A Preliminary Assessment of the Effects of Anvil Mine on the Environmental Quality of Rose Creek, Yukon

A PRELIMINARY ASSESSMENT OF THE EFFECTS OF ANVIL MINE ON THE ENVIRONMENTAL QUALITY OF ROSE CREEK, YUKON.

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INTRODUCTION

On December 12, 1972, the Department of Indian Affairs and Northern Development received an application for a Water Licence from Anvil Mining Corporation Limited of Faro, Yukon Territory. The mine plans to expand production from it's present capacity of 8,000 tpd to 10,000 tpd, and ultimately to 15,000 tpd.

The Yukon Water Board, which hears all such applications, determined that a preliminary survey of the Rose Creek watershed should be undertaken to document existing environmental conditions prior to identifying the terms and conditions for Anvil's Water Use Licence under the Northern Inland Waters Act. To satisfy the immediate needs of the Water Board, the Environmental Protection Service (Yukon District) offered on behalf of Environment Canada to conduct the preliminary field survey and identified the scope of the study needed to be as follows:

1. To determine the receiving water quality conditions at several key sites in Rose and Anvil Creeks and the Pelly River:
2. To assess the benthos community characteristics;
3. To determine the physical and chemical constituents of the sediments; and,
4. To determine fish species composition and trace heavy metal levels in fish.

This report presents data obtained in a short field survey carried out in mid-September, 1973.

ANVIL MINING CORPORATION LIMITED.

The Anvil mine and mill complex, located approximately

150 air miles Northeast of Whitehorse in the Yukon Territory (Fig. 1), has been in operation since September, 1969. The property is mined by conventional open pit methods (Bench mining with shovels and trucks) with a present average production of 8,000 tons of lead- zinc-silver ore per day. With the planned production rate increases, it is estimated that the existing open pit area and the 500,000 gal/day of natural groundwater gaining access to the mine workings is discharged from the pit through an old drainage ditch into the tailings pond.

At present production rates (8,000 tpd), the Anvil mill uses 4,320,000 gal/day of water to produce approximately 250 tpd of bulk concentrate, 700 tpd of lead, 350 tpd of zinc, plus 6,780 - 13,000 standard dry tons of tails/day. All "liquid" wastes leaving the mill are directed to an existing tailings impoundment covering approximately 57 acres, with a present decant overflow of 3-4,000,000 gal/day into Rose Creek. The expected average volume of decant overflow when the property is running full capacity will be 5 - 7,000,000 gal/day, provided that recirculation will not be practiced. During the study period there was no significant decant overflow from the tailings pond (ie< 5 gpm or 7,200 gpd).

DESCRIPTION OF STUDY AREA.

Rose Creek is one of several small streams draining the Anvil Mountain range, an area typified by mica schist massifs covered at the lower levels with coniferous and mixed northern forest. Faro Creek and the North Fork of Rose Creek are two small tributaries which, in addition to the main stem of Rose Creek directly below the confluence with its North Fork, drain the Anvil Mine Property (Fig. 2). Rose Creek joins with Anvil Creek at a distance of approximately 14 miles downstream from the mine before discharging into the Pelly River 11 miles further down.

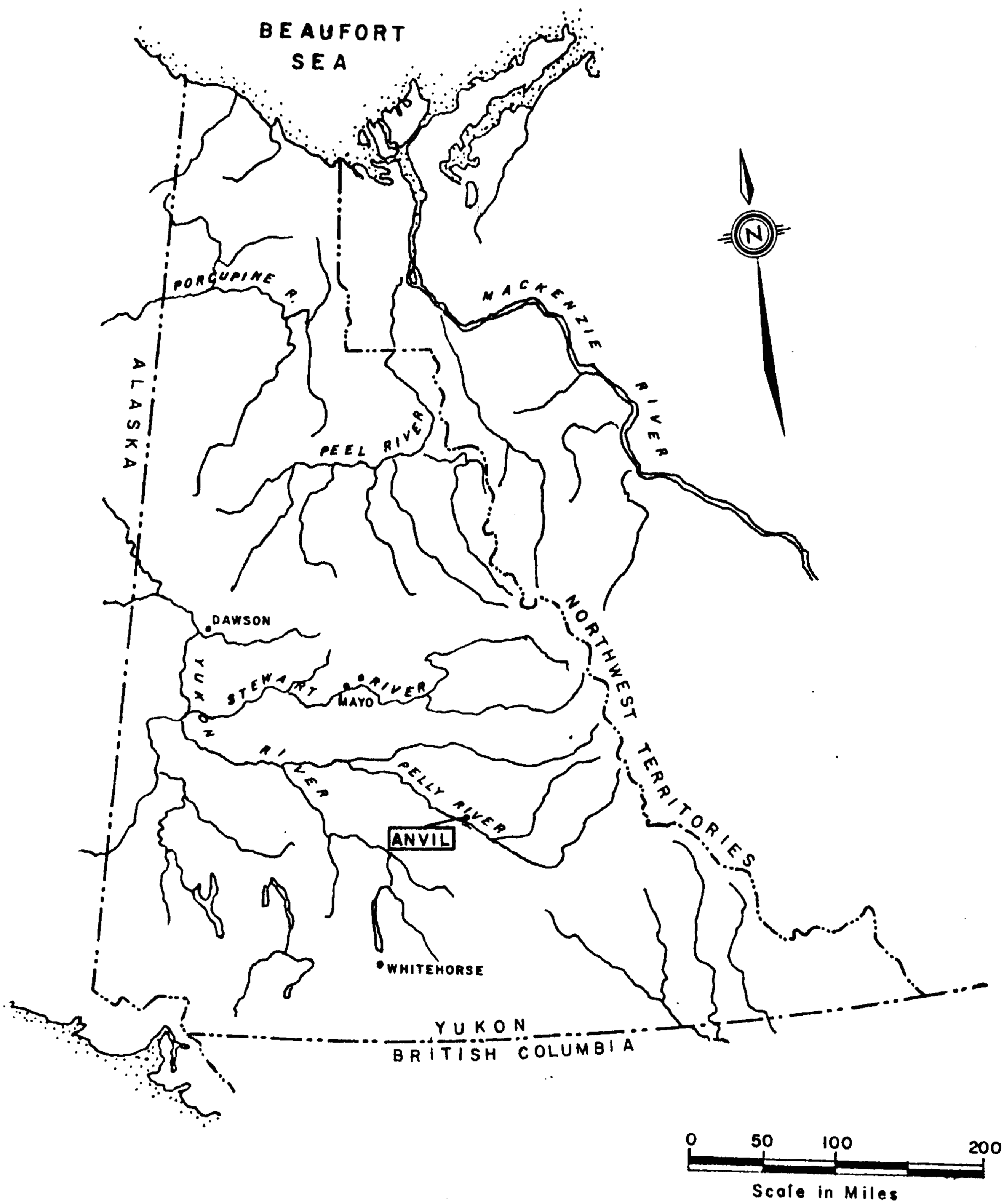


FIGURE I. ANVIL MINING CORPORATION LIMITED

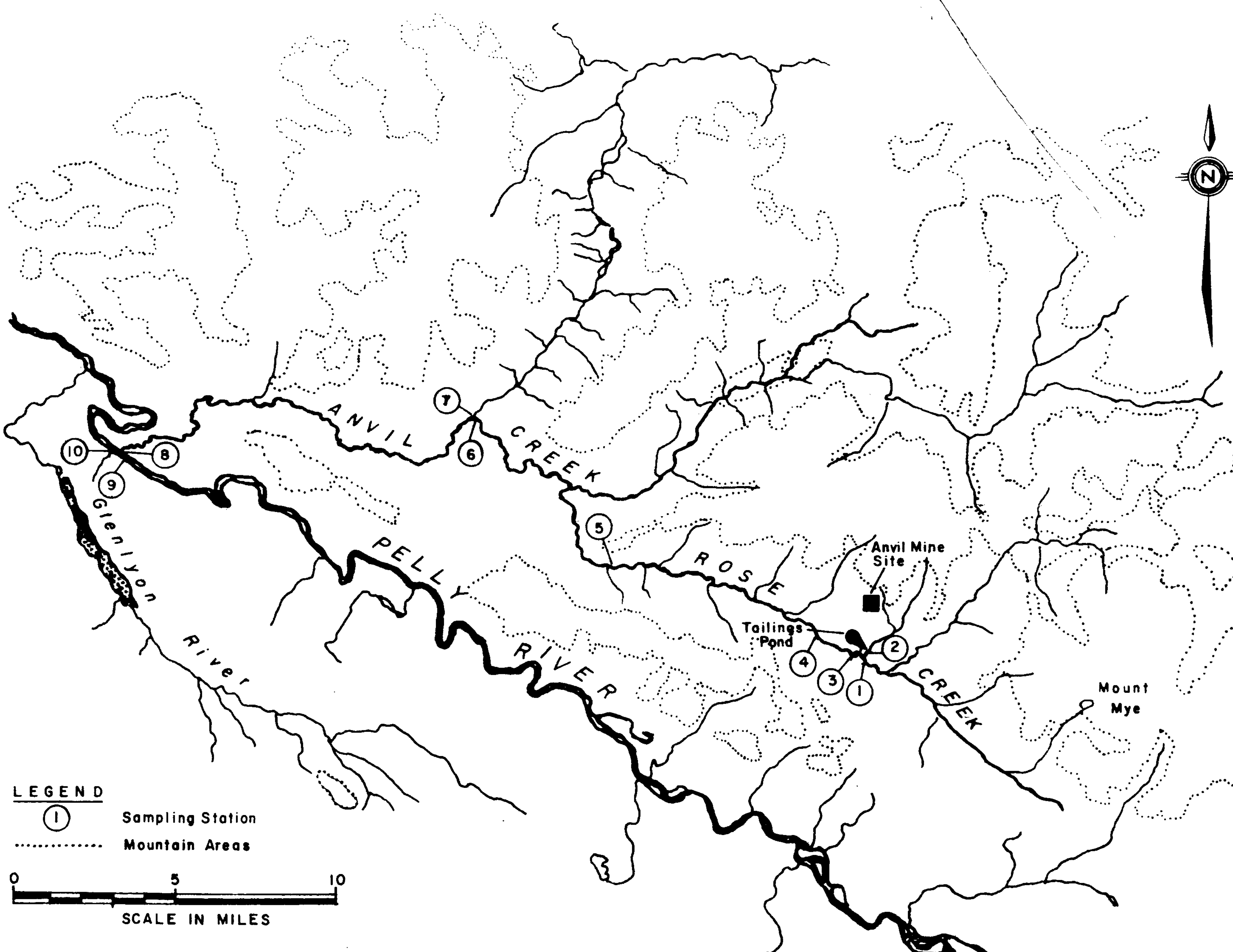


FIGURE 2. ANVIL MINING CORP. LTD. - SAMPLING STATIONS (Sept. 16-20,1973)

Several stream alterations have been made and more are proposed by Anvil Mining Corporation. All are of considerable importance to the Rose Creek system and should therefore be described. Figure 3 presents a more detailed layout of the immediate mine area. Important features of the map are: the location of the present and ultimate mining areas, the present diversion of Faro Creek around the pit area, the future diversion of Faro Creek as mining progresses, the course of minewater into the tailings area, the course of the North Fork and main stem of Rose Creek, the winter diversion of the North Fork of Rose Creek, the location of the freshwater pumphouse, the present tailings pond area, the location of the potential tailings pond area, and the 1973 EPS receiving water sampling stations in the vicinity of the mine.

Plates I to IX illustrate the general topography of the study area and highlight some of the key stations sampled.

METHODS AND MATERIALS.

The 1973 preliminary environmental quality survey of the Rose Creek system was carried out during the period September 17-21.

1. Sampling Stations

A total of 10 sampling stations were established. The sites selected are illustrated in Figures 2 and 3 and described in Table I. All stations were identified by embedding a 3 foot iron peg into the permanent stream bank and by marking nearby trees above the maximum winter snow level with fluorescent red survey tape and spray paint.

With the exception of the Pelly River stations, all sites were characterized by fast flowing water over shallow, well-gravelled riffle areas. The Pelly River stations were also shallow and gravelled, but in slow moving water at this time of the year.

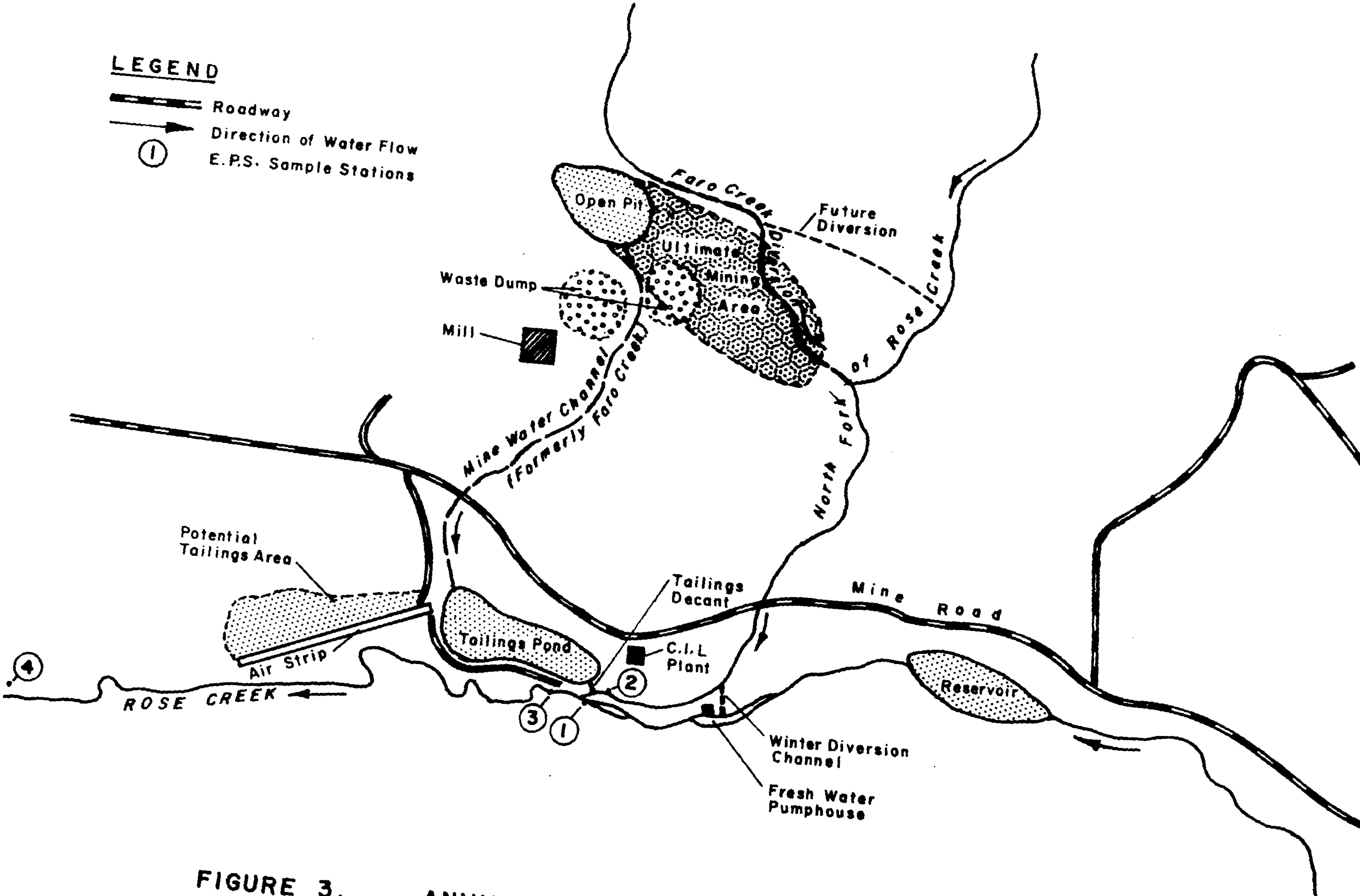


FIGURE 3. ANVIL MINE SITE

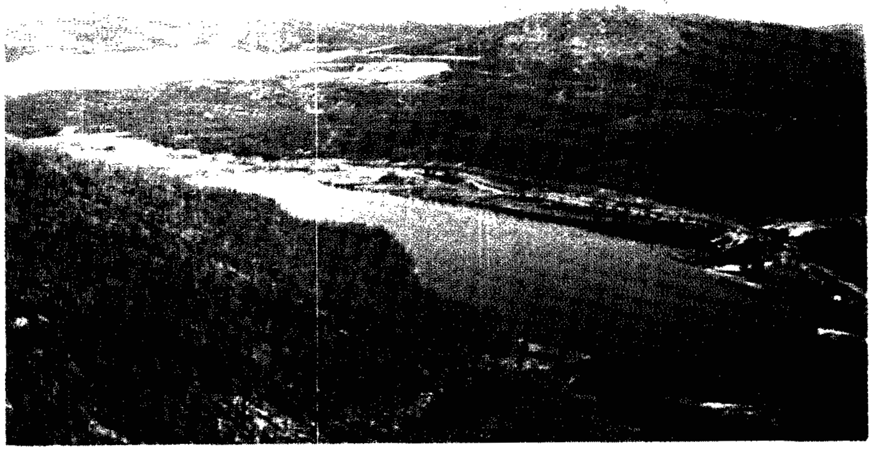


Plate 1. Anvil Mine - View N. W. Reservoir in foreground

Plate 2. Anvil Mine - View N.

Plate 3. Anvil Mine - Faro Creek Diversion.

Plate 4. Anvil Mine - View N. with Tailings Pond in foreground.

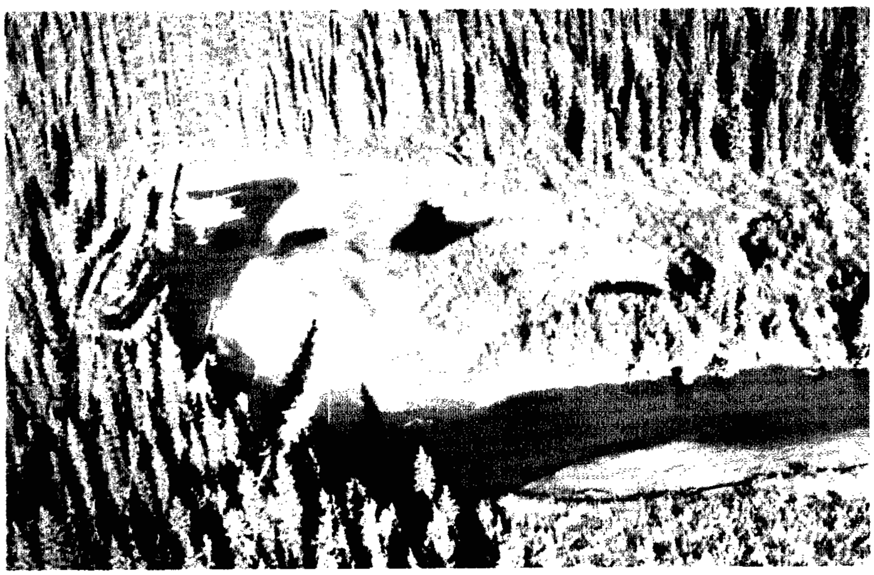


Plate 5. Rose Creek. Stn. #5. View N.

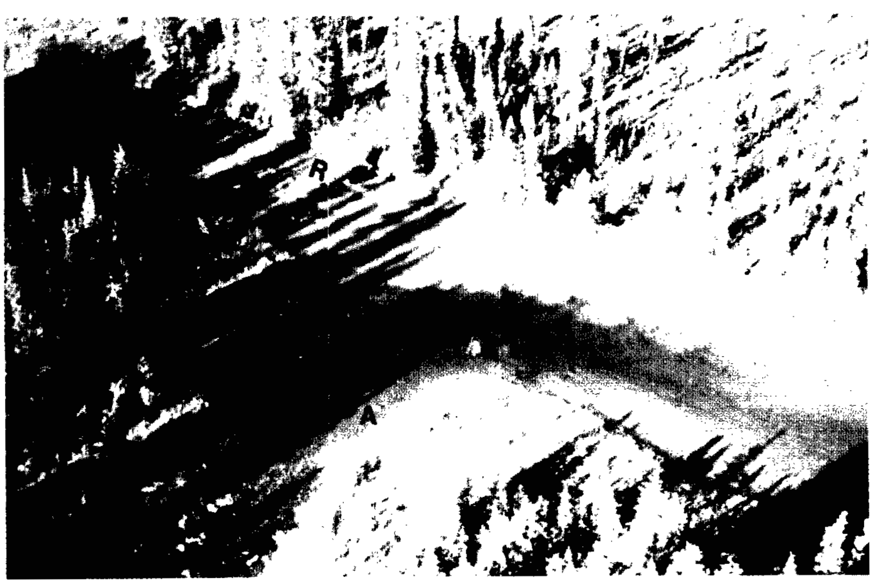


Plate 6. Rose Creek/Anvil Creek View S.W.

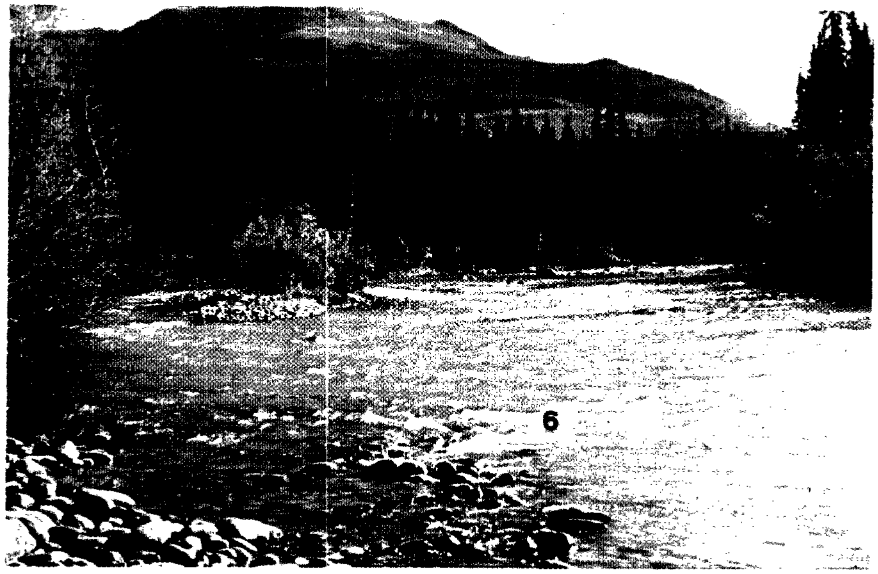


Plate 7. Anvil Creek. Stn. #6. View E.

Plate 8. Anvil Creek/Pelly River. Stns #8, #9, #10. View E.

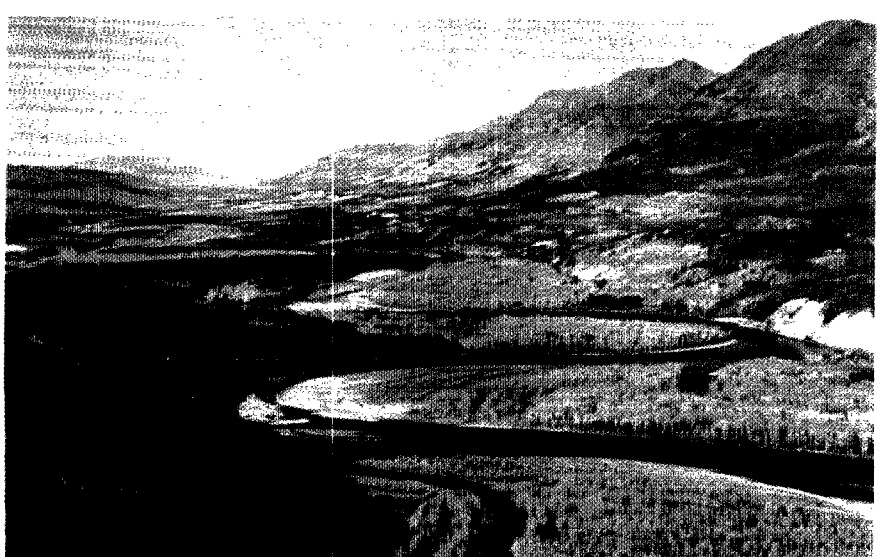


Plate 9. Pelly River - View N.W. from Faro.

TABLE I

1973 Anvil Mine Sampling Stations

1. Rose Creek below pumphouse 10 yards above confluence with North Fork of Rose Creek.
2. North Fork of Rose Creek 30 yards above tailings pond decant.
3. Rose Creek 20 yards below confluence with North Fork of Rose Creek.
4. Rose Creek approximately 2 miles below tailing pond decant.
5. Rose Creek approximately 8 miles below tailing pond decant.
6. Anvil Creek 30 yards above confluence with unidentified creek approximately 14 miles below tailings pond decant.
7. Unidentified creek 30 yards above confluence with Anvil Creek.
8. Anvil Creek 30 yards above confluence with Pelly River.
9. Pelly River 50 yards above confluence with Anvil Creek.
10. Pelly River 50 yards below confluence with Anvil Creek.

Stations 1-4 were accessible by vehicle. The remainder could be sampled only by helicopter because of time limitations and the low water conditions prevailing.

2. Water Quality Sampling.

Water temperature and pH were determined in the field with a thermometer and a Hach pH kit.

Samples for dissolved oxygen were collected in 300 ml BOD bottles, field-fixed with manganese sulfate and azide soltuion, and returned to the Department of Environment Cypress Creek laboratories in West Vancouver for titration with Sodium Thiosulfate.

A five gallon water sample was collected at each station plus the tailings pond with a plastic bucket. The buckets were sealed, and returned to the bioassay laboratory for static toxicity evaluations.

Three one liter samples of water were collected and placed in plastic bottles at each station plus the tailings pond. Bottle 1 was field-fixed with nitric acid for total heavy metal analysis. Bottle 2 was returned to the field hotel where 250 ml were removed, filtered through 0.45 μ membrane filters, and the filtrate preserved with nitric acid for dissolved heavy metal analysis. Bottle 3 remained untreated for color, turbidity, pH, alkalinity, conductivity, hardness, and solids analysis. All samples were returned to the Cypress Creek laboratories for analysis by the methods outlined in Davidson et al (1972).

3. Sediment Sampling

Three shallow core samples were collected from sand/gravel bars at each station with a hand corer, placed in separate "Whirl-Pack" bags, and returned to the West Vancouver laboratories for sediment size and total heavy metal analysis.

4. Biological Sampling.

Three quantitative samples of aquatic invertebrates were obtained from riffle areas at each station using a 1ft^2 circular sampler. The samples were preserved with formaldehyde and returned to the Department of Environment's North Vancouver laboratories for sorting, identification, and enumeration of the macro-organisms present. The data obtained were analyzed statistically using the Shannon-Wiener "diversity" index (H') and the "Evenness" index (J), as described by Pielou (1966, 1967). These functions are represented by the following formulae:

(a) Species Diversity (H') $= \Sigma\ p_i \log p_i$

where $p_i = n_i/N$

n_i = the number of individuals in the ith species

N = the total number of individuals sampled.

(b) Evenness (J) $= \dfrac{-\Sigma\ p_i \log p_i}{\log_s}$

where s = the total number of species sampled; and

$J_{max} = 1$.

Two qualitative samples of attached algae were collected from boulders at each station using a sampler developed by Stockner and Armstrong (1971). The samples were preserved with Lugol's solution and returned to the North Vancouver laboratories for sorting and identification of the flora present.

Test fishing using gill net, seine net, and angling techniques was attempted at each of station 1, 2, 4 and in the vicinity of 5. No fish were caught at any of these sites using these methods. It is recommended that in the future an electro-fishing technique be attempted as it may prove more successful.

However, one sample of fish, Arctic Grayling (Thymallus arcticus) was obtained by angling from the Anvil Mine pumphouse pond. This sample was frozen immediately "in the round" and returned to Cypress Creek for total heavy metal analysis.

RESULTS

1. Water Quality Sampling

Figure 4 summarizes the mean monthly flow data obtained by the Water Survey of Canada for Rose Creek below Faro Creek in 1968 and 1969. Unfortunately the data is neither complete nor up-to-date since monitoring at this site was discontinued in the summer of 1969. However, it does indicate that the peak flow for the year can be expected to occur during spring break-up (April-June), with secondary peaks occurring any time (depending on weather conditions) prior to freeze-up (October-November). During the winter, the flow in Rose Creek, as expected, is minimal.

Table II presents the water analysis results for total and dissolved metals in the samples collected from stations 1-10, and the tailings pond decant. From a toxicity point of view, the tailings pond decant contained slightly elevated levels of total (1.8 mg/l) and dissolved (0.12 mg/l) copper but no other toxic metals in significant concentrations. At the receiving stream stations only the total iron levels appeared to be unusually high. The Faro Creek diversion would be the most likely source of the excess iron as it is an open ditch around the pit area, and aerial reconnaissance had shown it to be discharging highly coloured water to Rose Creek a short distance above station 2 where the highest concentration of iron was recorded (10.6 mg/l). Iron levels remained above 3 mg/l to a point below station 4, approximately 2 miles below the tailings pond decant.

The non-metal water analysis results (Table III) indicate that during the study period the major effects of the mining activity were increases in non-filterable residue (NFR) and turbidity levels in Rose and Anvil Creeks. The greatest concentrations of both NFR

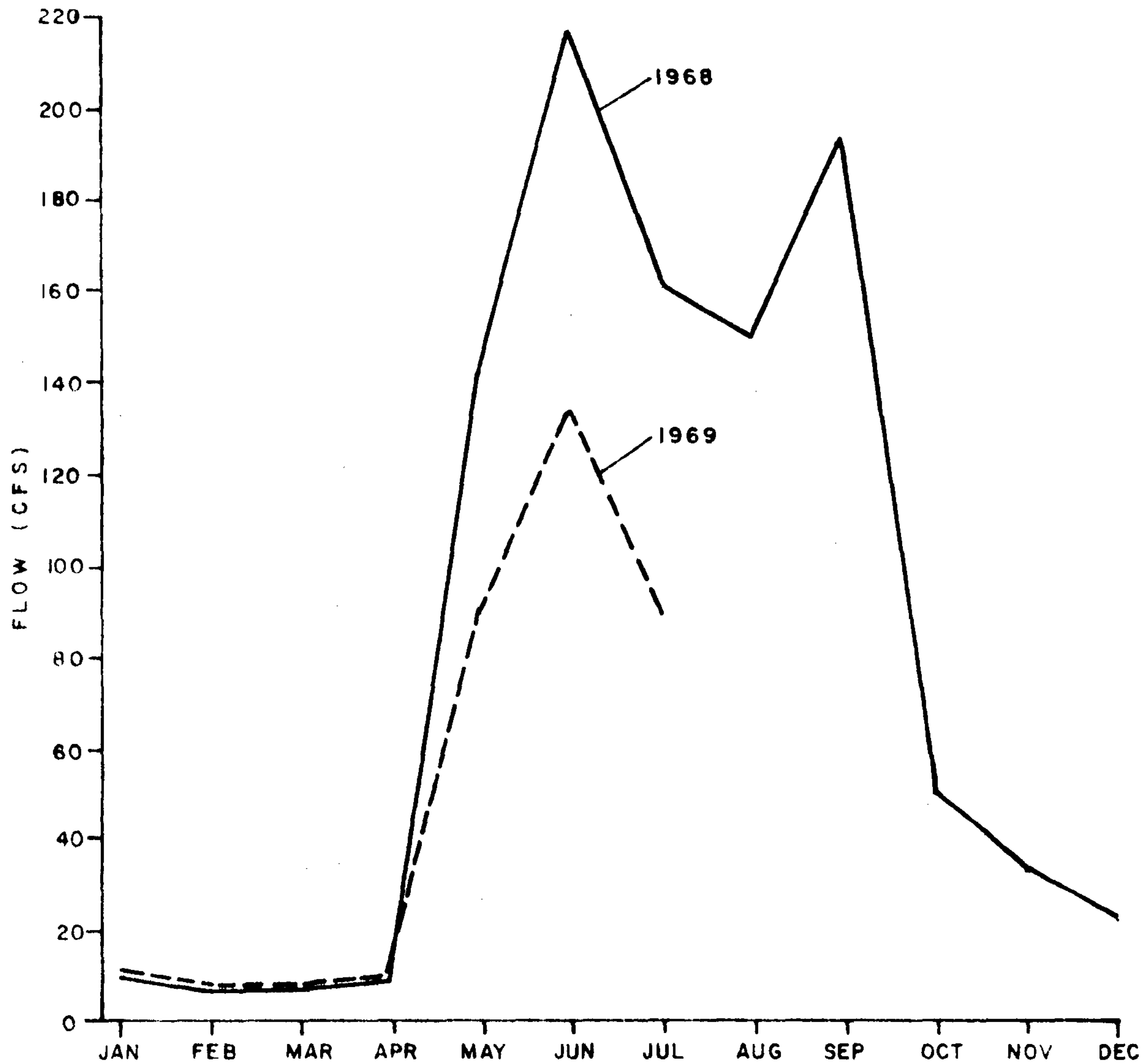


FIGURE 4. MEAN MONTHLY FLOW DATA FOR ROSE CREEK BELOW FARO CREEK RECORDED IN 1968 and 1969. (Data supplied by Water Survey of Canada).

Table II . Water Analysis Results - Total & Dissolved Metals.

Sampling Station	Station Location	Date Sampled	Fraction	Cu mg/l	Cd mg/l	Fe mg/l	Mn mg/l	Mo mg/l	Pb mg/l	Zn mg/l
Anvil Mine	Tailings Pond Decnt.	Sept. 20/73	Total	1.8	<0.03	0.54	< 0.05	**	<0.1	0.11
			Dissolved	0.12	<0.03	<0.06	< 0.05		<0.1	<0.01
Stn. #1	Rose Creek	Sept. 18/73	Total	<0.01	<0.03	0.25	< 0.06		0.3*	<0.01
			Dissolved	<0.01	<0.03	≈0.06*	< 0.05		<0.1	<0.01
Stn. #2	North Fork Rose Creek	Sept. 18/73	Total	0.02	<0.03	10.6	0.22		<0.1	0.095
			Dissolved	<0.01	<0.03	<0.06	0.06		<0.1	<0.01
Stn. #3	Rose Creek	Sept. 18/73	Total	<0.01	<0.03	3.3	0.08		<0.1	0.03
			Dissolved	<0.01	<0.03	<0.06	< 0.05		<0.1	<0.01
Stn. #4	Rose Creek	Sept. 18/73	Total	0.02	<0.03	6.3	0.50		<0.1	0.075
			Dissolved	<0.01	<0.03	0.06	0.41		<0.1	0.025
Stn. #5	Rose Creek	Sept. 19/73	Total	<0.01	<0.03	0.25	0.28		<0.1	0.075
			Dissolved	<0.01	<0.03	<0.06	0.22		<0.1	0.02
St. #6	Anvil Creek	Sept. 19/73	Total	<0.01	<0.03	1.4	0.13		<0.1	≈0.01
			Dissolved	<0.01	<0.03	<0.06	0.09		<0.1	<0.01
St. #7	Unidentified Creek	Sept. 19.73	Total	0.01	<0.03	0.60	0.10		<0.1	≈0.01
			Dissolved	<0.01	<0.03	≈0.06	< 0.05		<0.1	<0.01
St. #8	Anvil Creek	Sept. 20/73	Total	<0.01	<0.03	0.63	0.10		<0.1	<0.1
			Dissolved	<0.01	<0.03	0.06	0.06		<0.1	<0.1
St. #9	Pelly River	Sept. 20/73	Total	<0.01	<0.01	0.22	< 0.05		<0.1	≈0.01
			Dissolved	<0.01	<0.03	<0.06	< 0.05		<0.1	≈0.01
St. #10	Pelly River	Sept. 20/73	Total	0.01	<0.03	1.13	0.10		<0.1	≈0.01
			Dissolved	<0.01	<0.03	<0.06	0.05		<0.1	≈0.01

* probably due to sampling error
** molybdenum not determined due to high background interferences

Table III - Water Analysis Results - Non Metals.

Sampling Station	Station Location	Date Sampled	Field Temp °C	Field pH	D.O. mg/l	pH	Turbidity F.T. Units	Total Hardness mg/ℓ $CaCO_3$	Colour C.U.	Cond. μ mhos/cm	Total Alkalinity mg/ℓ $CaCO_3$	NFR mg/l
Anvil Mine	Tailings Pond Decant.	Sept. 20/73	-	-	-	10.6	19	49	7	1050	62.7	8.2
Stn. #1	Rose Creek	Sept. 18/73	6.5	8.2	10.7	8.1	1.2	98	15	187	88.2	2.5
Stn. #2	North Fork Rose Creek	Sept. 18/73	5.0	8.1	11.4	7.8	28	88	15	167	68.6	427
Stn. #3	Rose Creek	Sept. 18/73	6.0	8.0	10.8	7.9	15	88	15	188	74.5	155
Stn. #4	Rose Creek	Sept. 18/73	6.0	8.2	10.1	7.6	27	108	15	260	78.4	280
Stn. #5	Rose Creek	Sept. 19/73	4.5	8.5	11.3	7.8	15	108	10	254	83.3	116
Stn. #6	Anvil Creek	Sept. 19/73	2.5	8.6	12.1	7.8	7.2	118	10	260	96.0	42.3
Stn. #7	Unidentified Creek	Sept. 19/73	1.8	8.3	10.6	7.8	5.5	78	15	137	48.0	13
Stn. #8	Anvil Creek	Sept. 20/73	2.5	8.6	13.1	8.0	4.1	118	10	246	87.2	14.3
Stn. #9	Pelly River	Sept. 20/73	6.2	8.0	10.3	8.0	6.4	127	10	258	91.1	7.9
Stn. #10	Pelly River	Sept. 20/73	4.5	8.4	12.1	8.1	8.2	108	15	246	90.2	76.8

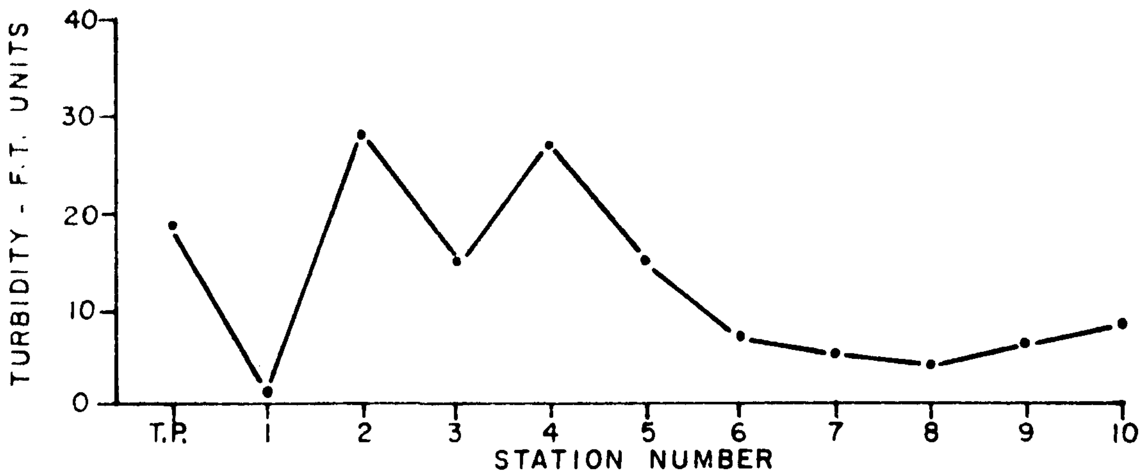
(427 mg/l) and turbidity (28 F.T. Units) were recorded at station 2, again suggesting that the Faro Creek diversion was the source of the problem. NFR and turbidity levels remained excessive throughout the length of Rose Creek (Figure 5 and Plate VI) and were maintained above "background" (Station 1 and 7) in Anvil Creek down to the Pelly River, which also carries a high sediment load.

The other chemical parameters measured did not appear to be affected by the mining activities at this time. Dissolved oxygen levels were at or near saturation (>10 mg/l); water temperatures were low, but normal (1.8-6.5^{o}C); pH's were slightly alkaline (≈8.0), but apparently normal; and the receiving waters were relatively hard (88-127 mg/l).

The results of the bioassays (Table IV) confirmed the water quality statistics. At the time of sampling, only the tailings pond decant was toxic (LT_{50} = 0.42 hr). Previous unpublished data had indicated that the high pH of the decant was the major cause of the toxicity observed, as neutralized samples proved to be consistently non-toxic. Since the tailings pond decant flow was negligible (3gpm). it is not possible to extrapolate possible toxic or otherwise deleterious effects of the effluent on Rose Creek below the pond. However it would be reasonable to assume that a pH effect would exist for some distance downstream if the normal daily discharge (4,000,000 gpd) was released.

2. Sediment Sampling.

Since the principal objective of the project was to assess possible effects of the mine on the receiving environment and because mining operations normally discharge only the smaller particle fractions, sampling was limited to sandbars rather than the main, consistently rocky, riffle areas. Figure 6 illustrates the particle size distributions



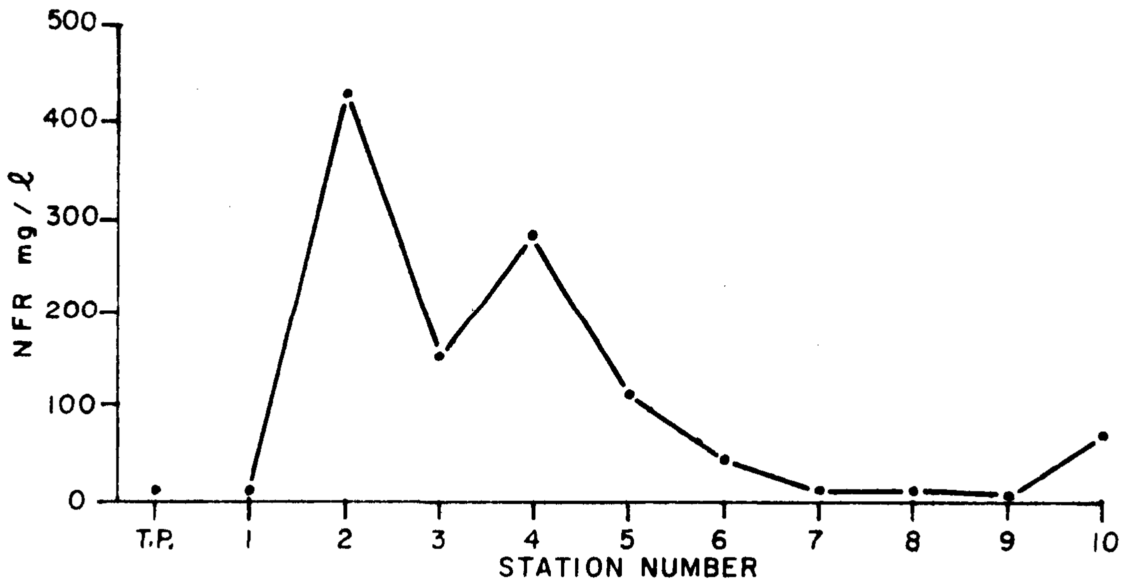


FIGURE 5 TURBIDITY AND NON-FILTERABLE RESIDUE RESULTS

Table IV . 96 HR LT_{50} Bioassay Results

Test Fish: - Juvenile Coho Salmon (*Oncorhynchus kisutch*) Acclimated to untreated Capilano Reservoir Tap Water at $11^oC \pm 1^oC$
5 Fish/Test Tank
Mean Fish Weight - 2.98 gm
Mean Fish Length - 6.4 cm
Test Tank Volume - 20 l
Dissolved Oxygen Content - 10.0 ± 1 mg/l

Sampling Station	Station Location	Date Sampled	Date Bioassay	Initial Sample pH	Final Sample pH	Temp Range ^oC	Loading Density gm/l	% Survival 96 Hr	LT_{50} Hr
Anvil Mine	Tailings Pond Decant	Sept 20/73	Sept 24/73	10.7	10.3	10.0-10.0	0.67	0	0.42
Stn. #1	Rose Creek	Sept 20/73	Sept 24/73	7.7	7.5	10.5-10.0	0.67	100	Not Estblished
Stn. #2	North Fork Rose Creek	Sept 20/73	Sept 24/73	7.8	7.4	10.5-10.0	0.67	100	" "
Stn. #3	Rose Creek	Sept 20/73	Sept 24/73	7.7	7.6	10.5-10.0	0.67	100	" "
Stn. #4	Rose Creek	Sept 20/73	Sept 24/73	7.7	7.7	10.5-10.0	0.67	100	" "
Stn. #5	Rose Creek	Sept 18/73	Sept 24/73	7.4	7.4	10.5-10.0	0.67	100	" "
Stn. #6	Anvil Creek	Sept 18/73	Sept 24/73	8.0	7.8	10.5-10.0	0.67	100	" "
Stn. #7	Unidentified Creek	Sept 18/73	Sept 24/73	7.5	7.4	10.5-10.0	0.67	100	" "
Stn. #8	Anvil Creek	Sept 18/73	Sept 24/73	7.9	7.7	10.5-10.0	0.67	100	" "
Stn. #10	Pelly River	Sept 18/73	Sept 24/73	8.0	7.8	10.5-10.0	0.67	100	" "

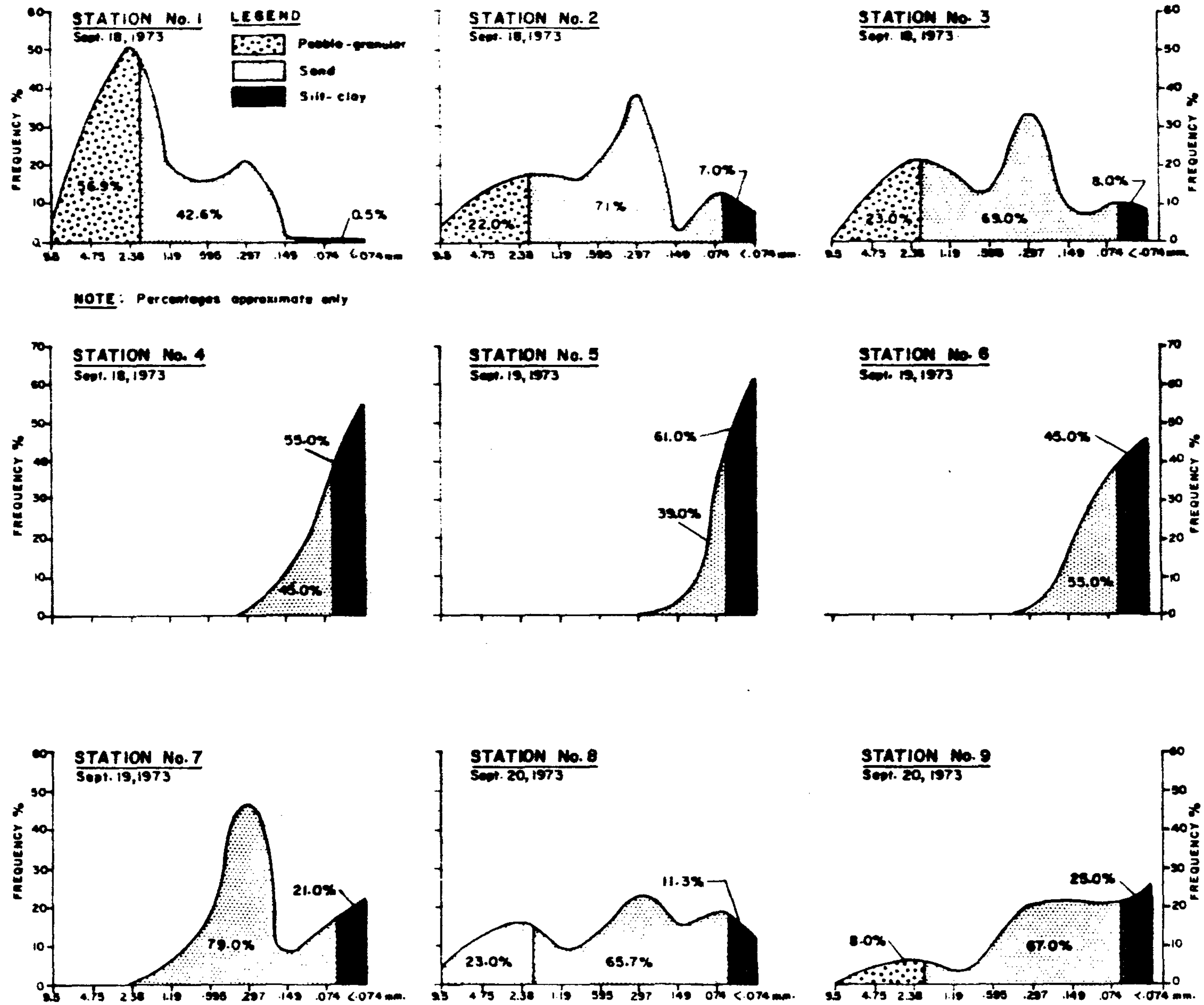


FIGURE 6 SEDIMENT PARTICLE SIZE DISTRIBUTIONS

for the sediments collected at stations 1-9. The most pertinent observation to be made is that stations 4, 5, and 6 had the highest percentages of silt-clay of all stations sampled. This would be predictable since aerial reconnaissance had shown this portion of the creek channel to be the widest and most meandering and therefore probably the slowest in terms of velocity. The reduced velocities would result in precipitation of the finer suspended sediment fractions in Rose Creek, be they from mine activities or due to natural erosion.

It was hoped that the heavy metal analyses of the sediments would shed some light on the origin of the finer fractions. The results (Table V) reveal very few consistent trends. The data pertaining to total volatile residue, copper, cadmium, and manganese did not indicate build-ups directly attributable to the mine operation. Total iron, lead, and zinc were most concentrated in the sediment collected at station 2 (71,000, 830, and 2,000 µg/gm, respectively). The next highest concentration for all three parameters was recorded at station 6, approximately fourteen miles downstream on Anvil Creek. From the data obtained, it would appear that more comprehensive sampling is required to delineate possible build-ups of heavy metals in the sediments of the Rose-Anvil system, although such a survey would not seem to be warranted at this time.

3. Biological Sampling.

Appendix I summarizes all of the raw data from samples collected for invertebrate analysis during the preliminary Anvil Mine survey. A total of 38 species of macro-invertebrates representing 5 phyla were found. They are listed in Table VI complete with their higher classification and where available, common names. As would be expected, insects dominated the populations in terms of both numbers of species and total numbers at all stations. In fact, of the 30 species of

Table V . Sediment Analysis - Total Metals & Total Volatile Residue.

Sampling Station	Station Location	Date Sampled	Total Volatile Residue mg/gm	Cu µg/gm	Cd µg/gm	Fe µg/gm	Mn µg/gm	Mo µg/gm	Pb µg/gm	Zn µg/gm
Stn. #1	Rose Creek	Sept. 18/73	12.6	64	23	34,000	700	*	280	270
Stn. #2	North Fork Rose Creek	Sept. 18/73	24.4	68	<15	71,000	500		830	2000
Stn. #3	Rose Creek	Sept. 18/73	10.5	48	<15	28,000	390		274	290
Stn. #4	Rose Creek	Sept. 18/73	13.9	24	<15	29,000	460		83	180
Stn. #5	Rose Creek	Sept. 19/73	22.8	44	<15	34,000	490		280	440
Stn. #6	Anvil Creek	Sept. 19/73	36.5	93	<15	45,000	590		650	1100
Stn. #7	Unidentified Creek	Sept. 19/73	28.8	40	<15	27.000	670		<45	130
Stn. #8	Anvil Creek	Sept. 20/73	12.8	100	<15	27,000	500		175	275
Stn. #9	Pelly River	--	--	--	--	--	--		--	--
Stn. #10	Pelly River	Sept. 20/73	16.3	61	<15	28,000	530		290	380

* Molybdenum not determined due to high background interferences

Table VI

Invertebrate Species List.

Phylum Arthropoda

Class Arachnida

Order Acarina (mites)

Superfamily Hydracarinae (water mites)

mite sp. #1

mite sp. #2

Class Crustacea

Subclass Ostracoda (seed shrimps)

sp.

Subclass Copepoda

Order Harpacticoida

sp.

Order Cyclopoida

sp.

Order Calanoida

sp.

Class Insecta

Order Plecoptera (stoneflies)

Family Perlodidae

Subfamily Isoperlinae

Isoperla sp.

Family Nemouridae

Subfamily Capniinae

Capnia (prob. *nearctica*)

Paracapnia sp.

Order Ephemeroptera (Mayflies)

Family Heptageniidae

Subfamily Heptageniinae

Cinygmula sp.

Cinygma sp.

Epeorus (=*Iron*) sp.

Rithrogena sp.

Family Tricorythodidae

prob. *Tricorythodes* sp.

Family Ephemerellidae

prob. *Ephemerella* sp.

Order Homoptera (aphids, leafhoppers)

sp.

Order Diptera (true flies, mosquitoes, midges)

Family Tendipedidae (Midges)

Subfamily Hydrobaeninae

Spaniotoma sp.

Coryoneura sp.

Tendiped spp. pupae

Family Tipulidae (Crane flies)

Subfamily Limoniinae

Dicranota sp.

adult sp.

Family Simuliidae (Blackflies)

Simulium sp.

Family Musidae

sp.

Family Psychodidae (Mothflies)

sp. (prob. *Pericoma* sp.)

Family Ceratopogonidae (Biting midges)

prob. Probezzia sp.

adult Dipteran sp.

Order Trichoptera (caddisflies)

Family Hydroptilidae ("micro"-caddisflies)

prob. Ochotrichia sp.

Neotrichia sp. or Mayatrichia sp.

Family Calamoceratidae (triangular tube-case makers)

prob. Notiomyia sp.

Family Psychomiidae (tunnel-dwellers)

prob. Polycentropus sp.

Family Brachycentridae (square or cylindrical tube-case makers)

Brachycentrus sp.

Family Hydropsychidae (net-dwellers)

Diplectrona sp.

Order Coleoptera (beetles)

Family Dryopidae

sp.

Family Psephenidae (riffle beetles)

sp.

Phylum Cnidaria

Class Hydrozoa

Order Hydroida

Family Hydridae

Hydra sp.

Phylum Nematoda (round worms)

spp.

Phylum Platyhelminthes (flatworms)

Class Turbellaria (free-living flatworms)

Order Tricladida

sp.

Phylum Annelida (segmented worms)

Class Oligochaeta

(prob. Family Naididae)

Chaetogaster (prob. diastrophus)

Total # spp. = 38

insects recorded, only the stoneflies (Isoperla, Capnia and Paracapnia), the midges (Spaniotoma and Corynoneura), and the blackfly (Simulium) contributed significantly to the population densities found. The remaining organisms, when present, were generally represented by fewer than five individuals.

Table VII presents the results of the species diversity and evenness calculations obtained from the raw data. Figures 7a, b, and c, graphically depict the total number of species found per square foot, the total number of organisms per square foot, and the diversity-evenness results, respectively, as determined for all stations sampled. The general trends observed were as follows: Stations 1, 6, and 7 had the greatest variety of species represented, the highest total densities of macro-invertebrates, and among the highest diversities. Stations 2, 3, 4, and 5 on the other hand, had the fewest species, the lowest population densities, and generally lower diversity values. The diversity figure for station 3 was artifically inflated, but this was primarily attributable to the very even distribution (as indicated by the high evenness value) of the number of individuals representing the species. The results for stations 8, 9, and 10 were generally intermediate between those of the two previously discussed divisions. This would probably be due to the fact that they are located on, or in the case of station 8, directly adjacent to, the Pelly River, which would exert a totally different set of physical and chemical stresses on the populations present.

Appendix II summarizes all of the algae data collected during the study period, and Figure 8 illustrates the distribution of algal species between the mine and Pelly River. Stations 1 and 9 displayed the greatest diversity of species while station 2 showed the least. Unfortunately not much is known of the effects of mine activities on specific algal species, but one thing appears certain - discharges from Faro Creek were affecting the algal population at station 2.

Table VII. Summary of Diversity (H') and Evenness (J) Results.

Station Number	Sample	Species Diversity (H')	Evenness (J)
1	A	1.7526	0.6833
	B	1.63	0.5639
	C	1.5003	0.6257
2	A	1.3864	1.0
	B	1.0986	1.0
	C	0	0
3	A	1.3662	0.9617
	B	1.2697	0.7889
	C	1.4681	0.9122
4	A	0	0
	B	0	0
	C	0.6365	0.9183
5	A	1.551	0.7059
	B	1.0867	0.6065
	C	0.9612	0.5972
6	A	1.9847	0.7987
	B	2.0263	0.6555
	C	1.5285	0.5959
7	A	1.9971	0.7375
	B	2.338	0.7940
	C	1.9012	0.6457
8	A	1.3024	0.5928
	B	1.0431	0.6481
	C	1.4852	0.7632
9	A	0.5403	0.3357
	B	0.7522	0.4198
	C	0.8562	0.4118
10	A	0.3938	0.2024
	B	0.6868	0.3126
	C	0.8071	0.4148

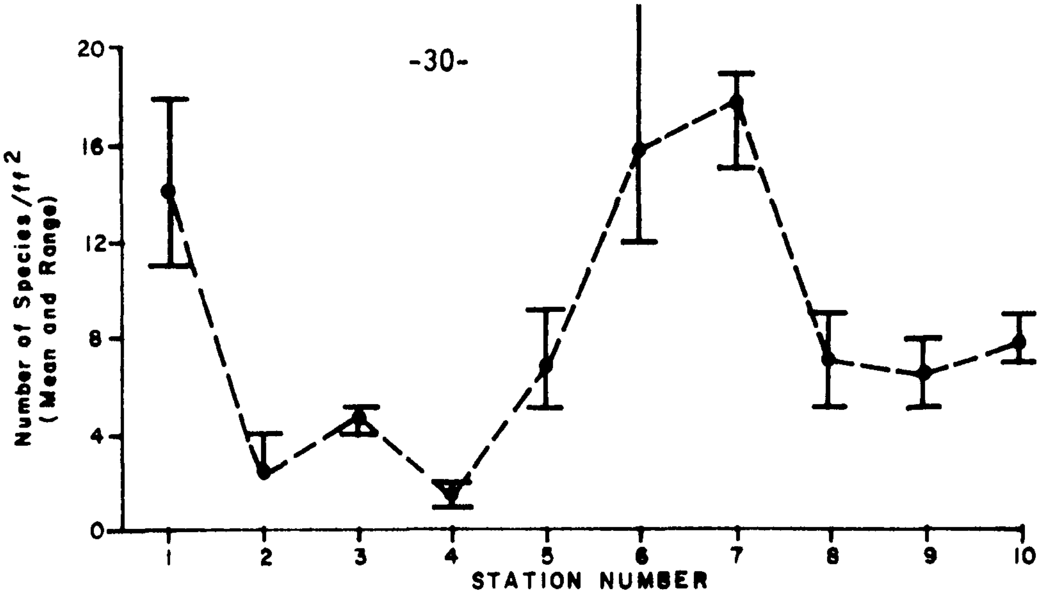


FIGURE 7a. NUMBER OF SPECIES PER SQUARE FOOT

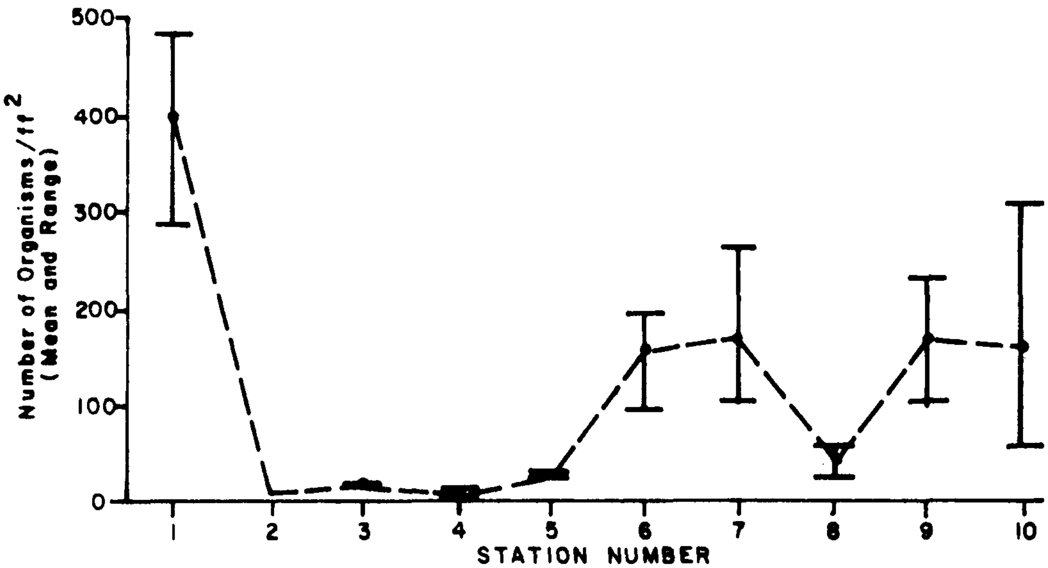


FIGURE 7b. TOTAL NUMBER OF ORGANISMS PER SQUARE FOOT

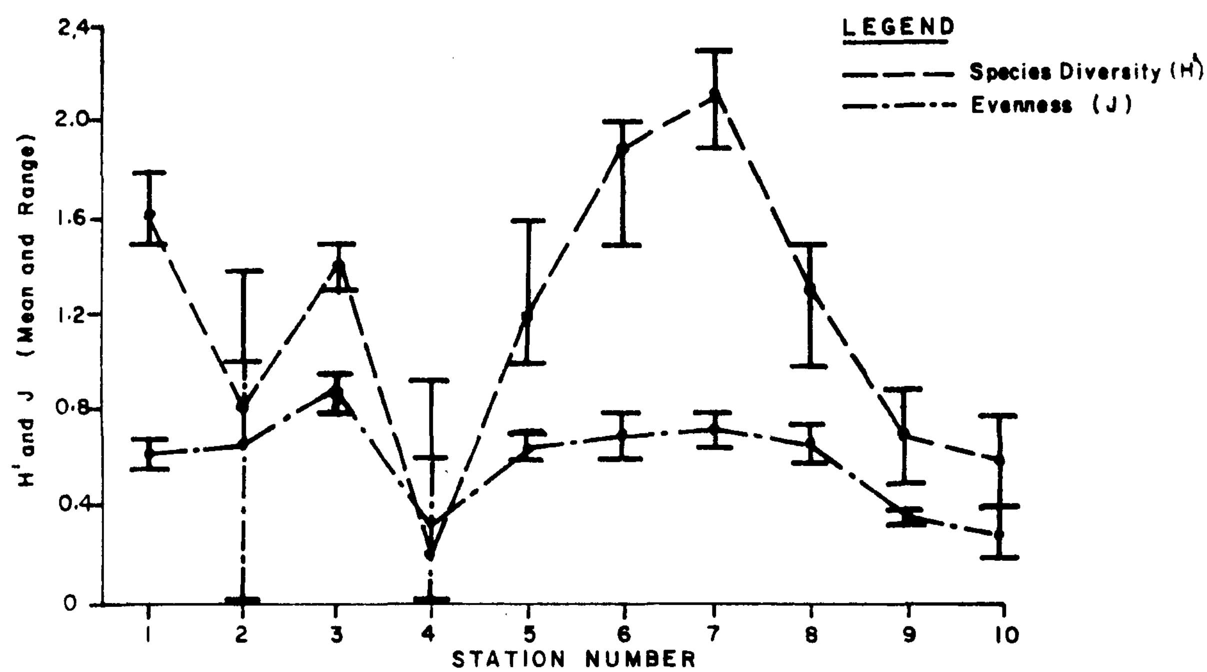


FIGURE 7c. DIVERSITY AND EVENNESS INDICIES

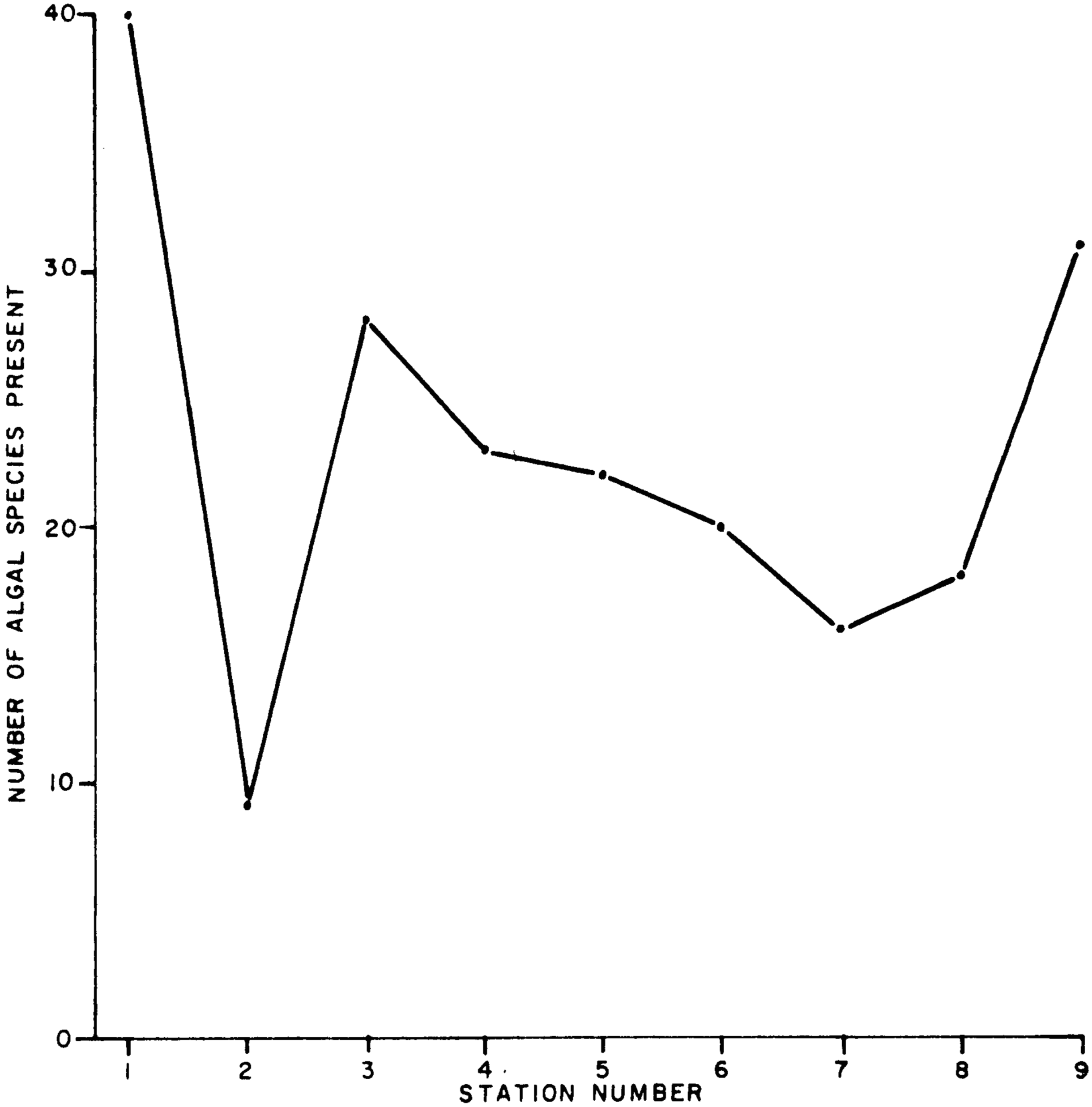


FIGURE 8 NUMBER OF ALGAL SPECIES RECORDED PER STATION

The species recorded there, particularly Gomphonema parvulum, Synedra ulna and Fragilaria crotonensis, must be relatively tolerant of high sediment loads, as they were present in considerable numbers (Appendix II).

As stated earlier in the report, fish were caught only in the pumphouse pond above station 1. The fish are to be analyzed for heavy metal content but this has not yet been completed. The aerial survey showed that Rose and Anvil Creeks below the mine were generally swift, shallow streams with very few deep pools; a criterion preferred by fish such as Arctic Grayling for feeding, resting, and overwintering. It is, therefore, entirely possible that no fish were present in the stream below the mine, particularly at this time of year. However before a definitive statement on fish populations can be made, a more intensive survey utilizing electro-fishing is required. Our helicopter pilot reported good Grayling angling in the lakes feeding the North Fork of Rose Creek as well as the Anvil Lakes. Thus, they do exist well up the system and they may migrate down to the Pelly River at certain times.

In addition to Grayling , the Northern Operations Branch of the Fisheries and Marine Service have reported Chinook salmon to be present in the Pelly River and in a few of the small tributaries upstream of Anvil Creek in certain years. None were observed in Anvil Creek in 1973, but there would appear to be a good possibility that they do use the system for spawning some years.

DISCUSSION

The results of the preliminary survey demonstrate clearly the detrimental effects of the Faro Creek diversion on Rose and Anvil Creeks. These effects were manifested by high suspended solids and therefore high turbidity levels, created by erosion along the banks of the diversion channel. High suspended solids loading of streams and rivers are a natural occurrence in this part of the Yukon during periods of high run-off (W. Waugh, personal communication). This phenomenon alone probably results in a certain reduction of the flora and fauna standing crops at these times of the year. However, in the case of the Rose-Anvil system where high suspended solids loading would appear to have been a continuing feature throughout at least the summer, the deleterious effects would be compounded.

The influences of sediment upon fish, bottom organisms, and algae have been well documented by numerous reseachers. For adult fish it seems to be a generally accepted fact that for suspended solids to have a direct lethal effect, the concentrations must be exceedingly high (Griffin, 1938; Wallen, 1951; and Herbert and Merkens, 1961). Where lethal effects have been observed, the agent was usually determined to be physical clogging and/or damage to the gills. Of course, the fish do not have to be killed to be directly influenced. Sumner and Smith (1939) and Smith (1940) reported that King salmon avoided the muddy water of the Yuba River, California in preference for the clear water of a relatively small tributary. Cooper (1956) noted that Sockeye salmon migrated through the Fraser River during high turbidities but spawn in tributaries where turbidities are low.

McPhail & Lindsay (1970) report that "Arctic grayling are characteristically found in schools in clear water throughout most lakes and streams in the North. They may also be taken at several points along the MacKenzie and Yukon rivers, but usually where clear tributaries enter."

This should not be taken to mean that grayling cannot reside in streams which are continually laden with silt or which carry a high silt load during freshet conditions, but it does suggest that clear waters are preferred. The main stems of Rose and Anvil Creeks which receive run-off from Faro Creek would not be able to satisfy this criterion at the moment.

McPhail & Lindsey (1970) also state that Grayling usually spawn in small streams over a gravel or rocky bottom. Extensive investigations have been carried out on the deleterious effects of sediment upon salmonid eggs and alevins. Some of the more applicable observations made are those contained in the statements of Cooper's (1956) work on the probable damage to Sockeye salmon runs in the Horsefly River, British Columbia, from proposed placer mining operations:

> "In the normal course of events the principal source of sediment in streams in British Columbia is the spring freshet passing down the stream, with consequent bank wash and bed scour. As the freshet passes, the availability of transportable sediment decreases rapidly and in river reaches where the scour action is great, the bed is left relatively free of fine sediments and the water becomes relatively clear. This annual cycle is considered to be an essential characteristic of rivers in which the best salmon spawning grounds are located. However, if this normal pattern is altered by the artificial introduction of sediment during the period of declining discharge when such sediments would not normally be available to the river, some deposition of sediment will take place in the interstices of the bed materials, particularly near the river banks. It is not possible to estimate the bed material composition that will result from a given discharge and concentration of given particle sizes. In regions of large scour the amount of deposition of fine materials probably would be small but it is a fair assumption that in order to preserve the stream bed in its normal condition, normal relationships between discharge and sediment size and concentrations should be maintained."

> "It may be concluded from this experiment that the deposition of sediment on gravel spawning beds would cause reduction in survival rates of eggs and alevins in proportion to the reduction in flow of water through the gravel."

Grayling do not bury their eggs in the streambed as do salmon but the smothering effects of excessive siltation may be similar, and where silt would not settle out, the abrasive action of settling particles could be equally damaging.

The deleterious effect of high suspended solids loads on macro-invertebrate populations has also been well documented. A more recent example was that reported by Gammon (1970) working on the effects of stonedust sediment from a crushed limestone quarry on the macro-invertebrates of a small, central Indiana stream. In his study he found that light inputs which increased the suspended solids loads less than 40 mg/l resulted in a 25% reduction in macro-invertebrate density below the quarry. Heavy inputs, causing increases of more than 120 mg/l including some deposition of sediment, resulted in a 60% reduction in population density.

The contaminated flow of the Faro Creek diversion, would cause similar effects through the inorganic sediment discharge. NFR (suspended solids) levels were greater than 100 mg/l above the background values at each of stations 2, 3, 4, and 5. It would, therefore, be reasonable to assume that the greatly reduced macro-invertebrate populations found at these stations were at least partly a result of the increased suspended sediments levels.

The effects of the sediment load in Rose and Anvil Creeks on the algae populations were less clearly defined. Sediment is believed to destroy algae by abrasive action, by simply covering the bottom of the stream with a blanket of silt, or by reducing the light needed for photosynthesis (Cordone and Kelley, 1961). The great reduction in species diversity recorded at staton 2 is probably attributable to a combination of these three criteria.

Unfortunately, the preliminary study was not able to evaluate the impact of increased pH which would probably have existed to some degree if the mine tailings decant had been discharged to Rose Creek at its normal operating flow of 4,000,000 gpd instead of 5 gpm as observed (7,200 gpd). The tailings decant has an average pH of 10.0 - 10.5 and it would be reasonable to assume that some effect would be felt (Brown, 1957). Since decant had been discharged throughout the summer prior to the survey, the increased pH of the receiving stream directly below the decant point might have contributed in part to the reduced macro-invertebrate populations found at stations 3, 4, and 5. If the tailings pond decant flow was increased to 7,000,000 gpd as proposed and pH was maintained above 10.0, the pH effect, if it exists, would be magnified.

The other chemical and physical constituents of both the tailings pond decant and of the Faro Creek diversion did not appear to cause any detrimental environmental consequences during the study period, and would not be expected to pose a problem, even if normal tailings decant flows existed.

In summary, the major problems in Rose and Anvil Creeks would appear to be the high suspended solids loading and turbidity resulting from the Faro Creek diversion, and the possible pH effect resulting from the discharge of tailings decant to the receiving environment. If the suspended solids from the diversion could be removed (either through sedimentation in a settling pond or the tailings pond area; or by proper rip-rapping or other protection of the diversion channel from continuing erosion) and if the tailings pond water itself could be recycled, or neutralized, there would appear to be no reason why the condition of the Rose-Anvil system below the mine could not return to a more natural ecological state.

ACKNOWLEDGEMENTS

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Waugh, W., Personal communication with helicopter pilot who is very familiar with the area.

APPENDIX I

Numbers of macro-organisms recorded at stations 1 - 10 in september, 1973.

STATION NUMBER	1			2			3			4			5		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
mite sp. #1															
mite sp. #2					1										
ostracod sp.	1	1													
harpacticoid copepod sp.	1	2													
cyclopoid copepod sp.		1													
calanoid copepod sp.															
Isoperla sp.	54	119	80				2	7	4				1	1	
Capnia (prob *nearctica*)	27	36	36				3		2				1	2	2
Paracapnia sp.	56	54	57						1						
Cinygmula sp.	2														
Cinygma sp.	1														
Epeorus (=Iron) sp.		1	3										1	1	
Rithrogena sp.															
Tricorythodes sp.							3						2		
Ephemerella sp.															
Homopteran sp.		1													
Spaniotoma sp.	31	46	37	1	1		2	4	3	2		2	10	16	13
Corynoneura sp.	100	204	208						1						
Tendiped spp. pupae													2		1
Dicranota sp.	2	4	6	1											
adult Tipulid sp.				1									1		
Simulium sp.		2													
Simulium sp. pupae															
Musid sp.		1													
Pericoma sp.		1													
Probezzia sp.															
adult Dipteran sp.			1					1			1	1	1		1
Ochotrichia sp.		1													
Neotrichia or *Mayatrichia* sp.															
Notiomyia sp.								1							
Polycentropus sp.								1							
Brachycentrus sp.															
Diplectrona sp.															
Dryopid sp.			1												
Psephenid sp															
Hydra sp.	7	6													
Nematode spp.	1	1	1	1	1									1	
Triclad sp.															
Chaetogaster (*diastrophus*)	3	1	1										6	2	1

STATION NUMBER	6			7			8			9			10		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
mite sp. #1		1		1						1			1		1
mite sp. #2		1			5	1					2	2			
ostracod sp.															
harpacticoid copepod sp.															
cyclopoid copepod sp.															
calanoid copepod sp.					2	4									
Isoperla sp.	16	17	13	9	3	3	2	2	5			1	9	2	
Capnia (prob. *nearctica*)	34	50	93		9	10	35	17	23	40	47	90	285	101	51
Paracapnia sp.		3		18	13	20	1								
Cinygmula sp.															
Cinygma sp.			2				1			4				1	
Epeorus (=*Iron*) sp.	10	6	3		1	4			2				4	2	1
Rithrogena sp.		2	2		1	1									2
Tricorythodes sp.	1														
Ephemerella sp.		5													
Homopteran sp.		1			1		1								
Spaniotoma sp.	11	62	44	45	32	103	9	5	6	58	118	137	9	8	4
Corynoneura sp.		1		1			1								
Tendiped spp. pupae	4	3	7		2	3		1	1	1	1	1		1	
Dicranota sp.				1			2						1	1	2
adult Tipulid sp.															
Simulium sp.	4	13		11	31	48	4	1	6		1			1	
Simulium sp. pupae	1	1		3		39									
Musid sp.		3		5	2	3									
Pericoma sp.															
Probezzia sp.		1													
adult Dipteran sp.	3	5	3			1								2	2
Ochotrichia sp.	4	4	1	1	6										
Neotrichia or *Mayatrichia* sp.	9	3	6	3	8	11									
Notiomyia sp.															
Polycentropus sp.				4											
Brachycentrus sp.			2		1	2			2		1	1	1		
Diplectrona sp.				2	2	2									
Dryopid sp.															
Psephenid sp.				1											
Hydra sp.															
Nematode spp.		3	3	2	5	6						2			
Triclad sp.		1			1	2									
Chaetogaster (*diastrophus*)	5	4	1	2	8	2						1			

APPENDIX II

Anvil Mine study- phytoplankton (Algae)

STATION #1

ALGAL TYPE	CELL COUNT/10 cc	CELL COUNT/litre
Bacillariophyceae (diatoms)		
Achnanthes flexella	539	53900
Achnanthes minutissima	46,918	4,691,800
Achnanthes sp.	2696	269,600
Amphora sp.	270	27,000
Cocconeis sp.	270	27,000
Cymbella turgida	2966	296,600
Diatoma tenue var. elongatum	56,355	5,635,500
Eunotia sp.	11,595	1,159,500
Eunotia sp.	2157	215,700
Fragilaria construens	1079	107,900
Fragilaria crotonensis var. oregona	270	27,000
Fragilaria pinnata	1348	134,800
Fragilaria vaucheriae	8629	862,900
Gomphonema olivaceum	270	27,000
Gomphonema c.f. parvulum (on stalks)	2427	242,700
Hannaea arcus	539	53,900
Navicula exigua	270	27,000
Navicula c.f. pupula	1618	161,800
Navicula sp.	270	27,000
Nitzschia sp.	1887	188,700
Nitzschia holsatica	16,179	1,617,900
Nitzschia sp.	270	27,000
Rhoicosphenia curvata	1079	107,900
Synedra ulna	2157	215,700
Chlorophyceae (green algae)		
Mougeotia sp.	809	80,900
Ulothrix sp.	1348	134,800
Cylindrocapsa	1887	188,700
Cyanophyceae (blue-green algae)		
Hapalosiphon hibernicus	5123	512,300
Oscillatoria sp.	1348	134,800
Spirulina sp.	539	53,900
Protozoa	270	27,000

STATION #1 sample 2

Gomphonema geminatum

Closterium sp.

Cymbella cistula

Cosmarium sp.

Cymbella parva

Staurastrum sp.

Navicula lanceolata

Tabellaria flocculosa

Nostoc sp. in clusters

Draparnaldia sp. (acuta)

many filaments of: *Fragilaria vaucheriae*

at least three species of *Mougeotia*

strands of *Diatoma tenue var. elongatum*

BRYOPHYTA (mosses)

Class Musci

Fontinalaceae

Dichelyma falcatum

STATION #2

ALGAL TYPE	CELL COUNT/10 cc	CELL COUNT/litre
Bacillariophyceae		
Cymbella turgida	2	200
Fragilaria crotonensis	539	53,900
Fragilaria vaucheriae	270	27,000
Gomphonema olivaceum	2	200
Gomphonema c.f. parvulum	1887	188,700
Hannaea arcus	8	800
Navicula c.f. dicephala	270	27,000
Nitzschia palea	18	1800
Synedra ulna	1348	134,800

STATION #3

ALGAL TYPE	CELL COUNT/10 cc	CELL COUNT/litre
Bacillariophyceae		
Achnanthes minutissima	4045	404,500
Cymbella cistula	270	27,000
Cymbella turgida	7280	728,000
Diatoma tenue var. elongatum	27,504	2,750 ,400
Eunotia sp.	4854	485,400
Eunotia sp.	2157	215,700
Fragilaria construens	4045	404,500
Fragilaria crotonensis	809	80,900
Fragilaria pinnata	270	27,000
Fragilaria vaucheriae	8629	862,900
Gomphonema olivaceum	539	53,900
Gomphonema c.f. parvulum (on stalks)	10,246	1,024,600
Hannaea arcus	1079	107,900
Navicula exigua	809	80,900
Navicula c.f. lanceolata	270	27,000
Navicula c.f. dicephala	809	80,900
Nitzschia dissipata	270	27,000
Nitzschia holsatica	1348	134,800
Nitzschia palea	809	80,900
Nitzschia sublinearis	539	53,900
Synedra acus	270	27,000
Synedra mazamaensis	270	27,000
Synedra ulna	809	80,900
Chlorophyceae		
Chlamydomonas sp.	270	27,000
Ulothrix sp.	3236	323,600
STATION #3 sample 2		
Uronema sp.		
Microspora sp.		
Closterium sp.		

STATION #4

ALGAL TYPE	CELL COUNT/10 cc	CELL COUNT/litre
Bacillariophyceae		
Achnanthes minutissima	809	80,900
Cymbella turgida	6202	620,200
Diatoma tenue var. elongatum	5662	566,200
Eunotia sp.	539	53,900
Eunotia sp.	270	27,000
Fragilaria construens	7011	701,100
Fragilaria crotonensis	809	80,900
Fragilaria vaucheriae	10,246	1,024,600
Gomphonema olivaceum	1887	188,700
Gomphonema parvulum (on stalks)	13,212	1,321,200
Hannaea arcus var. amphioxys	2157	215,700
Hannaea arcus	1618	161,800
Navicula c.f. pupula	1887	188,700
Navicula c.f. dicephala	4314	431,400
Navicula sp.	270	27,000
Navicula sp.	270	27,000
Nitzschia palea	270	27,000
Nitzschia c.f. sublinearis	1348	134,800
Synedra ulna	1079	107,900
Chlorophyceae		
Cosmarium sp.	539	53,900
Ulothrix sp.	4584	458,400

STATION #4 sample 2

Pleurodiscus sp. (unsure since some cells have only one disc chloroplast)

Oscillatoria sp.

STATION #5

ALGAL TYPE	CELL COUNT/10 cc	CELL COUNT/litre
Bacillariophyceae		
Achnanthes sp.	270	27,000
Amphipleura pellucida	2	200
Cocconeis sp.	270	27,000
Cymbella turgida	2157	215,700
Diatoma tenue var. elongatum	809	80,900
Eunotia sp.	539	53,900
Fragilaria construens	1079	107,900
Fragilaria crotonensis	270	27,000
Fragilaria vaucheriae	2427	242,700
Gomphonema geminatum	4	400
Gomphonema olivaceum	2	200
Gomphonema parvulum	1887	188,700
Hannaea arcus	12	1200
Melosira tenuissima	4	400
Navicula c.f. pupula	539	53,900
Navicula c.f. dicephala	539	53,900
Navicula sp.	809	80,900
Nitzschia palea	2	200
Synedra ulna	10	1000
Chlorophyceae		
Mougeotia sp.	539	53,900

STATION #5 sample 2

Cylindrocapsa sp. filament

Cosmarium sp.

STATION #6

ALGAL TYPE	CELL COUNT/10 cc	CELL COUNT/litre
Bacillariophyceae		
Achnanthes minutissima	6738	673,800
Amphipleura pellucida	6738	673,800
Cymbella turgida (on stalks)	6738	673,800
Diatoma tenue var. elongatum	13,488	1,348,800
Eunotia sp.	10,113	1,011,300
Fragilaria vaucheriae	3375	337,500
Gomphonema geminatum	6738	673,800
Gomphonema olivaceum	3375	337,500
Gomphonema c.f. parvulum (on stalks)	20,225	2,022,500
Navicula c.f. dicephala	13,488	1,348,800
Navicula sp.	16,850	1,685,000
Nitzschia capitata	6738	673,800
Nitzschia palea	3375	337,500
Nitzschia c.f. sublinearis	3375	337,500
Nitzschia sp.	3375	337,500
Rhoicosphenia curvata	6738	673,800
Synedra acus	3375	337,500

STATION #6 sample 2

Hannaea arcus

Cymbella cistula on stalks

Nitzschia holsatica

STATION #7

ALGAL TYPE	CELL COUNT/10 cc	CELL COUNT/litre
Bacillariophyceae		
Cymbella turgida	16,850	1,685,000
Fragilaria construens	6738	673,800
Fragilaria vaucheriae	26,963	2,696,300
Gomphonema constrictum var. capitata	3375	337,500
Gomphonema olivaceum	13,488	1,348,800
Gomphonema parvulum	3375	337,500
Hannaea arcus	16,850	1,685,000
Meridion circulare	26,963	2,696,300
Navicula exigua	3375	337,500
Navicula c.f. dicephala	3375	337,500
Pinnularia sp.	3375	337,500
Synedra acus	13,488	1,348,800
Synedra ulna	6738	673,800
Tabellaria fenestrata	3375	337,500

STATION #7 sample 2

Nitzschia palea

Denticula sp.

STATION # 8

ALGAL TYPE	CELL COUNT/10 cc	CELL COUNT/litre
Bacillariophyceae		
Cocconeis sp.	270	27,000
Cymbella cistula		
(on stalks)	539	53,900
Denticula sp.	8	800
Diatoma tenue var elongatum	1079	107,900
Eunotia sp.	270	27,000
Fragilaria construens	1079	107,900
Fragilaria vaucheriae	809	80,900
Gomphonema parvulum		
(on stalks)	539	53,900
Hannaea arcus	270	27,000
Navicula exigua	270	27,000
Navicula sp.	539	53,900
Nitzschia palea	270	27,000
Nitzschia c.f. sublinearis	809	80,900
Synedra ulna	539	53,900
Chlorophyceae		
Closterium sp.	4	400
Ulothrix sp. (tenuissima)	140	14,000
Cylindrocapsa sp.	·26	2,600

STATION #8 sample 2

Cymbella turgida

STATION #9

ALGAL TYPE	CELL COUNT/10 cc	CELL COUNT/litre
Bacillariophyceae		
Achnanthes flexella	26,964	2,696,400
Achnanthes minutissima	33,705	3,370,500
Amphipleura pellucida	13,482	1,348,200
Cocconeis calcar	6741	674,100
Cymbella cistula	13,482	1,348,200
Cymbella turgida	141,562	14,156,200
Diatoma tenue var. elongatum	53,929	5,392,900
Eunotia sp.	13,482	1,348,200
Fragilaria construens	47,187	4,718,700
Fragilaria vaucheriae	337,054	33,705,400
Gomphonema parvulum	60,670	6,067,000
Hannaea arcus	20,223	2,022,300
Meridion circulare	13,482	1,348,200
Navicula exigua	80,893	8,089,300
Navicula lanceolata	20,223	2,022,300
Navicula c.f. pupula	33,705	3,370,500
Navicula c.f. subcapitata	20,223	2,022,300
Nitzschia capitata	94,375	9,437,500
Nitzschia c.f. littoralis	6741	674,100
Nitzschia palea	208,973	20,897,300
Nitzschia spectabilis	94,375	9,437,500
Nitzschia c.f. sublinearis	6741	674,100
Opheophora sp.	6741	674,100
Pinnularia sp.	60,670	6,067,000
Pinnularia sp.	6741	674,100
Rhoicosphenia curvata	13,482	1,348,200
Stauroneis c.f. minor	13,482	1,348,200
Surirella sp.	6741	674,100
Synedra mazamaensis	6741	674,100
Synedra ulna	80,893	8,089,300
Chlorophyceae		
Ulothrix sp.	20,223	2,022,300