Environment Canada
Environnement Canada

Environmental Protection
Protection de l'environnement

An Environmental Assessment of the Watershed Adjacent to Hallmark Resources, Smithers, B.C.

Surveillance Report
EPS 5-PR-74-6

Pacific Region
February, 1975

ENVIRONMENTAL PROTECTION SERVICE REPORT SERIES

Surveillance reports present the results of monitoring programs carried out by the Environmental Protection Service. These reports will usually be published on a regular basis.

Other categories in the EPS series include such groups as Regulation, Codes and Protocols, Policy and Planning, Technical Appraisal, Technology Development, Surveillance and Reprints of Published Papers.

Inquiries pertaining to Environmental Protection Service Reports should be directed to the Environmental Protection Service, Department of the Environment, Kapilano 100, Park Royal, West Vancouver, B.C. V7T 1A2.

AN ENVIRONMENTAL ASSESSMENT OF THE WATERSHED ADJACENT TO HALLMARK RESOURCES, SMITHERS, B.C.

by

R.L.Hallam, R.H. Kussat, M. Jones

Canada
Department of the Environment
Environmental Protection Service
Pacific Region
Vancouver, B.C.

Report Number EPS 5-PR-74-6

February, 1975

ABSTRACT

The Fulton River drainage system services the water requirements of a diversified local economy. Chapman and Fulton Lakes support a varied sport fishery and wildlife resource. The multimillion dollar federal Fish enhancement installations at the mouth of the Fulton River are of paramount importance not only to the Babine area but also to the Prince Rupert fishing industry.

One of the mines on this watershed, Hallmark Resources Ltd., has in the past posed a hazard to the aquatic biota. In July 1974 the Environmental Protection Service conducted a survey of the existing chemical, physical and biological parameters of Cronin Creek and its tributaries adjacent to the mine site to assess abatement measures instituted by the new management of the mine.

Near pristine conditions were encountered in the waterhsed in the vicinity of the Hallmark property. The natural waters were found to be soft with low levels of residues, metals and biogenic salts. A diversified biota was recorded and indexed.

By relating future survey results to the chemical, physical and biological conditions established in this report, minor degradation of water quality can be detected and corrective measures can be recommended before detrimental effects become a major issue.

RÉSUMÉ

Le système d'écoulement des eaux de la rivière Fulton pourvoit aux besoins d'une économie locale diversifiée. Les lacs Chapman et Fulton offrent aux sportifs sa faune et ses poissons. Les installations de plusieurs millions de dollars du gouvernement fédéral, à l'embouchure de la rivière Fulton, sont d'une importance primordiale non seulement pour la région de Babine, mais aussi pour l'industrie de la pêche à Prince Rupert.

Une des mines situées dans ce bassin hydrographique, la Hallmark Resources Ltd., présentait autrefois un danger pour la vie aquatique de cette région. En juillet 1974, le Service de protection de l'Environnement a mené une étude de base pour découvrir les paramètres chimique, physique et biologique du ruisseau Cronin et de ses affluents dans la région de la mine, pour juger de l'efficacité des mesures prises par la nouvelle direction pour réduire la pollution des eaux.

On a retrouvé les conditions naturelles d'autrefois dans ce bassin près de l'emplacement de la compagnie Hallmark. Les eaux naturelles se révélèrent douces et porteuses d'une faible quantité de dépôts, de métaux et de sels biogénétiques. On a observé et classé les spécimens de cette vie aquatique variée. Il est possible de découvrir une faible détérioration de l'environnement en comparant après coup les observations (chimiques, physiques et biologiques) à celles de l'étude de base. On peut dans ce cas proposer des mesures pour empêcher que des éléments nocifs n'en viennent à créer un problème majeur.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Plate 1: HALLMARK RESOURCES LTD.

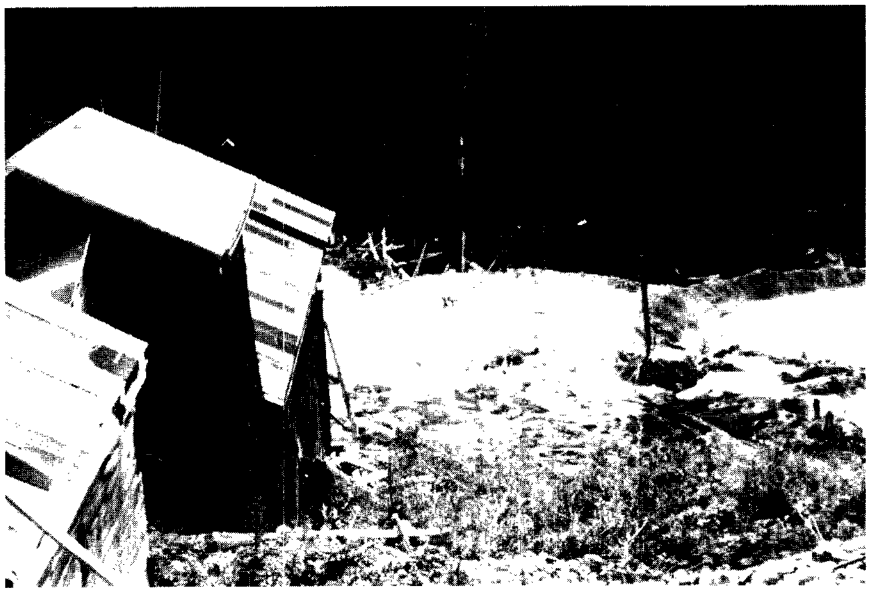

Plate 2: OLD TAILINGS FACILITIES

Plate 3: NEW TAILINGS FACILITIES

1. INTRODUCTION

The Environmental Protection Service is engaged in monitoring programs of the various industrial concerns that constitute potential hazards to the receiving water quality. The Water and Land Quality Group is specifically concerned with measuring deleterious effects to the fisheries resource as specified in the Fisheries Act.

Information gathered from these studies provides a basis for early detection of possible environmental damage and subsequent recommendations for remedial action. This surveillance report presents the results of selected physical, chemical and biological parameters of Cronin Creek and the watershed adjacent to Hallmark Resources Ltd., on July 25, 1974.

2. THE STUDY AREA

Cronin Creek and the various tributaries under study lie within the mineralized Babine Range approximately 20 air mailes northeast of Smithers, B.C., midway between the Bulkley River Valley and the Babine Lake Basin (Figure 1).

The underlying bedrock of this mountainous area consists of Paleozoic sediments with Tertiary extrusions. Long and continued erosion of the granitic cores of some mountains has exposed outcroppings with surface minerals of wide variability. The thin layer of lithic podzols support a "fragmented subalpine spruce-pine forest." The coniferous canopy hosts stands of western black and white spruce, alpine fir and pioneer lodgepole pine. Boreal deciduous species of aspen, poplar and white birch that are typical of the Babine Lake shoreline also border the water courses of the study area. Mt. Hyland and Mt. Cronin, two nearby peaks, are glaciated and the annual snowpak of over 60 inches persists until late July.

Cronin Creek and its tributaries drain and transect the area adjacent to the Hallmark development before discharging to Chapman Lake, 5 miles east of the property. Peamouth Chub, rainbow and cutthroat trout

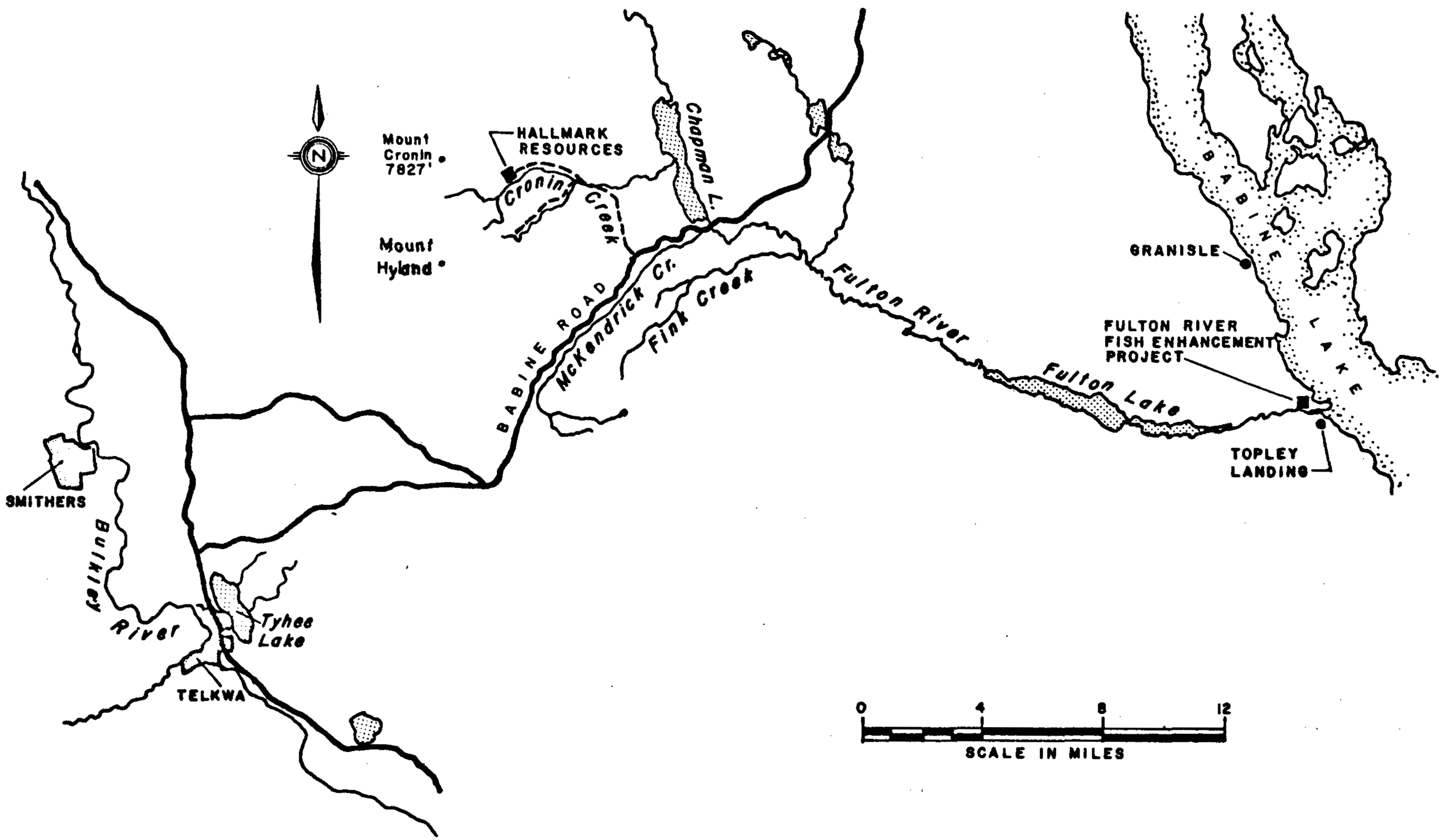

FIGURE I LOCATION MAP OF HALLMARK RESOURCES inhabit Cronin Creek to within approximately two miles of the mine site. A log jam at that point limits their upstream migration. In addition to the aforementioned species Chapman and Fulton Lakes support populations of lake trout, lake white fish and long nose suckers. Salmonids were historically excluded from these two lakes by a waterfall situated at the outflow of Fulton Lake. The Fulton Dam now occupies this site.

Chapman Lake drains to the Fulton River which then flows easterly toward Babine Lake. An $8 million natural resource enhancement project at the mouth of the river, developed by the Fisheries and Marine Services, utilizes water from this system for the incubation of sockeye fry in more than 5 miles of artificial spawning channels. The enhancement project with design expectations for increasing the annual catch by one million fish, will increase the landed value by $5 million (Smith, A.D., 1973a).

3. HALLMARK RESOURCES LTD. (N.P.L.)

The property of Hallmark Resources is located on the north side of Cronin Creek, five miles west of Chapman Lake and three miles east of Cronin Mountain. It is one of the oldest commercially-operated mine-mill complexes in British Columbia. Ore production commenced in the early part of the century and has been carried out on a small scale of the last 21 years.

The silver, gold, lead, zinc, cadmium and copper ore deposits are found in quartz veins and fractured zones of rhyolite above the 5,000 foot level of Cronin Mountain. Recent exploration has uncovered several new veins on the surface which infer ore reserves of open pit dimensions.

Present annual production is limited by the severity of the extended winters and the high elevation of the ore body. Working of the various shafts and drifts begins in early June and ends in late November. As a result the mine is required to produce 7,300 short tons of ore per annum over six month period to supply the mill at a rate of 40 tons per day. The present production rate of 40 tons per day is scheduled to increase to 70 tons per day in 1975 when the needed rehabilitation of the ore dressing mill is completed.

The extractive metallurgical process consists of grinding the ore and drawing off lead and zinc concentrates from denver flotation cells. Silver, gold, copper and zinc are found reporting to the lead concentrate while lead, silver, cadium and gold are found reporting to the zinc concentrate.

Reagent requirements are varied and extensive. In the lead circuit Methylisobutylcarbinol (M.I.B.C.)is used as a frother with Z-200 or Aerofloat 31 as a promoter. Z-238, 343 and 350 are also required for promotion while small amounts of NaCN and $ZnSO_4$ are used as iron and sphalerite depressants, respectively.

In the zinc circuit lime is used for pH adjustment and M.I.B.C. produces the needed froth. $CuSO_4.XH_2O$, Z-350 and Z-343 are used in varying amounts to proportion the concentrate quality.

Mill tailings are conveyed by launder at a rate of 25,000 IGPD to two small impoundments excavated from the valley walls approximately 1,000 feet east of the mill site. The decant water is then reclaimed and returned to the mill for process re-use. Although the excavated material used for the impoundment dykes is considered impermeable, a seepage reclaim ditch is provided. Details of the construction may be obtained from the Wright Engineers Ltd. (1973) report on the Cronin Mines tailings pond design. Seepage or runoff is intercepted before it reaches Cronin Creek and returned to the tailings pond. Present impoundment facilities are adequate for two years while indications are that the mine could operate for 50 years or more.

During the sampling activities flow rates were high, but not excessive and there was no evidence of seepage from the tailings dams. Because of the highly toxic reagents contained in the tailings (Hawley 1972b) it is conceivable that, during the heavy spring runoff, tailings supernatant and water from the reclaim ditch could constitute a hazard to the biota of Cronin Creek, Chapman Lake, and possibly the lower reaches of the Fulton River System. This possibility should not be discounted, particularly during peak run-off periods. For example, in 1971, the British Columbia Fish and Wildlife Branch documented fish kills which resulted from the accidental discharging of mill tailings into Cronin Creek by the previous owners, Kindrat Mines Ltd. However, the present owners have instituted several improvements such as relocating the tailings impoundments away from the creek banks, directing surface runoff around the mill property and increasing surveillance of the reclaim system. These measures, if maintained, are likely to significantly reduce the possibility of a reoccurence of the 1971 mishap.

4. MATERIALS AND METHODS

4.1 Monitoring Stations

Six permanent stations were established for this baseline survey and future monitoring of the water quality adjacent to the mining site. All sites were marked with two-foot wooden stakes displaying fluorescent red paint and the station number. A seventh station representing the tailings pond decant water was also established but will vary in location as new tailings ponds are utilized. The mill site, tailings ponds and sampling stations are indicated in Figure 2. Four stations, including the control were selected for biological documentation.

All creek stations were typified by shallow fast running water with large aggregate bottom substrate and no aquatic macrophytes. Table 1 provides a brief description of each site and an explanation of its monitoring function. All sites are easily accessible from existing roadways.

4.2 Measurement of Physical Parameters

Water temperatures were determined in the field with a centigrade thermometer. The flow rates of Higgins Creek and the three stations on Cronin Creek were measured with the aid of a Teledyne Gurley-622 flowmeter. These readings, combined with average depths and widths of the stream (measured with a steel tape) were used to calculate approximate stream flows.

One litre samples of water were collected at each site, and stored in polyethylene bottles until analysed for residue content. Within six hours of collection, turbidity and conductivity measurements were also made on the samples with a Hach 1860A Turbidimeter and a Seibold LTB conductivity meter.

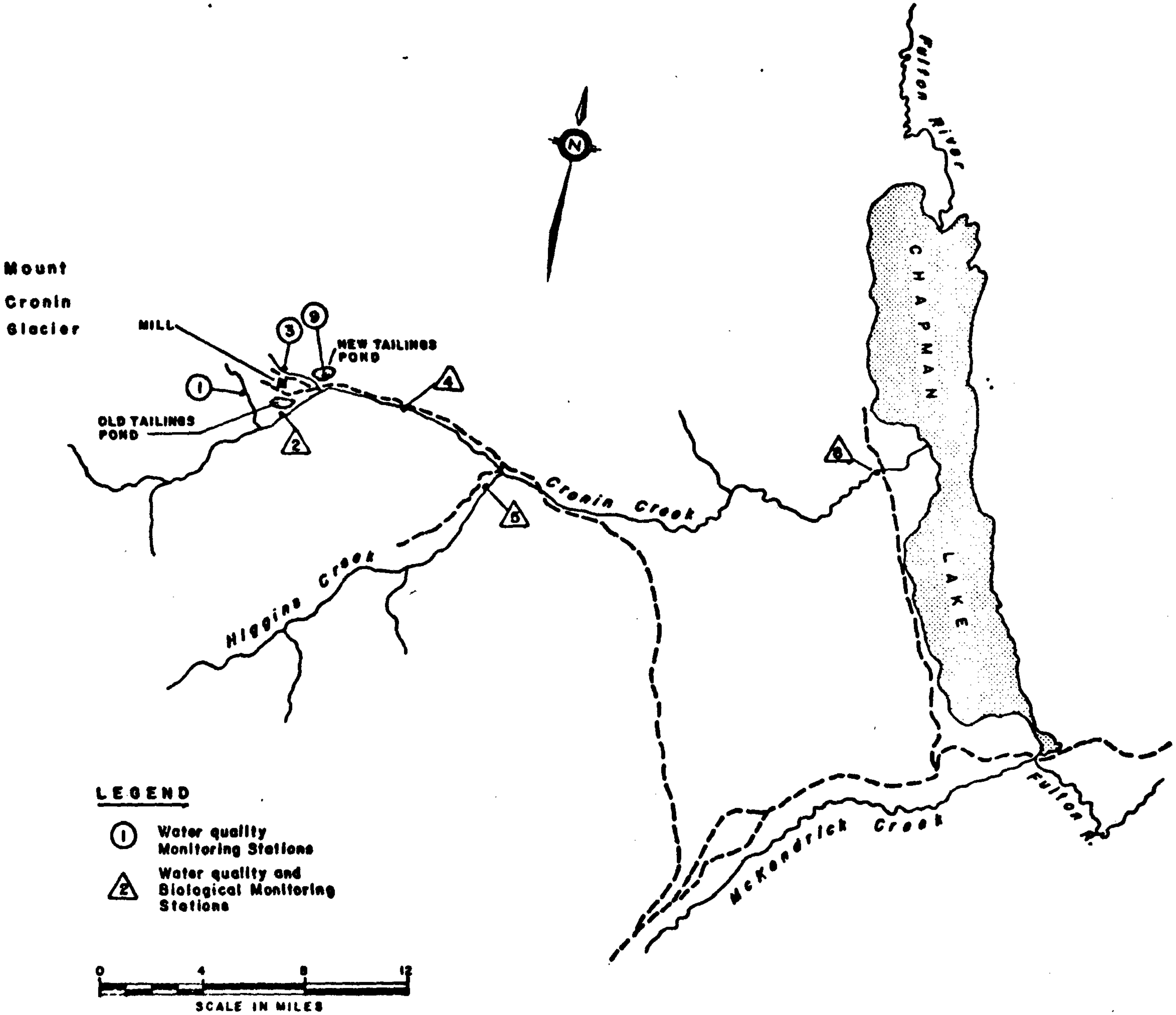

FIGURE 2 LOCATION MAP OF SAMPLE SITES AND ADJACENT WATERSHED TO HALLMARK RESOURCES LIMITED

TABLE 1: HALLMARK RESOURCES LTD. MONITORING STATIONS

Station Number	Function	Description
1	Mine drainage	18" boulders, interstices filled with 1 to 3 inch aggregate. Steep drop, well shaded with forest canopy. Algal layer on large rocks.
2	Cronin Creek. Above influence of ore dressing plant	Main channel - 6" rock with 1 to 3 inch stones, sand bars consisting of pea gravel and coarse sand. Much log debris transversing stream. Algal layer on large rocks. Open to some sunlight.
3	Mine drainage above influence of ore dressing plant.	3 to 8 inch rock, mixed with pea gravel and coarse sand.
4	Cronin Creek prior to the addition of Higgins Creek - includes effects of ore dressing plant	Main channel 6 to 8 inch boulders with 1 to 3 inch rock. Bend with inside sand bar. Braided above and below station. Open to some sunlight. Algal growth on larger rocks.
5	Higgins Creek. Total flow before entering Cronin Creek. Control.	Approximately 30^{0} slope, cascading over 2 foot boulders. Pools behind boulders filled with sand. Algae covered rocks. Well shaded by forest canopy.
6.	Cronin Creek	Channelized area, fast flowing riffle. Assorted 1 to 6 inch rock, complete exposure to sun.
9	Tailings pond decant water	

Total residues were computed as the material remaining in a vessel after total evaporation in a muffle furnace at 103°C for 2 hours. Filterable residues are that portion of the total residue which pass through a 4.25 cm Whatman GF/C filter paper and remain in a vessel after total evaporation at 103°C for 2 hours (APHA, 1971). Analyses for total, filterable and nonfilterable residues were performed at the Environment Canada Water Quality Laboratory in West Vancouver.

4.3 Water Chemistry

The Winkler Method for dissolved oxygen (D.O.) determination was employed (APHA, 1971). A 300 ml sample collected in a B.O.D. bottle was preserved in the field with 2 mls of alkali-iodide-azide reagent and 2 mls of manganous sulfate solution. Titration against a .025N sodium thiosulfate solution was completed within six hours of preservation. The pH of the water was determined in the field with a narrow range "Hach Kit."

Two one-litre samples were collected at each site in polyethylene bottles. The first was preserved in the field with 5 mls of concentrated HNO_3 for extractable metal analyses. The second was filtered using a Sartorious membrane filtering apparatus and 0.45 μ cellulose nitrate paper. The filtrate was preserved with 5 mls of concentrated HNO_3 and analysed for dissolved metals.

Metal analyses were performed at the Environment Canada Water Quality Laboratory in West Vancouver. Direct aspiration in conjunction with a Jarrel-Ash 82-800 atomic absorption unit was employed in the analyses of all metals except lead which was previously complexed with ammonium 1-pyrrolidine - dithiocarbamate (A.P.D.C.)extracted and aspirated (Smith, A.E. 1973b, Smith A.E. 1973c)

4.4. Biological Assessment

4.4.1 Bionutrients. An additional one litre water sample was collected at each station for nitrate, phosphate and sulfate content and kept cool and in the dark until analysed. Samples were analysed four weeks from the date of collecting.

Total NO_2 and NO_3 are determined using the Technicon automated system. NO_3 is reduced to NO_2 on a copper-cadmium column and acidified. Under acidic conditions NO_2 reacts with sulfanilamide and N-1-naphthylethylenediamine dihydrochloride to form a reddish purple azo dye. The intensity of the dye is measured at 550 $m\mu$ using a 5 cm flow cell.

Phosphates are converted to orthophosphates by acid digestion. These react with the molybdate ion $(MoO_4)^{-2}$ to form complex heteropolyacids which are in turn reduced with ascorbic acid to form a molybdenum blue complex colour. The absorbance is measured at 882 $m\mu$ on a Technicon colorimeter.

Sulfate concentrations are determined by titration against a known concentration of barium chloride in a non-aqueous medium at a pH range of 1.5 to 4.0. Interferences are removed by ion exchange. Thorin is used as an indicator causing a peachy pink endpoint.

Determination of these bionutrients (biogenic salts) was also performed at the Environment Canada Water Quality Laboratory located at West Vancouver. Details of the methods employed are described in APHA(1971).

4.4.2 Periphyton. A sample of algae was collected from rock scrapings at stations 2, 4 and 5 and placed into separate jars with water from the same point. These samples were examined at Environment Canada Fresh Water Biology Laboratory in North Vancouver with the aid of a Wild M40 inverted microscope and several biological keys (Prescott, 1962; Prescott 1970; Patrick and Reimer, 1966). The dominant species present were identified and a literature search was made for inference of their habitat preference to water quality.

4.4.3 Benthic Invertebrates. Three separate samples for population distribution of benthic organisms were obtained from riffle areas of stations 2, 4, 5 and 6 with a one square foot circular sampler. The samples were later preserved with a formalin solution and forwarded to the Environment Canada Fresh Water Biology Laboratory at North Vancouver for sorting, classification and enumeration. Identification was achieved using a Wild M5 Stereo Microscope, a Wild M11 Compound Microscope and biological keys: including Pennak (1953), Ward and Whipple (1959), and Usinger (1968).

The invertebrate data was subjected to two different analyses:

(a) Organisms were placed into groups with respect to their sensitivity to pollution in accordance with MacKenthun's (1969) standards. Mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), categorize clean waters, while sludgeworms can tolerate a large amount of pollution.

(b) The Wilhm and Dorris (1968) measure of diversity ($\bar{d}$), which relates benthic communities to water quality was also applied. The formula which was first derived by Margalef (1956) from information theory and expanded by Wilhm and Dorris (1968) is as follows:

$$\bar{d} = - \sum_{i=1}^{s} \frac{n_i}{n} \log_2 \frac{n_i}{n}$$

where $\bar{d}$ = diversity per sample
n_i = total number of individuals per taxon
n = total number of individuals per sample
s = total number of taxa

The diversity index ($\bar{d}$) is a numerical value which represents the relative "variety of life" in the sample by relating the number of individuals in each taxon to the total number of taxa.

Wilhm (1968) and Cole (1973) felt that values of less than one from the index ($\bar{d}$) were more representative of areas of heavy pollution while values above 3 suggested clean and/or highly productive water.

Pielou's (1966, 1977) "evenness" index (J) presented below was also determined

$$J = - \sum \frac{\frac{n_i}{n} \log_2 \frac{n_i}{n}}{\log_a}$$

Where Jmax = 1
a = total number of species sampled

The evenness index (J) is a measure of proportionate distribution of the numbers in each taxa. In a normal population the numbers are more or less evenly distributed between each taxa. Therefore, the higher the value of J the more normal the population distribution and the more valid the value of d. Statistical calculations were performed on a Hewlett Packard 9830A computer.

5. RESULTS and DISCUSSION

5.1 Physical Parameters

Although generally not directly toxic, physical parameters such as turbidity, temperature and flow rates often influence the quality of the aquatic environment and the natural biota as much as chemical pollutants. Vast changes in these physical characteristics may result when tailings from a mining operation are discharged directly into receiving waters.

Turbidity conductivity and residue measurements are summarized in Table 2. Turbidity as determined by the Nephelometric method, which measures scattered light from a formazin polymer standard (APHA, 1971) indicated that all the streams and the tailings pond supernatent were relatively clear. Formazin Turbidity Units (FTU's) of less than 5 are essentially transparent while values of 100 appear slightly translucent to the eye. Because the mill had been shut down for an eight hour period prior to the study, the tailings pond supernatent (13 FTU's) was probably clearer than normal. This would, however, indicate that the tailings possessed excellent settling characteristics.

Total residues and filterable fractions were low (<50ppm) and indicative of clear water except at the unnamed creek draining the mine area (Station 3). Even at this station total residues were moderate but the tailings pond supernatent contained levels that could markedly influence the water quality of Cronin Creek if allowed to escape. Waters with 80 to 400 ppm concentrations of suspended solids sometimes support fisheries, but are poor even in the lower part of this range, while greater than 400 ppm concentrations are totally unsuitable for fish life (Gammon, 1970).

TABLE 2: TURBIDITY, RESIDUE AND CONDUCTIVITY MEASUREMENTS,

July 25, 1974

Station	Turbidity FTU's	Total Residues ppm± 2.5	Non-Filtrable Residues ppm± 2.5	Filtrable Residues* ppm± 2.5	Conductivity umho-cm^{-1}
1	4.5	42	42	<2.5	84
2	1.9	45	45	<2.5	68
3	2.9	135	135	<2.5	250
4	1.8	36	36	<2.5	74
5	.9	30	30	<2.5	69
6	2.0	35	35	<2.5	92
9	13.0	658	654	4.0	430

* obtained by subtraction

Conductivity, which is a measure of the water's ability to conduct electrical current, is also associated with the total filtrable residue content. Approximately 60% to 70% of filtrable residues in most natural waters are attributable to concentrations of electrically mobile ionic constituents. This relationship appears to hold true here except in the case of the tailings. This may be due to high levels of non-ionized soluble organics, and non-ionized colloidal inorganics resulting from flotation agents.

Heavy silting can be deleterious to macro-invertebrates and fish populations. Most molluscs require solid surfaces on which to attach. Mayfly populations abandon areas subjected to scouring by fine sand particles. Silting reduces the number of sheltered crevices which many benthic organisms seek out and often results in the "silting-over" and possible asphyxiation of developing fish eggs. Gross siltation can cause physical damage to gill membranes, resulting in reduced gaseous exchange and behavioral abnormalities. Direct entry of tailings into the watershed would undoubtedly result in deleterious effects on the biota of Cronin Creek and possibly the fisheries resource downstream as previously documented in 1973 and would therefore not be acceptable.

At the time of sampling there was no indication of seepage from the new tailings impounments. However, below Station 2 there was definite evidence that tailings had recently been allowed to escape from an old tailings impoundment probably during a mill upset. An emergency basin able to contain spills and intermittent surges from the mill complex could eliminate potentially deleterious discharges of this nature.

Water temperatures, dissolved oxygen and % saturation are depicted in figure 3. All streams drain runoff from the melting snopak and probably a portion of a nearby glacier. Stream temperatures were slightly above freezing and increased as distance from their origin. Conversely, dissolved oxygen levels decreased slightly.

Dissolved oxygen, not usually a problem associated with mine effluents was found to be above 100% saturation at all sample sites (temperature and altitude corrected).

Termperature is an important factor in stream ecology. Periodism and cercadian rhythms of the many aquatic organisms are dependant on natural seasonal changes in temperature. Fecundity rates, the number of generations per year, biomass production and the species present are also related to the prevailing conditions. Trout, the dominant species in Chapman Lake, are very sensitive to fluctuations in ambient conditions and cannot sustain temperatures above 25^{o}C or shortages of O_2 for long periods (Hynes, 1970).

Approximate flow rates were recorded during the survey. As a general rule, flow rates of these streams reach their maximum in the early summer, after spring rains and melting snow. Minimum flow rates can be expected in mid-winter.

Flow rates of Cronin and Higgins Creek on July 25, 1974 were as follows: Station 2, 35 cfs; Station 4, 49 cfs; Station 5, 45 cfs; Station 6, 89 cfs.

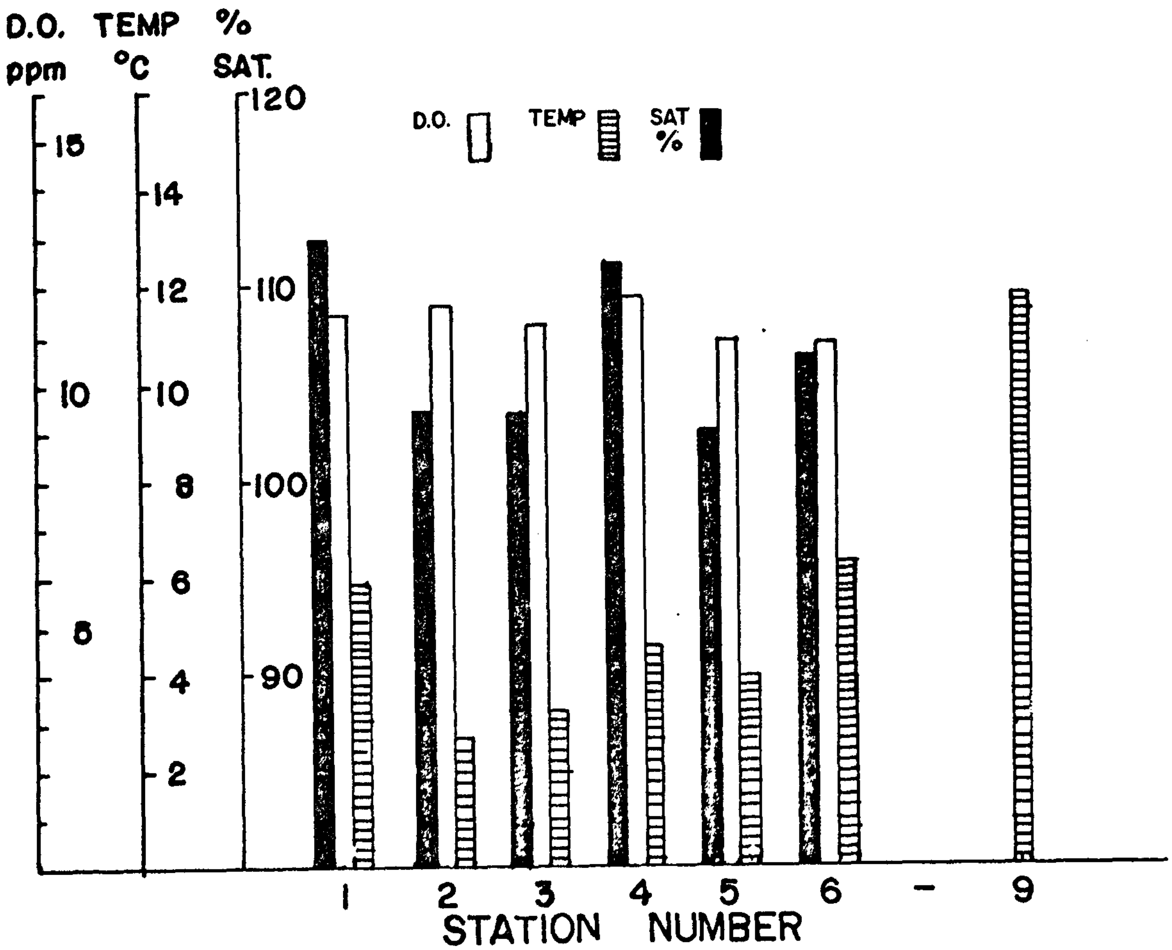

Figure 3: DISSOLVED OXYGEN, PERCENTAGE SATURATION and TEMPERATURE MEASUREMENTS. July 25, 1974.

5.2 Water Chemistry

A summary of the heavy metal content of the water samples is presented in Table 3 together with a calculated hardness value. These provide an effective index to which future water quality changes may be related.

The waters (except for the tailings) adjacent to the Hallmark property were found to be low in total calcium and Magnesium and therefore considered soft in terms of total hardness (100 ppm $CaCO_3$ equivalents). Water low in calcium and Magnesium ions (soft) increase the toxicity.

TABLE 3: HARDNESS, TOTAL METAL, AND DISSOLVED METAL ANALYSIS

July 25, 1974

Station Number		Ca	Mg	Hardness $CaCO_3$*	Cd ±0.01	Cu ±0.01	Cr ±0.02	Fe ±0.03	Mo ±0.1	Mi ±0.1	Pb ±0.02	Zn ±0.01
		Concentration mg/l										
1	Total	5.0	15.6	77	< 0.01	0.02	<.02	.26	< .1		0.03	.09
	Dissolved				< 0.01	< 0.01		<.03		< .1	0.04	.06
2	Total	5.8	1.7	21	< 0.01	0.03	<.02	.13	< .1		0.02	.01
	Dissolved				< 0.01	< 0.01		<.03		< .1	< 0.02	.01
3	Total	18.0	13.0	100	< 0.01	0.02	<.02	.27	< .1		< 0.02	.02
	Dissolved				< 0.01	0.01		<.03		< .1	< 0.02	< .01
4	Total	6.5	1.8	24	< 0.01	0.02	<.02	.12	< .1		0.03	.03
	Dissolved				< 0.01	< 0.01		<.03		< .1	0.03	< .01
5	Total	5.4	3.4	28	< 0.01	0.03	<.02	.18	< .1		< 0.02	.01
	Dissolved				< 0.01	< 0.01		<.03		< .1	0.02	< .01
6	Total	7.0	2.0	26	< 0.01	0.03	<.02	.12	< .1		< 0.02	.03
	Dissolved				< 0.01	< 0.01		<.03		< .1	0.02	< .01
9	Total	119.0	7.25	320	< 0.01	0.05	<.02	.25	< .1		0.12	.10
	Dissolved				< 0.01	< 0.01		<.03		< .1	0.05	.01

* Calculated $CaCO_3$ equivalents (mg/l) (APHA, 1971)
(Ca x 2.497) + (Mg x 4.116)

of many metals to aquatic life by several fold (E.P.A., 1973). For instance cadmium (Cd) which itself acts synergistically with Zinc and other metals to increase toxic effects is considered "safe" at 0.03 mg/l in hard waters but "safe" only at 0.0004 mg/l in soft waters (E.P.A., 1973).

Station 1 which drains the mine area appears to be higher than normal in dissolved zinc (0.06 mg/l) indicating that leaching may be occurring. Zinc, which is also greatly affected by water hardness, is regarded acceptable at the 0.03 mg/l level in hard water (E.P.A., 1973). In soft water such as Cronin Creek a larger safety margin should be considered as 0.04 ppm zinc in soft water prevented the hatching of rainbow trout (McKee & Wolf, 1963).

The U.S. Environmental Protection Agency also recommends that the concentration of lead in water should not exceed 0.03 mg/l (E.P.A., 1973). In order to protect the aquatic life of Cronin Creek, mine drainage above the mill site should be kept to a minimum.

The total concentration of iron was well below toxic thresholds (0.2 mg/l) (McKee and Wolf, 1963) and in all cases undetectable in the dissolved state. Chromium, molybdenum and nickel were also below detectable concentrations.

The tailings supernatant was found to be extremely hard (320 ppm $CaCO_3$ equivalents) but very low in dissolved metal content. No fish bioassay of the tailings supernatant has been conducted. However, it would appear that if the tailings were acutely toxic to fish, factors other than metals would be suspect.

pH values, presented in Figure 4 are considered "normal" for aquatic life and within the acceptable range of 6.0 to 9.0 (Todd, 1970).

5.3 Biological Assessment

5.3.1 Benthic Invertebrates. Populations of invertebrates, each with their unique requirements have proven to be excellent indicators of changes in their environment. All organisms have specific tolerance ranges to many different environmental factors. Some are highly tolerant of modified conditions, others are moderately tolerant and those that cannot cope with even small environmental changes are highly intolerant.

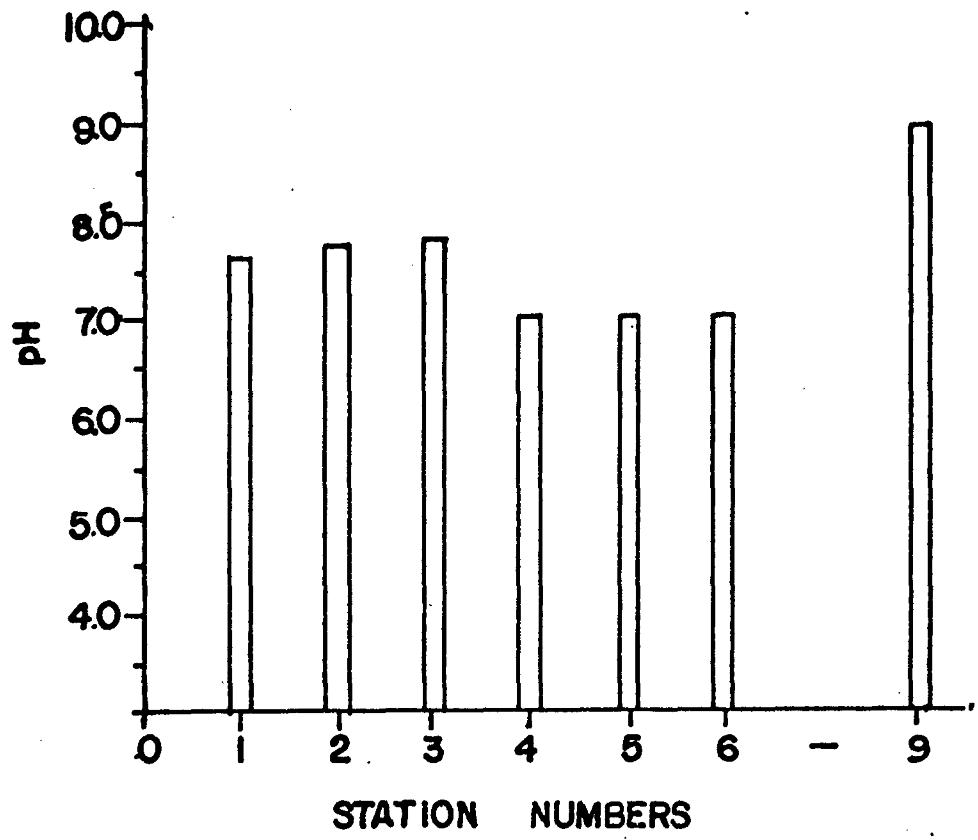

Figure 4: pH of NATURAL WATERS and TAILINGS SUPERNATENT. July 25, 1974.

In pristine ecological conditions a diversified flora and fauna exists (tolerant and non-tolerant) in a highly integrated, interdependent system. Evan a subtle disruption of this system may manifest itself in a large re-adjustment in the relative population proportions. For example, a change in the nutrient supply may cause reduced numbers of some species while others become more prominent.

Biological communities are excellent indicators of environmental stress. Community structure will adjust to stress by shifts in species diversity, density and dominance (Smith, R.L. 1966). However, sudden changes in the biota also occur quite naturally from season to season and year to year. It must be remembered that in most communities there lies a redundancy in members at any one tropic level and this protects most species from total elimination by fluctuating seasonal changes. Therefore, biological data, biotic indices and significant changes in biological communities must be analysed by an experienced ecologist who has an understanding of the interaction of the environment and fauna.

Table 4 represents the combined counts of three invertebrate samples of the summer program. The invertebrates were identified to family and then placed into one of three groups. Group 1 is considered highly tolerant of polluted waters, Group II, moderately tolerant, and Group III, very intolerant. Figure 5 graphically shows the relative proportions of these three groups at Stations 2, 4, 5 and 6.

The data indicates that in all cases Groups II and III are well represented with only limited representation from Group I (e.g. 1% to 2% at each station.) In optimum conditions, however, Group III usually forms the larger proportion. Diptera, especially Tendipedidae (midges) formed the bulk of Group II, while Ephemeroptera (Mayflies) and Plecoptera (Stoneflies) formed the majority in Group III. A future rise in the proportion of Group I at the expense of Group III may be indicative of a degrading environment. The invertebrate distribution here indicates that the waters of Cronin Creek are in satisfactory conditions. It also suggests that the quality has improved drastically since the late 1960's. Invertebrate sampling at that time revealed a complete absence of organisms downstream of the mine.

The calculated values for d (diversity) and J (evenness) for each site sampled on the survey are presented in table 5. Diversity indices of the benthic communities near the Hallmark development averaged 2.010. This relatively low average may be attributable to the lack of accumulated nutrients in these cold northern streams, or to the recovery of the stream biota from the earlier discharge of tailings to Cronin Creek. It has also been suggested that some sensitivity of the index is lost when diversities are based on higher taxonomic categories (Egloff & Brakel, 1973).

Phycologists believe that most species of algae are available in all streams (if thoroughly examined) and flourish when conditions become suitable(opportunists.)

TABLE 4: POPULATION DISTRIBUTIONS OF BENTHIC INVERTEBRATES AT STATIONS 2, 4, 5 AND 6. July 25th,1974

	Station Number			
	2	4	5	6
Group I (pollution Tolerant)				
Oligochaeta		2	3	1
Platyhelminthes, Rhabdocoel	1			
Group II (moderately tolerant)				
Diptera				
Helidae				1
Deuterophlebiidae		1	1	
Empididae	19	5	8	
Simuliidae	2	2	16	1
Tendipedidae	296	45	605	136
Rhagionidae			2	1
Dolichopodidae			5	
Arachnida				
Hydracarina sp. 1	30	27	179	23
Hydracarina sp. 2		1	4	2
Group III (intolerant)				
Coleoptera Elmidae			1	
Ephemeroptera				
Baetidae	3	1	45	8
Heptageniidae	22	35	214	45
Plecoptera				
Perlodidae	44	10	27	26
Chloroperlidae	2		4	
Trichoptera Rhyacophilidae	4	3	5	3
TOTAL INDIVIDUALS	423	131	1,120	247
TOTAL TAXA	10	11	15	11

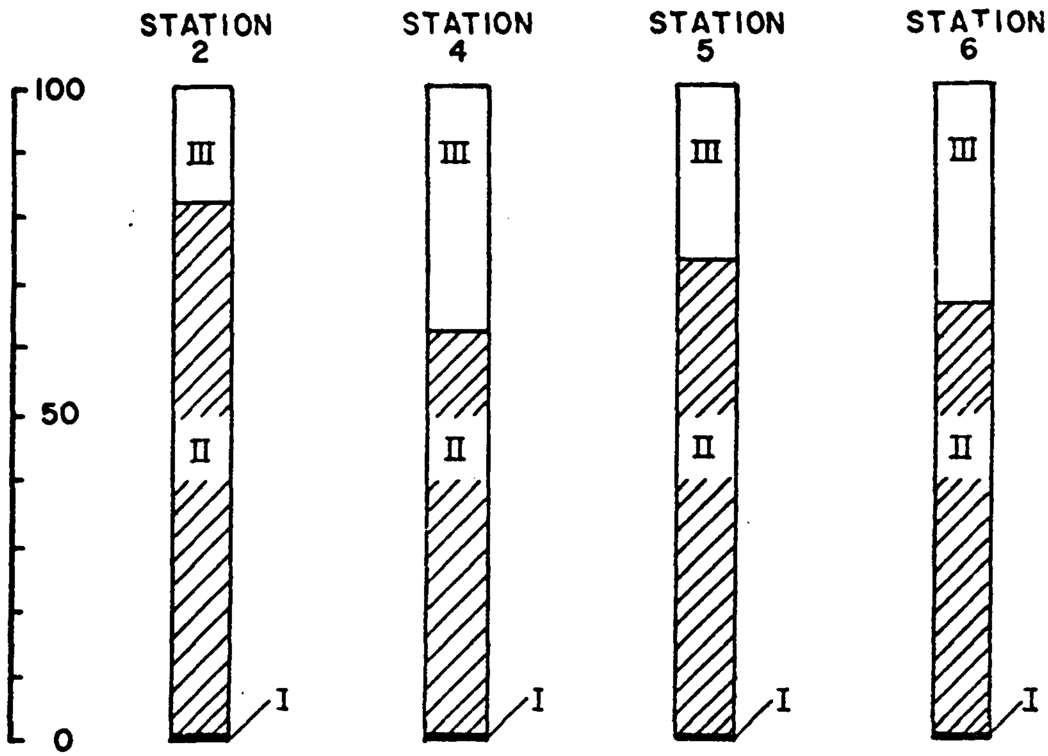

Figure 5: THE PERCENTAGE DISTRIBUTION OF GROUPS I, II AND III FOR STATIONS 2, 4, 5 and 6. July 25, 1974.

Table 5: CALCULATED VALUES OF $\bar{d}$ AND J FOR STATIONS 2, 4, 5 AND 6. July 25, 1974.

Station	$\bar{d}$	J (evenness)
2	1.602	0.482
4	2.434	0.703
5	1.999	0.512
6	2.005	0.580

$\bar{x}\ \bar{d} = 2.010$

5.3.2. Periphyton

Large algae blooms result from nutrient excess, changes in temperature, changes in flow and other factors which are sometimes linked with industrial discharges (Hynes 1970). During the biological survey no blooms were observed. Table 6 lists the dominant species from rock scrapings at stations 2, 4, and 5.

Palmer (1963) listed three of the dominant species present at these stations (Oscillatoria, Gomphonema, Euglena) as "highly tolerant of pollution". However little is known of the relationship between pollutants and the tolerance of various algae species. In future surveys periphyton populations would have to be quantified in a similar manner as the benthic invertebrates to facilitate supporting water quality assessment.

5.3.3. Bionutrients

Table 7 summarizes the bionutrient content of the water at each station. Natural sulfate (SO_4) levels originate from leaching of common minerals, the oxidation of pyrites or as the oxidized state of organic matter in the sulfur cycle. They were found to be in low concentrations in all streams, but slightly elevated levels of SO_4 at station 3 gave further indication that leaching might be occurring at the mine site. The high levels of sulfates in the tailings ponds were primarily due to breakdown products of the mill reagents such as Z-350, Z-343, Z-238 (all xanthates), $ZnSO_4$ (depressant), and $CuSO_4$ (activating agent) (Hawley 1972a, Hawley 1972b).

In most instances, NO_3, NO_2 and PO_4 were undetectable in the natural waters. The tailing supernatant produced measurable amounts but well below hazardous levels as discussed by McKee and Wolf (1963). Even the use of Aerofloat 31, an amyl dithiophosphoric acid promoter, showed no significant accumulation of PO_4 in the tailings.

Hypothetically the discharge of excessive amounts of biogenic salts to Cronin Creek could result in the overabundant growth of algae and zooplankton in both Chapman and Fulton Lakes. In extremes this can result in concomitant odors, reduction in oxygen from accelerated eutrophication of the two reservoirs. What effect this may have on the developing fish eggs and algae growth in the spawning gravels downstream is not known.

TABLE 6: THE DOMINANT SPECIES OF ALGAE FOUND ON LARGE ROCKS AT STATIONS 2, 4, and 5. July 25, 1974

Station	Cyanophyceae (Blue green algae)	Bacillariophyceae (Diatoms)	Chlorophyceae (Green algae)
2	Oscillatoria	Hannaea arcus Meridion circulare Gomphonema sp. Diatoma sp. Synedra sp.	Volvocales Euglena
4		Hannaea arcus Diatoma sp. Synedra sp.	Thorea
5		Hannaea arcus Diatoma sp. Synedra sp. Meridion circulare	Thorea

TABLE 7: BIONUTRIENT ANALYSES, July 25, 1974

Station	NO_2 mgN/l ±.005	NO_2 mgN/l ±.001	SO_4 mg/l ± 5.0	PO_4 mgP/l ± .005
1	<.01	<.005	7	.011
2	<.01	<.005	6	<.01
3	<.01	<.005	12	<.01
4	<.01	<.005	6	<.01
5	<.01	<.005	5	<.01
6	<.01	<.005	6	.021
9	.77	.066	110	.020

< indicates less than the detection limit

6. CONCLUSIONS

Physical, chemical and biological measurements in Cronin Creek upstream and downstream of the mine revealed no obvious adverse effects on the aquatic environment. A diversified macroinvertebrate biota was recorded. The chemical and biological parameters documented should provide an effective baseline to future monitoring.

Drainage from above the mill site (Stations 2 and 3) contained slightly elevated levels of metals, residues and sulfates indicating that leaching may be occurring on the exposed rock faces of the wasterock or mine. Tests should be performed on samples of wasterock and exposed faces of below grade ore to determine if an acid generation potential exists. If these tests prove positive and leaching becomes self generating through microbial action to produce excesses of sulfuric acid, continuous monitoring and pH treatment of the mine drainage may be necessary.

The Hallmark operation has resulted in adverse effects on the local fisheries in the past but the incorporation of abatement facilities has minimized the likelihood of a reoccurrance. If production is to contine as planned, new tailings impoundments will have to be developed as the capacity of existing facilities will only meet 1976 requirements.

In addition to new impoundments, emergency facilities should be provided in the event that the recycle pumps should fail. Cronin Creek cannot be considered a dumping ground even under emergency situations.

If open pit projections are realized, the operation is expected to result in topographical changes, mill relocation and new impoundment needs. In the event of expansion or changes in mining methods Environment Canada should be consulted in the early stages of the development design to minimize environmental damage to the watershed in general and to ensure that optimum water quality is maintained for salmonid production at the Fulton River enhancement facilities.

7. ACKNOWLEDGEMENTS

The authors wish to acknowledge the following individuals. Their efforts formed the basis of this report:

Mr. Bob Allan of the B.C. Fish and Wildlife Branch for his field assistance of the sampling program. Mr. Bryan Kelso (E.P.S. Biologist) for the computerized statistical analyses of benthic population. Ms. Jane Lee (E.P.S. Biologist) for the algal identification and various confirmations on benthic invertebrate identification. The technical staff of Environment Canada Water Quality Laboratory for the residue, nutrient and metal analyses.

We would also like to thank Hallmark Resources Ltd., for their cooperation extended to us during our sampling activities.

8. REFERENCES

A.P.H.A., 1971
Standard Methods for the Examination of Water and Wastewater, 13th Edition, 874 pp.

COLE, R.A., 1973
Stream Community Response to Nutrient Enrichment, Journal WPCF, Vol. 45, No. 9, 1874-1888.

EGLOFF, D.A. and W.H. BRAKEL, 1973
Stream Pollution and a Simplified Diversity Index. Journal WCPF, Vol. 45, No. 11, 2269-2275.

E.P.A., 1973
Water Quality Criteria 1972, U.S. Government Printing Office, Washington, D.C.

GAMMON, J.R., 1970
The Effects of Inorganic Sediment on Stream Biota. Water Pollution Control Research Series. 18050 DWC 12/70 Water Quality Office, Environmental Protection Agency, 141 pp.

HAWLEY, J.R., 1972 (a)
The Problem of Acid Mine Drainage in the Province of Ontario, Ministry of the Environment, Toronto, Ontario.

HAWLEY, J.R., 1972 (b)
Use, Characteristics and Toxicity of Mine-Mill Reagents in Ontario, Ministry of the Environment, Toronto, Ontario.

Hynes, H.B.N., 1970
The Ecology of Running Waters, University of Toronto Press.

McKEE, J.E. and H.W. Wolf, 1963
Water Quality Criteria, The Resources Agency of California State Water Resources Control Board, Publication No. 3-A.

MACKENTHUS, L.M., 1969
The Practice of Water Pollution Biology, U.S. Department of the Interior, Federal Water Pollution Control Administration, Division of Technical Support.

MARGALEF, R., 1956
Informacion y diversidad especifica en las comunidades de organismos. Inv. Pesquera, Vol. 3, P. 99-106. Cited in Wilhm and Dorris (1968)

PALMER, C.M., 1963
The Effects of Pollution on River Algae, Annals of the N.Y. Acadamy of Science 108(2) 389-395.

PATRICK, R. and C.W. REIMER, 1966
The Diatoms of the United States. The Livingston Publishing Co., Philadelphia.

PENNAK, R.W., 1953
Fresh Water Invertebrates of the United States. The Ronald Press Co., New York.

PIELOU, E.C., 1966
Shannon's formula as a measure of specific diversity: its use and misuse. Amer. Natur. 100 (914): 463-465.

PIELOU, E.C., 1967
The Use of information theory in the study of diversity of biological populations. Proc. Fifth Berkeley Symposium on Mathematical Statistics and Probability 4: 163-177.

PRESCOTT, G.W., 1962
Algae of the Western Great Lakes Area. William C. Brown Co., Dubuque, Iowa.

PRESCOTT, G.W., 1970
How to Know the Fresh Water Algae. 2nd Ed., William C.Brown Co., Dubuque, Iowa.

SMITH, A.D. 1973 (a)
Babine Watershed Change Program Annual Report for 1972. Fisheries and Marine Service, Fisheries Branch Research and Development Directorate, Pacific Biological Station, Nanaimo, B.C.

SMITH A.E., 1973 (b)
The Analyst, Bol 98, pp 65-68.

SMITH, A.E., 1973 (c)
The Analyst, Vol. 98, pp. 209-212

SMITH, R.L., 1966
Ecology and Field Biology, Harper and Row, New York.

TODD, D.K., 1970
The Water Encylopedia, The Maple Press.

USINGER, R.L. et al., 1968.
Aquatic Insects of California, University of California Press.

WARD, H.B. and G.C. CHANDLER, 1918
Fresh Water Biology, 2nd Ed., John Wiley and Sons Inc., New York.

WILHM, J.L. and T.C. DORRIS, 1968
Biological Parameters for Water Quality Criteria,
Bioscience 18, 477-481.

WRIGHT ENGINEERS LTD., 1968
Hallmark Resources Ltd. (N.P.L.) Cronin Mine, Near Smithers,
B.C. Report on Tailings Pond Design, Project No. 730-100,
Vancouver, B.C.