THE EFFECT OF EQUITY SILVER MINE ON GOOSLY LAKE

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Summary

This report consists of data tables and interpretation on Goosly Lake, near the Equity Silver Mine, near Houston, British Columbia. Goosly Lake is the closest large water body to the minesite, and has received contaminants from the minesite in the form of seepages, spills, and treated acid mine drainage. The Waste Management Branch has examined conditions in the lake to determine the effect of these contaminants on lake water quality and biota.

The data shows clear evidence of increased concentrations of certain trace metals during the spring of 1982 after a spill of sulphuric acid on the minesite in late 1981. Since the beginning of the discharge of treated acid mine drainage, sulphate has continued to rise in concentration in the lake. Lake pH and hardness may be influenced by the treated AMD as well. The lake is not as well buffered against strong acid as the inlet stream. Fish tissue zinc and liver cadmium exceed the provincial mean. Elevated hepatic metallothionein has been found in some fish livers taken from the lake. A species of metal sensitive phytoplankton has recently appeared but it is not known to have previously existed in the lake prior to mine start-up.

Some preliminary water quality objectives and a suggested monitoring program are included. These suggestions will be followed up by a comprehensive assessment of the Buck and Foxy-Maxan systems to be carried out in 1987.

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Part 1 Water Quality

Introduction

Goosly Lake lies about 5 km from the Equity Silver Mine. The mine elevation is 1280 m above sea level, the lake lies at 900 m above sea level (Figure 1). The main drainage from the minesite is Bessemer Creek, which joins Buck Creek 0.5 km above the lake. Since the start of mining in 1980, there have been higher than background concentrations of sulphate, suspended solids, nitrate and various heavy metals in Bessemer Creek, which may be having an effect on Goosly Lake. While the lake contains a recreational trout fishery, it is of minor importance. The lake is very important, however, in that it drains to the lower Buck Creek system which is a major spawning and rearing stream for salmon, steelhead and resident trouts. Buck Creek also is used as a domestic water supply by residents on Buck Flats near Houston. If water quality declines in Goosly Lake, the consequences will eventually be felt downstream. Of particular concern is contamination by metals such as copper, zinc, arsenic and cadmium. These metals are known to be toxic to aquatic organisms at low concentrations, and their toxicities can be synergistic if the metals occur together (Finlayson and Verrue 1982). For these reasons it is unacceptable for Goosly Lake to be contaminated.

The major waste of interest here is waste rock which is acid generating. The formation of acid mine drainage (AMD) and its chemical characteristics is documented elsewhere. Despite efforts to collect and treat AMD at the minesite, water quality in Bessemer Creek has been influenced by spills and seepages from time to time. In April of 1984, 1985 and 1986, the creek water was toxic to fish due to excess copper and zinc.

Since a 1981 spill of sulphuric acid at the minesite and the subsequent discovery of acid mine drainage a large amount of water quality data for the lake have been collected. These data include water chemistry, biological materials and sediment chemistry. The data were collected in order to define environmental changes brought on by the metals and other contaminants being loaded to the system by Bessemer Creek. This report will summarize and assess the variables of importance and assess the effect of the mine drainage on the lake. Based on these findings, recommendations are needed for lake water quality objectives, and an appropriate monitoring program for the future.

Morphometric data for Goosly Lake are found in Table 1.

Table 1 Goosly Lake Morphometric Data

elevation	900 m	max. depth	23 m
area	241.5 ha	perimeter	12,039 m
volume	24,869 dam^3	flushing rate	0.9 yr
mean depth	10.3 m	retention time	1.1 yr

Very little water quality data are available for Goosly Lake prior to mine start-up. This fact has limited our ability to assess whether changes have taken place in the lake.

Methods

Sampling locations on Buck and Bessemer Creek, and in the lake are shown in Figure 1. Sites on Buck and Bessemer Creek have been sampled intensively by both Equity and the Waste Management Branch since early in 1982. Lake water was sampled through the ice over that winter. May 1982 was our first opportunity to examine the lake by boat and take standard limnological measurements. Grab samples in sreams were analyzed for major ions, nutrients and metals. Metal samples were field filtered and acidified. All samples were usually shipped to the Ministry of Environment Lab the same day as collected. Samples in Goosly Lake were collected from a boat using a 4 litre Van Dorn bottle designed for preventing metal contamination.

Table 2 outlines our monitoring activities on the lake to the end of 1985. It shows we made eleven visits to the lake between 1982 and 1985. Four visits were made in 1986. Site 0700084 at mid-lake was sampled consistently. Variables measured on each occasion include profiles of temperature and oxygen, total and dissolved metals, major ions (sulphate, nutrients) and phytoplankton. Sediments, fish tissues and zooplankton have been collected less frequently.

Loadings to the Lake Since 1981

Bessemer Creek and Goosly Lake were sampled intensively over the winter following the acid spill in late 1981. What follows is a rough calculation of

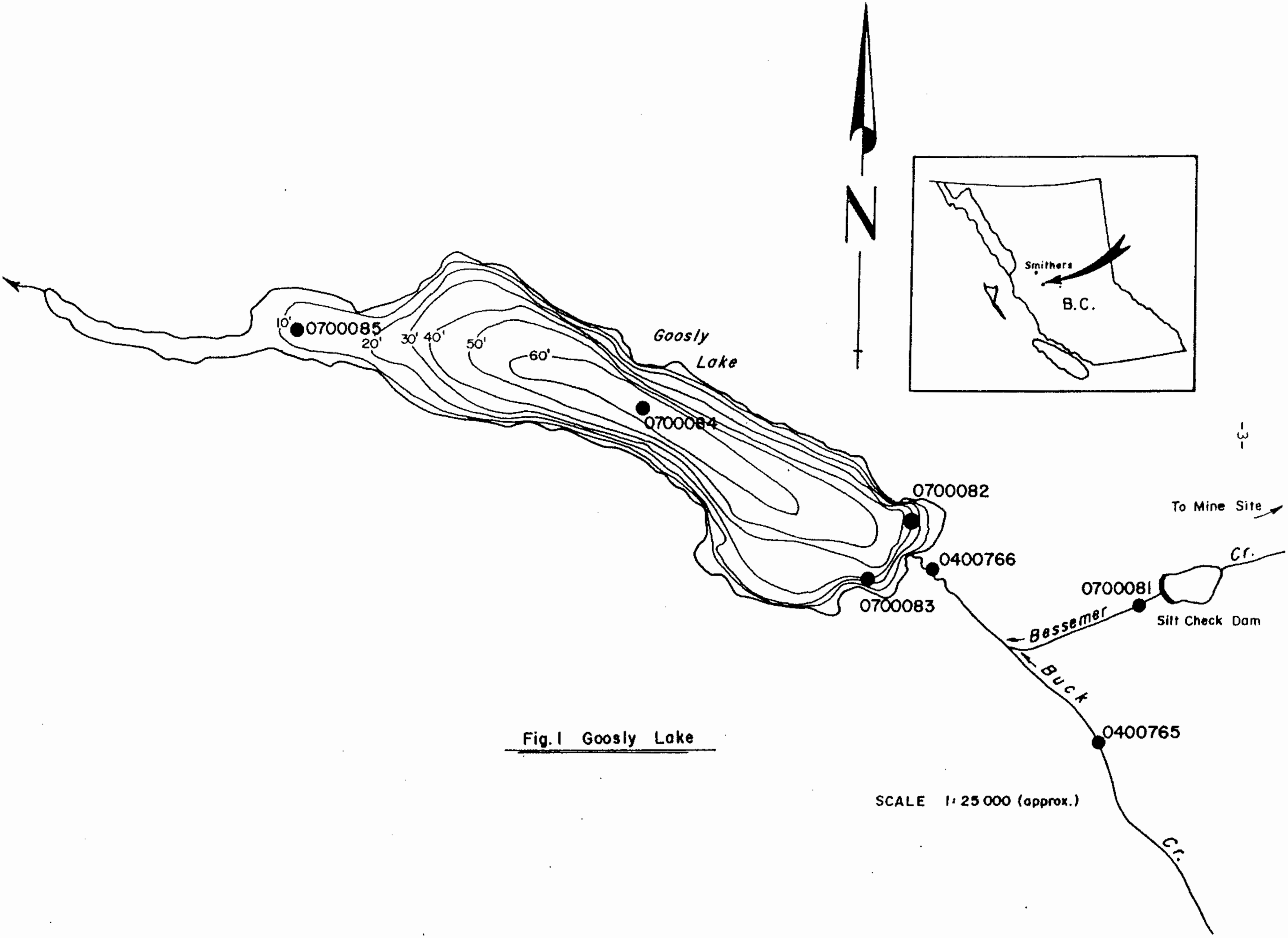

Fig. 1 Goosly Lake

TABLE 2
MONITORING ACTIVITIES ON GOOSLY LAKE, 1982-1985

site	depth (m)	T-DO Profile	Secchi	T & D Metals	Major Ions	Sediment	Fish Tissue	Phyto-plankton	Zoo-plankton
	20 May 1982								
0700082	1,5,8	X	X	X	X			X	
0700084	0,1,5,8,15	X	X	X	X			X	
0700085	1	X	X	X	X			X	
	20 September 1982								
0700082	0,1,3,5,8	X		X	X			X	
0700084	0,1,5,8,15	X		X	X			X	
0700085	0,1	X		X	X			X	
	14 October 1982								
0700084							X		
	4 May 1983								
0700084	0,10			X	X		X	X	X
	16 May 1984								
0700084	2,16	X		X	X			X	X
near 0700082	cores					X			
	15 August 1984								
0700084	1,3,10	X		X	X			X	X
	5 February 1985								
7 sites	2 depths	X		X	X				
	28 May 1985								
0700084	1,16	X	X	X		X	X	X	X
0700085	0		X	X	X				
0700082	0		X	X	X	X	X		
	17 July 1985								
0700084	1,16	X	X	X	X	X		X	X
0700085						X			
0700082						X			
	19 August 1985								
0700084	2,15	X	X	X	X			X	X
	30 October 1985								
0700084	1,14	X	X	X	X			X	X

how much metal flowed into the lake in the first year of measurement. According to the hydrology study (Kerr, Priestman, 1983) mean annual discharge is 14 $l/s/km^2$ for streams in the area. The Bessemer drainage, excluding the Southern Tail Pit, is 8.1 km^2. Therefore the mean flow is 113.4 l/s or 0.1134 m^3/s, (9798 m^3/day). Similarly, Buck Creek flows emanate from a 55 km^2 watershed, resulting in a mean flow of 770 l/s (6653 m^3/d).

If we multiply these flows by the mean concentration of contaminants, an estimate of loadings to Buck Creek and the lake, over and above natural loads, can be made.

Table 3 shows loadings in kg/d for sulphate, total (T) copper, dissolved (D) copper, total zinc and dissolved zinc, for the period 81/11/20 to 82/11/16 (year 1) at stations on upper Buck Creek, Bessemer Creek and at the lake inlet.

Table 3 Loadings to Goosly Lake
Year 1: 81/11/20 to 82/11/16
(kg/d)

	Natural (control) loadings + Upper Buck Creek 0700765	Bessemer Ck = 0700081	Predicted Loading to Goosly Lake
sulphate	459	2743	3202
T Cu	1.13	6.2	7.33
D Cu	.12	5.10	5.22
T Zn	1.60	6.22	7.82
D Zn	.67	4.50	5.17

Once again, baseline data is poor for upper Buck and Bessemer Creek prior to mine start-up. According to data assembled in Osborne and Hallam (1982) average baseline (preoperational) values for Bessemer and Buck Creeks are as follows.

Table 4 Preoperational Values for Sulphate, Cu and Zn
in Buck and Bessemer Creeks

	BUCK CREEK +				BESSEMER CREEK =				PREDICTED LOADING TO GOOSLY LAKE kg/d
	mean value mg/l	S.D.	N	kg/d	mean value mg/l	S.D.	N	kg/d	
SO_4	10		1	665	27.5	23.4	4	229	894
T Cu	.02	.012	4	1.30	.071	.14	13	.69	1.99
D Cu	.0066	.0028	3	.43	.013	.0045	5	.13	.56
T Zn	.028	.026	4	1.86	.084	.19	15	.82	2.68
D Zn	.007	.0028	3	.46	.017	.009	6	.16	.62

From Table 4, loadings calculated on Buck Creek predischarge measurements are not much different from loadings shown in Table 3. However loadings from Bessemer are 12 times higher for SO_4, 9 times higher for total copper, 39 times higher for dissolved copper, 8 times higher for total zinc and 28 times higher for dissolved zinc in the year following the acid spill.

Overall, total loads of sulphate and metals to the lake during the period following the acid spill was higher than natural loadings and we thought this would be evident in chemical analyses of lake water. Total loading to Goosly Lake in year one increased 3.5 times for SO_4, 3.7 times for total copper, 9.3 times for dissolved copper, 2.9 times for total zinc and 8.3 times for dissolved zinc. It was also reasonable to assume, since the flushing rate is approximately .9x/year, that most of the material coming from the mine would still be in the lake. Our chief fear, in sampling the lake for the first time in 1982, was that whatever impacts there might have been had already happened.

Goosly Lake Water Quality

Table 5 presents a summary of major physical and chemical constituents in Goosly Lake. These will be discussed in turn.

A. Temperature and Dissolved Oxygen

Goosly is a typical dimictic lake with a normal temperature and oxygen regime. Dissolved oxygen is not shown in Table 5. We sample as soon after break-up as possible in order to catch the lake at spring overturn. During this period the lake is iso-thermal and well aerated to the bottom. The mixing at overturn also offers an opportunity to sample when all the water in the lake should theoretically have the same chemistry.

Mid-summer profiles reveal a well developed thermocline. Differences in the concentration of sulphate, conductivity and pH are evident between the epilimnion and hypolimnion in the summer of 1985. These differences disappear during fall overturn as shown by the 85/10/30 results in Table 5.

B. Suspended Solids and Turbidity

Measurements of suspended solids since 82/05/26 show a reasonably uniform pattern. Suspended solids at the mid-lake station are generally low, between 2 and 5 mg/l. Visual observation from the air in May of 1985 showed

TABLE 5
GOOSLY LAKE DATA FOR SITE 0700084
1982-86

Date	Depth (m)	pH	Cond uS/cm	Temp °C	Colour True units	SO_4 mg/l	Alk Tot mg/l	Hard ness mg/l	Chlor a ug/l	TKN mg/l	NH_3 ug/l	NO_2 NO_3 ug/l	Tot P ug/l	Ca T ug/l	Mg T ug/l
82/05/26	0			5					6.4						
	1	7.37	125	4.5	75	15.5			5.6				24		
	5	7.37	130	4.2	60	15.5			6.1				24		
	8	7.35	130	4.2	75	15.5							24		
	15	7.33	130	4.0	75	16							27		
82/09/20	0			16					1.9						
	1	7.1	107	15	40	15.2	35.6	43.3	2.3	.28	8	<20	19	12.1	3.2
	5	7.0	106	13	40	15.5	35.7	43.2	2.2	.28	5	<20	15	12.1	2.8
	8	6.8	104	11	50	15.2	34.4			.27	<5	50	16		
	15	6.8	107	6.2	50	15.4	35.2	44		.14	<5	140	17	12.2	3.3
83/05/04	0	7.2	105			14.2	36.7	42.1		.40	8	70	25	11.2	3.4
	10	7.2	109			14.2	37.5	47.4		.34	7	90	26	13.2	3.4
84/05/16	2	7.2	107	5.7	50	13.5	38.2	47.5	6.5	.40	<5	<20	28	12.8	4.1
	16	7.1	114	4.5	50	14.5	40.7	52		.32	<5	<20	24	13.3	4.6
84/08/15	1	7.6	102	16.6	40	11.8	38.7	40.4	4.0	.43	19	<20	24	12.2	3.5
	3			16.5											
	10	7.0	103	8.6	50	12.4	37.5	41.2		.35	<5	30	29	12.2	3.5
85/05/28	1	7.4	88	9.8	56	8.8	35.2	40.6	5.2	.45	16	<20	34	11.0	3.2
	16	7.3	107	4.5	40	10.9	42.3	47.5		.33	17	70	27	12.8	3.8
85/07/17	1	7.5	132	19.2	40	24.7	37.2	57.1	1.9	.33	9	<20	13	16.0	4.2
	16	6.9	104	6.4	40	10.6	40.6	47.2		.40	<5	110	35	12.9	3.8
85/08/19	2	7.1	133	16	28	25.2	36.3	57.5	5.5		12	<20		16.5	4.2
	15	6.5	107	6.9	40	11.8	37.9	46.7			10	120		13.5	3.7
85/10/30	1	7.5	132	5	50	21.6	40.5	58.6	18.9	.35	<5	<20	23	16.5	4.2
	14	7.5	128	4.8	40	21.4	40.4	57.8		.35	<5	<20	25	16.5	4.2
86/06/02	1	7.3	120	10.1	36	20.8	35.1	51.4	3.6	.43	<5	<2	22	13.9	4.1
	17	7.3	145	4.2	24	23.6	45.9	55.8		-	<5	-	30	16.4	4.8
86/07/16	1	7.3	140	15.3	70	32.6	33.8	61.1	5.1	.43	<5	<20	21	16.8	4.7
	13	7.0	127	5.9	60	23.6	39.4	53.8		.32	<5	4	20	14.2	4.5
86/08/11	1	7.5	142	19.5	50	33.1	34.5	63.6	3.3	.46	10	<20	14	17.8	4.5
	18	7.0	131	5.5	60	23.2	40.1	58.7		.36	5	90	33	15.8	4.7
86/09/30	1	7.3	143		50	30.9	36.2	57.2		.34	<5	<2	14	15.5	4.48
	18	6.9	137		40	22.3	42.9	55.4		.34	35	12	37	14.7	4.54

a plume of particulate material spreading into the lake from the mouth of Buck Creek. This material spreads and settles out in the east basin of the lake, and appears not to be measured at mid-lake. The origin of the sediment is presumed to be the upper Buck Creek watershed including material from the mine via Bessemer Creek.

Turbidity is measured in two ways. The Environmental Lab measures turbidity using a nephelometer. We utilize a Secchi disc in the field to determine light transmission at the lake surface. Nephelometer turbidity was measured in 1985 in the epilimnion and hypolimnion as follows:

Turbidity (N.T.U.) in Goosly Lake 1985

	85/05/28	85/07/17	85/08/19	85/10/30
Epilimnion	3.3	0.6	0.7	1.6
Hypolimnion	2.5	2.5	2.0	1.6

Here, turbidity is influenced at mid-lake by the freshet. As well, hypolimnetic turbidity appears more stable and higher than epilimnetic turbidity. It is felt this turbidity is induced by suspended particles smaller than those measured as suspended sediment (i.e. smaller than 1 micron). This means the particles are finely ground bits of mineral or organic matter or both. This requires further investigation to determine if the turbidity can be linked to metals levels. Table 9 shows that hypolimnetic iron is usually higher than surface values during the summer. It needs to be established if this turbidity and the iron are correlated, and if it originates from the Bessemer system.

Generally, secchi disc readings show no discernable trend. If algal standing crop declines, we expect surface clarity to increase.

C. pH, Sulphate, Alkalinity and Hardness

No pre-operation sulphate samples were taken in Goosly Lake so we do not have a good feel for the original levels. Sulphate is the major anion in acid mine drainage, and our calculations show that several tonnes of it entered the lake following the acid spill (Table 3). Sulphate was measured in the lake through ice holes at the east end from 81/11/27 by Waste Management Branch at stations 0700082 and 0700083. Mid-Goosly lake, station 0700084 was not sampled until 82/05/26. The data for the two east lake stations clearly shows two jumps in sulphate concentration between 81/12/10 and 81/12/31, and another between 82/04/01 and 82/04/15. The pattern in the lake suggests the station 0700082 is more influenced than the other, and values measured at 0700083 merely reflect normal hysteresis effects. A third increase occurred 82/03/05 and appeared to influence both stations (see Table 6). Sulphate levels in 1983, 1984 and early 1985 seem to be consistently in the 11 to 15 mg/l range, and during intensive sampling on 85/02/05 sulphate was very consistent at 12.4 (n = 13, S.D. = .2, Table 11). On the basis of these data it is evident that the spill and acid mine drainage influenced the lake in early 1982.

There is strong evidence of a trend toward higher concentrations of sulphate in the lake since then. Treated acid mine drainage has been discharged to the Bessemer Creek drainage (and subsequently to Buck Creek and Goosly Lake) since late May, 1985. During the period May to July 1985, 256,000 m^3 were discharged. Table 5 shows a definite discontinuity in the level of sulphate and calcium in Goosly Lake beginning in July 1985. The abrupt change is followed by a trend to higher concentrations through 1986. While pH and sulphate are negatively correlated in rainfall several studies indicate that in surface waters pH and sulphate are positively correlated (Krug 1985). There appears to be a weak positive correlation (r = .641, 95% confidence) between pH and sulphate since the discontinuity which occurred in July 1985. This correlation is most noticeable while the lake is stratified in the summer months with higher pH and higher sulphate concentrations in the epilimnion. This is most likely due to the Buck Creek discharge remaining in the epilimnion and not mixing with the cooler more dense water of the hypolimnion.

Calcium (and possibly magnesium) concentrations are increasing in the lake. It is assumed that the increase in calcium concentration is a result of liming (CaO) the acid mine drainage. If the calcium was from natural sources within the watershed there would be a noticeable increase in alkalinty. This is because in pristine freshwater calcium is accompanied by a proportional amount of bicarbonate.

Note in Table 5 that alkalinity has not increased. Indeed, alkalinity in Goosly Lake was approximately half the value of alkalinity in the inlet stream in February 1985. Figure 3 (page 22) shows titration curves indicating the volume of .02 N H_2SO_4 required to depress the pH of lake and creek water down to pH 4.5. Figure 3 shows that the lake is only half as well buffered against strong acid as the inlet stream.

The present conditions suggest alkalinity is not changing, hardness is slightly increasing, and pH seems to be increasing with addition of the treated AMD.

D. Nitrate

Nitrate, (NO_3) and Ammonia (NH_3) are the major forms of inorganic nitrogen in the lake. Nitrate and nitrite plus total Kjeldahl nitrogen (TKN) equals total nitrogen in the water. Kjeldahl N is a measure of all the organic forms of N plus ammonia. Nitrates are being monitored in the lake because of the possibility of nitrate enrichment from mine runoff which may contain explosives residues. Also, a shift in the proprtion of TKN which is ammonia may reflect a change in the nutrient dynamics in the lake. But as Nordin (1985) points out, the dynamics of nitrogen are tricky to interpret.

The forms of N in Table 5 show a slight increase in TKN from 1982 to 1983. Ammonia concentrations are variable but low. We feel the presence of ammonia on some occasions and absence on others may reflect respiration and decomposition in the lake. The same probably applies to nitrate, and no consistent trend appears in the data.

E. Conductance

Conductance increases with more dissolved ions, so that if sulphate or metals increase so should conductance. Table 5 and Table 6 show this relationship

TABLE 6

CONCENTRATION OF SELECTED VARIABLES, EAST GOOSLY LAKE

SITE 0700082 (WMB DATA)

Date	Sulphate mg/l	Conductance	pH	D Cu mg/l	D Zn mg/l
81/11/27	17.3	124	7.32		
81/12/10	23.6	152	7.07		
81/12/17	20	139	7.15	.003	.006
81/12/31	24.1	156	7.12	.002	.008
81/01/18	14.5	140	6.7	.007	<.005
82/02/04	12.9	129	7.33	.005	.009
82/03/05	37.3	262	7.24	.003	<.005
82/03/11	11.9	128	6.16	ND	<.005
82/03/17	12.2	130	7.28	.004	.03
82/03/24	12.2	121	7.19	.003	.012
82/04/01	26.5	230	6.86	.006	<.005
82/04/17	29	257	7.47	.004	<.005
82/04/15	29.3	276	7.45	.007	<.005
82/04/26	15.5	ND	7.41	ND	<.005

clearly, as conductance is elevated during periods of elevated sulphate. Recent data (Table 5) shows conductance declined slightly after May 1982 and then increased after the discharge of treated AMD. These conductances are measured as specific conductance by the Environmental Lab, and are not field measurements. The conductance measured in the spring of 1982 at the mid-Goosly station does suggest influence from the acid spill.

F. Colour

Colour affects light transmission in water, and since light drives the lake ecosystem, we monitor colour regularly. True colour is the water colour after it has been filtered to remove colour inducing particles. True colour was initially high in the lake in May 1982, and appears to have declined in the years since (see Table 5). It is expected that the lake is more coloured after freshet, but the higher colour in May 1982 is not repeated in subsequent spring samplings. Colour is high again in July and August 1986. Further monitoring is required to determine if this is the beginning of a trend.

G. Heavy Metals

The priority metals in the Equity discharge are As, Al, Cu, Fe, Sb, Zn, Cd. Unpublished criteria for the protection of aquatic life are as follows.

Metal (total)	Criterion* (ug/l)	Background in lake (ug/l)
As	50	< 10 dissolved, n = 2
Al**	50	unknown
Cu**	2	< 5 dissolved, n = 2
Fe	300	200 dissolved, n = 2
Sb**	50	< 25 dissolved n = 2
Zn	50	< 5 dissolved n = 2
Cd**	0.2	unknown

* from Working Criteria for Water Quality, 1985, Ministry of Environment unpublished table

** when hardness is less than 100 mg/l, pH 7.0

Federal and U.S. criteria for metals specify total metals. This is because the chemistry of metal transformations in the environment is poorly understood. It is possible for metals which are not dissolved, but are labile, or loosely chelated with organics to become biologically available.

Baseline metals levels in Goosly Lake were only measured as dissolved metal by Beak Consultants in July and October, 1973. Since October 1981 vast numbers of metals samples have been taken in the lake at various stations in order to detect if metals were on the increase due to increased loading from Bessemer Creek.

Heavy metals measurements taken by Waste Management Branch between November 1981 and April 1982 are not reported in Appendices 8, 9, 10, 11 of the Equity (1986) report. Equity reports data from 82/04/28 onward. The earlier data shows some influence of the acid spill. Tables 7 and 8 show an increase in the concentration of copper and zinc during the early 1982 period. Sampling date 82/03/05 shows extremes in sulphate (Table 6) but no corresponding blip in metals. It is expected that if sulphate increases, other contaminants would be present at the same time. During the early spring 1982 period, no detectable increases in As, Sb or Cd were found. Aluminum was not measured. Iron values are high and variable. It is expected that total iron would vary with TSS, and be higher during spring runoff. There is some evidence of this in the data, but no recent value approaches the peak of 1.2 mg/l Fe T on 81/12/10 at site 0700083.

Table 9 shows heavy metal data for mid-Goosly Lake. Samples are collected at different depths at this site. Arsenic is generally less than detectable, however the earlier monitoring missed any values which may have fallen between the old detection limit of 5 ug/l and the new one of 1 ug/l. The copper data show a slight elevation in 1982 over more recent values. Copper is consistently measurable in the lake. It cannot be determined if present values are consistently higher than predischarge values. Note that total Cu is frequently above the aquatic life criterion of 2 ug/l. Dissolved copper is also at or above this criterion ($x = 2.5$, $n = 18$).

Buck Creek itself is a major source of iron, and the mine's influence over iron levels in the lake are difficult to deduce. The high degree of "noise" or variability in these data may be due to the mine but upper Buck iron data are also highly variable. Note epilemnetic iron is low in August of 1984 and 1985. Total iron has exceeded the aquatic life criterion in 10 out of 19 samples at mid-Goosly Lake.

TABLE 7
GOOSLY LAKE HEAVY METALS FOR SITE 0700082

Date	As T	As D	Al T	Al D	Cu T	Cu D	Fe T	Fe D	Sb T	Sb D	Zn T	Zn D	Cd T	Cd D
	ug/l		ug/l		ug/l		mg/l		ug/l		ug/l		ug/l	
81/12/10	<5	<5	not		4		.99		<5	<5	20			
81/12/17	<5	<5	measured		3	3	.66	.3	<5	<5	9	6		
81/12/31	<5	<5			5	2	.9	.6	<5	<5	14	8		
82/01/18	<5	5			9	7	.58	.28	<5	<5	13	<5		
82/02/04	<5				13	6			<5	<5		9	<.5	<.5
82/03/05	<5				7	3			<5	<5	<5	<5		
82/03/11	<5				1				<5	<5	<5	<5		
82/03/17	<5				4	4			<5	<5	31	30		
82/03/24	5	<5			3	3			<5	<5	14	12		
82/04/01	<5				6	6			<5	<5	5	<5		
82/04/07	9	<5			4	4			<5	<5	<5	<5		
82/04/15	12	<5			7	7			<5	<5	<5	<5		
82/04/28	<5					1			<5	<5		<5		

TABLE 8
GOOSLY LAKE HEAVY METALS FOR SITE 0700083

Date	As T	As D	Al T	Al D	Cu T	Cu D	Fe T	Fe D	Sb T	Sb D	Zn T	Zn D	Cd T	Cd D
	ug/l		ug/l		ug/l		mg/l		ug/l		ug/l		ug/l	
81/12/10	<5	<5	not		4	NS	1.2		<5	<5	20			
81/12/17	5	<5	measured		5	3	.33	.25	<5	<5	40	4		
81/12/31	<5	<5			4	3	.3	.2	<5	<5	35	15		
82/01/18	5	<5			5	5	.49	.27	<5	<5	15	<5		
82/02/04	<5	<5			3	3			<5	<5	<5	<5	<.5	<.5
82/03/05	<5	<5			6	3			<5	<5	<5	<5		
82/03/11	8	<5			5	NS			<5	<5	<5	NS		
82/03/17	<5	<5			7	3			<5	<5	<5	<5		
82/03/24	6	<5			4	4			<5	<5	5	NS		
82/04/01	5	<5			3	3			<5	<5	6	<5		
82/04/07	5	<5			1	1			<5	<5	5	<5		
82/04/17	5	<5			NS	NS			<5	<5	<5	<5		
82/04/28	<5	<5				2			<5	<5		<5		

NS = not sampled

TABLE 9
HEAVY METALS AT MID-GOOSLY LAKE SITE 0700084

DATE	Depth m	pH	Cond uS/cm	As T ug/L	As D ug/L	Cu T ug/L	Cu D ug/L	Fe T mg/L	Fe D mg/L	Zn T ug/L	Zn D ug/L	Al T mg/L	Al D mg/L	Sb T ug/L	Sb D ug/L	Cd T ug/L	Cd D ug/L
82/05/26	5	7.37	130	<5	<5	4	4	.36	.2	7		.21	.08		<5		
82/05/26	15	7.33	130	<5	<5	5	5	.43	.22	15	13	.25	.09		<5		
82/09/20	1	7.1	107			4	4	.13	.08	<5	<5	.07	<.02		<5		
	5	7.0	106			4		.11	.08	<5	<5	.02	<.02		<5		
	15	6.8	104			4	4	.41	.19	<5	<5	.12	<.02		<5	<.5	<.5
83/05/04	0	7.2	105	<5	<5	3	3	.36	.2	<5	<5		.11			<.5	<.5
	10	7.2	109	<5	<5	5	4	.44	.22	16	13	.17	.12				
84/05/16	2	7.2	107	<1	<1	3	3	.41	.21	6	<5	.08	.08				
	16	7.1	114	<1	<1	2	2	.4	.23	<5	<1	<.02	<.02	<5	<5		
84/08/15	1	7.6	102	<1	<1	2	2	.06	.06	<5	<5	.05	<.02			<.5	<.5
	10	7.0	103	<1	<1	2	2	.2	.18	<5	<5	.06	.04			<.5	<.5
85/05/28	1	7.4	88	<1	<1	1	1	.5	.23	<5	<5	.2	.09			<.5	<.5
	16	7.3	107	<1	<1	3	2	.47	.26	<5	<5	.14	.04			<.5	<.5
85/07/17	1	7.5	132	<1	<1	4	2	.18	.15	10	5	.05	.05			<.5	<.5
	16	6.9	104	<1	<1	2	2	.48	.25	<5	<5	.1	.04			<.5	<.5
85/08/19	2	7.1	133	<1	<1	3	<1	.06	.06	5	5	<.02	<.02			<.5	<.5
	15	6.5	107	<1	<1	4	1	.32	.27	<5	<5	.06	.06			<.5	<.5
85/10/30	1	7.5	132	3	<1	4	3	.18	.12	5	5	.06	.05			<.5	<.5
	14	7.5	128	2	<1	2	1	.19	.10	<5	<5	.05	<.02			<.5	<.5
86/06/02	1	7.3	120	<1	<1	3	3	.31	.16	<5	<5	.13	.03			<.5	<.5
	17	7.3	145	<1	<1	2	2	.50	.24	<5	<5	.11	<.02			<.5	<.5
86/07/16	1	7.3	140	<1	<1	3	3	.20	.13	<5	<5	.06	.03			<.5	<.5
	13	7.0	127	<1	<1	2	2	.23	.13	<5	<5	.07	.04			<.5	<.5
86/08/11	1	7.5	142	<1	<1	3	2	.10	.10	<5	<5	.06	.04			<.5	<.5
	18	7.0	131	<1	<1	2	2	.35	.17	20	<5					<.5	<.5
86/09/30	1	7.3	143	<1	<1	3	2	.07	.01	<5	<5	.03	.02			<.5	<.5
	18	6.9	137	1	<1	2	2	.33	.07	<5	<5	.07	<2			<.5	<.5

Zinc values in the lake appear to be slightly elevated in early 1982. There are ocasional measurable zinc results since then. No consistent elevation in zinc is apparent. A slight rise in hypolimnetic zinc on 83/05/04 may reflect heavier loadings during the 1983 freshet. Unfortunately only one visit was made that year. Hypolimnetic zinc concentrations are elevated again on 86/08/11.

Aluminum is variable and does not appear to follow a pattern. Total aluminum generally exceeds the objective for aquatic life. Dissolved aluminum is generally less than 20 to 90 ug/l. Dissolved Al was high in May of 1983. No explanation can be offered.

No antimony or cadmium has been measured at this site, or elsewhere in the lake.

The metals data show several important things. First, Cu, Zn and Fe concentrations rose in the lake during the spring of 1982 and then fell, but it cannot be clearly determined if they fell to background levels. Second, total copper, iron and aluminum are present in concentrations which meet or exceed published criteria to protect aquatic life. Therefore there is no extra capacity in the lake for additional metals from the mining operation. Third, metals such as As, Sb and Cd are consistently below detection until now, and should be watched for future change.

H. Trophic Status

Spring overturn total phosphorus in 1985 averaged 30.5 ug/l for the 2 depths measured on 85/05/26. Mean summer chlorophyll a concentration was 7.7 ug/L in 1985. Based on the spring overturn P, and using the phosphorus - chlorophyll a relationship developed for B.C. lakes (Nordin and McKean, 1984) the mean summer chlorophyll a predicted is 6.9 ug/l. We feel that this result is close enough and that Goosly Lake fits the model reasonably well. Based on these findings, Goosly Lake was marginally eutrophic in 1985.

In 1982, the lake was only sampled in May and September, so there are only 2 samples to calculate mean chlorophyll a. However, spring overturn phosphorus was 24 ug/l on 82/05/26 and this predicts a summer chlorophyll mean of 5.4 ug/l. The measured mean chlorophyll a, from two samples, was 4.1 ug/l. The following table summarizes the foregoing.

	[P] spring overturn	measured mean chlorophyll a	predicted* mean chlorophyll a
1982	24 ug/l	4.1 ug/l	5.4 ug/l
1985	30.5 ug/l	7.7 ug/l	6.9 ug/l

* predicted from the relationship:

Log_{10} [chlorophyll a] = .9873 Log_{10}[P] - .6231

(Nordin & McKean, 1984)

So, in 1982, the spring phosphorus concentration overpredicted actual algal biomass (given the limitations in the data) while in 1985, it underpredicted the algal biomass. Is the lower relative production in 1982 an artifact of the acid spill? We probably won't know the answer to this, but we do need three to five consecutive measurements of standing crop in the lake in order to properly relate nutrients to algae production. This is extremely important to do in order to see distinct changes in the lake standing crop.

Sediment Metals

Sediments were analyzed for metal content in 1984 and 1985. Table 10 summarizes the findings for the lake. Cores were taken at 2 sites adjacent to station 0700082. Sites 1 and 2 were approximately 50 m and 150 m from the mouth of Buck Creek. The cores were divided into 5 cm segments, and each was analyzed separately. Recent discharges of metals laden sediment, if deposited in Goosly Lake, should show up in higher numbers in the 0-5 cm segment, compared to segments lower in the core. This was obvious in Aldrich Lake near Smithers (Maclean, 1983). Table 10 shows the results of the core segment analysis. The segments 0-5 cm means a 5 cm segment from the surface

TABLE 10
GOOSLY LAKE SEDIMENT METALS
metal ug/g dry wt. unless noted

	Al mg/g	As	Ba	Ca mg/g	Cd	Cr	Cu	Fe mg/g	Mg mg/g	Mn	Ni	Pb	Sr	Zn	P mg/g	% vol res
0700082																
84/05/16																
site 1 0 - 5 cm	9.01	34	178	6.55	<1	18	54	28.1 k	4.83 k	790	26	23	93	94	1.49	
5 - 10 cm	9.09	34	142	4.9	<1	18	49	26.3	4.81	507	26	23	61	85	1.35	
site 2 0 - 5 cm	13.6	40	216	6.6	<1	27	75	33.7	5.8	831	33	31	93	116	1.64	
5 - 10 cm	11.7	49	182	5.92	<1	26	75	28.2	5.48	665	34	34	79	106	1.33	
10 - 20 cm	11.1	37	173	5.2	<1	26	54	26.3	5.7	537	32	28	70	94	1.4	
85/05/28 0 cm	9.7	<25	228	7.69	<1	29	58	32	4.93	1160	23	35	86	104	1.84	12.1
85/07/17 0 cm	12.8	20	315	7.3	<1	29	85	41.1	5.1	1810	29	40	106	205	2.39	15.5
0700084																
85/05/28 0 cm	15.3	35	479	8.72	<1	41	89	51.8	6.1	3270	31	58	101	154	2.57	19.4
85/07/17 0 cm	15.6	18.7	469	7.72	<1	31	85	48.7	5.4	2890	32	46	121	123	2.67	20.6
0700085																
85/07/17 0 cm	9.3	12.1	175	8.64	<1	27	86	23.4	3.52	605	27	67	111	86	2.25	31.2
0400766																
85/07/17 0 cm	7.04	11.6	114	5.6	<1	19	21	22.5	4.23	405	19	39	66	70	1.7	4.1
provincial mean n = 202	19	40.4	165		1	36	42	28.2	9.26	866	29	42	102	90	1.36	28.6

of the core downward for 5 cm. The next 5 cm constitutes the next segment analyzed, etc. Also, Table 10 shows more recent sediment analyses for sites 0700082, 0700084 and 0700085, as well as a July, 1985 sediment sample from Buck Creek. Also, a row is shown giving mean metals values in dry weight measure for over 200 B.C. lakes. (McKean, 1985)

Cores do not show signficant recent elevations in metals. At site 2, Al, Fe, Mn and Zn seem a bit higher, but may reflect natural variability. Metals in sediments are generally lower at the lake's west end, farthest from the mouth of Buck Creek. If you look at metals values from east to west on 85/07/17, some show a strong gradient such as Zn and As. Others appear more concentrated at mid-lake, such as Al, Ba, and Fe. It cannot be stated with certainty that the gradients observed are due to mine influence. However, they are of enough interest that sediments should continue to be analyzed periodically.

Winter Water Quality Survey

On 5 February 1985, detailed water chemistry samples were collected at 7 locations on the lake, as well as in upper Buck Creek, Bessemer Creek, and in Buck Creek above the lake. The purpose of this work was primarily to determine if sulphate or other constituents in the runoff from the mine were present in a concentration gradient from east to west. Under winter conditions the lake is thermally stratified with the coldest, least dense water just under the ice. It was thought that accumulation effects, if any, would be evident after several months of frozen conditions, which eliminates wind mixing. Sample locations are shown in Figure 2. Sampling results are displayed in Table 11. The influence of sulphate on Buck Creek is apparent by comparing site 0400765 with site 0400766. However there was no evidence of sulphate or other AMD constituents building up in the east portion of the lake. Note the trend toward higher turbidity at depth at sites 3, 4 and 5.

Alkalinity titration curves for the creeks and the lake from 85/02/05 are shown in Figure 3. These show the volume of .02 N H_2SO_4 titrant required to lower the pH of 100 ml of the sample to pH 4.5. The streams are better buffered than the lake. The addition of strong acid will consume the

TABLE 11
FEBRUARY 5, 1985
WINTER WATER QUALITY SURVEY RESULTS

SITE	DEPTH	pH	COND	TURB NTU	ALK 4.5	HARD DISS	SO_4 DISS	Cu D	Cu T	Fe D	Fe T	Zn D	Ca D	Ca T	Mg D	Mg T
0400765		7.6	150	2.3	77.3	71.8	3.9	<1	.001	.95	1.48	<.005	18.4	20	6.27	6.49
0700081		7.3	740	.9	87.6	339	202	.01	.02	.02	.06	.03	98.6	98.7	22.6	23.3
0400766		7.3	173	7.8	83.6	83.9	10	.001	.003	1.8	7.45	.005	21.9	24.3	7.09	7.61
Goosly Lk 1	2 m	7.3	113	1.2	44.1	50.6	12.3	.003	.006	.27	.35	<.005	13.2	13.2	4.28	4.57
	12 m	7.3	113	1.0	44.5	49.2	12.2	.007	.007	.35	.41	<.005	12.7	13.8	4.25	4.63
Goosly Lk 2	2 m	7.3	112	1.0	44	49.7	12.3	.001	.005	.26	.40	<.005	12.7	13.5	4.34	4.49
	8 m	7.3	111	1.4	44.1	49.1	12.3	.002	.002	.22	.37	<.005	12.7	13.7	4.23	4.49
Goosly Lk 3	2 m	7.3	106	.7	40.1	47.8	12.7	.002	.004	.10	.16	<.005	12.5	12.6	4.03	4.13
	10 m	7.2	106	1.2	41.1	23.3	12.4	.002	.003	.098	.25	<.005	9	12.4	.21	4.25
Goosly Lk 4	2 m	7.3	106	.7	39.8	44.1	12.6	.001	.004	.15	.15	<.005	11.4	12	3.79	4.17
	6 m	7.0	109	2.6	42.8	47.9	12.1	.002	.003	.24	.42	<.005	12.6	13.1	3.98	4.39
Goosly Lk 5	2 m	7.5	106	.8	41.8	47.0	12.6	<10	.004	.13	.18		11.8	12.5	4.27	4.27
	15 m	7.0	110	4.0	44.4	49.6	12.2	.002	.004	.30	.61		12.4	12.4	4.52	4.52
Goosly Lk 6	2 m	7.3	106	.6	41.0	47.5	12.8	.001	.003	.10	.17	<.005	12.4	12.4	4.02	4.34
Goosly Lk 7	2 m	7.2	109	1.2	46.2	42.8	12.6	.001	.002	.32	.46	<.005	13.6	13.6	4.57	4.63
	8 m	7.3	110	1.0	43.3	49.8	12.7	.002	.002	.23	.41	<.005	13.1	13.1	4.16	4.48

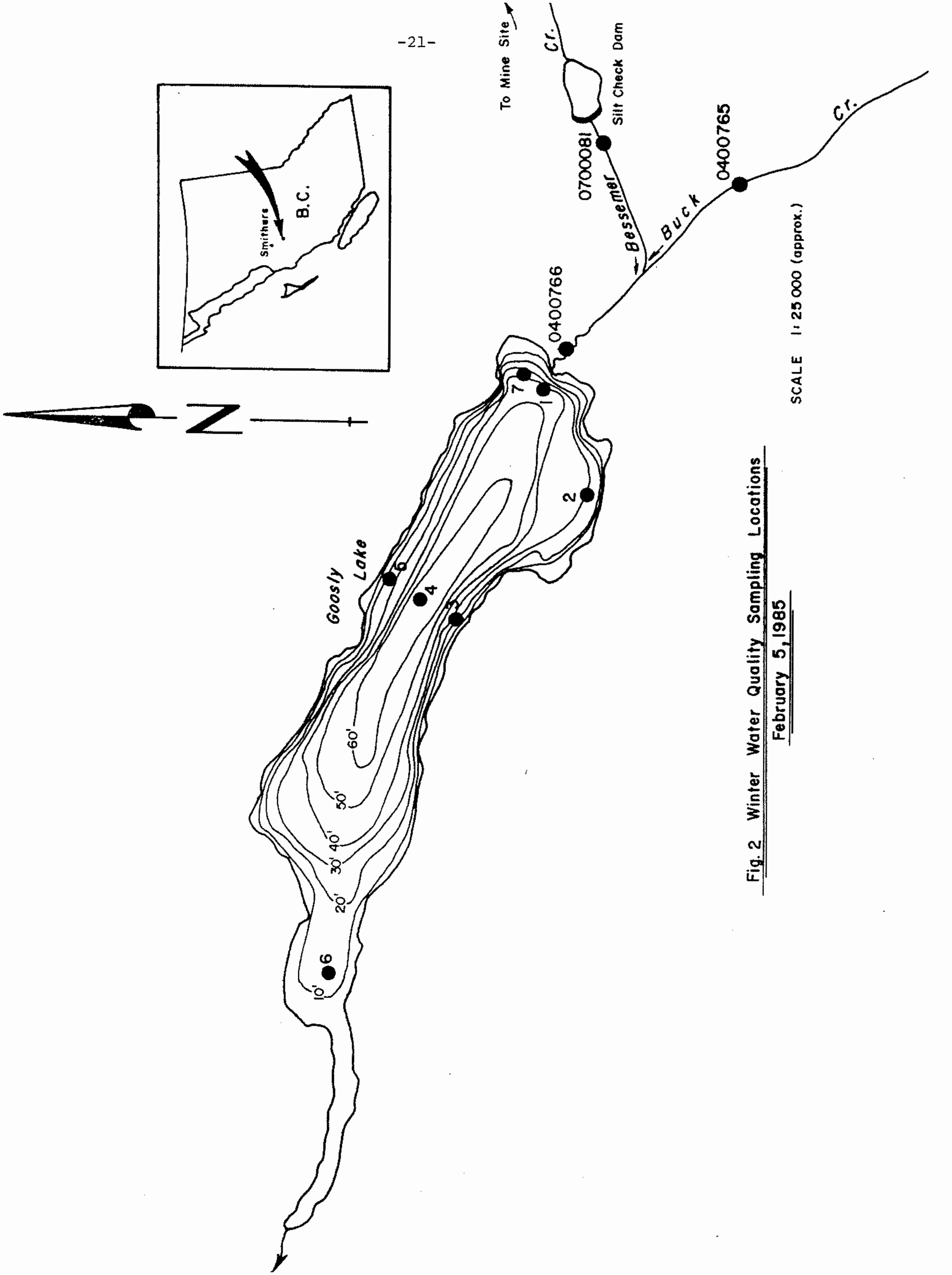

Fig. 2 Winter Water Quality Sampling Locations February 5, 1985

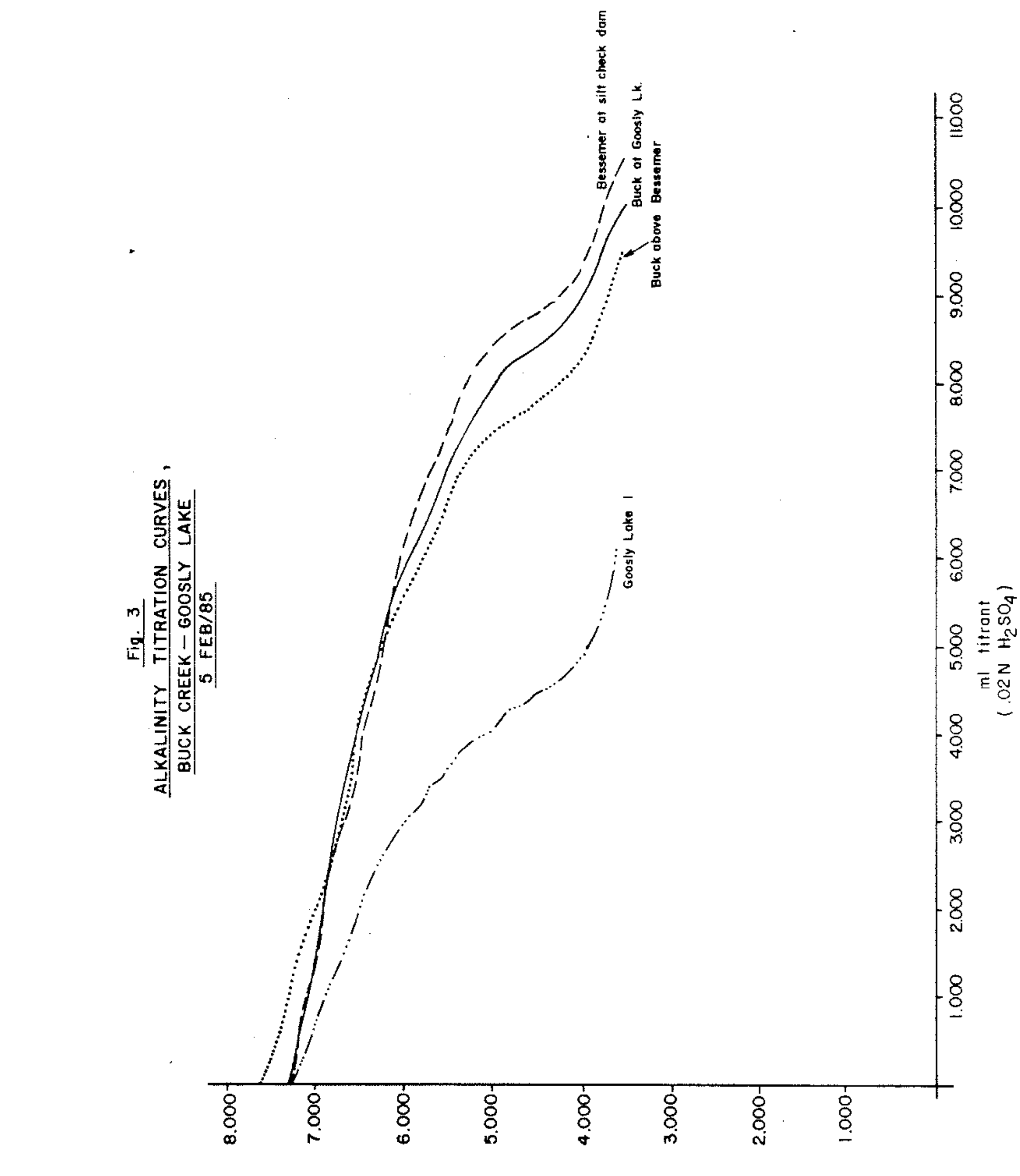

Fig. 3
ALKALINITY TITRATION CURVES,
BUCK CREEK — GOOSLY LAKE
5 FEB/85

bicarbonate alkalinity in the lake, and the pH will drop. Once alkalinity in a lake is exhausted, there is no further protection from acidic inputs. Normally bicarbonate concentration will be associated with 80-90% of the Ca + Mg in the lake water. When a lake acidifies, SO_4 will replace bicarbonate as the equilibrium anion. Bicarbonate converts to CO_2 and escapes to the atmosphere. This situation is not occurring in Goosly Lake, but the lake is more sensitive to acid than the streams. A drop in alkalinity in the lake would signal that some corrective action is warranted. This variable needs to be monitored carefully in future.

Part 2 - Biology

Introduction

The monitoring of biological community structure and the levels of trace metals in fish tissue in Goosly Lake was started in 1982 by the Waste Management Branch. The design of the monitoring program was to determine biological changes attributable to mine influences on the lake. The monitoring strategy of documenting phytoplankton and zooplankton hierarchial dominance was hoped to provide the detection of significant biological change before severe consequences developed. Similarly, changes in levels of metals in fish tissue would provide evidence of changes in water quality before conditions of chronic or acute toxicity were reached. As concentrations of metals in fish tissue tend to integrate the wide temporal fluctuations of metals in the water column, they can provide a useful monitoring tool.

Methods

Phytoplankton

Surface grab samples were taken for identification and enumeration of the phytoplankton community. 1.25 litre water samples collected in polyethylene bottles were preserved using Lugol's solution and sent to the Ministry of Environment's Laboratory for analysis. Tables 12-17 present the results.

Zooplankton

Samples were taken for identification and enumeration of the zooplankton community using a Wisconsin zooplankton net with a .07 mm mesh. Lake bottom to lake surface vertical tows of approximately 18 metres provided samples that were preserved in 5% formalin. Samples were sent to the Ministry's Environmental Laboratory for taxonomic and numerical analysis. Tables 18-20 present the results.

Fish Tissue

Rainbow trout (Salmo gairdneri) were gill netted or angled near the inlet of Buck Creek to the lake and the dorsal muscle and livers dissected out. Tissue was placed in clean whirlpacks, frozen and subsequently shipped to the Environmental Laboratory for analysis. Livers were sent to the University of Victoria's Department of Biochemistry for metal and hepatic metallothionein analysis. Results are presented in Tables 21-23.

Results and Discussion

Phytoplankton

Phytoplankton monitoring programs may be directed to provide systematic information that will show detectible changes in the aquatic biota. Changes in hierarchial dominance which are a result of mining disturbances in the watershed should be represented by a decline in metal sensitive forms such as Tabellaria fenestrata, Asterionella formosa and Rhizosolenia. According to Besch et al (1982) Tabellaria fenestrata has low resistance to zinc (0.1-0.2 mg/L Zn) and copper. Asterionella formosa is killed in concentrations of 0.2 mg/l Copper (Palmer 1964). These concentrations have never been approached in Goosly Lake. The species remain as sub-dominants.

Tables 12 and 13 which present the results for 1982, demonstrate the large amount of variance found in the analysis of the phytoplankton community at different locations within Goosly Lake. Further phytoplankton analysis was restricted to the single mid-lake deep station. Table 14 summarizes the 1982 sampling for the mid-lake deep station. The phytoplankton association appears typical for a meso-eutrophic lake system with a dominance shift from diatoms (orders: Centrales and Penales) to blue-green and green algae (orders: Oscillatoriales and Chlorococcales) occurring through the growing season. Metal sensitive species such as the diatoms Tabellaria fenestrata and Asterionella (possibly formosa) are sub dominants forming 18% of the association on September 21, 1982.

Table 15 presents the results for 1983. Triplicate samples were taken at the mid-lake deep station. The table shows that surface grab sampling for phytoplankton results in highly variable numerical counts. While the extreme variance precludes interpreting the data quantitatively, the results can still be used in qualitative interpretations of dominance/sub-dominance and presence/absence of the algal association. As in the 1982 sampling the 1983 association typifies that of a meso-eutrophic lake system, although in 1983 the dominant species in the spring is the flagellate Chroomonas acuta. The metal sensitive species Tabellaria fenestra and Asterionella formosa are present but in low numbers. As no further samples were taken during 1983 it is unknown if these species became sub dominants during the growing season.

Table 16 presents the results for 1984. Asterionella formosa and Tabellaria spp. although present as sub-dominants to the blue-green assocation on August 15/84 are still present in sufficient numbers to indicate that there has been no significant change in the algal association as a result of changes in trace metal concentrations.

Table 17 presents the results for 1985. Asterionella formosa and Tabellaria spp. again are present as sub-dominant in the algal association. Rhizosolenia is present in low numbers. Analysis of phytoplankton species composition in Buttle Lake (Roch et al, 1985) suggests that Rhizosolenia is intolerant to metal concentrations and its absence is an indicator of heavy metal contamination. The absence of Rhizosolenia in Goosly Lake until 1985 could be a result of the influence of the acid spill and acid mine drainage on water quality. As no pre-operational phytoplankton data is available no definite conclusions can be made at this time but it will be of considerable interest to follow the presence/absence of Rhizosolenia in subsequent sampling programs. The two phytoplankton analyses completed for 1986 at the time of writing indicate that <u>Rhizosolenia eriensus</u> is present as a dominant algae, constituting 12% of the standing crop. The emergence of Rhizosolenia suggests that its numbers were suppresed by elevated metals presumably caused by the acid spill and periodic AMD seeps into Bessemer Creek.

Zooplankton

Table 18 presents the analysis for May 4, 1983 and shows good similarity in triplicate sampling for zooplankton. As a result future sampling was limited to one replicate. Insufficient zooplankton data have been collected to date to allow interpretation of any trend or change in the zooplankton association. The following table (Baudoin, 1974) documents the susceptibility of some zooplankton to metal toxicity:

species	metal	conc.	toxicity
Daphnia hyalina	Zn	.040 mg/l	48 hr LC50
Daphnia hyalina	Cu	.005 mg/l	48 hr LC50
Cyclops abyssorum	Zn	5.5 mg/l	48 hr LC50
Cyclops abyssorum	Cu	2.5 mg/l	48 hr LC50
Eudiaptumus padanus	Cu/Zn	.5 mg/l	48 hr LC50

Baudoin (1974) found a linear relationship between metal concentration and median effective time without any evidence of a lethal threshold over 10 day period. The toxicity curve for zinc shows a 96 hr LC50 at a concentration of approximately 10 ug/l. The lack of information regarding lethal thresholds makes it difficult to extrapolate a safe level of metal concentrations to protect zooplankton in Goosly Lake. An established criteria to protect invertebrates in the Great Lakes is 5 ug/l for copper and 30 ug/l for zinc (IJC, 1976).

Goosly Lake water approached concentrations of 5 ug/l copper during 1982 at the mid-lake site and was as high as 9 and 13 ug/l in early 1982 at the east end of the lake. Zinc concentration is elevated on occasion at the mid lake site but no consistent elevation is apparent (Table 9). As zooplankton sampling equipment had not arrived for the 1982 sampling season no data is available on the zooplankton association for that year.

Concentrations of zinc and copper at the east site (0700083) were elevated enough during late 1981 and early 1982 to result in some zooplankton toxicity near the inlet of Buck Creek. These toxic concentrations had been diluted sufficiently at the mid lake site to avoid any acutely toxic effects.

Fish Tissue Metal Residues

Mean metal concentrations in rainbow trout tissue from Goosly Lake (Table 21) can be compared to mean metal concentrations in tissue from pristine British Columbia lakes, i.e. lakes which receive no pollution discharges (Table 22). Mean zinc concentration in the muscle tissue of Goosly Lake rainblow trout is significantly higher than the provincial mean for samples collected in 1982 ($P < 0.01$, $n=15$) and again in 1985 ($P < 0.05$, $n=4$). Mean zinc concentration in the liver tissue of Goosly Lake trout is not significantly different from pristine trout. Copper concentrations in muscle tissue does not differ significantly in 1982 or 1985 and copper concentration in liver tissue does not differ significantly in the 1982 analysis when compared to the B.C. mean for pristine lakes. Arsenic and lead concentrations could not be compared due to the high detection limit results. Cadmium concentrations at a mean concentration of 14.8 ug/g in liver tissue is significantly elevated above the provincial mean of 1.0 ($P<0.01$, $n=10$).

Roch <u>et al</u> (1985) found that in the Campbell River drainage mean zinc concentration in rainbow trout muscle is significantly correlated with the zinc concentration in the water but copper, cadmium and lead concentrations were not. From this we expect the zinc concentrations in Goosly Lake water to be elevated. As discussed in section 3, zinc values have been elevated slightly on occasion but no consistent elevation in zinc is apparent in Goosly Lake. To bioaccumulate Zn at concentrations of 33 ug/g in Rainbow trout it is estimated that the fish would be exposed to water concentrations greater than 100 ug/l. This estimate is based on zinc levels found in fish in the Campbell River drainage. Buck Creek below Bessemer Creek has exceeded 100 ug/L on occasion during 1981 and 1982. As the fish were netted immediately beside

TABLE 21

METALS IN RAINBOW TROUT (SALMO GAIRDNERI) FROM GOOSLY LAKE

DATE	# FISH	TISSUE	Ca mg/g x	Ca mg/g s	Cu ug/g x	Cu ug/g s	Al ug/g x	Al ug/g s	As ug/g x	Pb ug/g x	Fe ug/g x	Fe ug/g s	Zn ug/g x	Zn ug/g s	Sr ug/g x	Sr ug/g s	Cd ug/g x	Cd ug/g s
82/10/14	15	muscle	1.3	1.0	1.6	.74	5.6	5.3	<25	<11	34.5	18	33.2	7.4	2.9	2.9	<1	—
82/10/14	10	liver	—	—	257	175	—	—	—	—	—	—	141	22	—	—	14.8	3.4
83/05/04	1	muscle	.8	—	<1	—	<2	—	<25	<10	<1	—	16	—	1	—	<1	—
85/05/28	4	muscle	1.3	.33	1.9	1.3	3	<2	<0.1	<11	29.5	8.6	33.5	14.6	2	1	<1	
85/05/28		liver																

TABLE 22

METALS IN RAINBOW TROUT (SALMO GAIRDNERI) FROM PRISTINE B.C. LAKES

	TISSUE	Ca mg/g x	Ca mg/g s	Cu ug/g x	Cu ug/g s	Al ug/g x	Al ug/g s	As ug/g x	Pb ug/g x	Fe ug/g x	Fe ug/g s	Zn ug/g x	Zn ug/g s	Sr ug/g x	Sr ug/g s	Cd ug/g x	Cd ug/g s
B.C. MEANS FOR PRISTINE LAKES*	muscle	1.87	.29	1.9	1.0	7.8	7.1	.1	1.8	34.7	31.4	19.2	6.2	2.8	2.9		
	liver	.30	.14	202.4	162.9	13.2	12.4	.1	34	1384	998	118.9	41.9	1.5	.8	1.0	
																1.22	.66
# FISH BELOW DETECTION LIMIT FOR B.C. MEANS**	muscle	0		37		34		98	69	0		0		37		97	
	liver	0		0		30		76	52	0		1		64		72	
# FISH ABOVE DETECTION LIMIT FOR B.C. MEANS**	muscle	97		56		63		2	31	96		97		60		0	
	liver	79		74		49		6	30	79		78		15		7	

* Thanks to Colin McKean for providing unpublished data.

**In the analysis for metals in tissue the metal concentrations are often below the analytical laboratories detection limit. As no definitive statistical method has been devised for handling less than detection values these were not included in the calculation of the mean for pristine lakes. This of course skews the mean values higher than they actually are.

the inlet of Buck Creek it is probable that they have been exposed to zinc concentrations significantly greater than that found at the Goosly Lake sampling sites (i.e. the fish had been upstream).

Roch _et al_ also found that copper and cadmium concentrations in liver tissue were correlated to the concentration in water but zinc concentrations were not. This finding is supported by the Goosly Lake data and is probably a result of the different binding affinities of metals as metallothionein (with copper > cadmium > zinc).

Hepatic Metallothionein

The measurement of heavy metals in fish tissue can provide an estimation of the amount of biologically available metal in the environment but does not give an indication of toxic effects. Roch _et al_ (1982) suggest that part of the metal accumulated in fish tissue can be non-specifically bound and without any biological effect. For these reasons it has been suggested (Roch 1982) that a biochemical measure of metallothionein be used to assess the response of fish to the toxic effects of metals.

The protein metallothionein is synthesized in the livers of fish on exposure to the metals cadmium, copper, zinc, and mercury. As metallothionein concentration in livers increases proportionally to the concentration of zinc, copper, cadmium in the water its analysis is a useful quantitative measure of the degree of exposure of rainbow trout to heavy metals (Roch 1982). Figure 4 demonstrates the significant correlation between hepatic metalothionein levels and metal contamination as measured by zinc concentration ($r = 0.913$, $n = 12$). Roch and McCarter (1984) have shown a relationship between metallothionein concentration and LC50s in rainbow trout livers. They calculated that a concentration of 100 nanomoles metallothionein per gram of liver corresponds to .25 toxic units (where a LC_{10} = 1 toxic unit). This concentration is interpreted as having a minimal biological effect. The table below shows the expected metallothionein concentration from various metal concentrations in the Campbell River system.

Metal Concentrations and Metallothionein Concentration

Location	metal concentration (ug/l)			metallothionein (n moles/g)	
	Zinc	Copper	Cadmium		
Upper Quinsam	<5	<1	<0.5	56±19	n=17
John Hart	44 ±9	<1	<0.5	103±37	n=18
North Buttle	112±14	2.6±1.5	<0.5	130±56	n=18
South Buttle	140±32	132±6.8	0.8±0.3	180±66	n=15

Table 23 summarizes the metallothionein data for Goosly Lake. The metallothionein concentration of a single male rainbow trout angled in 1983 was 46± 12 nanomoles/g. This is considered a low level and indicates that trout had not been chronically exposed to higher than background concentrations of heavy metals. The mean concentration of metallothionein in rainbow trout collected in 1985 was 65.5 nanomoles/g. This mean concentration is similar to rainbow trout concentrations (40-70 nanomoles/g) found in Upper Quinsam Lake. Of interest in the 1985 analysis is the extremely low concentration of

metallothionein found in gravid female fish. In future sampling, eggs from gravid fish will be analyzed for metal concentrations to determine whether the eggs have preferentially bound metals. Two female fish show elevated metallothionein concentrations of 126 and 168 nanomoles/g. These two elevated metallothionein values could only have been induced by exposure of the fish to metals at some unknown location in the lake or Buck Creek.

It should be noted that fish livers were extracted from freshly killed trout and field frozen. However the livers were not trans shipped to the laboratory on dry ice and may have thawed in transit. This might tend to lower the results if metals become unbound by enzyme action in thawed tissue.

One of the problems interpreting metallothionein data is the problem of fish mobility. The development of an in situ fish holding monitoring program (see further monitoring) should help to resolve this problem in analysis.

We consider the use of hepatic metallothionein, in conjunction with tissue and water chemistry analyses, is a useful technique for identifying a biological response in aquatic organisms at levels of metal concentration that

Fig. 4

Hepatic Metallothionein vs Zinc in Buttle Lake, B.C.

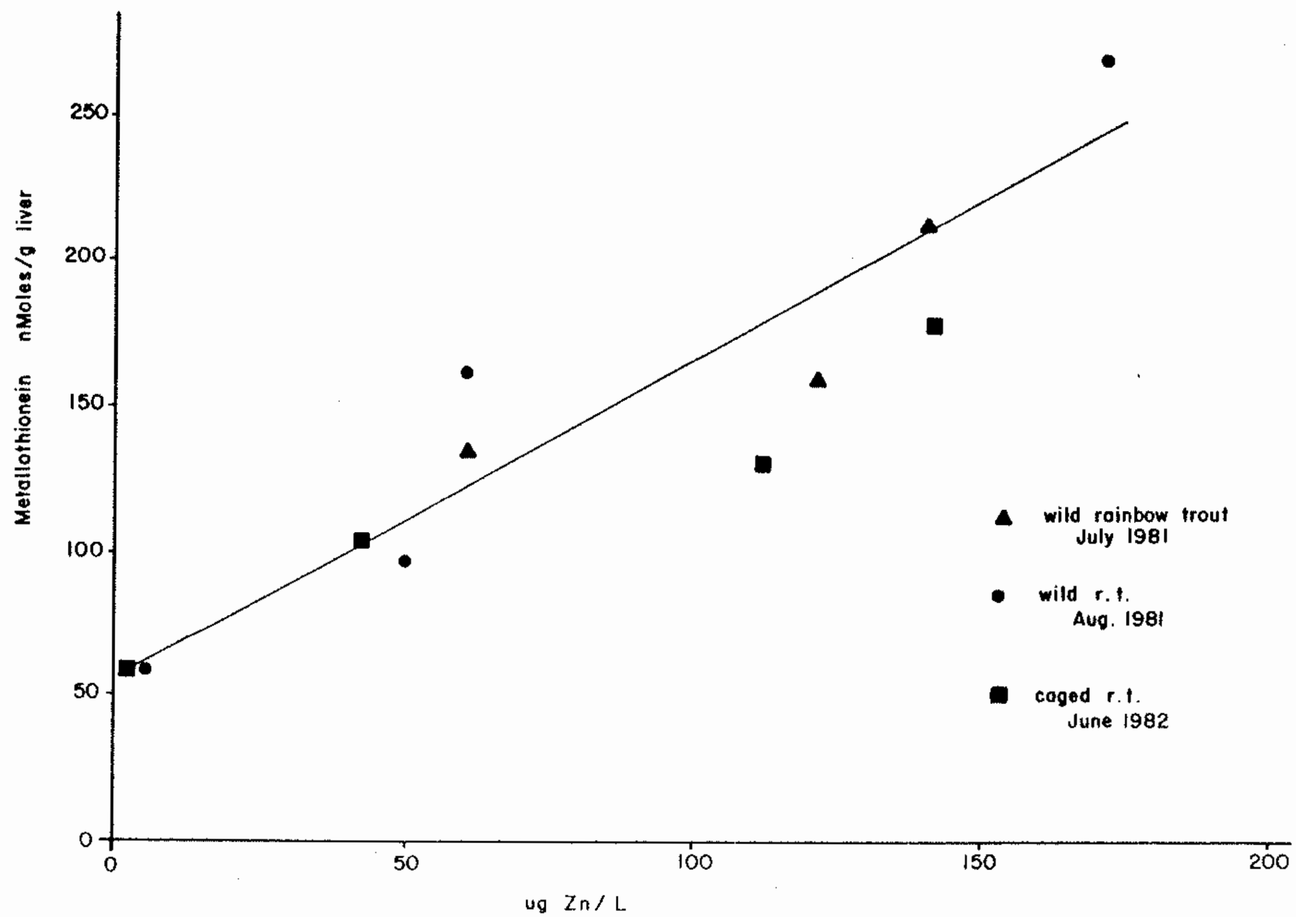

TABLE 23

HEPATIC METALLOTHIONEIN CONCENTRATION FROM RAINBOW TROUT FROM GOOSLY LAKE

DATE	FISH AGE (years)	FISH LENGTH (cm)	SEX	METALLOTHIONEIN NANOMOLES/g
83/05/04	6	35	male	46 ± 12
85/05/28	3+	23.6	female (gravid)	28
	3+	22.0	female (gravid)	22
	3	17.8	female	126
	3	17.7	female	168
	2	15.5	female	46
	2	13.4	male	39
	2	14.2	female	71
	2	13.2	female	66
			mean	65.5
			standard deviation	± 52

are lower than necessary to kill fish outright. So, if a technique was developed to provide a controlled exposure of fish to Bessemer or Buck Creek water a comparison could be made with responses by fish in a control area and to findings in the literature. This provides a sub-lethal bioassay result which is essentially an early warning of the potential for acute toxicity. It also addresses the problem of missing slugs of metals in the creek with a relatively infrequent water sampling program.

Part 3 Water Quality Objectives and Monitoring

Water quality in the lake needs to be protected in order to maintain aquatic life, drinking water quality in lower Buck Creek, and recreation potential. Of these uses, the most sensitive is aquatic life. Therefore if water quality objectives are set to protect aquatic life, the other uses are also protected. In addition to measuring variables directly related to aquatic life, our previous work suggests a few others need to be measured in order to properly characterize conditions in the lake, and to serve as indicators of a change in the lake water chemistry. The Ministry of Environment will be developing formal water quality objectives for the Buck Creek and Foxy-Maxan Creek systems. This work will build on the Bulkley River objectives which already exist (Nijman 1986). The following objectives and monitoring program are initial suggestions and will be followed by the more comprehensive work. The following is a list of suggested water quality objectives which are aimed at protecting aquatic life and as useful monitors of changes in the lake.

Table 24 Suggested Water Quality Objectives for Goosly Lake

variable	objective*
pH	6.8 - 7.8
Total Copper	.004 mg/L
Total Zinc	.05 mg/L
Total Al	.05 mg/L
Total As	.05 mg/L
Total Fe	.3 mg/L
Sulphate	30.0 mg/L**
Turbidity	background +5 NTU**

* Objectives are yearly averages for all lake samples for the epilimnion and hyoplimnion and calculated with 95% confidence limits for each.

** These are intended to draw attention to possible changes in the lake.

The rationale for each is as follows. For pH, a rise above 7.8 will signal a significant change in pH in the lake. The metals are designated as total metals. The copper objective is slightly higher than the mean mid-lake copper concentration since 1982 (x = 3.28, SD = 1.4, n=25). Hardness seems to be increasing in the lake, so it is felt that the copper objective can be raised to the nearest integer. Other metal objectives are recommended criteria in Reeder (1979), except iron, which is a working criteria (Ministry of Environment, 1985). The sulphate objective is a threshold, or warning level, which could signal the progressive concentration of sulphate in the lake. The turbidity objective is based on recommendations by Singleton (1985).

Progressive deterioration of water quality in the lake will necessitate putting further restrictions on the quality of effluent leaving the mine property.

Monitoring

The purposes of monitoring are to determine if water quality objectives are being met, to identify biological responses to the introduction of contaminants, and to catch this response in time to avoid a severe impact on the lake. Monitoring at Goosly Lake must be designed to take into account the following factors:

a) baseline data is poor to nonexistent
b) there is evidence of an increase in metals particularly during the 1982 freshet
c) the source of turbidity in the hypolimnion needs to be identified
d) metals like copper and iron are already exceeding criteria designed to protect aquatic life
e) a metallothionein response has been seen in Goosly Lake fish
f) zinc and cadmium in fish tissues exceed the provincial mean
g) phytoplankton and zooplankton composition are useful monitors of environmental change
h) contamination in Bessemer Creek reaches a peak during a pre-freshet period lasting several weeks
i) treated acid mine drainage is discharged to the lake (approximately 250,000 cubic meters in 1985 and in 1986)

The suggested program for the lake consists of a combination of components including water chemistry and biology, sediment analysis and fish tissue analysis. The program elements are shown in Table 25.

TABLE 25 SUGGESTED MONITORING PROGRAM FOR GOOSLY LAKE AT SITE 0700084

	May	Early August	October
Temp & D.O. Profile	X	X	X
T & D metals	X	X	X
Sulphate	X	X	X
Turbidity	X	X	X
Suspended Solids	X	X	X
Alkalinity	X	X	X
True colour	X	X	X
pH	X	X	X
Conductance	X	X	X
Phosphorus	X		
Chlorophyll _a_	X	X	X
Zooplankton		X	
Sediments	bi-annually, 3 sites in the lake		
Fish tissue metals	X		
Hepatic metallothionein	special program		

The program includes sampling sessions at spring overturn (May) in early August, and fall overturn (October). Phosphorus would be collected at spring overturn and be compared to mean summer chlorophyll _a_ concentration. In May and October water quality sampling depths should be 1 m and 14 m. In August, samples should come from above and below the thermocline. Actually, 1 m and 14 m depths serve as a good guideline. Phosphorus should be collected during spring overturn, at 3 depths, surface, middle and near bottom. Chlorophyll _a_ should be analyzed from a sample consisting of 200 ml aliquots taken from 0, 1, 2, 4 m, and filtered and preserved in the conventional way. Zooplankton should be collected by vertical haul from bottom to surface with a net with a pore size of 80 microns, and identified to species for those greater than 10% dominance. Due to the large variance in phytoplankton sampling triplicate surface grab samples should be taken.

Although there are many vagaries such as fish mobility in the analysis of Goosly Lake rainbow trout for metal concentrations in tissue the sampling should continue on an annual basis to establish trends. The elevation of zinc in muscle tissue and the elevation of cadmium in liver tissue needs to be documented over the long term. Any gravid fish netted should have a tissue analysis performed on their eggs to determine if metals are being preferentially bound to the eggs.

The problem of fish mobility and their interchange from Goosly Lake to Buck Creek above and below Bessemer Creek can be resolved by an in situ program. The program would involve holding hatchery trout at the water quality sites in Buck and Bessemer Creek, and in the lake, for a four week period in the spring. Following four weeks of exposure, the fish would be killed and their tissues analyzed to compare the metals levels and hepatic metallothionein between control and impact sites.

References

Austin A., Deniseger J. and Clark M.J.R. (1985) Lake Algal Populations and Physico-Chemical Changes After 14 Years Input of Metallic Mining Wastes Water Res. Vol 19. No. 3, pp 299-308

Baudoin M.F., Scoppa P. (1974) Acute Toxicity of Various Metals to Freshwater Zooplankton. Bull, Environ. Contam. Toxicol. 12:745-75

Besch W.K., Ricard M., and Cantin R. (1972) Benthic Diatoms as Indicators of Mining Pollution in the Northwest Miramichi River System, New Brunswick, Canada IWT Rev. ges Hydrobiol. 47

Brierly, Corale 1982 Microbiological Mining Scientific American 247(2):44-53

Finlayson, B.J. and K. M. Verue, 1982 Toxicities of Copper, Zinc and Cadmium Mixtures to Juvenile Chinook Salmon Trans. Am. Fish Soc. 111:645-650.

International Joint Commission (1976) Report of the Water Quality Objectives Subcommittee. Appendix A to the Water Quality Board Report to the IJC. International Joint Commission. Windsor

Kerr, Priestman & Assoc. Ltd. 1983 Hydrology Study for Equity Silver Mines Limited

Krug, E.C., Isaacson P.J. and Frink C.R. (1985) Appraisal of some Current Hypotheses Describing Acidification of Watersheds JAPCA 35:109-114

Kleinmann, R., D. Crerar and R. Pacelli 1981 Biogeochemistry of Acid Mine Drainage and a Method to Control Acid Formation. Mining Engineering March, unpaged reprint

McKean, C.J.P., 1985 Water Management Branch, Victoria, B.C., Unpublished Data: Metal Concentrations in Lake Sediments

Maclean, D.B. 1983 Aldrich Lake: A Data Report on Water Quality and Biological Data from the Receiving Waters of the Area around the Abandoned Duthie Mine Ministry of Environment, Waste Management Branch Report 83.05

Ministry of Environment, 1985 Unpublished Table: Working Criteria for Water Quality. Water Management Branch, Victoria, B.C.

Nijman, R. 1986 Bulkley River Basin Water Quality Assessment and Objectives British Columbia Ministry of Environment, Victoria

Nordin, R. 1985 Water Quality Criteria for Nutrients and Algae Ministry of Environment, Victoria, B.C.

Nordin R. and C.J.P. McKean 1984 Shawnigan Lake Water Quality Study Ministry of Environment, Victoria, B.C.

Osborne, V. and R. Hallam 1982 Summary of Environmental Information for the Equity Silver Mine E.P.S. Report, April

Palmer C.M. (1964) Algae in Water Supplies of the U.S. Algae and Man (Edited by Jackson D.) pp 239-261, Plenum Press, New York

Reeder, S. 1979 Guidelines for Surface Water Quality. Preamble. Inland Waters Directorate, Ottawa

Roch M. and McCarter J.A. (1984) Hepatic Metallothionein Production and Resistance to Heavy Metals by Rainbow Trout (Salmo gairdneri) -- I. Exposed to an Artificial Mixture of Zinc, Copper and Cadmium. Comp. Biochem, Physiol. 77C: 71-75

Roch M., McCarter J.A., Matheson A.T., Clark M.J.R., and Olafson R.W., (1982) Hepatic Metallothionein in Rainbow Trout (Salmo gairdneri) as an Indicator of Metal Pollution in the Campbell River System. Can J Fish Aquat Sc. 39:1596-1601

Roch M., Nordin R.N., Austin A., McKean C.J.P., Deniseger J., Kathman R.D., McCarter J.A. and Clark M.J.R. (1985) The Effects of Heavy Metal Contamination on the Aquatic Biota of Buttle Lake and the Campbell River Drainage. Arch. Environ. Contam. Toxicol. 14, 347-362

Singleton, H. J. 1985 Water Quality Criteria for Particulate Matter Ministry of Environment, Victoria, B.C.

TABLE 12
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE
May 26, 1982
organisms, cells/ml

ALGAL GENUS	East End Inlet	Middle 0700084	West End Outlet	
ORDER: Oscillatoriales				
Aphanizomenon				
Anabena circinalis				
Anabena flos-aquae			.2	
Anabena spiroides				
ORDER: Cryptomonadales				
Cryptomonas	1.37	2.7	.15	
Chroomonas acuta	4.11	8.2	7.2	
ORDER: Crysomonadales				
Mallomonas	5.4	4.11	3.43	
Dinobryon (divergens)	4.11	.04	.1	
ORDER: Chroococcales				
Aphanothece				
Aphanothece clathrata				
Aphanothece elachista				
Coelosphaerium naegelianum				
Gomphosphaeria		2.2	3	
ORDER: Chlorococcales				
Schroderia				
Botryococcus brauni				
Oocystis				
Ankistrodesmus (falcatus)	9.6	20.6	37	
Crucigenia				
Dictosphaerium				
Scenedesmus	.08		.08	
Kirchneriella				
Nephrocytium				
ORDER: Peridiniales				
Ceratium			.02	
ORDER: Volvocales				
Pandorina				
ORDER: Desmidiales				
Cosmarium				
Staurastrum				
Arthrodesmus				

TABLE 12
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE
May 26, 1982
organisms, cells/ml

ALGAL GENUS	East End Inlet	Middle 0700084	West End Outlet	
ORDER: Tetrasporales				
Gloeocystis		.08	.24	
Elakatothrix			.04	
ORDER: Euglenales				
Trachelomonas				
ORDER: Rhizochrysidales				
Diceras				
ORDER: Centrales				
Stephanodiscus	4.11	4.1	.32	
Cyclotella (glomerta)	1.37	143		
Melosira (italica)	9.59	10.9	.64	
ORDER: Penales				
Rhizosolenia			.04	
Cymbella	1.37	.02	.04	
Tabellaria		.06	.24	
Nitzschia		.02	.06	
Synedra			.04	
Cocconeis		.02	.08	
Fragilaria (construens)	6.85	.2	.8	
Achnanthes	1.37		.04	
Asterionella (formosa)	1.37	.08	.02	
Gomphonema		.08	.02	
Meridion	4.11	.08		
Eunotia				
Navicula				
Pinnularia				
Surirella	2.74		.02	
TOTAL	57.6	196.5	53.9	
# GENERA/SPECIES	15	18	24	

TABLE 13
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
Sept. 21, 1982
organisms, cells/ml

ALGAL GENUS	East End Inlet	Middle 0700084	West End Inlet	
ORDER: Oscillatoriales				
Aphanizomenon	7.2	2.6	2.4	
Anabena circinalis				
Anabena flos-aquae	97.3	54	100	
Anabena spiroides				
ORDER: Cryptomonadales				
Cryptomonas	.12	.69		
Chroomonas acuta	58.2	8.22	4.23	
ORDER: Crysomonadales				
Mallomonas	2.82	.09	.4	
Dinobryon (divergens)	.78	.96	22.6	
ORDER: Chroococcales				
Aphanothece				
Aphanothece clathrata				
Aphanothece elachista				
Coelosphaerium naegelianum	18	5	1.7	
Gomphosphaeria				
ORDER: Chlorococcales				
Schroderia		23.3		
Botryococcus brauni	23.4	19.5	6	
Oocystis	.14	.12	.24	
Ankistrodesmus	2.35	7.5	5.17	
Crucigenia	.08	.04		
Dictosphaerium	3	6.16	11	
Scenedesmus	.96	.6	.08	
Kirchneriella	.16	.16	32	
Nephrocytium	8.22		12.7	
Chroococcus				
ORDER: Peridiniales				
Ceratium	.3	.02	.06	
ORDER: Volvocales				
Pandorina	.48		.24	
ORDER: Desmidiales				
Cosmarium	.01	.01	.13	
Staurastrum	.18	.01		
Arthrodesmus	.78	.75		

TABLE 13
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
Sept. 21, 1982
organisms, cells/ml

ALGAL GENUS	East End Inlet	Middle 0700084	West End Inlet	
ORDER: Tetrasporales				
Gloeocystis	3.84	.28	.32	
Elakatothrix	.6	.12	.52	
ORDER: Euglenales				
Trachelomonas	.03		.02	
ORDER: Rhizochrysidales				
Diceras	.01	.03	.01	
ORDER: Centrales				
Stephanodiscus				
Cyclotella (glomerta)	14.1	1.37	.8	
Melosira (italica)	1.92	.72	1	
Rhizosolenia				
ORDER: Penales				
Cymbella				
Tabellaria (fenestra)	36.7	16.4	46	
Nitzschia	.01		.03	
Synedra				
Cocconeis			.06	
Fragilaria (construens)	.94	.69	.4	
Achnanthes	.02		.06	
Asterionella (formosa)	2.82	12.3	48.4	
Gomphonema	.02			
Meridion				
Eunotia				
Navicula			.07	
Pinnularia				
Surirella				
TOTAL	285.5	161.5	296.6	
# GENERA/SPECIES	32	25	29	

TABLE 14
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
1982
organisms, cells/ml

ALGAL GENUS	May 26/82	Sept 21/82		
ORDER: Oscillatoriales				
Aphanizomenon		2.6		
Anabena circinalis				
Anabena flos-aquae		54		
Anabena spiroides				
ORDER: Cryptomonadales				
Cryptomonas	2.7	.69		
Chroomonas acuta	8.2	8.22		
ORDER: Crysomonadales				
Mallomonas	4.11	.09		
Dinobryon (divergens)	.04	.96		
ORDER: Chroococcales				
Aphanothece				
Aphanothece clathrata				
Aphanothece elachista				
Coelosphaerium naegelianum		5		
Gomphosphaeria	2.2			
Chroococcus				
ORDER: Chlorococcales				
Schroderia		23.3		
Botryococcus brauni		19.5		
Oocystis		.12		
Ankistrodesmus	20.6	7.5		
Crucigenia		.04		
Dictosphaerium		6.16		
Scenedesmus		.6		
Kirchneriella		.16		
Nephrocytium				
ORDER: Peridiniales				
Ceratium		.02		
ORDER: Volvocales				
Pandorina				
ORDER: Desmidiales				
Cosmarium		.01		
Staurastrum		.01		
Arthrodesmus		.75		

TABLE 14
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
1982
organisms, cells/ml

ALGAL GENUS	May 26/82	Sept 21/82		
ORDER: Tetrasporales				
Gloeocystis		.28		
Elakatothrix	.08	.12		
ORDER: Euglenales				
Trachelomonas				
ORDER: Rhizochrysidales				
Diceras		.03		
ORDER: Centrales				
Stephanodiscus	4.1			
Cyclotella (glomerta)	143	1.37		
Melosira (italica)	10.9	.72		
Rhizosolenia				
ORDER: Penales				
Cymbella	.02			
Tabellaria fenestrata	.06	16.4		
Nitzschia	.02			
Synedra				
Cocconeis	.02			
Fragilaria (construens)	.2	.69		
Achnanthes				
Asterionella (formosa)	.08	12.3		
Gomphonema	.08			
Meridion	.08			
Eunotia				
Navicula				
Pinnularia				
Surirella				
TOTAL	196.5	161.5		
# GENERA/SPECIES	18	27		

TABLE 15
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
May 4, 1983
organisms, cells/ml

ALGAL GENUS	replicate 1	replicate 2	replicate 3	mean
ORDER: Oscillatoriales				
Aphanizomenon				
Anabena		.85	.13	.5 (n=2)
Anabena circinalis				
Anabena flos-aquae				
Anabena spiroides				
ORDER: Cryptomonadales				
Cryptomonas	1.37	1.38		1.38 (n=2)
Chroomonas acuta	95.9	61.7	9.6	56.7 (n=3)
ORDER: Crysomonadales				
Mallomonas	2.74	11	.69	4.8 (n=1)
Dinobryon (divergens)	.01	.04	.69	.25 (n=3)
ORDER: Chroococcales				
Aphanothece				
Aphanothece clathrata				
Aphanothece elachista				
Coelosphaerium naegelianum				
Gomphosphaeria		.78		.78 (n=1)
Chroococcus				
ORDER: Chlorococcales				
Schroderia		.06		
Botryococcus brauni	.2	.8		.5 (n=2)
Oocystis				
Ankistrodesmus (falcatus)	12.4	13.7	11.0	12.4 (n=3)
Crucigenia				
Dictosphaerium				
Scenedesmus		.04	.04	.04 (n=2)
Kirchneriella				
Nephrocytium				
ORDER: Peridiniales				
Ceratium				
ORDER: Volvocales				
Pandorina				
ORDER: Desmidiales				
Cosmarium		.01		.01 (n=1)
Staurastrum				
Arthrodesmus				

TABLE 15
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
May 4, 1983
organisms, cells/ml

ALGAL GENUS	replicate 1	replicate 2	replicate 3	mean
ORDER: Tetrasporales				
Gloeocystis	.01	.01		.02 (n=2)
Elakatothrix		.02		.01 (n=1)
ORDER: Euglenales				
Trachelomonas		.06	.03	.05 (n=2)
ORDER: Rhizochrysidales				
Diceras				
ORDER: Centrales				
Stephanodiscus	3.43			3.43 (n=1)
Cyclotella (glomerta)		3.43	1.37	2.4 (n=1)
Melosira (italica)	30.1	3.43	1.37	11.6 (n=3)
Rhizosolenia		.02		.02 (n=1)
ORDER: Penales				
Cymbella	.01	.02	.03	.03 (n=3)
Tabellaria	.16	.09	.06	.1 (n=1)
Nitzschia	.01	.07		.04 (n=2)
Synedra				
Cocconeis				
Fragilaria (construens)	.69	2.7	.69	1.4 (n=3)
Achnanthes	.02		.02	.02 (n=3)
Asterionella (formosa)	.12	.06	1.38	.52 (n=3)
Gomphonema	.03		.02	.03 (n=2)
Meridion			.03	.03 (n=1)
Eunotia				
Navicula		.08	.02	.05 (n=2)
Pinnularia				
Surirella				
TOTAL	147.2	100.35	27.2	97.1
# GENERA/SPECIES	16	23	17	26

TABLE 16
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
1984

organisms cells/ml

ALGAL GENUS	May 16/84	Aug 15/84		
ORDER: Oscillatoriales				
Aphanizomenon				
Anabena circinalis		190		
Anabena flos-aquae		1504		
Anabena spiroides		292		
ORDER: Cryptomonadales				
Cryptomonas		2.3		
Chroomonas acuta		187		
ORDER: Crysomonadales				
Mallomonas spp	9.0	1.2		
Dinobryon (divergens)		3.5		
ORDER: Chroococcales				
Aphanothece		1752		
Aphanothece clathrata				
Aphanothece elachista		38.3		
Coelosphaerium naegelianum		46		
Gomphosphaeria		15.3		
Chroococcus		9.4		
ORDER: Chlorococcales				
Schroderia				
Botryococcus brauni		46		
Oocystis		2		
Ankistrodesmus		7		
Crucigenia		23		
Dictosphaerium				
Scenedesmus		4		
Sphaerocystis		4		
Kirchneriella				
Nephrocytium				
ORDER: Peridiniales				
Ceratium				
ORDER: Volvocales				
Pandorina				
ORDER: Desmidiales				
Cosmarium				
Staurastrum		present		
Arthrodesmus				

TABLE 16

PHYTOPLANKTON ANALYSIS

GOOSLY LAKE - SITE #0700084

1984

organisms cells/ml

ALGAL GENUS	May 16/84	Aug 15/84		
ORDER: Tetrasporales				
Gloeocystis				
Elakatothrix		17.6		
ORDER: Euglenales				
Trachelomonas				
ORDER: Rhizochrysidales				
Diceras		1		
ORDER: Centrales				
Stephanodiscus				
Cyclotella (glomerta)	11.6	33.6		
Melosira (italica)	46.5	55.5		
Rhizosolenia		present		
ORDER: Penales				
Cymbella		present		
Tabellaria	.3	23.9		
Nitzschia				
Synedra				
Cocconeis				
Fragilaria (construens)	.2			
Achnanthes	.2	present		
Asterionella (formosa)	.2	38.2		
Gomphonema	.4			
Meridion				
Eunotia				
Navicula	.2			
Pinnularia				
Surirella				
TOTAL	68.6	4295.8		
# GENERA/SPECIES	9	28		

TABLE 17
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
1985

organisms cells/ml

ALGAL GENUS	May 28/85	Jul 17/85	Aug 19/85	Oct 30/85
ORDER: Oscillatoriales				
Aphanizomenon				
Anabena circinalis				
Anabena flos-aquae		18	81	present
Anabena spiroides				
ORDER: Cryptomonadales				
Cryptomonas	85	present	19	9
Chroomonas acuta	1217	26	239	58
ORDER: Crysomonadales				
Mallomonas	19	20	2	6
Dinobryon (divergens)		543	3	
ORDER: Chroococcales				
Aphanothece		2628	1170 (possibly)	
Aphanothece clathrata		146		
Aphanothece elachista				
Coelosphaerium naegelianum			12	
Gomphosphaeria			6	
Chroococcus				
ORDER: Chlorococcales				
Schroderia				
Botryococcus brauni				
Oocystis		12	26	9
Ankistrodesmus	204	3	1	6
Crucigenia			9	
Dictosphaerium		56		
Scenedesmus		23		
Kirchneriella				
Nephrocytium				
ORDER: Peridiniales				
Ceratium		3	1	
ORDER: Volvocales				
Pandorina				
ORDER: Desmidiales				
Cosmarium				
Staurastrum		2	1	
Arthrodesmus				

(bracketed species) of >10% dominance

TABLE 17
PHYTOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
1985

organisms cells/ml

ALGAL GENUS	May 28/85	Jul 17/85	Aug 19/85	Oct 30/85
ORDER: Tetrasporales				
Gloeocystis		44	17	
Elakatothrix	present	29		
ORDER: Euglenales				
Trachelomonas			1	
ORDER: Rhizochrysidales				
Diceras		3		
ORDER: Centrales				
Stephanodiscus	9		3	26
Cyclotella (glomerta)	19	23	13	5
Melosira (italica)	162	14	66	2771
Rhizosolenia		48	2	
ORDER: Penales				
Cymbella				
Tabellaria		37	2	13
Nitzschia	9	9	6	
Synedra	16	5	4	21
Cocconeis	3		6	present
Fragilaria (construens)	41		82	28
Achnanthes	31		6	21
Asterionella (formosa)		292	28	5
Gomphonema			3	
Meridion			3	
Eunotia			3	
Navicula			3	5
Pinnularia				3
Surirella				
TOTAL	1815	3984	1818	2986
# GENERA/SPECIES	14	22	30	17

TABLE 18
ZOOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
May 4, 1983

GENUS/SPECIES	Replicate 1 # organisms cells/m3	Replicate 2 # organisms cells/m3	Replicate 3 # organisms cells/m3	Mean # organisms cells/m3
CLASS: Rotifera				
Kellicottia spp				
Kellicottia longispina	8,625	6,256	10,680	8,520 (n=3)
Keratella spp	2,070	2,392	3,600	2,687 (n=3)
Keratella cochlearis				
Filinia	115	46	480	214 (n=3)
Polyarthra				
Asplancha				
CLASS: Crustacea				
SUBCLASS: Copepoda (Nauplius spp immature)	25,185	27,232	21,120	25,512 (n=3)
ORDER: Eucopepoda				
SUBORDER: Cyclopoida				
Cyclops bicuspidatus (adult and copepodite)	11,500	11,488	14,040	12,343 (n=3)
SUBORDER: Calanoida				
Diaptomus				
SUBCLASS: Branchiopoda				
ORDER: Cladocera	345 (imm)	184 (imm)	60 (imm)	163 (n=3)
Bosmina spp	575		180	378
Bosmina coregoni				
Daphnia spp				
Daphnia longiremis				
Diaphanosoma				
Leptodora				
TOTAL #	48,415	47,598	50,160	48,724 (n=3)
# GENERA/SPECIES PRESENT	6	5	6	σ= 1069

imm = immature

TABLE 19
ZOOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
1984

GENUS/SPECIES	May 16 # organisms cells/m^3	August 15 # organisms cells/m^3		
CLASS: Rotifera				
Kellicottia spp				
Kellicottia longispina	1,340	802		
Keratella spp	114			
Keratella cochlearis		1,979		
Filinia	428	802		
Polyarthra		535		
Asplancha				
CLASS: Crustacea				
SUBCLASS: Copepoda (Nauplius spp immature)	7,700	18,289		
ORDER: Eucopepoda				
SUBORDER: Cyclopoida				
Cyclops bicuspidatus (adult and copepodite)	3,366	4,118		
SUBORDER: Calanoida				
Diaptomus		53		
SUBCLASS: Branchiopoda				
ORDER: Cladocera				
Bosmina spp	29	428		
Bosmina coregoni				
Daphnia spp		535		
Daphnia longiremis		1,444		
Diaphanosoma				
Leptodora				
TOTAL #	12,977	28,985		
# GENERA/SPECIES PRESENT	6	10		

TABLE 20
ZOOPLANKTON ANALYSIS
GOOSLY LAKE - SITE #0700084
1985

GENUS/SPECIES	May 28 # organisms cells/m^3	July 17 # organisms cells/m^3	August 19 # organisms cells/m^3	Sept 30 # organisms cells/m^3
CLASS: Rotifera				
Kellicottia spp			257	
Kellicottia longispina	206	1,412		1,096
Keratella spp	59	565	86	449
Keratella cochlearis		4,859	2,781	1,492
Filinia	266	791	86	
Polyarthra	59	452	856	599
Asplancha			43	150
CLASS: Crustacea				
SUBCLASS: Copepoda (Nauplius spp immature)	4,404	7,966	28,064	10,941
ORDER: Eucopepoda				
SUBORDER: Cyclopoida				
Cyclops bicuspidatus (adult and copepodite)	3,074	7,006	8,000	3,829
SUBORDER: Calanoida				
Diaptomus		225	43	102
SUBCLASS: Branchiopoda				
ORDER: Cladocera				
Bosmina spp		169		
Bosmina coregoni			1,112	647
Daphnia spp	89	339	1,027	348
Daphnia longiremis		1,186	2,567	
Diaphanosoma		226	257	
Leptodora		present		
TOTAL #	8,157	25,197	45,179	19,653
# GENERA/SPECIES PRESENT	7	13	13	10