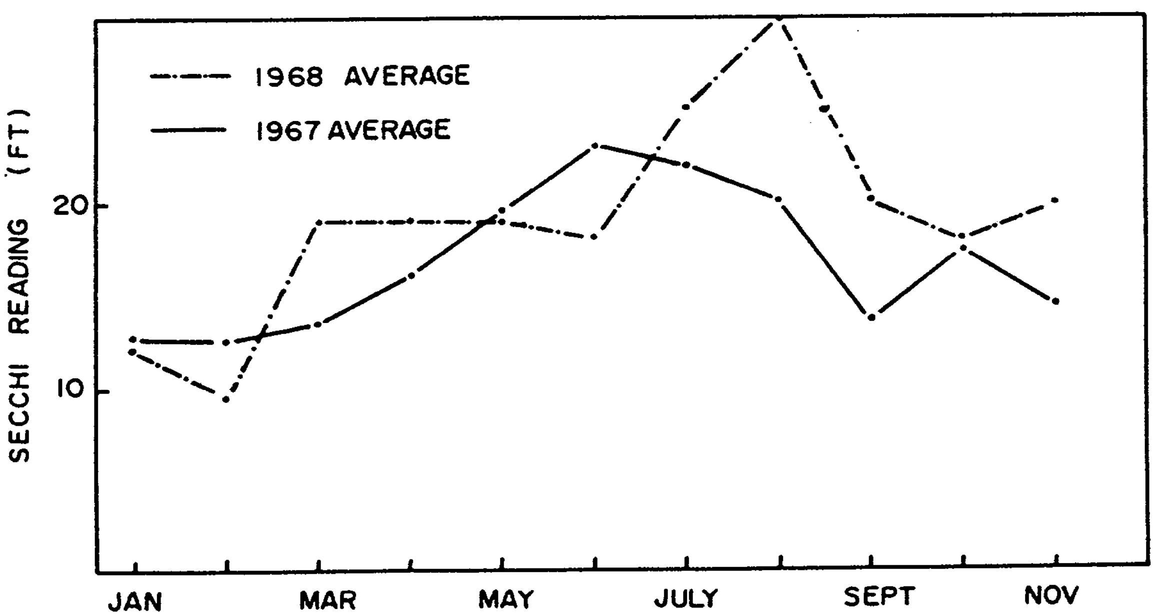

Figure 1-7 1967 and 1968 Average Secchi Disc Values, Maynard Lake

In November 1973, some 10 months after the mine shutdown and after the fall turnover, EPS conducted a survey of Benson Lake to determine early recovery of physical and chemical characteristics, and to assess any continued impacts to the biota (Hallam et al. 1974). A marked reduction in turbidity was noted, although total metal concentrations in lake water and fish tissue were unchanged in 1971 and 1973. The lake bottom was still devoid of life, and resident trout were still feeding on drift organisms and appeared to display slow growth as a result.

2 - Methods

2.0 METHODS

2.1 Lake Morphometry

A bathymetric map of Benson Lake was constructed from timed depth profiles taken at a slow speed along predefined transects using a Lowrance X16 Computer Sonar sounder. Soundings were conducted on November 3, 1989. From the sounding charts and the resulting bathymetric map, a number of morphometric parameters were calculated (Hutchinson 1957). The calculated parameters included:

- maximum length;
- maximum breadth;
- area;
- volume;
- maximum depth;
- mean depth;
- relative depth;
- shoreline length; and
- shoreline development factor.

Lake volume was calculated as the area under the hypsographic curve.

The maximum length is a measure of the longest fetch available for wind effects. The relative depth is an expression of maximum depth with respect to mean diameter and is an indicator of lake stability. The shoreline development factor is the ratio of shoreline length to the length of the circumference of a circle with the same area of the lake. The shoreline development factor is indicative of the potential for littoral community development in proportion to the lake volume.

2.2 Staff and Crest Gauges

Staff gauges, consisting of one or more 1 m water survey gauge plates, were mounted on lengths of 2" x 4" lumber which were fixed to structures thought to be stable at the streams edge. Staff gauges were attached to bridge abutments at the inlet of Benson River on November 3, 1989 and Craft Creek on March 4, 1990 (Figure 1-1). Gauges were fastened to stumps or well embedded deadwood at the outlet into Benson River, and at the mouths of Raging River and Craft Creek on November 2-3, 1989 (Figure 1-1). Crest gauges to measure the maximum stage of the river between readings were strapped to each staff gauge. Depth readings were taken from crest gauges to the nearest mm with a tape measure.

Two field trips were conducted to position the gauges. Gauges were installed at low water on November 2-3, 1989. A second field trip on March 4, 1990 was conducted to check gauge condition and monitor depths. Unfortunately, access was difficult due to high water and a boat was not available. Staff gauge readings were taken, but some crest gauges were not checked or reset. Over the winter, the gauges near the mouth of Craft Creek was carried away by high flows. A hopefully more secure site at the mainline bridge was therefore selected and replacements gauges installed on March 4, 1990.

2.3 Stream Profile and Discharge

In the proximity of each gauge site, a stream profile site was selected on November 4, 1989 which could be safely waded at low flow. At these sites, the width of the wetted channel was measured to the nearest 10 cm with a surveyor tape. At set intervals of 1 to 3 m, depending on the stream width, depth measurements were taken with a wading rod (to the nearest cm). The data were then used to prepare stream profiles .

Two of the profile sites were changed during the March 4, 1990 trip. The inlet site on the Benson River was moved because the original site was too deep to wade, while the Craft Creek site appeared too turbulent for an accurate discharge measurement.

Current velocity measurements were taken at 60% of the depth below the surface at each interval along the profile. Velocity was measured with a Marsh McBirney flow meter to the nearest 0.5 cm/s. This depth approximates the mean velocities at depths <0.76 m (Nielsen and Johnson 1983). Discharge was approximated by summing the products of velocity x depth x interval width for each interval of the profile.

3 - Results and Discussion

3.0 RESULTS AND DISCUSSION

3.1 Lake Morphometry

Benson Lake is approximately 2.1 km long at the longest fetch which is oriented NW-SE (Figure 3-1). Mean breadth (width) is 0.35 km at right angles to the maximum fetch. The lake is relatively deep with a maximum depth of 54 m and a mean depth of 25.5 m. The area of the lake surface was estimated at 7.73 x 10^5 m^2. The relative depth is 5.4% which indicates Benson Lake is a small, but deep lake which probably has quite high stability (Wetzel 1975). The shoreline is 5.4 km long, while the shoreline development factor is 1.7. This factor suggests the lake is elliptical in shape but has only moderate potential for littoral community development (Wetzel 1975).

Although the units and differences between isopleths differ, the present bathymetry of Benson Lake (Figure 3-1) is similar to that observed in 1970 (Figure 1-2). However, the deeper portions of the lake differ slightly. The area within the 50 m isopleth in Figure 3-1 is much smaller than the area within the 170 ft (52 m) isopleth in Figure 1-2.

3.2 Staff and Crest Gauges

Staff and crest gauge data collected to date are listed in Table 3-1 and the sites located on Figure 1-1. The gauges in the lake outlet were measuring the stage of the Benson River on November 3, 1989, but were more indicative of lake level on March 4, 1990. Therefore, a second station was installed downstream of the outlet and just below the mainline bridge on March 4, 1990. Unfortunately, its location is also tenuous, and a third more stable site should be established below the outlet of the lake. This would require access by boat.

3.3 Stream Profiles and Discharge

The stream profiles at each of the discharge sites are given in Figures 3-2 to 3-7 along with the raw profile data. Discharge calculations and corresponding staff gauge readings are summarized in Table 3-2. While these data are not sufficient to produce hydrographic rating curves, the data can be used to comment on the accuracy of the discharge measurements. The net inflow in November 1989 can be calculated as

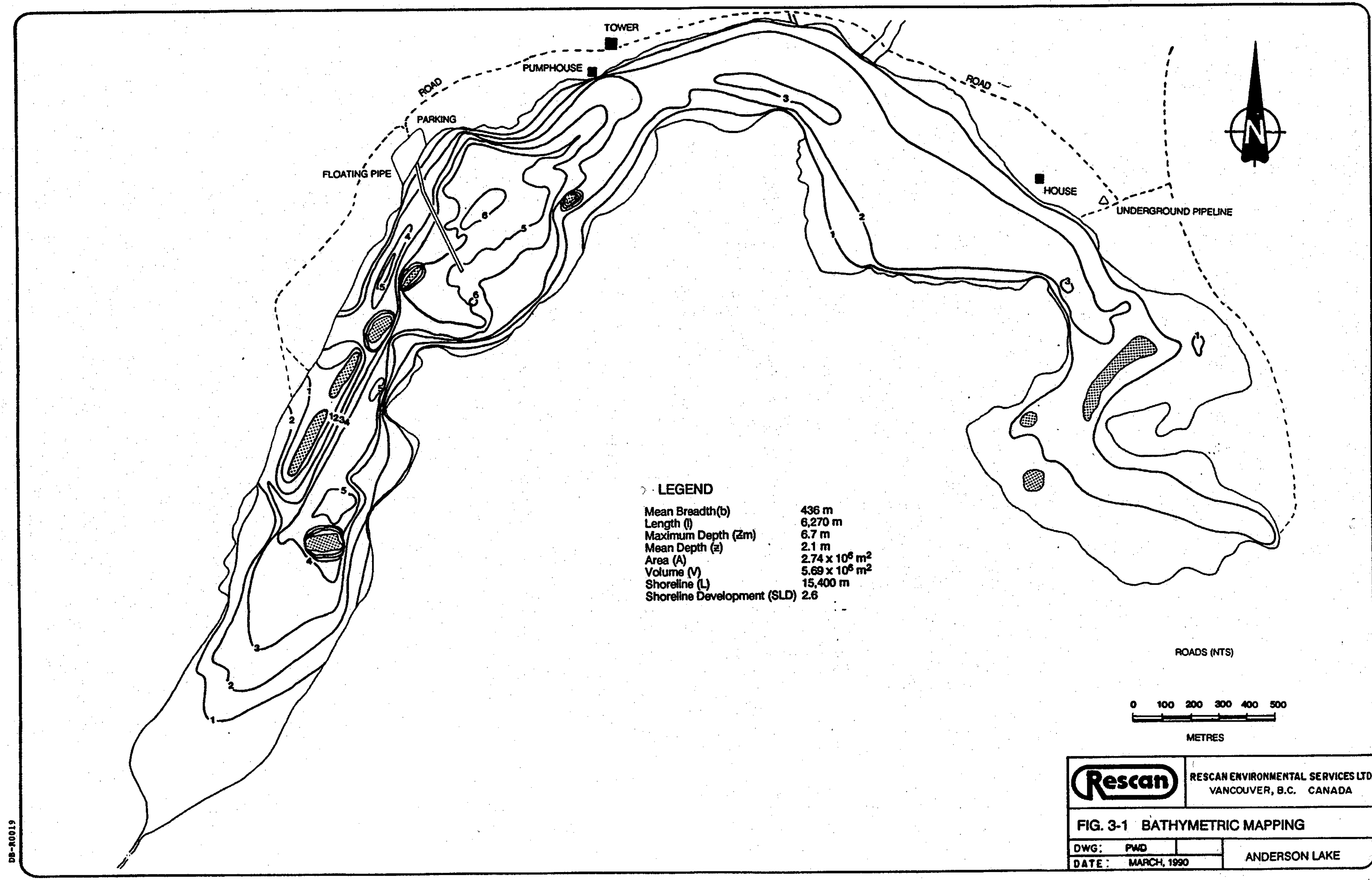
TOWER
PUMPHOUSE
ROAD
PARKING
FLOATING PIPE
ROAD
HOUSE
UNDERGROUND PIPELINE
LEGEND
Mean Breadth(b) 436 m
Length (l) 6,270 m
Maximum Depth (Zm) 6.7 m
Mean Depth (z) 2.1 m
Area (A) 2.74 x 10⁶ m²
Volume (V) 5.69 x 10⁶ m²
Shoreline (L) 15,400 m
Shoreline Development (SLD) 2.6
ROADS (NTS)
0 100 200 300 400 500
METRES
Rescan
RESCAN ENVIRONMENTAL SERVICES LTD.
VANCOUVER, B.C. CANADA
FIG. 3-1 BATHYMETRIC MAPPING
DWG: PWD
DATE: MARCH, 1990
ANDERSON LAKE
DB-R0019

Table 3-1

A Summary of Staff Gauge and Crest Gauge Stream Depths Collected from the Benson Lake Drainage During November 1989 and March 1990.

Stream	Location	Date	Depth(m) Staff gauge	Crest gauge
Benson R.	Lake outlet	11/02/89	0.500	
		11/03/89	0.525	
		03/04/90	0.960	
	Outlet bridge	03/04/90	0.840	
Craft Cr.*	Near mouth	11/02/89	0.209	
	At bridge	03/04/90	0.450	
Benson R.	Lake inlet	11/03/89	0.693	
		03/04/90	0.790	1.01
Raging R.	Pump house	11/03/89	0.030	
		03/04/90	0.180	

* **The two sets of staff gauge and discharge measurements for Craft Creek were taken at different sites.**

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Figure 3-2: Outlet Benson River stream profile and current data at a site located approximately 30 m upstream of the main road bridge, November 3, 1989.

Scale 1:200

Profile and Current Data: Stream width = 36.6 m

Distance from the South Bank (m)	Depth (cm)	Current (cm/s)
3	47	12
6	56	58
9	66	72
12	69	50
15	60	59
18	62	49
21	67	45
24	47	36
27	50	20
30	41	15
33	80	25
36	70	32

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Figure 3-3: Craft Creek stream profile and current data at a site located 50 m upstream of the main road bridge, November 3, 1989.

Scale 1:100

Profile and Current Data: Stream width = 8.9 m

Distance from the East Bank (m)	Depth (cm)	Current (cm/s)
1	35	65
2	54	55
3	61	51
4	55	0
5	57	18
6	80	62
7	67	268
8	50	53

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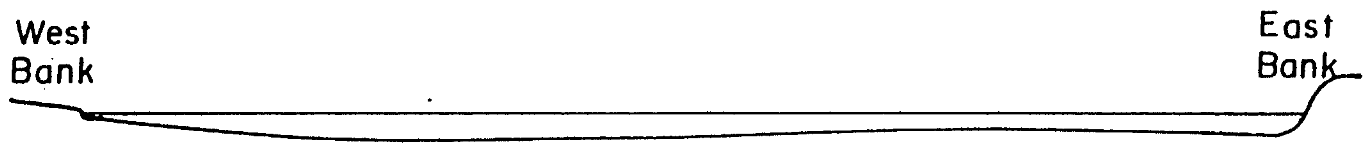
Figure 3-4: Craft Creek stream profile and current data at a site located <100 m downstream of the main road bridge, March 4, 1990.

Scale 1:50



<u>Profile and Current Data</u>: Stream width = 11 m

Distance from the East Bank (m)	Depth* (cm)	Current (cm/s)
2	6.1	24
4	33.5	32
6	62.5	41
8	82.3	35
10	33.5	15

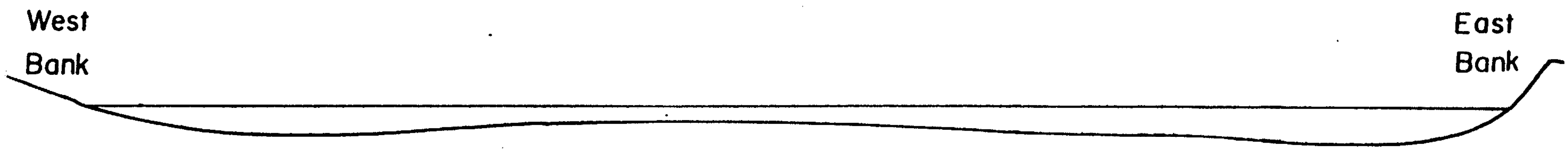
* - calculated by applying a factor of 30.48 to field measurements in feet.

Rescan

DB-R0022

Figure 3-5: **Inlet Benson River stream profile and current data at a site located approximately 15 m upstream of the pump house access road bridge, November 3, 1989.**

Scale 1:100



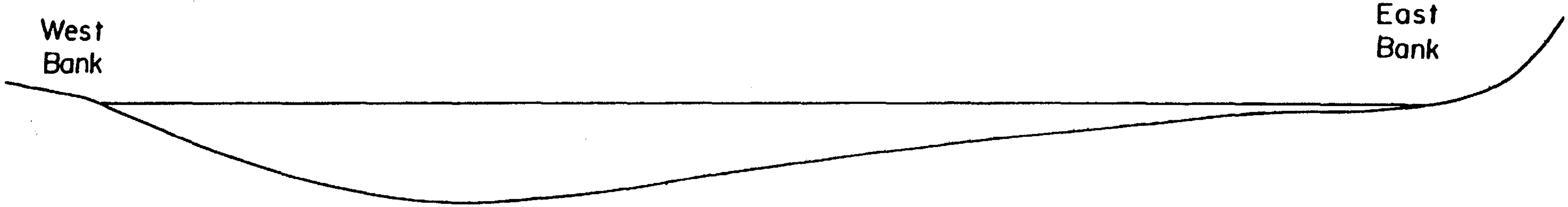
Profile and Current Data: **Stream width = 23.2 m**

Distance from the East Bank (m)	Depth (cm)	Current (cm/s)
2	50	21
4	55	50
6	56	67
8	47	43
10	40	58
12	39	21
14	28	28
16	31	22
18	48	18
20	45	28
22	30	15

DB-R0022

Figure 3-6: Inlet Benson River stream profile and current data at a site located approximately 10 m downstream of the pump house access road bridge, March 4, 1990.

Scale 1:100



Profile and Current Data: Stream width = 32.8 m

Distance from the West Bank (m)	Depth* (cm)	Current (cm/s)
3	27.4	23
6	59.4	29
9	61.0	38
12	76.2	44
15	67.1	42
18	61.0	45
21	47.2	40
24	47.2	37
27	48.8	32
30	56.4	22.5

* - calculated by applying a factor of 30.48 to field measurements in feet.

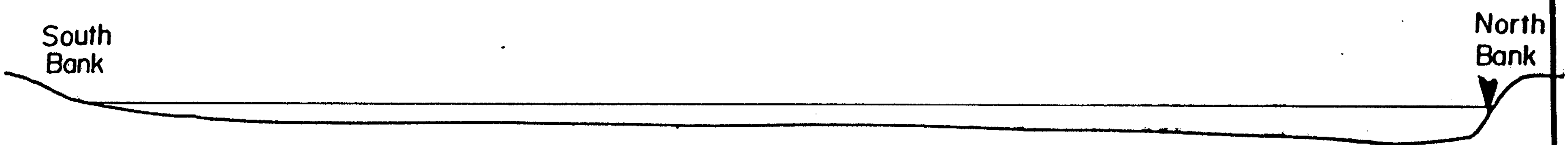
Rescan

DB-R0022

Figure 3-7: Raging River stream profile and current data at the staff/crest gauge site located approximately 30 m upstream of the mount, November 3, 1989

Scale 1:100

▼- Staff and Crest Gauge Site



Profile and Current Data: Stream width = 23 m

Distance from the South Bank (m)	Depth (cm)	Current (cm/s)
3	37	29
5	40	34
7	34	38
9	48	29
11	53	44
13	40	29
15	53	73
17	45	31
19	52	82
22	50	25

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Table 3-2

Discharge Estimates for Streams in the Benson Lake Drainage During November 1989 and March 1990.

Stream	Date	Staff Gauge Depth (m)	Discharge (m/3s)
Benson R. (lakeoutlet)	11/03/89	0.525	8.5
Craft Cr.*	11/03/89	0.209	1.9
	03/04/90	0.450	1.4
Benson R. (lake inlet)	11/03/89	0.693	3.35
	03/04/90	0.790	6.0
Raging R.	11/03/89	0.030	4.15

* **The two sets of staff gauge and discharge measurements for Craft Creek were taken at different sites.**

9.5 m3/s, while the outflow through Benson River was 8.5 m3/s. While the methods involve opportunity for incorporation of variability, this difference appears significant. The reasons may be in the use of turbulent profile sites for a discharge model that assumes laminar flows. To utilize acceptable sites, however, considerable effort will have to be made to install cross-stream cables and more velocity measurements will be required at the greater depths encountered.

References

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