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MANUSCRIPT REPORT

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BASE METAL MINE WATER POLLUTION

on the

NEPISIGUIT RIVER, NEW BRUNSWICK

by

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HALIFAX, N.S.**

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BASE METAL MINE WATER POLLUTION ON THE
NEPISIGUIT RIVER, NEW BRUNSWICK

INTRODUCTION

The geological conditions in Northeastern New Brunswick are highly suitable for the extraction of base metals, particularly copper, zinc, and lead (Boyle et al, 1966). As a result, several base metal mining operations have been established in the watershed of the Nepisiguit River. Drainage from these mines, both natural and intentional, contains high concentrations of base metal ions and has caused a serious deterioration of the aquatic environment. This has resulted in the disappearance of Atlantic salmon and other game fish from the lower reaches of the Nepisiguit system (Table I).

Table I Department of Fisheries and Forestry statistics of the yearly values for rod days, number of adult Atlantic salmon caught, and total weight, for the Nepisiguit River during the period 1951-1970.

YEAR	ROD DAYS	NO. OF FISH	TOTAL POUNDS
1951	1776	326	2295
1952	1765	445	3280
1953	2035	637	5395
1954	1640	1297	9480
1955	2275	931	6740
1956	1686	506	3350
1957	3130	725	5855
1958	3540	1048	7470
1959	2150	461	4025
1960	905	243	1500
1961	1360	338	2170
1962	1570	516	3660
1963	878	344	1488
1964	557	445	2098
1965	271	619	1931
1966	818	799	2887
1967	604	498	1844
1968	551	60	588
1969	480	37	246
1970	97	0	0

The contaminated drainage waters originating at the number 6 (Figure 1) open pit mining operation of New Brunswick Mining and Smelting Corporation Ltd. (Bathurst, N.B.) has been regarded as a serious threat to the Nepisiguit River ecosystem. Although mining operations have been conducted at the No. 6 site for at least 18 years, recent activities at the open pit have now accentuated the drainage pollution problem. The contaminated drainage has caused the virtual elimination of all fish populations in the 25 miles of river below the mine. Mine water quality monitoring information gathered by the Resource Development Branch (Canadian Fisheries Service) since 1965 shows the serious deterioration of the river that has occurred (Table II).

Table II. Mean annual zinc concentrations (ppb) determined at stations B#6-4 and B#6-6 below No. 6 open pit mine on the Nepisiguit River during 1965 - 1970.

Station No. & Description	1965	1966	1967	1968	1969	1970
B#6-4 Nepisiguit at mouth of Knight Brook	160	1663	28944	56944	7200*	42375
B#6-6 Nepisiguit one mile below Knight Brook	650	102	659	1540	1767	-

* one sample only

In the summer of 1969 the water quality monitoring program was supplemented with biological toxicity testing at a few selected stations. The project was extended in 1970 to determine the relationship between mine drainage and heavy metal concentrations of the Nepisiguit River, and the influence of these heavy metal concentrations on fish survival. Also assessed was the bioassay technique used by the Resource Development Branch to determine heavy metal toxicity, and the value of the "Toxic Unit" concept as an all encompassing term for expressing the water quality of a system as it relates to fish survival.

THE PROBLEM

The mining industry in northeastern New Brunswick is centred upon the extraction and concentration of pyritic ore bodies for heavy metal content notably copper, lead, zinc, and silver. Unfortunately, the exposure of these massive and disseminated sulfide ores to moisture and oxidative conditions results in a series of chemical reactions whereby iron sulfides are oxidized to form ferrous and ferric sulphate and sulphuric acid. Increased acidity accelerates the initial conversion of sulphides, generating more acid. Heavy and trace metal ore components, such as copper and zinc, being more soluble at lower pH levels, are released into solution. This is the basic source of acid mine water and heavy metal pollution.

Mining companies, being profit-motivated, are primarily interested in high yield ore formations. Large quantities of unusable "waste-rock" are discarded during the mine process in both shaft and open pit operations. The waste material is generally piled where most convenient for the mine operators on a time-motion efficiency basis, and, until recently, little concern was given to the water pollution-problems this practice could create.

"Waste rock" piles were generally deposited along river banks, or in bogs drained by brooks. Weathering (oxidation) and leaching of these "waste rock" piles soon generated acid resulting in the release of heavy metals; high rainfall in the mining area accentuated the problem. The highly contaminated, toxic water has caused a serious deterioration in the water quality throughout the region. Mine water pollution has now eliminated the once productive fishery resource of the lower reaches of the Nepisiguit River.

Northeastern New Brunswick is affected by three major, but closely related, sources of mine water pollution. The first source is where water either overflows from, or drains, abandoned open pits, or is being actively pumped from operational open pits. Examples include: the open pit at Heath Steele Mines; the test pit at Chester Mines; the caved-in shaft at Wedge mine; the old Bathurst iron mine pit; and the No. 6 pit at Brunswick Mining and Smelting.

The second source of mining pollution is created by surface drainage and leaching from uncovered ore reserves and from "waste rock" stockpiled, in drainage areas. These practices have caused serious mine water pollution at many locations including Heath Steele Mines, Chester Mines, and,

most notably, at the No. 6 open pit property of Brunswick Mining and Smelting.

The third source of mining pollution results from the release of effluent from the base metal concentrating process into river systems. Tailings effluent contains concentrations of heavy metals which are uneconomical to extract but are many orders of magnitude above the lethal threshold of fish. Tailings are generally impounded and maintained at high pH (above 10) by the addition of lime or limestone, to precipitate out heavy metals, thus retaining them in the tailings pond. Unfortunately, in some instances, the action of sulphur bacteria has considerably complicated the effectiveness of tailings ponds (Schmidt and Conn, 1968; Zitko, 1970). In general though, tailings ponds have effectively reduced the incidence of heavy metal contamination in the area. This third source of mining pollution does not apply to the Brunswick #6 property nor to the mine water pollution problem on the Nepisiguit River.

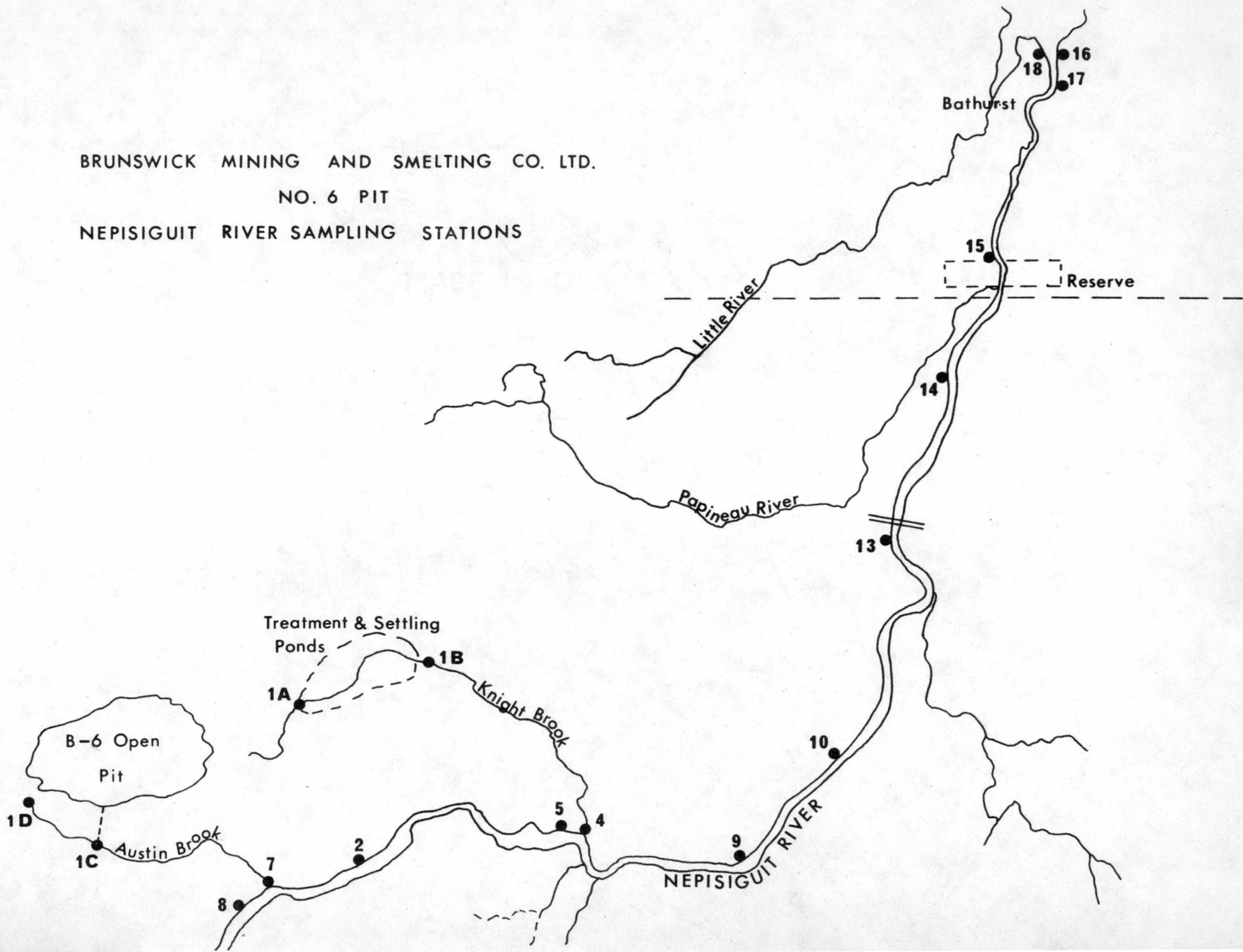
The contamination of Austin Brook (Figure 1) has been caused by the discharge of water pumped from the Brunswick No. 6 open pit, and by leaching from "waste rock" piles in the vicinity of the brook. The contamination of Knight Brook (Figure 1) has arisen solely from leaching and drainage from a series of "waste rock" dumps piled at the headwaters of the brook.

PARAMETERS INFLUENCING THE ACUTE TOXICITY OF HEAVY METALS TO SALMONIDS

The acute toxicity of heavy metals to salmonids was studied in detail by Lloyd (1960, 1961a, 1961b) and Lloyd and Herbert (1962) using rainbow trout, (Salmo gairdnerii Richardson). In these papers, the authors showed that a highly significant inverse relationship existed between fish survival (toxicity) and water hardness. Furthermore, Lloyd (1961b) was able to add up the toxic effects of copper and zinc in mixtures by expressing each concentration as a proportion of the "lethal threshold" instead of using conventional chemical units. Using these principles, Sprague (1964) determined the lethal levels of copper and zinc to juvenile Atlantic salmon (Salmo salar) at a total water hardness of 20 mg/l and 17°C, to be 48 ppb and 600 ppb, respectively. These findings, in addition to the results on the synergistic effect of heavy metals on Atlantic salmon (Sprague, 1965), were in close agreement with the work of Lloyd and Herbert (1962) on rainbow trout.

Figure 1. Brunswick Mining and Smelting Co. Ltd.
No. 6 pit Nepisiguit River sampling
stations.

BRUNSWICK MINING AND SMELTING CO. LTD.
NO. 6 PIT
NEPISIGUIT RIVER SAMPLING STATIONS



With the exception of zinc, acute toxicity of heavy metal ions usually increases with increasing temperature (Sprague, 1964; Zitko, 1970). In the case of zinc, the lethal threshold at 50°C is about 1/3 of the level at 17°C.

Maximum acute toxicity of copper and zinc occurs at pH between 6 and 7; the pH dependence of toxicity appears to be caused specifically by hydrogen and hydroxyl ions (Zitko, 1970). It may, for example, be due to electric change of proteins in bio-membranes which may slow down the uptake of heavy-metal ions or prevent the ions from reaching their target sites (Zitko, 1970).

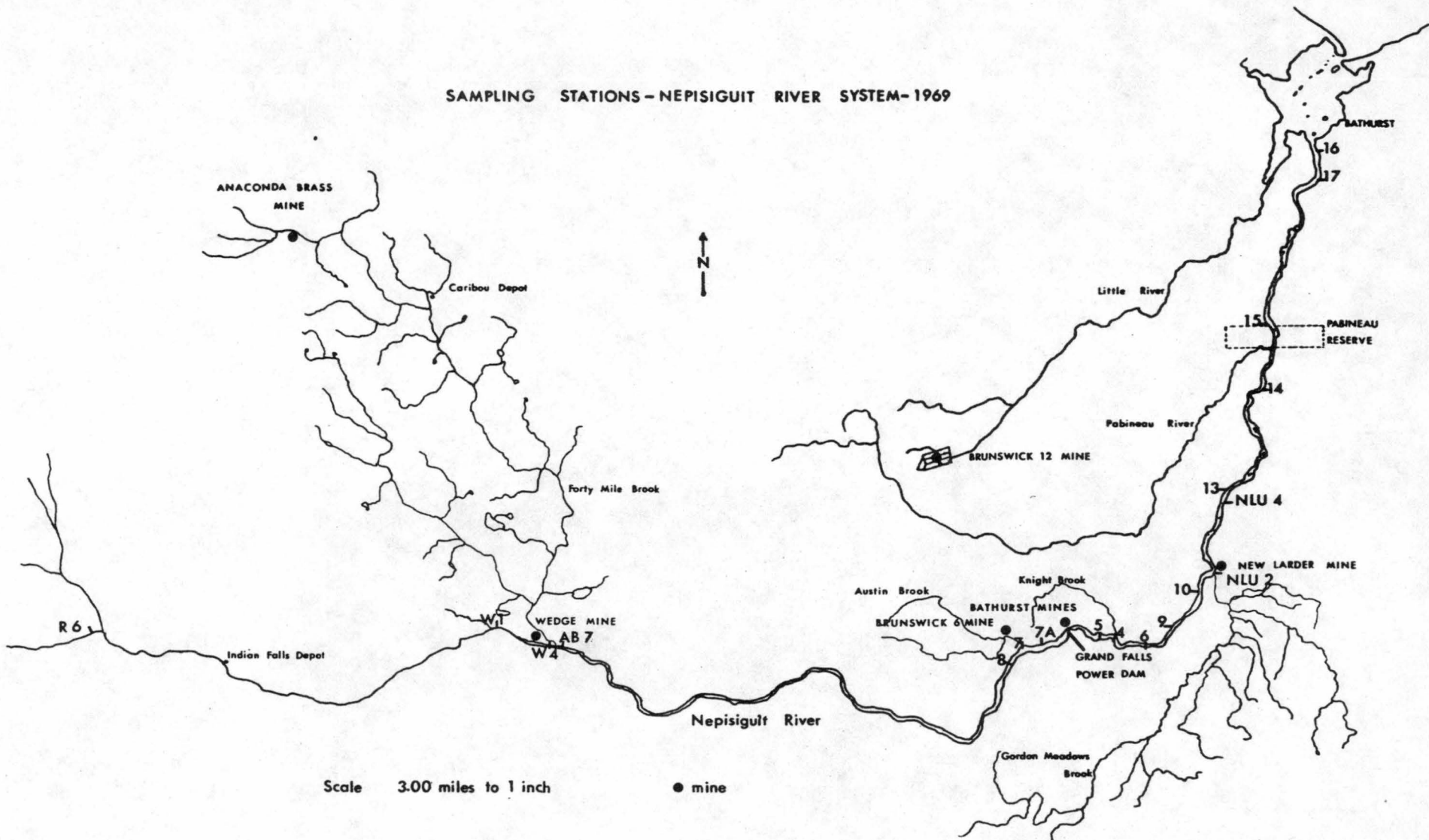
Although experimental evidence is scarce, chelating agents, such as humic compounds, have been reported to decrease the toxicity of metal ions by binding them into organic complexes (Grande, 1966; Sprague, 1968). Grande (1966) showed that an increase in the concentration of humic substances, from 1.26 to 4.65 ppm of KNO_3 oxygen, increased the lethal threshold of copper to Atlantic salmon fingerlings from 40 to 100 ppb. This factor would be of prime importance in northeastern New Brunswick rivers where the concentration of humic compounds in water ranges as high as 10-15 ppm (Zitko, 1970).

MATERIALS AND METHODS

A series of stations, previously established by the Resource Development Branch (Figure 1) were used to monitor the Brunswick 6 operation. Figure 2 illustrates the principal stations used to monitor all mining activity on the Nepisiguit River. Table III describes the location of the sampling stations used in the present study. An asterisk denotes those stations at which bioassay tests were conducted.

Figure 2. Nepisiguit River mine water sampling stations.

SAMPLING STATIONS - NEPISIGUIT RIVER SYSTEM - 1969



Scale 3.00 miles to 1 inch

● mine

Table III. Water quality and bioassay testing stations along the Nepisiguit River, New Brunswick. The stations are arranged in sequence, beginning with station R-6, upstream from all mining influence, and continuing downstream to station B #6-18, at the mouth of the river. The location of each station is as follows:

STATION	
R-6	- Nepisiguit, above Portage Brook (above all mining properties)
W-1	- Nepisiguit, above Wedge mine, approx. $\frac{1}{2}$ mile
AB-7	- Nepisiguit, below 40 Mile Brook at bridge on Mines Road
* B#6-8	- Nepisiguit, 100 yds. above mouth of Austin Brook
* B#6-7	- Nepisiguit, at mouth of Austin Brook
B#6-2	- Nepisiguit, midway between Austin and Grand Falls Dam
* B#6-5	- Nepisiguit, above Knight Brook
* B#6-4	- Nepisiguit, at mouth of Knight Brook
B#6-6	- Nepisiguit, 1 mile below Knight Brook
B#6-9	- Nepisiguit, 2 miles below Knight Brook
B#6-10	- Nepisiguit, 3 miles below Knight Brook
* B#6-13	- Nepisiguit, at bridge near NLU Mine
* B#6-14	- Nepisiguit, at Pabineau Falls
B#6-15	- Nepisiguit, below Pabineau River, at Reserve
* B#6-17	- Nepisiguit, above Bathurst, at water pump station
* B#6-16	- Nepisiguit, at Irving Pier in Bathurst Harbour
* B#6-18	- Nepisiguit, opposite Irving Pier in Bathurst Harbour (below pulp mill)

Bioassay test facilities were established at the South Esk Fish Culture Station near Newcastle, N.B., and initial toxicity determinations were begun in July, 1969.

Juvenile Atlantic salmon (Salmo salar) were used for all experiments. All bioassays conducted were "static" tests, in which the TD50 (time until 50% mortality) was determined for fish exposed to 20 liters of 100% river water over a period of 96 hours. All bioassays were run at ambient brook water temperature by cooling the tanks containing the test solution in troughs with flowing brook

water. This produced natural daily and seasonal water temperature fluctuations to which wild Nepisiguit stock would be exposed. Dissolved oxygen concentrations were maintained above 6ppm or 80% saturation by continuous aeration, and pH was adjusted when necessary to $7^{\circ}\text{C}(\pm .5^{\circ}\text{C})$.

When test water temperature was brought to within 1°C of brook water temperature determinations were made of dissolved oxygen, temperature, and conductivity, with a Hydrolab IIA Portable Water Quality Analyzer, and pH with a Beckman Model N pH meter. Ten fish were introduced to the test tanks and observed on a regular basis, throughout the 96 hour test period. Dead fish were removed and length, weight, and time to mortality data were recorded. After 96 hours, or when all fish had died, the chemical-physical parameters were redetermined. Control tests, using 10 fish in "unpolluted" hatchery brook water, followed the same procedure described above and accompanied each series of tests.

Mine water samples were collected by Resource Development staff in 100 ml and 1 liter polyethylene bottles washed and cleaned by the Department of Energy Mines and Resource's Water Quality Laboratory at Moncton, New Brunswick. All water samples were submitted to the Moncton laboratory and analyzed by their standard methods for turbidity, color, pH, conductance, Ca^{++} , Mg^{++} , Fe^{+++} , Cu^{++} , Zn^{++} , Pb^{++} , Cl^{-} and total hardness. The main factors considered in this report were copper, zinc, lead, and total hardness.

In relating the effect of metal concentrations to the survival of juvenile Atlantic salmon, the individual ion concentrations were expressed as proportions of their threshold or incipient lethal levels (ILL) at the particular water hardness tested, as described by Lloyd and Herbert, 1962, and recommended by Sprague (Departmental communication, 1962). The incipient lethal level is considered to be that level of the lethal identity beyond which the organism can no longer survive for an indefinite period of time (Fry, 1947). Previous terminology has been adopted (Bergstrom and Vallin, 1937) by assigning a value of 1.0 toxic units to the incipient lethal level of any toxicant. In this manner, toxic unit fractions can be calculated for the individual ion concentrations in a water sample (e.g. copper, zinc and lead) and then combined to produce a single expression for the toxicity of that solution. This method greatly facilitates the interpretation of toxicity data in which the bioassay test solutions contain mixtures of toxicants.

RESULTS

Appendix I summarizes the data for all parameters measured at all sample stations for 1970 as well as their mean 1970 values, standard deviations, and standard errors.

Figures 3a and 3b show the 1970 seasonal fluctuations of copper at 13 stations, extending from station R-6, above the influence of all mining activity, to station B#6-17, at the mouth of the Nepisiguit, at Bathurst. Figure 3a illustrates the relatively high natural background levels of copper present in the river system, and the significant seasonal fluctuations that occur. The influence of mining activity, on the copper content of the Nepisiguit river water is negligible down to the mouth of Knight Brook (Station B#6-4). At this point (Figure 3b), extremely high concentrations of copper (mean value 2080 ppm \pm 619, Appendix I) are released into the Nepisiguit and directly affect the water quality down to a point between stations B#6-9 and B#6-10, a distance of approximately 2½ miles. Thereafter, the copper content of the Nepisiguit is diminished by dilution and the settling out of copper to the point where the concentrations approach the background values observed above the influence of Knight Brook.

The effect of mining activity on the zinc content of the Nepisiguit River is far more pronounced than its effects on copper. This is shown in figures 4a and 4b, where the seasonal data collected for 9 stations in 1970 have been presented. Station R-6 water contained very low concentrations of zinc with a mean value of 10 \pm 6.25 ppb (Appendix I) and a maximum of 40 ppb on September 30th (Figure 4a). Station AB-7, downstream from R-6, had a slightly higher mean concentration of 56 ppb (Appendix I) and maximums of 70 ppb in September and November (Figure 4a). At station B#6-8, just above the influence of the open pit on the Nepisiguit, the mean value for zinc had increased to 66 ppb (Appendix I). At station B#6-7, where Austin Brook water reaches the Nepisiguit, high concentrations of zinc are added to the system. The fluctuations (Figure 4a) do not follow the natural seasonal pattern observed for copper (Figure 3a) indicating that the changes were due to the open pit mining activities of Brunswick Mining and Smelting Corporation. The mean value determined for zinc at station B#6-7 was 6843 ppb \pm 1651 (Appendix I) and the observed maximum of 23,500 ppb was recorded on November 10th, 1970. The mean concentrations of zinc at stations B#6-2 and B#6-5 diminished from the high levels found at station B#6-7, but remained higher than the values

Figure 3a. 1970 seasonal copper fluctuations
(in ppb) recorded at stations R-6,
AB-7, B#6-8, B#6-10, B#6-7 and
B#6-2 on the Nepisiguit River.

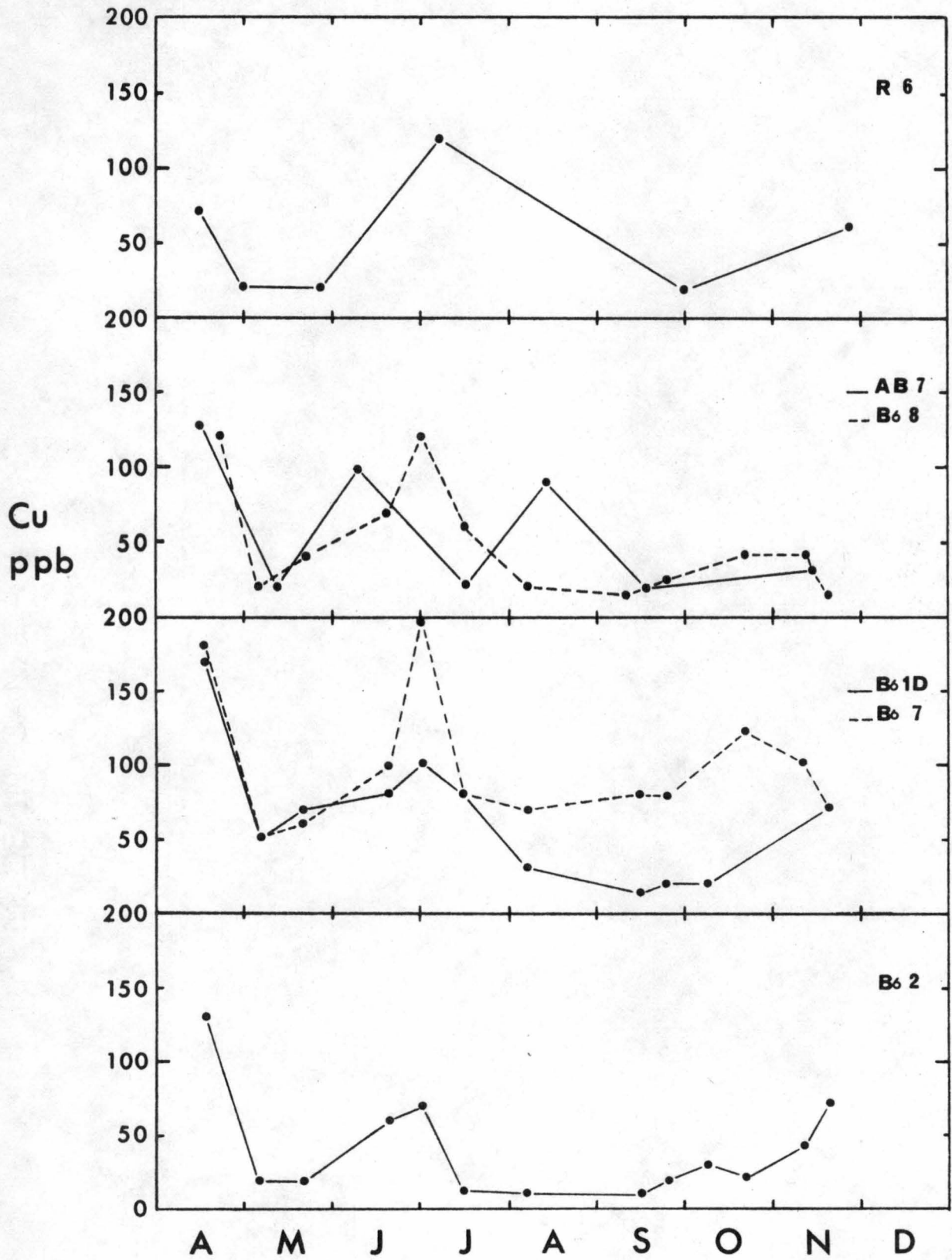


Figure 3b. 1970 seasonal copper fluctuations
(in ppb) recorded at stations
B#6-5, B#6-4, B#6-9, B#6-10,
B#6-14, B#6-15 and B#6-17 on the
Nepisiguit River.

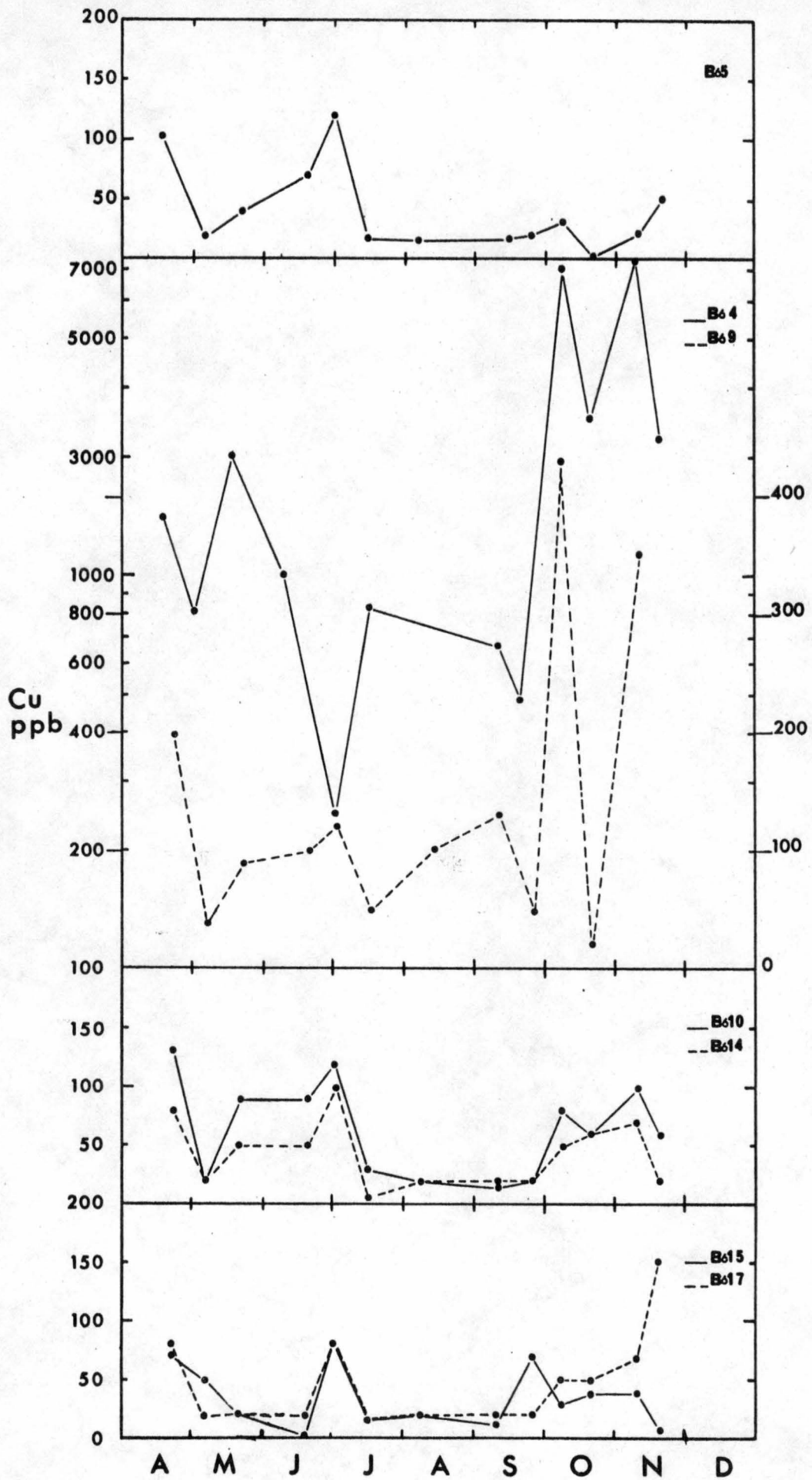


Figure 4a. 1970 seasonal zinc fluctuations
(in ppb) recorded at stations R-6,
AB-7, B#6-7, and B#6-2 on the
Nepisiguit River.

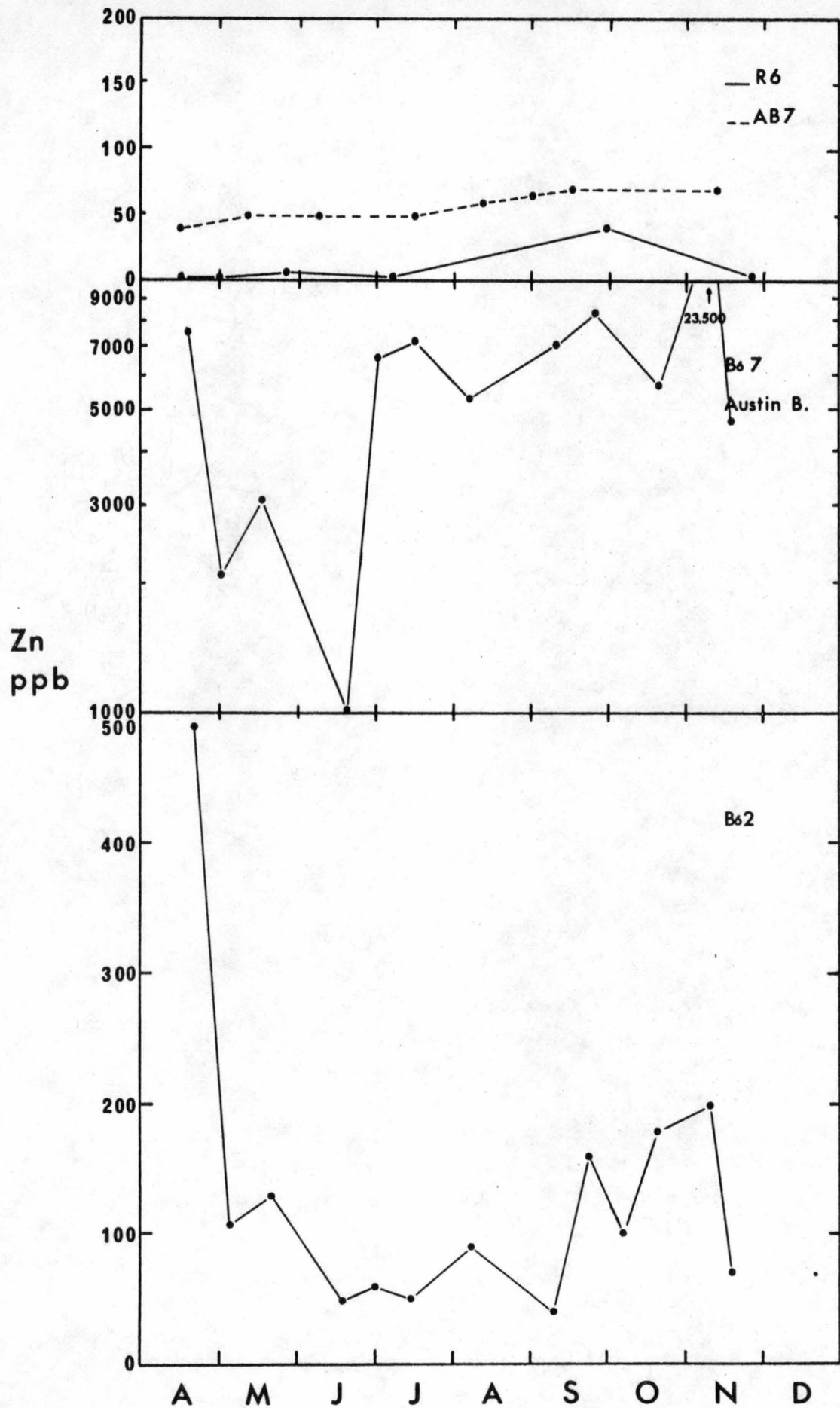
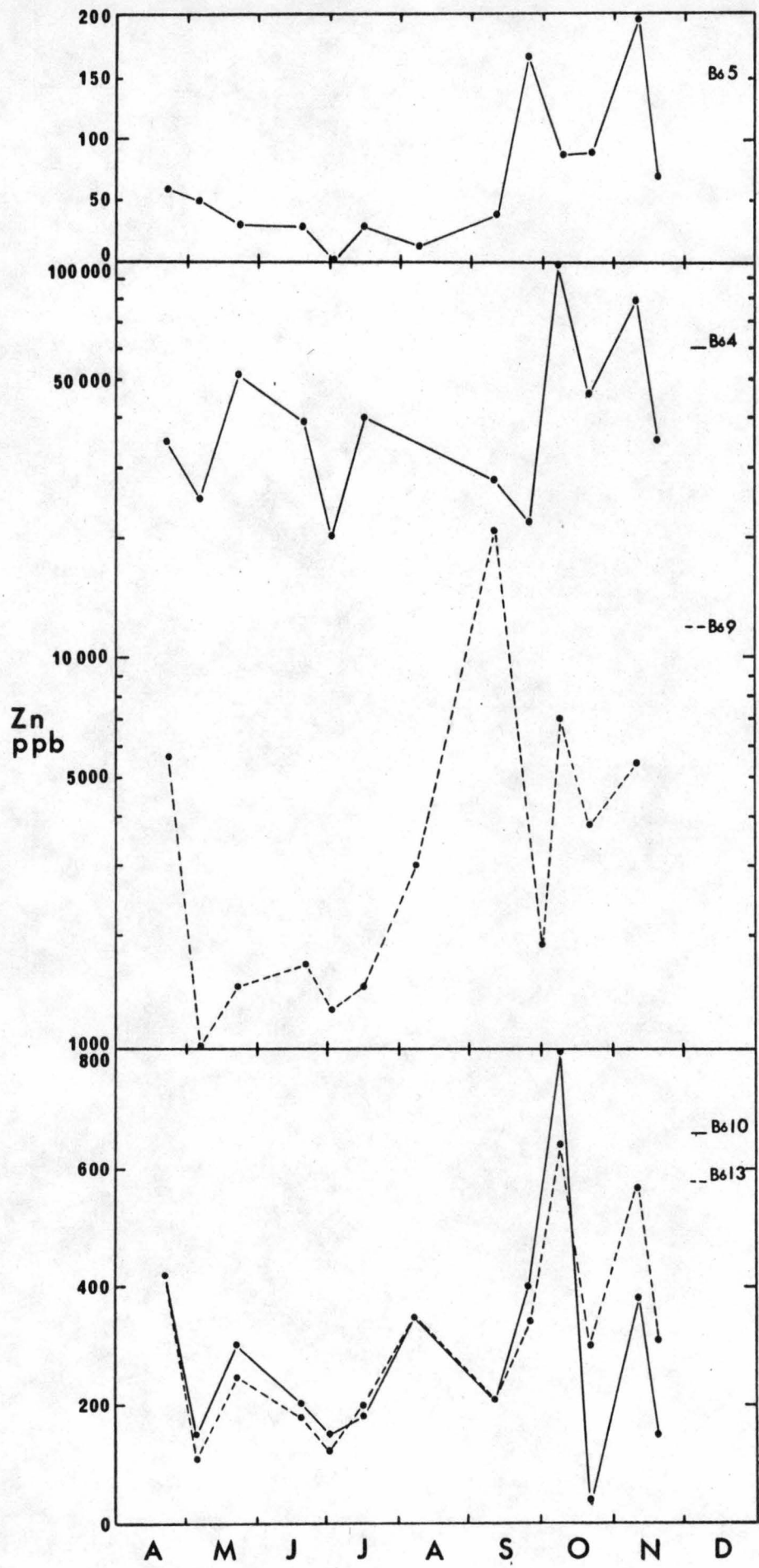


Figure 4b. 1970 seasonal zinc fluctuations
(in ppb) recorded at stations
B#6-5, B#6-4, B#6-7, B#6-10 and
B#6-13 on the Nepisiguit River.



for stations upstream of Austin Brook. Furthermore, the seasonal fluctuations noted at station B#6-7 were generally observed at the two downstream stations.

At station B#6-4, where Knight Brook enters the Nepisiguit, the most significant influx of zinc occurred (Figure 4b) with a mean of $42,375 \text{ ppb} \pm 6838$ (Appendix I) and a maximum of 99,000 ppb in October. The seasonal pattern observed at station B#6-4 was carried through to the mouth of Bathurst Harbour (Station B#6-17), a distance of approximately 18 miles. This demonstrates the influence of the mine effluent and contaminated drainage waters generated and released into Knight Brook. There was a general decrease in the heavy metal concentrations with downstream distance (Appendix I); but the heavy metal concentrations were well above the levels recorded upstream from the Brunswick No. 6 mine. Furthermore, the concentration of zinc declined to $127 \text{ ppb} \pm 24$ at station B#6-15 (Appendix I), whereafter, zinc content increased steadily to the mouth of Bathurst Harbour ($291 \text{ ppb} \pm 61$). This increase of heavy metal content which was observed with both zinc and copper in the estuary might be attributed to the influence of salt water intrusion and mixing.

Bioassay toxicity evaluations were conducted on water collected at 8 stations during 1969 and 1970 from station B#6-8 to the mouth of the Nepisiguit River. Table IV summarizes the means and standard errors calculated for toxic units and percentage survival after 96 hours, at all stations tested. These data are presented graphically in Figure 5.

Table IV Means and Standard errors for Toxic Units and % Survival of Juvenile Atlantic Salmon after exposure for 96 hours.

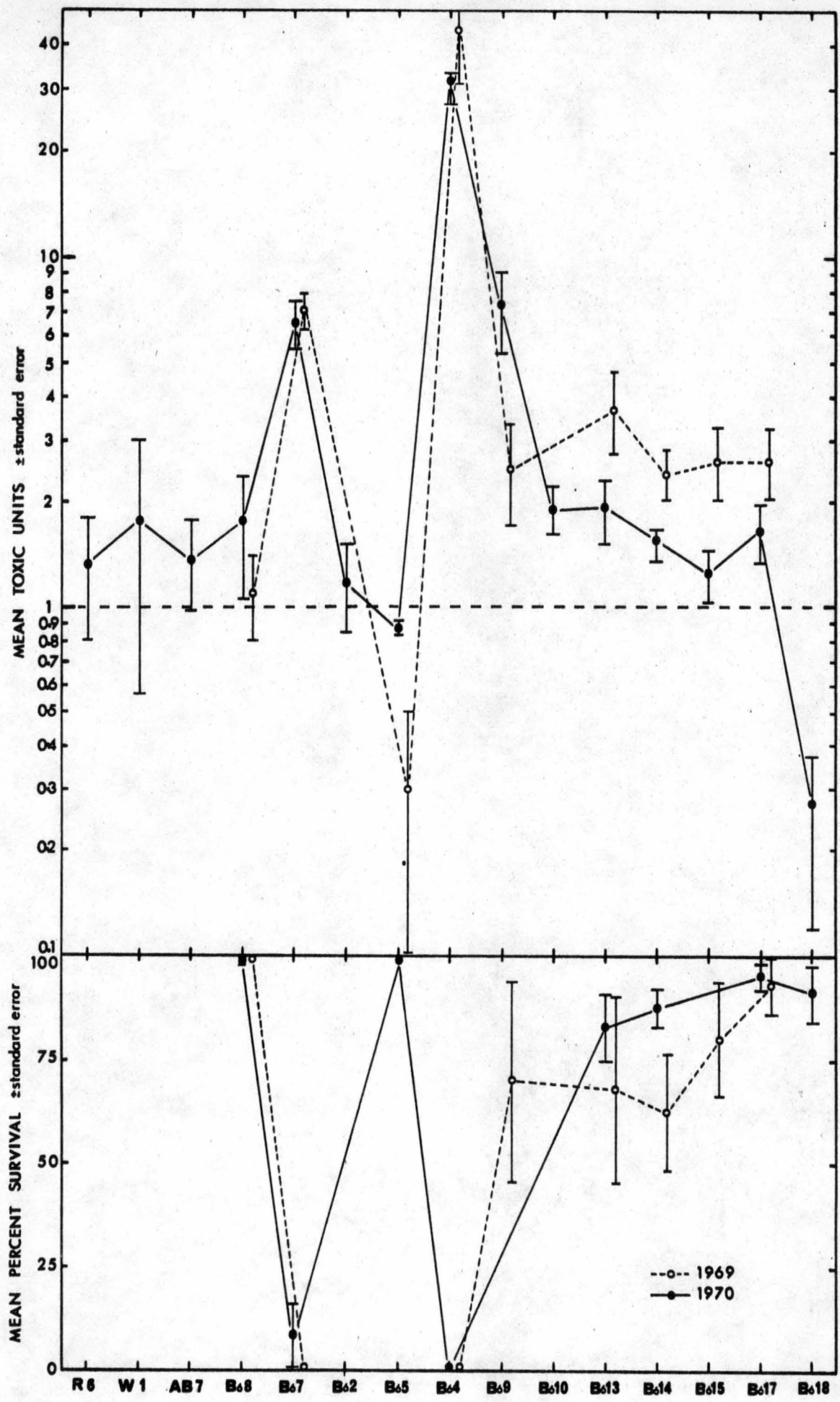
1969 Station	No. of tests or samples	Toxic Units	% Survival after 96 hours
B# 6-8	4	1.1 + 0.3	100
B# 6-7	1	7.1 ± 0.8	0
B# 6-5	4	0.3 ± 0.2	-
B# 6-4	1	44.7 ± 13.1	0
B# 6-9	3	2.5 ± 0.8	70 + 23.8
B# 6-13	1	3.7 ± 1.0	68.2 ± 20.8
B# 6-14	3	2.4 ± 0.4	62.5 ± 14.3
B# 6-15	3	2.6 ± 0.6	80 ± 13.3
B# 6-17	3	2.6 ± 0.6	93 ± 6.8
1970			
R-6	6	1.33 + 0.5	
W-1	2	1.75 ± 1.2	
AB-7	7	1.36 ± 0.4	
B# 6-8	12	1.75 ± 0.7	97.5 + 1.8
B# 6-7	12	6.47 ± 1.1	9.2 ± 8.3
B# 6-2	13	1.18 ± 0.3	
B# 6-5	13	0.87 ± 0.2	100
B# 6-4	12	32.35 ± 5.3	0
B# 6-9	12	7.24 ± 1.9	
B# 6-10	12	1.89 ± 0.3	
B# 6-13	13	1.92 ± 0.4	83.0 + 7.5
B# 6-14	13	1.54 ± 0.2	87.7 ± 4.7
B# 6-15	13	1.26 ± 0.2	
B# 6-17	13	1.65 ± 0.3	95.0 + 2.8
B# 6-18	9	0.1 ± 0.1	92.2 ± 5.7

The results support the observations of Thomas and Traversy, 1965 and Boyle et al, 1966, that "natural background levels" of heavy metals in the waters of north-eastern New Brunswick were relatively high. The mean toxic unit concentration of 1.33 ± 0.5 for station R-6, which is, as yet, unaffected by mining activity was above the calculated lethal threshold level for salmon. Similar results were recorded for other relatively undisturbed areas such as stations W-1, AB-7, and B# 6-8.

The influence of surface drainage from the Brunswick No. 6 open pit mine on the water quality of the Nepisiguit River is clearly evident in Figure 5. Toxic unit concentrations rose to mean 1969 and 1970 values of 6.47 ± 1.1 and 32.35 ± 5.3 , and 7.1 ± 0.8 and 44.7 ± 13.1 , for stations B# 6-7 (Austin) and B# 6-4 (Knight), respectively. These high values resulted in almost complete mortality in all bioassays conducted during the two years of testing at these stations. Of the 12 sampling periods tested for station B# 6-7, 100% survival occurred once (Appendix I), and the mean TD50 for the remaining tests was 11.75 hrs. The lethal effects of effluent released through Austin Brook (B# 6-7) were short-lived, the toxicity having been reduced to "natural background levels" by the time water reached station B# 6-2 (1 mile downstream). Knight Brook effluent (B# 6-4) was considerably more detrimental to the environment. Complete mortality occurred in the 11 tests conducted during 1970, with an average TD50 of only 6.27 hours. In 1969, the mean toxic unit concentrations remained above the "background level" from Knight Brook down to Bathurst Harbour (Station 17, Figure 5). High mortality occurred at all stations except at Bathurst Harbour, where the mean survival value for salmon was $93\% \pm 6.8$. Conditions improved in 1970 in that the toxic unit concentrations had been reduced to "background levels" by the time water reached station B# 6-10 (3 miles downstream from B# 6-4) and mortality rates were reduced at all stations below Knight Brook, as compared to the 1969 values. A slight depression in survival rate occurred at station B# 6-18 which is believed to be attributable to the nearby Consolidated Bathurst Pulp and Paper Mill. The mean toxic unit concentration (0.1) was the lowest recorded for all stations during the two years tested.

Recently, several workers (Grande, 1966; Sprague, 1968) have indicated that dissolved organic substances, e.g. humic acids, function as chelating agents to bind heavy metals, thus decreasing their toxicity to fish. Keeping in mind that 1.0 toxic unit is the calculated threshold or incipient lethal level of any toxicant to fish, an attempt was made to determine indirectly, the buffering

Figure 5. The mean toxic unit concentrations and mean percent survival values for juvenile Atlantic salmon at 15 stations along the Nepisiguit River in 1969 and 1970.



effect of the naturally occurring organic compounds in the Nepisiguit River, on the toxicity of the base metal ions to fish.

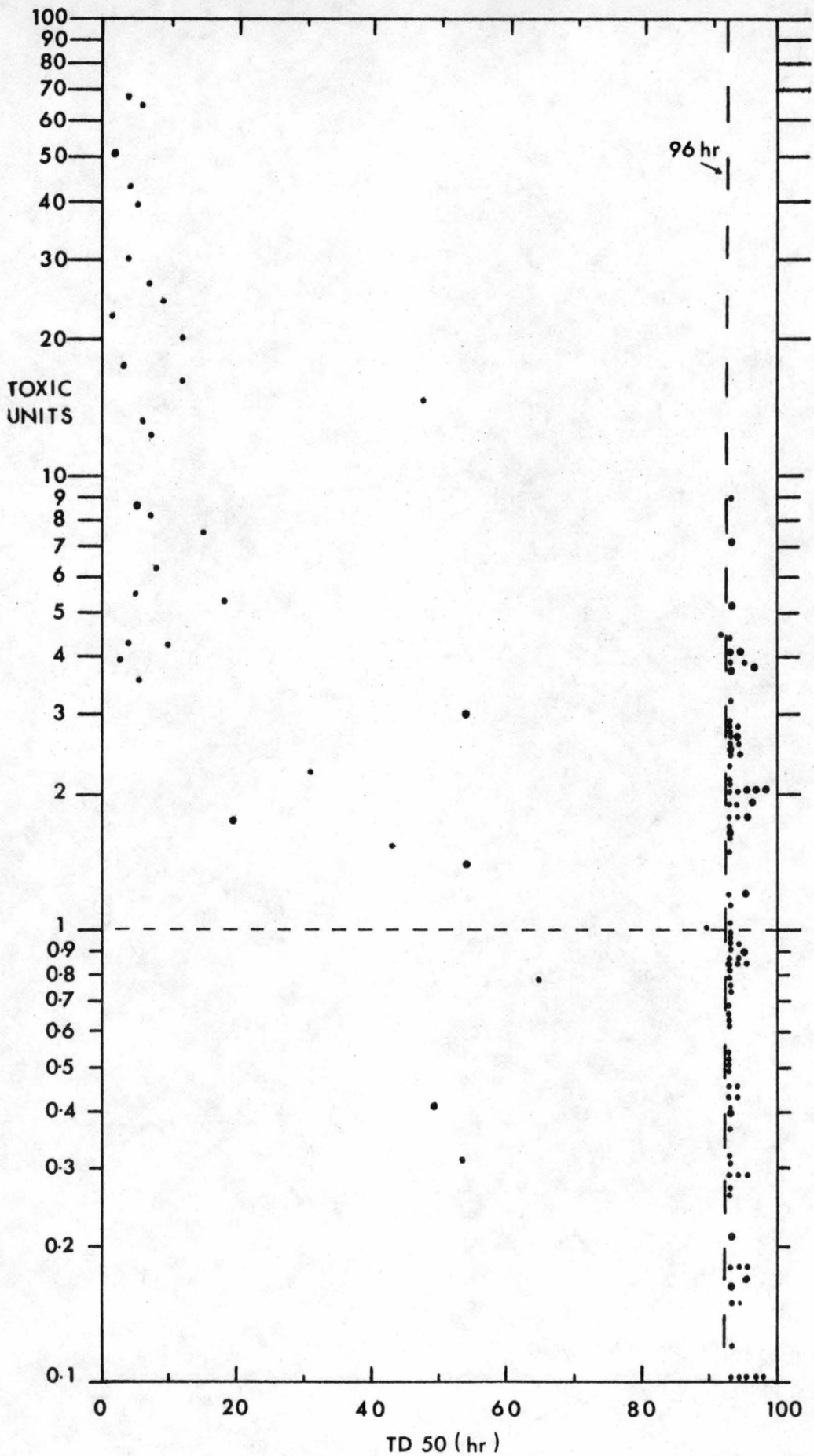
Figure 6 presents the TD50 versus toxic unit concentration data (from Appendix I) for all the bioassay tests conducted during the two years of monitoring. Of the 55 experiments conducted at concentrations of 1 toxic unit or less, only 3 tests (5.4%) produced TD50 survival times of less than 96 hours. Significant numbers of tests with TD50's of less than 96 hours did not begin to occur until a concentration of greater than 5 toxic units was attained but evidence of "overkill" (extreme toxicities producing short survival times) began to occur at 3.5 toxic units. These observations suggest that something, most likely organic matter, such as humic acids (Zitko, 1970), is decreasing the toxicity of otherwise deadly concentrations of heavy metal ions. This possibility must be verified in the near future.

DISCUSSION

The results of the present study dramatically illustrate the detrimental effects to the aquatic environment that can result when mine site drainage is not adequately contained or treated. In the present study, the poor containment of surface drainage has seriously degraded the water quality, and therefore the entire ecosystem, of the lower Nepisiguit River. The results of the water sampling program which was started in 1965 show that the dissolved heavy metal ion concentrations have been increasing steadily to acute, or near lethal levels, at several water sampling stations. Coupled with these findings has been a serious decline of the Nepisiguit River's Atlantic salmon resource, almost to the point of extinction. These results can be largely attributed to the open pit mining activities of Brunswick Mining and Smelting Corporation Ltd.

In reporting the data, it has become apparent that several sources of error exist in estimating the toxicity of heavy metal ion concentrations to juvenile salmon. Although these errors will not significantly alter the overall conclusions, they must be considered for the development of future heavy metal and trace metal study programs. The "toxic unit" concept used in this and many other papers (Southgate, 1932; Bergstrom and Vallin, 1937; Bucksteeg, 1961; Herbert and Van Dyke, 1964; Sprague, 1965) as a pollution index, facilitates interpretation of results, but assumes that all the major factors influencing fish survival are accounted for

Figure 6. The toxic unit versus TD50 results recorded for 130 bioassays conducted on Nepisiguit River water in 1969 and 1970.



• 1969
• 1970

in the toxic unit calculation. More information is required on several environmental factors which contribute to heavy metal toxicity, before a meaningful evaluation of water quality-toxicity data can be made, and used, in the establishment of mine water quality standards. Over-looking biological or chemical information in the derivation of "toxic units" would give rise to an over-estimation of the toxicity of a mine water sample. This has, in fact, happened in the present study. The observed incipient lethal level occurred at a concentration of between 4 and 5 toxic units, well above the predicted value of 1 toxic unit.

Perhaps the most significant contributor to this over-estimation is the chelating and therefore "detoxifying" effect of dissolved organic substances, such as humic acids. Zitko (1970) reported that the concentration of humic substances in the Northwest Miramichi was 10-15 mg/l, and would bind up to 1.5 mg/l of copper or zinc. Transformed into toxic units and expressed at a hardness of 20 mg/l, this could theoretically overestimate the toxicity by between 2.5 and 30 toxic units--a most serious error! Humic compounds have not been analyzed for the Nepisiguit River, but are believed to occur at similar concentrations to those of the Miramichi system. As zinc is the major contributor to heavy metal toxicity of the Nepisiguit, the number of toxic units bound up by humic substances would probably be near the bottom of the theoretical range (between 2.5 and 5.0).

Another, but less significant error, which would tend to overestimate the heavy metal toxicity, is the bioassay procedure used in the present study. All the water samples for heavy metal analysis were collected prior to bioassay testing. Tests for water quality were not repeated during, or after, the test period. Therefore, no estimates of heavy metal ion (the toxic component) loss could be made. Sprague (1964a) found that measured zinc concentrations agreed with the theoretical or "intended" concentrations, but measured concentrations of copper were about 80% of the theoretical strengths. He attributed this discrepancy to: adsorption (plating out) of relatively significant amounts of metal ion on to the walls of the apparatus, metal ion uptake by fish, and the chelation of metal ions with soluble organic matter and colloids in the water. In the present study, static tests were used, and the test solutions were never replaced during the 96 hr. test period, creating an environment conducive to the reactions previously discussed. Sprague, in his work, used a continuous flow bioassay procedure which replaced the test solution continually. Unfortunately, the large volumes of test water required would not be suitable for the measurement of toxicity in natural waters, on a monitoring basis.

Approximately 27 liters of Nepisiguit water would have been required every 1 $\frac{1}{2}$ hrs. Thus, static bioassay tests remain most feasible for our purposes; however, in order to eliminate as many sources of error as possible, the bioassay test water should be analyzed upon the completion of each toxicity determination.

Acclimation is reported to be a significant factor affecting the survival responses of test fish to lethal or near lethal heavy metal concentrations. Lloyd (1960) demonstrated that rainbow trout exposed to concentrations of heavy metals below the threshold value, acquired an increased resistance to higher, lethal concentrations. Grande (1968) noted that the lethal levels of heavy metals, and the thresholds for avoidance reactions found by Sprague (1964 a & b, 1968a), were considerably lower than the actual concentrations of copper and zinc found by analyses in soft Norwegian lakes and rivers, which support good populations of Atlantic salmon and trout. Test fish used in the present study were reared in hatchery brook water containing 20 ppb copper and 30 ppb zinc and having a hardness of 23 mg/l. This represents 0.40 toxic units, far below the mean toxic unit values recorded at all but two stations on the Nepisiguit (stations B#6-5: 0.3 ± 0.2 ; B#6-18: 0.1 ± 0.1). Therefore, it is probable that Miramichi Hatchery fish would be considerably more susceptible to the higher heavy metal concentrations of the Nepisiguit River than would be the native Nepisiguit stock.

Most of the research discussed up to this point has been concerned with the acute toxicity of heavy metals to fish. However, in the long run, the sublethal effects of heavy metal toxicity, although not as direct and obvious in their action as acute levels, are probably far more significant to the survival of fish populations. In order to predict the future of the fishery resource in a particular river, it is essential to understand the interplay of the longer term sublethal effects, on aquatic organisms. These effects, although more subtle in their damage, may result in total destruction of the fishery resource just as effectively as will acute levels. For example, salmon eggs, exposed to sublethal concentrations of zinc, resulted in fewer eggs developing, and delayed hatching for most (Grande, 1968). This delay was attributed to the effect of zinc on the hatching process, rather than its effect on the embryo, but the end result would be more stress on the young fish, due to the various delays which occurred along the way. Grande also observed that sublethal concentrations inhibited hunger reactions in salmon fingerlings.

Avoidance of unfavourable areas by fish, is one of

the most important sublethal responses. This can lead to a chain reaction of undesirable events, especially when an anadromous species is involved. Sprague (1964b, 1968a), in his laboratory avoidance studies, found that Atlantic salmon parr avoided thresholds of 0.10 toxic units in experiments with copper, 0.14 toxic unit in tests with zinc, or 0.07 toxic unit of copper-zinc mixtures, in preference for laboratory water containing 0.05 toxic units. Rainbow trout demonstrated even stronger avoidance responses to sublethal concentrations. Their avoidance level for zinc was 0.01 toxic unit, and no significant differences were found in threshold avoidance levels between 9.5°C and 17°C. Sprague attributed the difference between species to behavioral differences ("young salmon tend to sit in one place in our test-trough, while rainbow trout swim more freely and thus become aware of any available choice between waters").

The Fisheries Research Board staff then directed their study towards in situ determinations of salmon avoidance levels. The North-west Miramichi River, in north-eastern New Brunswick, was the site for their experiments. In their work (Saunders and Sprague, 1967; Sprague, Elson and Saunders, 1965), they found that avoidance thresholds were higher in nature than previously determined in lab experiments. They observed that adult salmon avoided levels of between 0.35 and 0.43 toxic unit of copper and zinc, and determined that a level of 0.8 toxic unit may have blocked all upstream movement. However, the detoxifying effect of humic substances was not taken into account in calculating the toxic unit level. Had these detoxifying effects been considered, it is probable that the actual toxic unit avoidance level would have been lower and would have approached the laboratory avoidance level. Avoidance responses to heavy metals were observed to delay the early runs of Atlantic salmon and to reduce the number of fish passing through the fish-counting station on the N.W. Miramichi as compared to the pre-pollution records. Hence avoidance factors would result in fewer young salmon being produced and at a later-than-normal time. From the FRB avoidance work it is interesting to note that there was a 3.5 to 4.5 fold overestimation of the theoretical avoidance levels as determined in a laboratory when compared to the avoidance thresholds noted in field studies. These results correspond very closely to the 3.5 to 5 fold overestimation observed between the theoretical "toxic unit" and the actual fish survival information as reported in the present study. The findings certainly emphasize the importance of determining factors not yet incorporated in the "toxic unit" computation; such as temperature, pH, dissolved organic matter, suspended organic matter, humic acid derivatives, etc.

This report, by the Resource Development Pollution Section, is a first attempt at determining factors influencing heavy metal toxicity and the effects of base metal mining on the survival of an aquatic organism.

The results presented have produced a few discrepancies and have opened up several avenues for future research. With these in mind, the Northeastern New Brunswick Mine Water Quality Program was established in 1970, to resolve some of the problems associated with mining pollution. Research will be directed towards increasing the accuracy of the "toxic unit" calculation by the improvement and standardization of analytical methods for heavy and trace metals in water, and by studying the effects of organic chelating substances on heavy metal toxicity. Further studies will attempt to determine the sublethal effects associated with conditions of high water hardness, and the potential toxicity of process reagents to fish. It is hoped that the results emanating from these research projects will assist in establishing meaningful mine water quality standards for the Northeastern New Brunswick area.

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LITERATURE CITED

- Bergström, H., and S. Vallin. 1937. Vattenförorening genom avloppsvattnet från sulfatcellulosafabriker. Kungl. Lantbruksstyrelsen. Medd. Statens undersöknings - och försöksanstalt för sötvattensfisket (Stockholm), No. 13, 19 pp.
- Boyle, R. W., et al. 1966. Geochemistry of Pb, Zn, Cu, As, Sb, Mo, Sn, W, Ag, Ni, Co, Cr, Ba, and Mn in the waters and stream sediments of the Bathurst-Jacquet River District, New Brunswick. Department of Mines and Technical Surveys. Paper 65-42, 50 pp.
- Bucksteeg, W. 1961. Tests zur beurteilung von abwässern. Stadtehygiene 12; 180-184.
- Fry, F. E. J. 1947. Effects of the environment on animal activity. Univ. Toronto Stud., Biol-Ser., No. 55; Pub. Ontario Fish. Res. Lab., No. 68, 62 pp.
- Grande, M. 1966. Effect of copper and zinc on salmonid fishes. Advan. Water Pollut. Res., Proc. Int. Cont., 3rd, 1: 97-108.
- Herbert, D.W.M., and Jennifer M. Van Dyke. 1964. The toxicity to fish of mixtures of poisons - II. Copper-Ammonia and zinc-phenol mixtures. Ann. appl. Biol. 53: 415-421.
- Lloyd, R. 1960. The toxicity of zinc sulphate to rainbow trout. Ann. appl. Biol., 48 (1): 84-94.

- 1961 a. Effect of dissolved oxygen concentrations on the toxicity of several poisons to rainbow trout (Salmo gairdnerii Richardson). J. Exp. Biol., 38: 447-455.
- 1961 b. The toxicity of mixtures of zinc and copper sulphates to rainbow trout (Salmo gairdnerii Richardson). J. Exp. Biol., 38: 447-455.
- Lloyd, R., and D.W.M. Herbert. 1962. The effect of the environment on the toxicity of poisons to fish. J. Inst. Public Health Eng., July, 132-145.
- Saunders, R.L., and J.B. Sprague. 1967. Effects of copper-zinc mining pollution on a spawning migration of Atlantic salmon. Water Research, Pergammon Press, 1: 419-432.
- Schmidt, J.W., and K. Conn. 1969. A case study of acid production within the tailings disposal system and effluent receiving stream. Presented at the First Annual Meeting of the Canadian Mineral Processors, January 1969.
- Southgate, B.A. 1932. The toxicity of mixtures of poisons. Q.J. Pharm. Pharmac. 5: 639-648.
- Sprague, J.B. 1964a. Lethal concentrations of copper and zinc for young Atlantic salmon. J. Fish. Res. Bd. Canada, 21 (1): 17-26.
- Sprague, J.B. 1964b. Avoidance of copper zinc solutions by young salmon in the laboratory. J. Wat. Pollut. Control Fed., Aug., 990-1004.
- 1968a. Avoidance reactions of rainbow trout to zinc sulphate solutions. Water Research, Pergammon Press, 2: 367-372.
- Sprague, J.B. 1968b. Promising anti-pollutant: chelating agent NTA protects fish from copper and zinc. Nature, vol. 220, 1345-1346.
- Sprague, J. B., P.F. Elson and R.L. Saunders. 1965. Sublethal copper-zinc pollution in a salmon river - a field and laboratory study. Int. J. Air Wat. Poll., 9: 531-543.
- Sprague, J.B., and B. Ann Ramsay. 1965. Lethal levels of mixed copper-zinc solutions for juvenile salmon. J. Fish. Res. Bd. Canada, 22 (2): 425-432.

Thomas, J.F.J., and W.J. Traversy. 1965. Copper and zinc contents of waste waters and receiving stream waters at Brunswick Mine, New Brunswick. Department of Mines and Technical Surveys, Mines Branch Investigation Report IR 65-17, 10 pp.

Zitko, V. 1970. Mining pollution. Presented at Fisheries Research Board meeting, Halifax, August 1970.

Appendix I. Summary of 1970 Nepisiguit River sampling data.

Station 1D Austin Brook above Sump Pump Overflow.

Date	Cu(ppb)	Zn(ppb)	Pb(ppb)	T.U.	Hardness (mg/l)
22/4/70	170	390	140	3.81	20.7
5/5/70	50	160	50	1.58	14.7
21/5/70	70	230	10	2.40	14.1
19/6/70	80	350	40	1.52	31.0
1/7/70	100	230	13	2.45	18.7
15/7/70	80	360	100	1.59	29.0
7/8/70	30	170	5	0.51	39.9
10/9/70	14	40	0	0.40	16.6
24/9/70	20	120	0	0.51	23.2
7/10/70	20	100	5	0.65	16.4
18/11/70	70	800	5	2.40	23.5
N	11	11	11	11	11
\bar{x}	64.00	268.18	33.45	1.62	22.53
S	45.65	209.61	46.62	1.08	8.00
S.E. of Mean	± 13.75	± 63.14	± 14.04	± 0.33	± 2.41

Station 8 Nepisiguit, Above Austin Brook

Date	Cu(ppb)	Zn(ppb)	Pb(ppb)	T.U.	Hardness (mg/l)	TD50	% Surv.
22/4/70	120	40	0	9.05	3.0	96	80
5/5/70	20	30	50	0.68	11.6	96	100
21/5/70	40	18	0	1.30	11.6	96	100
19/6/70	70	0	8	1.79	15.2	96	100
1/7/70	120	100	5	2.71	18.4	96	100
15/7/70	60	60	6	1.28	20.1	96	100
7/8/70	20	90	5	0.46	23.7	96	90
10/9/70	17	90	0	0.46	20.3	96	100
24/9/70	50	180	0	1.24	20.3	96	100
20/10/70	40	80	5	0.97	18.5	96	100
10/11/70	40	50	0	0.95	18.0	96	100
18/11/70	14	50	5	0.12	78.1	96	100
N	12	12	12	12	12		12
\bar{x}	50.92	65.67	7.00	1.75	21.57		97.50
S	36.65	47.37	13.86	2.40	18.64		6.22
S.E. of Mean	± 10.59	± 13.69	± 4.01	± 0.69	± 5.39		± 1.80

Station 7 Nepisiguit, Mouth of Austin Brook

Date	Cu(ppb)	Zn(ppb)	Pb(ppb)	T.U.	Hardness	TD50	% Surv.
22/4/70	180	7,500	12	8.00	47.3	6.40	0
5/5/70	50	2,200	5	3.57	25.6	5.50	0
21/5/70	60	3,200	20	3.91	39.0	2.77	0
19/6/70	100	910	20	2.45	30.5	96	100
1/7/70	200	6,600	60	4.26	118.0	4.05	0
15/7/70	80	7,200	60	4.26	106.8	10.50	0
7/8/70	70	5,300	110	7.59	26.4	14.40	0
10/9/70	80	7,000	30	5.23	71.0	4.85	0
24/9/70	80	8,400	30	6.16	71.8	8.00	0
20/10/70	120	5,600	20	5.32	58.4	17.70	0
10/11/70	100	23,500	100	12.13	153.8	7.28	0
18/11/70	70	4,700	30	14.81	8.73	47.80	10
N	12	12	12	12	12		12
x	99	6,843	41	6.47	63.1		9.17
S	47	5,713	34	3.68	43.6	11.75	28.75
S.E. of Mean	± 13.58	$\pm 1,651$	± 9.8	± 1.1	± 12.6		8.3

Station 2 Nepisiguit, Midway Between Austin Mouth and Dam

Date	Cu(ppb)	Zn(ppb)	Pb(ppb)	T.U.	Hardness (mg/l)
22/4/70	130	490	14	4.15	15.0
5/5/70	20	110	0	0.84	11.7
21/5/70	20	130	0	0.85	12.1
19/6/70	60	50	8	1.61	15.2
1/7/70	70	60	5	1.81	15.9
15/7/70	17	50	6	0.41	20.1
7/8/70	11	90	5	0.32	22.4
10/9/70	9	40	0	0.26	19.1
24/9/70	20	160	0	0.64	19.5
7/10/70	30	110	5	0.12	13.9
20/10/70	20	180	15	0.71	18.1
10/11/70	40	200	16	1.05	20.9
18/11/70	70	70	10	2.61	10.6
N	13	13	13	13	13
x	40	134	6	1.18	16.5
S	35	119	5	1.14	3.8
S.E. of Mean	± 9.7	± 33.1	± 1.4	± 0.3	± 1.1

Station 5 Nepisiguit, above Knight Brook

Date	Cu(ppb)	Zn(ppb)	Pb(ppb)	T.U.	Hardness (mg/l)	TD50 (hr.)	% Surv.
22/4/70	100	60	5	2.66	14.9	96	100
5/5/70	20	50	0	0.79	10.7	96	100
21/5/70	40	30	0	1.49	10.4	96	100
19/6/70	70	30	8	1.53	18.5	96	100
1/7/70	120	0	5	2.81	16.4	96	100
15/7/70	14	30	6	0.32	20.3	96	100
7/8/70	13	17	0	0.26	22.0	96	100
10/9/70	17	40	0	0.41	19.1	96	100
24/9/70	20	170	0	0.65	19.5	96	100
7/10/70	30	90	12	0.81	17.8	96	100
20/10/70	0	90	5	0.15	17.1	96	100
10/11/70	20	200	0	0.69	19.9	96	100
18/11/70	50	70	5	0.54	18.3	96	100
N	13	13	13	13	13		
\bar{x}	39	68	3.5	.87	17.3		100
S	38	59	3.9	.75	3.5		0
S. E. of Mean	± 10.5	± 16.3	± 1.1	± 0.2	± 1.0		

Station 4 Nepisiguit, Mouth of Knight Brook

Date	Cu(ppb)	Zn(ppb)	Pb(ppb)	T.U.	Hardness (Mg/l)	TD50 (hr.)	% Surv.
22/4/70	1,400	35,000	12	26.81	100.0	7.25	0
5/5/70	820	20,500	50	16.36	96.3	12.20	0
21/5/70	2,000	51,000	50	30.12	148.3	4.30	0
19/6/70	1,000	39,000	50	24.16	116.0	8.70	0
1/7/70	250	20,000	20	13.16	94.5	6.00	0
15/7/70	830	40,000	50	22.76	129.0	1.50	0
10/9/70	670	28,000	20	17.13	118.0	3.38	0
24/9/70	490	22,000	20	39.36	21.1	5.10	0
7/10/70	6,000	99,000	80	68.11	143.0	3.84	0
20/10/70	2,500	44,000	30	43.12	81.6	4.25	0
10/11/70	6,800	76,000	100	65.76	133.9	6.84	0
18/11/70	2,200	34,000	50	20.95	59.9	11.94	0
N	12	12	12	12	12		
\bar{x}	2,080	42,375	44	32.35	103.6		0
S	2,142	23,658	26	18.42	36.7		
S.E. of Mean	± 619.1	$\pm 6,838$	± 7.5	± 5.3	± 10.6		

Station 9 Nepisiguit, Below Knight Brook

Date	Cu (ppb)	Zn (ppb)	Pb (ppb)	T.U.	Hardness (mg/l)
22/4/70	200	5,700	5	10.85	24.1
5/5/70	40	430	0	1.94	13.0
21/5/70	90	1,500	0	4.86	14.9
19/6/70	100	1,700	10	4.17	21.8
1/7/70	120	1,300	5	4.11	22.8
15/7/70	50	1,500	10	2.69	25.5
7/8/70	100	3,000	5	3.51	46.1
10/9/70	130	21,000	17	4.56	27.0
24/9/70	50	2,400	5	3.50	30.7
7/10/70	430	7,000	12	27.36	26.5
20/10/70	20	3,700	5	8.48	23.1
10/11/70	350	5,300	6	11.54	27.9
18/11/70	170	2,100	10	6.86	21.2
N	12	12	12	13	12
x	140	4,544	7	7.24	25.3
S	127	5,564	5	6.88	8.3
S.E. of Mean	± 36.7	± 1,608	± 1.4	± 1.91	± 2.4

Station 10 Nepisiguit, 3 miles below Knight Brook

Date	Cu (ppb)	Zn (ppb)	Pb (ppb)	T.U.	Hardness (mg/l)
22/4/70	130	420	0	3.77	16.6
5/5/70	20	150	0	0.99	11.2
21/5/70	90	300	0	3.30	12.1
19/6/70	90	200	8	2.50	16.1
1/7/70	120	150	5	1.89	28.1
15/7/70	30	180	6	0.83	20.8
7/8/70	20	350	0	0.77	25.3
10/9/70	14	210	9	0.59	19.5
24/9/70	20	400	0	0.93	21.1
7/10/70	80	800	16	2.95	18.2
10/11/70	100	700	6	2.15	19.9
18/11/70	70	330	5	1.92	19.5
N	12	12	12	12	12
x	65	349	5	1.89	19.03
S	43	210	5	1.08	4.81
S.E. of Mean	± 12.4	± 60.7	± 1.4	± 0.3	± 1.4

Station 13 Nepisiguit, Near bridge at NLU Mine

Date	Cu(ppb)	Zn(ppb)	Pb(ppb)	T.U.	Hardness (mg/l)	TD50 (hr)	% Surv.
22/4/70	150	420	5	4.67	14.5	94.0	60
5/5/70	20	110	5	0.80	12.3	96	100
21/5/70	20	250	0	1.08	12.1	96	90
19/6/70	7	180	5	0.32	27.1	54.0	60
1/7/70	100	120	7	2.62	16.1	96	100
15/7/70	8	200	6	0.43	21.2	96	100
7/8/70	100	350	5	2.27	22.8	30.70	10
10/9/70	30	210	10	0.92	19.5	96	100
24/9/70	20	340	0	0.86	20.7	96	70
7/10/70	50	640	20	2.08	17.8	96	90
20/10/70	50	360	9	1.80	16.2	96	100
10/11/70	120	590	10	3.24	19.9	96	100
18/11/70	150	310	10	3.81	17.8		
N	13	13	13	13	13		13
\bar{x}	63	314	8	1.92	18.3		83
S	53	211	4	1.37	4.3		27
S. E. of Mean	± 14.7	± 58.4	± 1.1	± 0.4	± 1.2		± 7.5

Station 14 Nepisiguit, Near Papineau Falls

Date	Cu(ppb)	Zn(ppb)	Pb(ppb)	T.U.	Hardness (mg/l)	TD50 (Hr.)	% Surv.
22/4/70	80	410	0	2.81	14.5	96	60
5/5/70	20	100	0	0.92	10.4	96	100
21/5/70	50	190	0	1.94	11.7	96	90
19/6/70	50	180	0	1.55	15.5	42.9	70
1/7/70	100	120	0	2.62	16.1	96	90
15/7/70	8	200	6	0.43	21.0	96	100
7/8/70	20	330	0	0.78	23.7	64.0	50
10/9/70	20	210	0	0.76	17.8	96	100
24/9/70	20	370	10	0.94	18.5	96	90
7/10/70	50	550	12	2.06	16.6	96	100
20/10/70	60	220	0	1.81	15.0	96	100
10/11/70	70	590	5	2.37	18.9	96	90
18/11/70	20	310	5	0.92	17.8	96	100
N	13	13	13	13	13		13
\bar{x}	44	291	1.54	1.54	16.8		87.7
S	28	155	.79	.79	3.6		16.9
S.E. of Mean	± 7.8	± 42.9	± 0.8	± 0.2	± 1.0		± 4.7

Station 15. Nepisiguit, Below Papineau River, at Reserve

Date	Cu (ppb)	Zn (ppb)	Pb (ppb)	T.U.	Hardness (mg/l)
22/4/70	70	70	11	2.74	10.0
5/5/70	50	60	0	1.98	9.7
21/5/70	20	130	0	0.99	10.4
19/6/70	0	100	5	0.17	15.2
1/7/70	80	70	5	2.24	14.5
15/7/70	14	140	6	0.46	21.0
7/8/70	20	100	0	0.57	18.7
10/8/70	12	80	7	0.45	14.6
24/9/70	70	150	13	1.79	17.4
7/10/70	30	180	8	1.18	13.3
20/10/70	40	40	9	1.20	12.6
10/11/70	50	380	5	1.80	16.6
18/11/70	20	150	5	0.75	15.4
<u>N</u>	13	13	13	13	13
<u>x</u>	37	127	6	1.26	14.6
<u>S</u>	26	87	4	.79	3.4
S.E. of Mean	± 7.2	± 24.1	± 1.1	± .2	± .9

Station 17. Nepisiguit, above Bathurst, at Water Pump Station

Date	Cu (ppb)	Zn (ppb)	Pb (ppb)	T.U.	Hardness (mg/l)	TD50 (hr.)	% Surv.
22/4/70	80	350	10	2.89	13.3	96	80
5/5/70	20	100	0	0.94	10.2	96	100
21/5/70	20	180	0	1.00	11.7	89.50	70
19/6/70	20	160	8	0.57	22.7	96	90
1/7/70	80	120	13	2.16	15.9	96	100
15/7/70	13	180	10	0.50	21.2	96	100
7/8/70	20	280	5	0.74	22.4	96	100
10/9/70	20	180	9			96	100
24/9/70	20	370	10	0.91	20.7	96	90
7/10/70	50	550	5	2.05	16.6	96	100
20/10/70	50	250	5	1.71	15.0	96	100
10/11/70	70	570	5	2.48	17.0	96	100
18/11/70	150	310	10	3.81	17.3	96	100
<u>N</u>	13	13	13	12	12		13
<u>x</u>	47	277	8	1.65	17.0		95
<u>S</u>	40	151	3	1.05	4.12		10
S. E. of Mean	± 11.1	± 41.7	± 0.8	± 0.3	± 1.19		± 2.8

Station 16 Nepisiguit, Bathurst, at Irving Pier

Date	Cu(ppb)	Zn(ppb)	Pb(ppb)	T.U.	Hardness (mg/l)	TD50 (hr.)	% Surv.
22/4/70	100	300	0	0.11	1080	96	100
5/5/70	50	120	0	0.48	64.0	96	90
21/5/70	50	150	0	0.18	241	96	100
19/6/70	40	80	8		1590	96	100
1/7/70	160	150	13	0.29	428	96	50
15/7/70	10	200	6	0.10	222	*26.1	30
7/8/70	50	140	0	0.09	591	96	100
10/9/70	30	200	0	0.10	396	96	100
24/9/70	20	390	12	0.08	657	96	100
7/10/70	60	560	16	0.61	104	96	100
20/10/70	40	300	9	0.31	131	96	100
10/11/70	70	460	19	0.29	293	96	100
18/11/70	100	280	10	0.18	587	96	100
N	13	13	13	12	13		13
x	60	256	9	0.24	491.1		90
S	40	144	5	0.17	433		23
S.E. of Mean	± 11.1	± 39.9	± 1.4	± .05	± 119.9		± 6.4

Station 18 Bathurst, opposite Irving Pier (below pulp mill)

Date	Cu(ppb)	Zn(ppb)	Pb(ppb)	T.U.	Hardness (mg/l)	TD50 (hr.)	% Surv.
19/6/70	0	100	10		1238	96	100
1/7/70	120	150	10	0.37	231	96	80
15/7/70	40	220	13		1394	942	50
7/8/70	50	170	0	0.15	314	96	100
10/9/70	40	230	9	0.10	569	96	100
24/9/70	20	410	10	0.18	249	96	100
7/10/70	60	560	12	0.53	152	96	100
20/10/70	60					96	100
10/11/70	70	490	14	0.27	451.7	96	100
N	9	8	8	6	8		9
x	51	291	10	.27	574.8		92.2
S	34	172	3	.16	477.7		17.2
S.E. of Mean	± 11.3	± 61.4	± 1.1	± .1	± 170.6		± 5.7

* Probably caused by pulpmill pollution.

Station AB7

Date	Cu (ppb)	Zn (ppb)	Pb (ppb)	T.U.	Hardness (mg/l)
15/4/70	130	40	20	3.02	17.1
12/5/70	20	50	0	0.72	11.8
9/6/70	100	50	0	2.46	16.2
16/7/70	20	50	0	0.45	21.5
13/8/70	90	60	5	1.65	23.6
17/9/70	20	70	0	0.50	19.9
12/11/70	30	70	6	0.70	20.0
N	7	7	7	7	7
\bar{x}	59	56	7	1.36	18.6
S	47	11	6	1.04	3.9
S.E. of Mean	± 18.1	± 4.2	± 2.3	± 0.4	± 1.5

Station W1

Date	Cu (ppb)	Zn (ppb)	Pb (ppb)	T.U.	Hardness (mg/l)
21/5/70	80	80	0	2.92	10.8
15/6/70	20	16	0	0.57	13.9
N	2	2	2	2	2
\bar{x}	50	48	0	1.75	12.35
S	42	45		1.66	2.19
S.E. of Mean	± 30	± 32.14		± 1.19	± 1.56

Station R6

Date	Cu (ppb)	Zn (ppb)	Pb (ppb)	T.U.	Hardness (mg/l)
15/4/70	70	0	0	1.73	15.7
30/4/70	20	0	0	0.59	12.4
26/5/70	20	6	0	0.70	10.8
7/7/70	120	0	0	3.11	14.8
30/9/70	20	40	8	0.52	17.0
26/11/70	60	0	6		
N	6	6	6	5	5
\bar{x}	52	10	4	1.33	14.1
S	40	15	3	1.11	2.5
S.E. of Mean	± 16.67	± 6.25	± 1.25	± 0.5	± 1.14