EXPLOITS RIVER INVESTIGATION - 1969

HEAVY METALS IN THE EXPLOITS RIVER

By Pat Chamut #82

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CONTENTS

Page

LIST OF TABLES ii

LIST OF FIGURES iii

INTRODUCTION 1

MATERIALS and METHODS 3

RESULTS and DISCUSSION 7

- Copper 8
- Zinc 11
- Lead 18
- Hardness 20
- Dissolved Oxygen 20
- pH 21
- Alkalinity 22
- Temperature 23
- Turbidity 23
- Effectiveness of Tailings Impoundment 24
- Extent of Tailings Deposits in Red Indian Lake 34
- Effect of River Flows on Heavy Metal Levels in the Exploits River 37
- Results of *In situ* Bioassays 41

CONCLUSIONS 42

RECOMMENDATIONS 43

REFERENCES 44

APPENDIX 1 49

APPENDIX 2 58

List of Tables

Table		Page
I	Concentrations of zinc toxic to various species of fish	12
II	Concentrations of lead toxic to various species of fish	19
III	Average pH values on the Exploits River above and below Grand Falls for the years 1961-66, 1967 1968 and 1969	21
IV	Summary of concentrations of heavy metals in the Exploits River, 1965-1969	26
V	Summary of water conditions and heavy metal concentrations at Station 1 (Buchans culvert), 1966-1969	27
VI	Summary of water conditions and heavy metal concentrations at Station 2 (Buchans Brook), 1966-1969	28
VII	Mean, standard deviation and standard error of concentrations of zinc in the Exploits River, 1965-1969	29
VIII	Mean, standard deviation and standard error of concentrations of copper in the Exploits River, 1965-1969	29
IX	Mean, standard deviation and standard error of the combined toxicity of copper and zinc (in toxic units) in the Exploits River, 1965-1969	29
X	Total heavy metal concentrations in Red Indian Lake bottom sediments (Cowley, 1963)	34
XI	Contributions of Buchans Brook and other sources to heavy metal concentrations in the Exploits River	37

List of Figures

Figure		Page
1	Exploits River, central and lower watershed area	4
2	Variation of zinc concentrations in the Exploits River 1965-69	31
3	Variation of copper concentrations in the Exploits River 1965-69	32
4	Variation of toxic units (derived from Cu - Zn concentrations in the Exploits River) from 1965-69	33
5	Dredging operations - Red Indian Lake	35
6	Variation of toxic units (Zn & Cu) in relation to river flow at Bond Bridge, June 1966	38
7	Variation of toxic units (Zn & Cu) in relation to river flow at Bond Bridge, August 1966	39

EXPLOITS RIVER INVESTIGATIONS - 1969

Heavy Metals in the Exploits River

INTRODUCTION

Pollution surveys have been carried out on the Exploits River and Red Indian Lake since 1961. The Exploits, the largest river in Newfoundland, drains a watershed of 4300 square miles and has the estimated ability to support a potential Atlantic salmon population of between 25,000 - 50,000 fish. The present population is between 1,500-3,000. Considerations are now being given to increasing the salmon population by clearing obstructions on the river, developing spawning channels and stocking small tributaries with juvenile fish.

The success of the development of the full Atlantic salmon potential of the Exploits River basin will depend greatly upon water quality in the river. Water quality in the river is adversely affected from two major sources of pollution. The river below Grand Falls receives domestic wastes from the towns of Grand Falls, Bishop's Falls and Windsor and effluent from the Price Newfoundland Pulp and Paper Mill at Grand Falls. The primary effect of these wastes is to lower the dissolved oxygen levels in the river during periods of low flow. In addition, fibre loss from the mill smothers bottom invertebrates, and the sulphite waste liquor which is discharged can be toxic to fish if present in sufficiently high concentrations. The second source of pollution is located at Buchans, site of the American Smelting and Refining Company Limited (ASARCO). This company releases heavy metals (primarily copper and zinc) into Red Indian Lake which eventually enter the Exploits River. These metals are toxic to fish in very small concentrations and it is important to know as much as possible about their present and future levels in the river and their possible effects on Atlantic salmon.

Although other forms of pollution affect the river, this report is concerned with the problems created by the heavy metals in the Exploits.

The American Smelting and Refining Company Ltd. has been operating at Buchans since 1927. This base metal mine produces copper concentrate (approximately 8,000 tons annually), zinc concentrate (65,000 tons), and lead concentrate (40,000 tons). In addition, small amounts of silver and gold are produced. Each year, ASARCO disposes of approximately 240,000 tons of tailings. Prior to 1965, the company discharged the wastes from the milling operation directly into Red Indian Lake via Buchans Brook. The problems created by this method of disposal were two-fold. The dissolved copper, zinc, and lead in the effluent was carried from Red Indian Lake directly into the Exploits River, and the solid wastes, which also contained precipitated heavy metals, settled out over the bottom of the lake in the vicinity of Buchans Brook. These heavy metals in the sediments slowly leach out and are also carried into the Exploits River. In December 1965, ASARCO constructed a tailings pond to minimize the discharge of heavy metals and settleable solids into Red Indian Lake. Although this impoundment reduced the amount of solids entering Red Indian Lake, appreciable amounts of dissolved heavy metals are still discharged into the lake. Coupled with the leaching of Cu, Zn and Pb out of the bottom sediments, critical levels of these metals are still present in the Exploits River. This department has been involved since 1961 in monitoring concentrations of heavy metals in the river and attempts have been made to determine their effects on fish in the river.

MATERIALS and METHODS

(1) Location of Sampling Stations

During 1969, two stations were sampled regularly on Buchans Brook, and five stations were sampled on the Exploits River to monitor routine parameters of water chemistry and heavy metal concentrations (see Fig. 1). The locations of these stations are described below.

Station 1 was located approximately 900 yards from the entrance to the town of Buchans at "Buchans Culvert". This stream flows under the highway and carries drainage from the mine tailings pond into Buchans Brook (lat. 48° 49' 30" N., long. 56° 50' 30" W.).

Station 2 was located in Buchans Brook where the highway crosses the brook, approximately 1,400 yards upstream from Red Indian Lake (lat. 48° 48' 15" No., Long. 56° 46' 55" W.). Tailings are carried in Buchans Brook into Red Indian Lake.

A total of 17 samples were collected at Stations 1 and 2 from July to December, 1969.

Station 3 was located at the head of the Exploits River, at the dam near Millertown (lat. 48° 45' 45" N., long. 56° 35' 58" W.).

Station 4 was located approximately 16 miles above the town of Badger, at a small provincial picnic site on the river (lat. 48° 50' 45" N., long. 56° 16' 00" W.).

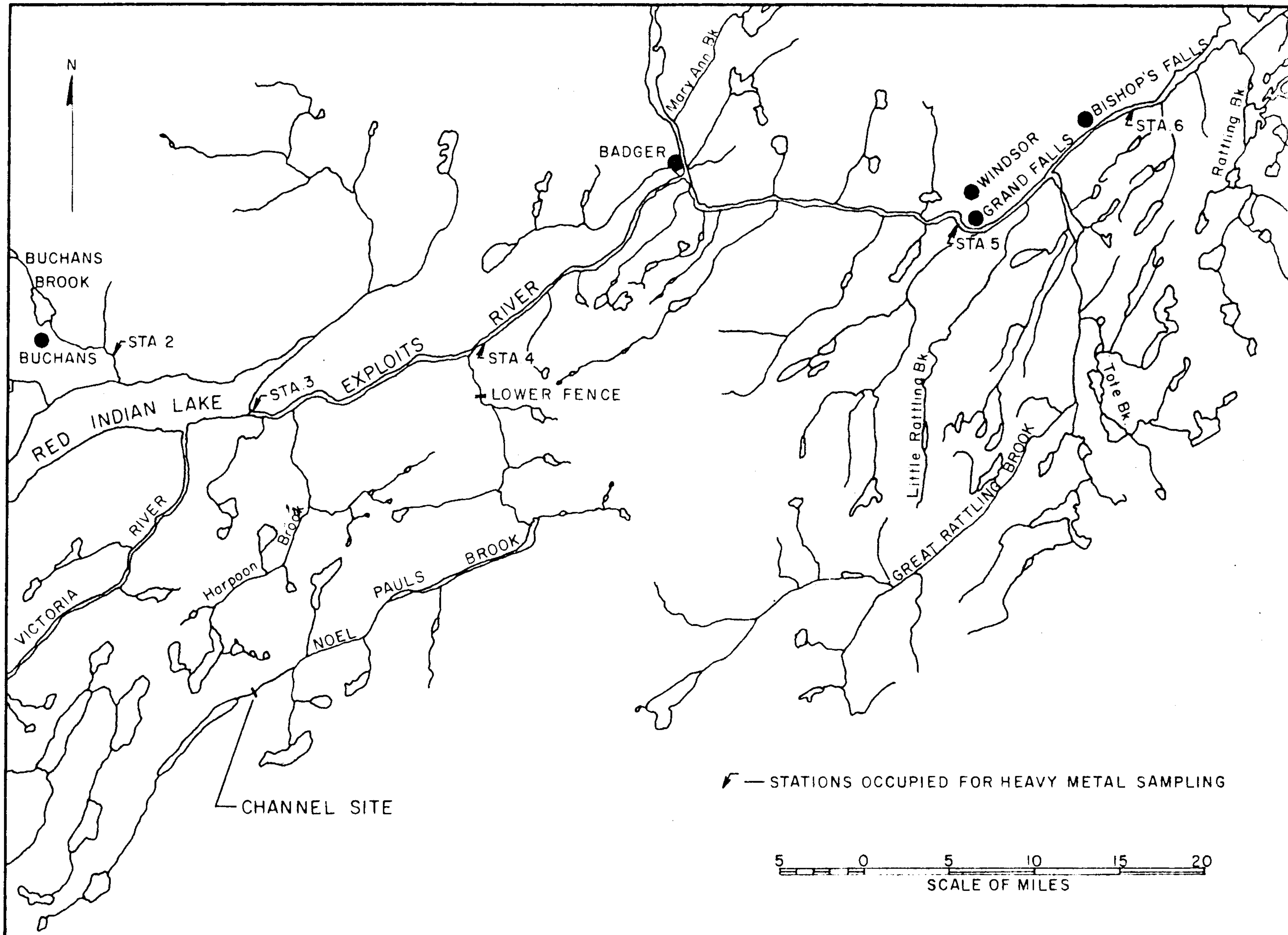

FIG. 1 EXPLOITS RIVER, CENTRAL AND LOWER WATERSHED AREA

Station 5 was located above Grand Falls, approximately 1,400 yards upstream from the Grand Falls dam (lat. 48° 56' 20" N., long. 55° 40' 45" W.).

Station 6, located at the Bishop's Falls railway trestle, was sampled infrequently during 1969. This station is approximately 10.6 miles downstream from Grand Falls (lat. 49° 00' 20" N., long. 55° 29' 30" W.).

Station 7 was located at the Sir Robert Bond Bridge on the Trans-Canada Highway, approximately 11.7 miles downstream from Grand Falls. This station is near the upstream limit of tidal influence (lat. 49° 01' 15" N., long. 55° 26' 45" W.).

With the exception of station 6 (Bishop's Falls trestle), only 7 samples were collected at each station on the Exploits River. The period of sampling was from July to November. Three samples were collected at station 6.

Sampling for dissolved oxygen was carried out at 5 stations below the Price Nfld. Pulp Mill. The location of these stations is described below.

1) Price bridge (approximately 200 yards downstream from the Price Nfld. Mill).

2) Grand Falls dump (approximately 1.8 miles downstream from Price bridge). Samples were collected in midstream from a boat.

3) Fox Farm (approximately 7.1 miles downstream from Price bridge). Samples were collected from the shore.

4) Bishop's Falls Trestle (station 6, described above).

5) Bond Bridge (station 7, described above).

Sampling was carried out on four occasions during July, August, September and October.

(2) Chemical and Physical Analyses

The following chemical and physical analyses were carried out on all samples collected.

a) Total hardness was determined by the Hach Man Ver hardness test (Water and waste water analysis procedures, 1967).

This method measures the total hardness as parts per million (ppm.) of calcium carbonate.

b) Total alkalinity was determined with methyl orange and 0.02 N sulphuric acid (Water and waste water analysis procedures, 1966).

c) Turbidity determinations were made using a Hach turbidity meter (model 2100). Results are given in Jackson turbidity units (J.T.U.).

d) pH was determined with a glass electrode Corning pH meter (model 10).

e) Specific conductance was determined with a Hellige specific conductivity meter.

f) Temperature measurements were carried out using a submersible electric thermometer (Applied Research Associates, model FT3) calibrated in fahrenheit degrees, and a pocket centigrade mercury thermometer.

g) Determinations of dissolved zinc, lead and copper were made with a type 82-270 Atomsorb atomic absorption flame emission spectrophotometer supplied by Fisher Scientific. An air-acetylene gas mixture was used as fuel in a tri-flame burner assembly. A hollow cathode lamp was used as a light source for determination of all three metals. The absorbances used to detect Cu, Zn and Pb were 3247.5Å, 2139 Å, and 2170 Å, respectively.

Copper concentrations were also determined by the wet chemical, SDDC method. In this test, copper is extracted with a 0.17 aqueous solution of sodium diethyldithiocarbamate. The resulting complex is then measured on a Bausch and Lombe Spectronic 20 spectrophotometer at 435 mu (Sprague and Carson, 1963).

h) Dissolved oxygen concentrations were determined by the Alsterberg modification of the Winkler method, using PAO instead of Sodium thiosulphate (Water and waste water analysis procedures, 1967).

Dissolved oxygen concentrations were measured only below Grand Falls.

After tabulation of the results of these analyses, the toxic units of copper, lead and zinc were calculated and summed for each sample to determine the total toxicity of dissolved heavy metals to salmon after the method of Sprague (1964).

RESULTS and DISCUSSION

Although the Exploits River is subject to pollution from sources other than the ASARCO mine, this report deals exclusively with the levels of heavy metals in the Exploits River and its watershed, and those chemical and physical factors which affect the toxicity and concentrations of these metals. Regular sampling of the river to determine concentrations of dissolved Cu, Zn and Pb is necessary because extremely small amounts are lethal to fish. Concentrations below levels which are directly toxic to fish exert a variety of chronic, or sublethal effects. Fish tend to grow less rapidly, and have a retarded sexual development when exposed to sublethal concentrations of heavy metals. There is also cytological damage to the gills, and deterioration of the liver, kidneys, heart, gonads, spleen and skeletal muscles. By preventing spawning, the avoidance reactions of salmon to sublethal concentrations of heavy metals can be as detrimental to fish populations as mortality.

In addition to monitoring levels of dissolved copper, zinc and lead, routine measurements of environmental factors (pH, hardness, temperature, dissolved oxygen, alkalinity and turbidity), must also be taken. Although these factors are not likely to exert a toxic effect on fish, they do modify the action of heavy metals and will be discussed in more detail later (see appendix tables 1 - 7 for tabulation of data collected in 1969).

(1) Copper Concentrations:

Concentrations of dissolved copper in the Exploits River during 1969 ranged from trace amounts to 257.0 ug/l. The mean value was 24.29 ug/l. Highest values of dissolved Cu were recorded at the Millertown dam (mean value from 7 samples was 65.28 ug/l). Concentrations decreased progressively downstream to station 7 (Bond Bridge mean value was 5.30 ug/l). This reduction is primarily a result of the increased dilution from water which enters the river below the dam, and by the adsorption of copper by clay minerals, humic acid and bottom muds (Riemer and Toth, 1970).

At stations 1 and 2 (Buchans culvert and Buchans brook), concentrations of dissolved Cu ranged from 5.0 - 70.0 ug/l and 5.0 - 93.0 ug/l respectively. The mean values were 34.53 ug/l and 29.65 ug/l.

Lethal levels of copper

Of the three heavy metals present as pollutants in the Exploits River, copper is the most toxic to fish. Jones (1938) found that Cu was toxic to the stickleback at a concentration of 20 ug/1 in soft water. He also noted that the addition of calcium salts to the solution greatly increased survival time. Lloyd (1961a), working on rainbow trout, observed that the concentration of copper in soft water (15-20 mg/1 $CaCo_3$) toxic to 50% of the fish was 44 ug/1. In hard water (320 mg/1 $CaCo_3$), the median lethal concentration increased to 1.1 mg/1. For Atlantic salmon in soft water (hardness less than 14 mg/1 as $CaCo_3$), the incipient lethal level for dissolved copper is 32 ug/1. (Sprague, 1964). In water over 20 mg/1 hardness, the incipient lethal level increases to 48 ug/1. The incipient lethal level (ILL) is defined as "that level of the environmental identity beyond which the organism can no longer live for an indefinite time" (Sprague, 1964). In experiments with salmon eggs and fry, it has been found that Cu levels of 40 - 60 ug/1 reduced the hatching success of eggs and was the lethal threshold concentration for fry (Grande, 1966).

Effect of Water Quality on the toxicity of copper

The toxicity of copper is affected by a number of factors. Hardness of the water is the most important. Increasing hardness decreases the lethal threshold. In the soft water of the Exploits River (average hardness is 9.35 mg/1), water hardness does not mitigate the toxicity of copper. The effect of temperature and pH on the toxicity of copper has not been clarified. However, these variables probably affect copper's toxicity in a manner similar to their effect on the toxicity of zinc, which will be discussed in the next section. Low values of dissolved oxygen increase the toxicity of copper (Skidmore, 1964; Lloyd, 1961b). More water is pumped across the gills when dissolved oxygen values are low, and this increases the amount of poison which reaches the gill epithelium, the site where heavy metals are absorbed. Dissolved oxygen values in the river above Grand Falls are usually near saturation and should not affect heavy metal toxicity. Enhancement of lethal action probably occurs below Grand Falls in the summer, when saturation values of oxygen have dropped to 56%.

Sublethal effects of copper

In addition to the toxic effect of copper, it also has a number of sublethal effects. In the laboratory, the threshold concentration for avoidance reactions for young Atlantic salmon was found to be 0.05 of the ILL (Sprague, Elson and Saunders, 1965). In nature, avoidance reactions are initiated at approximately 0.40 of the ILL (Saunders and Sprague, 1967). This avoidance reaction at times prevents a successful upstream migration of salmon.

Chronic effects of dissolved copper on reproduction and growth under conditions of prolonged exposure were examined by Mount (1968) and Mount and Stephen (1969). In hard water, the 96 hour median lethal concentration (96 hr. TL_m) for the fathead minnow was 430 ug/l. Below this level survival was possible, but reproduction was inhibited by levels of copper as low as 15 - 33 ug/l (3 - 7% of the 96 hr. TL_m). This essentially is the same as a lethal effect. More work is necessary to determine acceptable levels of copper and other pollutants for fish stocks which do not have survival as the only criterion.

Neglecting the sublethal effects of dissolved copper, the critical level of copper in soft water is usually accepted to be 32 ug/l. At values below this level, fish are able to survive indefinitely (Sprague, 1964). During 1969, this value was exceeded in 19.4% of the samples collected (6/31). It can be concluded that copper often occurs at undesirable levels, particularly when the toxicity contributed by zinc is considered.

(2) Zinc:

Dissolved zinc in the Exploits River in 1969 ranged from 33.0 - 665.0 ug/l. The mean value was 100.97. As was the case with copper, higher values were recorded at the Millertown dam (station 3) than near the mouth of the river. However, occasional concentrated "slugs" of zinc were detected in the lower reaches of the river (one value, 665 ug/l at station 6, Bishop's Falls trestle).

At station 1, Buchans culvert, zinc ranged from 66.0 - 4,200.0 ug/l, and averaged 675.0 ug/l. The mean value was 532.47 ug/l. The great fluctuation of zinc at these two stations is partly due to the flushing of tailings from the pond before an adequate settling of heavy metals has occurred, and partly a result of pH fluctuations. Low pH values tend to redissolve precipitated zinc compounds (Sprague, 1964).

Lethal levels of zinc to fish

Dissolved zinc is not as toxic to fish as is dissolved copper. A review of the concentrations lethal to various fish is listed below in Table I.

Table I. Concentrations of zinc toxic to various species of fish.

Test species	Exposure time	Lethal concentration	Water hardness	Author
Stickleback	8.5 days	0.300 mg/1	1 mg/1	Jones, 1938
Zebra fish	-	1.30 mg/1	10 mg/1	Skidmore, 1965
Fathead minnow				
a) egg	48 hr. TL_m	1.82 mg/1	174 - 198 mg/1	Pickering and Vigor, 1965
b) fry	24 hr. TL_m	0.95 mg/1	"	
Perch	5 day TL_m	16.0 mg/1	"hard"	Ball, 1967
Roach	5 day TL_m	17.3 mg/1	"hard"	Ball, 1967
Bream	5 day TL_m	14.3 mg/1	"hard"	Ball, 1967
Rainbow trout	5 day TL_m	4.6 mg/1	"hard"	Ball, 1967
Rainbow trout	48 hr. TL_m	2.46 mg/1	320 mg/1	Herbert and Vandyke, 1965
Rainbow trout	48 hr. TL_m	3.86 mg/1	320 mg/1	Herbert and Shurben, 1964
Atlantic salmon	7 day TL_m	0.600 mg/1	20 mg/1	Sprague, Elson and Saunders, 1965
Atlantic salmon	6 day TL_m	0.420 mg/1	14 mg/1	Sprague and Ramsay, 1965

It can be seen that salmonid fish are much more sensitive to zinc than the cyprinid fish, roach, bream and perch.

Effect of water quality on zinc toxicity

As was the case with copper, water hardness is the most important factor modifying the toxicity of zinc ions to fish. A decrease in water hardness from 20 mg/1 to 14 mg/1 increases the toxicity of zinc to Atlantic salmon by approximately 25%. The effect of temperature on resistance of Atlantic salmon to zinc has been examined by Sprague (1964). He found that survival in any given concentration of zinc was four times as long at 5°C as at 15°C and the incipient lethal level was at least 1.5 times higher. The ILL for zinc changed from about 600 ug/l at 15°C to 900 ug/l at 5°C. Lloyd(1965) agrees that a decrease in temperature increases the survival time of fish in toxic solutions, but the threshold lethal concentration is not increased. This is in agreement with the observations of Skidmore (1964). There aresimilar conflicting reports regarding the effect of pH on the toxicity of dissolved zinc. Sprague (1964) found that survival times in zinc solutions were increased at pH values above 8. This was attributed to the formation of insoluble $Zn(OH)_2$, which Sprague felt was not toxic to fish. Mount (1966), using a continuous flow bioassay apparatus, found zinc was more toxic at alkaline pH than in acid pH. These results are possibly due to the flow-through test system, which keeps precipitated zinc in solution. Mount observed that precipitated zinc accumulated between the gill filaments, where it caused the same reaction as dissolved zinc. The toxicity of zinc is also modified by the dissolved oxygen concentration. Lloyd (1960), using rainbow trout, found that over an exposure period of 1000 minutes, the concentration of zinc necessary to kill half the fish was 1.4 times greater at an oxygen concentration of 8.9 mg/l than it was at 3.8 mg/l. Lloyd postulated that more water is pumped across the gills under conditions of low dissolved oxygen, and this increases the amount of poison which reaches the gill epithelium, where heavy metals are absorbed (Lloyd, 1961b; 1965). Pickering (1968) found that Bluegills showed an increased mortality in zinc solutions as a result of low D.O. concentrations. The difference in the average TL_m value between dissolved oxygen values of 1.8 and 5.6 mg/l involved a factor of 1.5.

From the information summarized above, dissolved zinc is most toxic to fish under the following conditions: soft water, low values of dissolved oxygen, warm temperatures and high pH. With the exception of high values of pH, these conditions are often found in the Exploits River.

Sublethal effects of zinc

Although small concentrations of zinc may not result in the death of fish, they may have the following adverse effects, which are as deleterious as direct mortalities.

1) retardation of growth
2) histological changes
3) create an increased susceptibility to disease
4) inhibit reproductive processes
5) initiate avoidance reactions in spawning fish

Retardation of growth

The effect of zinc on the growth of fish has been investigated by Skidmore (1964), Brungs (1969) and Crandall and Goodnight (1962). Skidmore, and Crandall and Goodnight both showed that guppies grew much less rapidly than the control specimens when subjected to prolonged exposure to low concentrations of dissolved zinc. Growth of the fathead minnow was inhibited only at zinc concentrations above 2.8 mg/l (Brungs, 1969).

Histological changes

Prolonged exposure of guppies to low concentrations of zinc caused the epithelial cells of the gill to be sloughed off, and initiated an extensive deterioration of the liver, kidney, heart, gonad, spleen and skeletal muscles (Skidmore, 1964). Crandall and Goodnight (1962) noted that the guppy suffered retarded gonadal development, cardiac damage and blood cell destruction as a result of exposure to sublethal concentrations of zinc.

Increased susceptibility to disease

The infection of the Atlantic salmon by the bacterium *Aeromonas liquefaciens* in a river subject to copper and zinc pollution has been documented by Pippy and Hare (1969). The fish, subject to stress as a result of high water temperatures and sublethal concentrations of copper and zinc, were severely weakened and succumbed to the bacterial infection.

Inhibition of reproductive processes

Prolonged exposure of guppies to a zinc concentration of 1.15 mg/l resulted in a retarded gonadal development. Occasionally, degeneration of the gonadal tissue was also noted (Crandall and Goodnight, 1963).

Brungs (1969), in a more extensive investigation of the effect of zinc on reproduction in the fathead minnow, found a great reduction in the frequency of spawning and the number of eggs laid per female in the zinc solutions as compared with the control specimens. The number of eggs laid per female in a zinc concentration of 0.18 mg/l equaled only 17% of the egg production of the control females. It was also noted that eggs survived to hatching in a zinc concentration of 2.8 mg/l, but were not able to hatch successfully. On the basis of these results, the maximum acceptable concentration of zinc for the fathead minnow is less than 0.18 mg/l, even though this concentration is well below the level where mortality is significant (2.8 mg/l). Concentrations of zinc above this level reduced egg production significantly.

Avoidance reactions

In a laboratory study it has been shown that young salmon could detect and avoid very low concentrations of dissolved zinc. The threshold concentration at which avoidance reactions were initiated was found to be 5.6 ug/l. This is 0.01 of the lethal threshold concentration (Sprague, 1968). In nature, significant down-stream movements are initiated in spawning salmon when the level of zinc exceeds about 0.40 of the ILL. Levels higher than 0.8 ILL completely prevented upstream migration (Sprague, Elson and Saunders, 1965; Saunders and Sprague, 1967).

Since the sublethal effects of zinc and other heavy metals can be highly detrimental to fish, the method of establishing safe concentrations of pollutants on 50% mortality levels does not adequately protect the fish. More emphasis must be placed on basing safe levels of toxicants on the tolerance of the most sensitive stage in the life history of the fish.

Taking into account the water conditions in the Exploits River, the level of zinc causing a 50% mortality of Atlantic salmon has been computed by Sprague and Ramsay (1965) to be 420 ug/l. During 1969, this value was exceeded in only 2 of 31 samples collected. Most values were considerably below this critical value (mean of 31 samples was 100.97 ug/l). If dissolved zinc were the only toxicant entering the river, it would have been unlikely to have been a hazard to fish. However, appreciable amounts of copper and sometimes lead were also present and contributed to the total toxicity of the river. The cumulative effects of mixed copper-zinc solutions are discussed in the next section.

Lethal levels of mixed copper-zinc solutions

In a solution containing two or more toxicants, the threshold concentration of the mixture which produces a 50% mortality can be predicted by a simple summation of the concentrations of the individual poisons when the toxicants exert a joint similar action, as is the case with copper and zinc (Lloyd, 1961a). The concentration of each pollutant in toxic units is obtained by expressing the chemical concentration of the pollutants as fractions of their respective incipient lethal level (Sprague, Elson and Saunders, 1965; Saunders and Sprague, 1967). A value equal to or greater than 1.0 toxic unit is lethal to approximately 50% of the fish, and values approaching 0.40 toxic units initiate downstream movements in Atlantic salmon (Sprague, Elson and Saunders, 1965).

In the Exploits River, the total toxicity of dissolved heavy metals can be calculated by summing the individual toxicities of copper, zinc and lead. During 1969, 19.3% of the samples (6/31) had a value over 1.0 toxic units and 61.3% of the values (19/31) were over 0.40. The range of toxic units was 0.086-9.111 and the mean value was 1.137. If the fish in the Exploits River are as sensitive as those worked on by Sprague et al (1965), values over 1.0 toxic units are lethal to 50% of the population in one day. Based on this data, it would be expected that some mortality or blocking of upstream migration could have occurred during 1969, unless the high values recorded were merely "slugs" of pollutant and not indicative of average conditions. No information is available to aid in determining the hourly fluctuations of dissolved metals in the river.

(3) Lead:

Levels of dissolved lead in the Exploits River and Buchans Brook were monitored intermittently in 1969. Lead concentrations in the river ranged from 0.0 to 120.0 ug/1 and averaged 32.7 ug/1. In Buchans Brook the range was 12.0 - 290.0 ug/1 and the average was 88.9 ug/1.With the exception of a few occasions, lead concentrations were quite low and contributed little to the total toxicity of the heavy metals to fish.

Lethal levels of lead:

There is a wide range of values of lead reported to be toxic to a variety of fish. Concentrations of 0.1 to 75 mg Pb/1 have been reported to be acutely toxic (lethal within 96 hours) to fish (McKee and Wolf, 1963). This wide variation is a result of the many different species of fish tested, and the variety of test conditions employed (different dilution waters, temperature, pH and hardness). A brief summary of some concentrations of lead toxic to various salmonid fish is given in Table II.

In the Exploits River, 0.34 mg/1 of lead has been taken as the critical level for lead.

Table II. Concentrations of lead toxic to various species of fish.

Species tested	Exposure time	Lethal concentration Pb	Author
Rainbow trout	18 - 24 hours	1.4 mg/l	Anon. 1960
Brook trout	96 hours	3.12 mg/l	Dorfman and Whitworth 1969
Brown trout	-	0.33 mg/l	Carpenter, 1927
Coho salmon	48 hours	0.34 mg/l	Gill, Huguet and Pearson, 1960

Effect of water quality on lead

Like the other heavy metals previously discussed, the lethal action of lead is modified by environmental characteristics, primarily water hardness and dissolved oxygen. High values of water hardness decrease the toxicity of lead, and low values of dissolved oxygen increase the toxicity. (Brown, 1968). No information is available on the effect of fluctuations of temperature and pH.

Sublethal effects of lead

There have been few long term studies of the chronic toxicity of lead to fish. Dawson (1935) found that pronounced anemia was produced and abundant atypical thrombocytes were formed when catfish were held in a lead solution. Crandall and Goodnight (1963) exposed guppies to 1.24 and 3.12 mg Pb/liter for up to 129 days and reported histological changes, retarded gonadal development and reduced growth.

It is not likely that levels of dissolved lead in the Exploits River are ever high enough to be a threat to fish. The occasional high lead concentration is probably short in duration, and Dorfman and Whitworth (1969) have shown that "slug" doses of 15 mg/l of lead administered once a day to brook trout had little apparent effect. Continuous exposure of only 3.12 mg/l of lead killed 50% of the brook trout in 4 days however. It is unlikely that lead concentrations are ever sustained at a high enough level to affect fish in the Exploits River.

(4) Hardness:

The water of the Exploits River is very soft. The range of hardness in the river was 7.0 - 14.0 mg/l $CaCo_3$ and the mean value was 9.35 mg/l during 1969. Water hardness has no direct effect on fish. The importance of monitoring hardness lies in its influence on the toxicity of heavy metals to fish. As was described previously, an increase in hardness decreases the toxicity of dissolved Cu, Zn and Pb. With the soft water in the Exploits, there is no reduction in the toxicity of dissolved metals.

(5) Dissolved oxygen:

In 1969, D.O. samples were collected 3 times daily on four occasions in the Exploits River below Grand Falls. Minimum values of 5.4 mg/l (62% saturation) and 5.05 mg/l (56.5% saturation) were recorded during conditions of low river flow (less than 4,500 cfs.). Dissolved oxygen values recorded during 1969 are tabulated in appendix tables 8-11.

Values of dissolved oxygen as low as this may have a variety of adverse effects.

1) Spawning salmon tend to avoid low concentrations of dissolved oxygen (up to 4.5 mg/l) (Doudoroff and Warren 1962; Bishai, 1962).

2) Swimming ability of fish is impaired (Doudoroff, 1957; Doudoroff and Warren, 1962).

3) Food consumption decreases and there is a concomitant decrease in growth rate at D.O. concentrations near 5.0 mg/l (Herrmann _et al_ 1962).

In addition to these direct effects, low values of D.O. increase the sensitivity of fish to poisoning by heavy metals. It can be concluded that values of dissolved oxygen in the river below Grand Falls are often too low to encourage the development of a successful fish crop. Also, the situation with respect to dissolved oxygen could worsen in the future if river flows are not maintained above 5000 cfs.

Although no sampling for dissolved oxygen was carried out in the Exploits above Grand Falls, it is unlikely that values fell much below saturation levels.

(6) _pH_:

Values of pH during 1969 ranged from 5.87 - 7.09 (mean - 6.59) in the Exploits River. These slightly acidic conditions are usual for Newfoundland surface waters. The natural variation of pH from year to year is shown in Table III.

Table III. Average pH values on the Exploits River above and below Grand Falls for the years 1961-66, 1967, 1968 and 1969.

Year	Average pH above Grand Falls	Average pH below Grand Falls
1961-66	6.60	-
1967	6.35	6.20
1968	6.15	6.05
1969	6.70	6.38

The lower average pH values below Grand Falls are due to the discharge of acidic effluent from the Price Newfoundland Paper Mill.

For fish, the safe range of pH has been accepted to be approximately 5.0 - 9.5 (Tarzwell, 1957). Reliable tests have been carried out on salmonid fish, and have shown that a pH in this range is unlikely to be toxic to any stage of their life history.

In addition to mortalities, extreme values of pH may cause avoidance reactions, decrease growth, reduce the food supply and modify the toxicity of other poisons. Avoidance reactions are initiated only at pH values below 5.3 and above 7.4 for salmon parr (EIFAC, 1969a). For maximum productivity, optimum pH values lie between 6.5 and 8.5. The lower growth rate in acidic waters may be associated with a reduced food supply, caused by the inhibition of normal nutrient recirculation by the low pH values (EIFAC, 1969a). As was mentioned earlier, the toxicity of zinc is modified by the pH of the water (Mount, 1966). The toxicity of zinc to fathead minnows decreases with a reduction in pH from 8.6 to 6.0.

Apart from the effect pH has on productivity and the toxicity of zinc to fish, the pH in the Exploits River is not likely to be harmful to fish.

(7) Alkalinity:

Alkalinity, a measure of the buffering capacity of the water caused by the presence of hydroxyl, carbonate and bicarbonate ions, generally has no direct effect on fish. In the Exploits River, total alkalinity ranged from 4.0 - 12.0 mg/l. The mean was 7.02 mg/l. This is a normal range for Newfoundland waters.

(8) Temperature:

The average temperature during July and August in the Exploits River was 61.6°F (16.45°C) and the range was 57.0 - 67.0°F. In the Fall (September and October), the mean temperature dropped to 52.3°F (11.30°C). The European inland fisheries Advisory Commission working party on water quality criteria recommend a temperature of 20-21°C (68-70°F) as the upper permissible limit for salmonid fish (EIFAC, 1969b). Summer temperatures in the Exploits are well below this level.

(9) Turbidity:

Turbidity ranged from 0.50 - 1.80 Jackson turbidity units (mean, 0.99 JTU) on the Exploits River. Turbidity values above and below Grand Falls differed due to the discharge of effluent from the Price Nfld. Paper Mill located at Grand Falls. The average turbidity was 1.49 JTU at the Bond Bridge and 0.78 JTU above Grand Falls. These levels are far below those which are likely to harm fish (EIFAC, 1965).

In view of the planned development of the Exploits watershed to support an increased salmon population, an examination of the full extent of the heavy metal pollution and its effect on fish is necessary. Before considerable funds are spent in opening up the Exploits River, this Department must be assured that pollution barriers are not likely to block the migration of salmon upstream. To evaluate the present effects of heavy metals on fish and to predict possible future effects, the following points must be considered.

1) the effectiveness of the present system of mine tailings impoundment at Buchans. Has this tailings system, since

its inception in late 1965, significantly reduced the concentration of heavy metals entering the Exploits River?

2) the extent of tailings deposits on the bottom of Red Indian Lake. Does the leaching of heavy metals into solution significantly add to the concentration of copper, zinc and lead in the Exploits River?

3) the effect of river flow on heavy metal levels in the river. Is there any evidence that low flows are correlated with high levels of heavy metals in the river?

4) the tolerance of fish populations to fluctuating concentrations of dissolved Cu, Zn and Pb. In situ bioassays have been carried out in the Exploits River. The results from these tests are discussed in detail later.

Effectiveness of tailings impoundment

To determine how effective the tailings pond disposal system is in reducing heavy metals entering Red Indian Lake and the Exploits River, an analysis was made of the data collected from 1965-1969. Summaries of concentrations of heavy metals in the Exploits River from 1965-1969 and in Buchans Brook (stations 1 and 2) from 1966-1969 are given in Tables IV, V, and VI, respectively.

From the results in Table IV, it can be seen that the average levels of copper and zinc in the river decreased steadily from 1965 to 1968.

Levels were generally higher in 1969. This may be due to the low number of samples collected (31), or the lower average river flow during the summer of that year.

Regular sampling at stations 1 and 2 on Buchans Brook did not begin until 1967 (only 5 samples were collected during 1966). No data is available on heavy metal levels in the brook previous to the commencement of operation of the tailings pond in 1965. Mean levels of dissolved copper and zinc have not noticeably decreased from 1967 to 1969. It is probable that a substantial reduction in heavy metal levels occurred in Buchans Brook during late 1965 and 1966 and it is not likely that further reductions will occur in Buchans Brook with the present disposal system.

With the reduction of mean values of copper and zinc in the Exploits from 1965-1968, a similar decrease might be expected in dissolved heavy metal levels in Buchans Brook. This, however, is not the case. Levels of dissolved copper and zinc have not changed significantly from 1966 to 1969. The decrease in the Exploits is possibly due to the decreased amounts of suspended material entering Red Indian Lake. As a result of the tailings impoundment, much of the suspended solids are retained. The steady decrease of copper and zinc in the Exploits River might be explained by a lower rate of heavy metals entering solution.

The data on heavy metal concentrations in the Exploits River (1965-1969) were examined statistically to determine if the observed mean reduction was significant. The mean, standard deviation and standard error of levels of copper, zinc and their combined toxicity (as toxic units) were calculated. Results are in Tables VII, VIII, and IX).

Table 4 - Summary of Concentrations of Heavy Metals in the Exploits River, 1965-1969

Year	Copper (μg/1)		Zinc (μg/1)		Total Toxic Units			
	Range	Mean	Range	Mean	Range	Mean	% over 0.4	% over 1.0
1965	1.2-130.0	29.98	20.0-3400.0	328.60	.537-9.345	1.713	100% (121/121)	84% (101/121)
1966	2.0-77.0	13.29	35.0-485.0	169.63	.272-2.250	.815	91.5% (87/95)	15.8% (15/95)
1967	trace-46.0	9.18	12.0-232.0	126.15	.127-1.907	.597	72% (51/71)	7% (5/71)
1968	trace-18.0	5.65	14.0-187.0	60.95	.150-.797	.390	50.5% (53/105)	0% (0/123)
1969	trace-257.0	24.29	33.0-665.0	100.97	.086-9.111	1.137	61.3% (19/31)	19.3% (6/31)

Table V. Summary of water conditions and heavy metal concentrations at Station 1 (Buchans culvert), 1966-1969.

Year	Total hardness (mg/l)		Turbidity (J.T.U.)		pH		Copper (ug/l)		Zinc (ug/l)	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
1966[1]	22.0-198.0	89.00	5.0-600.0	152.40	6.44-6.85	6.71	7.5-258.0	102.60	246.0-545.0	430.0
1967	8.0-600.0	154.08	3.0-6200.0	496.12	3.60-7.47	6.33	5.0-290.0	87.58	30.0-48000.0	2945.83
1968	12.0-352.0	155.27	2.0-3500.0	386.25	5.75-7.65	6.81	trace-378.0	36.56	130.0-6600.0	1168.73
1969	80.0-221.0	128.17	5.4-320.0	63.83	6.09-7.40	6.72	5.0-70.0	34.53	66.0-4200.0	675.76

[1] only 5 samples collected

Table VI - Summary of Water conditions and heavy metal concentrations at Station 2 (Buchans Brook), 1966-1969.

Year	Total hardness (mg/l)		Turbidity (JTU)		pH		Copper (ug/l)		Zinc (ug/l)	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
1966[1]	16.0-98.0	44.25	6.0-600.0	188.00	6.48-7.42	6.87	25.0-60.0	40.00	388.0-545.0[2]	477.50
1967	6.0-33.0	17.46	3.5-46.0	10.46	5.44-7.24	6.33	4.0-57.0	19.32	125.0-2500.0	558.64
1968	8.0-40.0	17.98	1.0-223.0	28.17	5.60-7.04	6.28	trace-50.0	19.60	80.0-1180.0	411.38
1969	8.0-38.0	17.88	1.9-30.0	5.15	5.83-7.21	6.61	5.0-93.0	29.65	115.0-1096.0	532.47

[1] only 4 samples collected

[2] one value 215,000.0 ppb

Table VII. Mean, standard deviation and standard error of concentrations of zinc in the Exploits River, 1965-1969.

Year	Range (mg/l)	Mean mg/l	Number of samples (N)	Standard deviation	Standard error
1965	20.0-1030.0[1]	328.60	121	271.86	24.71
1966	35.0-485.0	169.63	95	68.22	7.00
1967	12.0-232.0	126.15	71	42.24	5.01
1968	14.0-187.0	60.95	123	75.61	6.81
1969	33.0-665.0	100.97	31	132.73	23.83

[1] one value 3400.0

Table VIII. Mean, standard deviation and standard error of concentrations of copper in the Exploits River, 1965-1969.

Year	Range (mg/l)	Mean mg/l	Number of samples (N)	Standard deviation	Standard error
1965	1.2 - 130.0	29.98	121	19.53	1.78
1966	2.0 - 77.0	13.29	97	12.71	1.29
1967	Trace - 46.0	9.18	71	8.89	1.05
1968	Trace - 18.0	5.65	123	3.75	0.338
1969	Trace - 101.0	24.29	31	50.59	9.08

Table IX. Mean, standard deviation and standard error of the combined toxicity of copper and zinc (in toxic units) in the Exploits River, 1965-1969.

Year	Range	Mean	Number of samples (N)	Standard deviation	Standard error
1965	0.537-4.702[1]	1.713	121	0.997	0.0906
1966	0.272-2.250	0.815	95	0.303	0.0310
1967	0.127-1.907	0.597	71	0.103	0.0122
1968	0.150-0.797	0.390	123	0.140	0.0126
1969	0.086-3.760[2]	0.686	28	0.969	0.1830

[1] one value 9.345

[2] one value 9.111

The mean, standard deviation and standard error are presented graphically, after the method of Hubbs and Perlmutter (1942), and Hubbs and Hubbs (1953) (see figures 2, 3 and 4). This method was designed to indicate and to test the significance of the difference between the means of a number of samples. It also clearly illustrates any trends. The statistical significance of the difference between any two means is apparent by comparing the relative overlap, or separation of the rectangles delineating twice the standard error. "Statistical adequacy" is indicated when the rectangles outlining twice the standard error about any two means meet end to end. When there is considerable separation between these rectangles, a high reliability is indicated that the observed differences are statistically significant.

In figures 2, 3 and 4, it can be seen for the years 1965-1968, that the concentrations in the Exploits River of copper, zinc and their combined toxicity decreased significantly. This indicates that the tailings pond disposal system was effective in reducing heavy metals in the river. Levels of copper and zinc in 1969 reversed the trend observed in the years 1965-1968, returning to somewhat higher levels. This increase may be partially a result of inadequate sampling however. Hubbs and Hubbs (1953) point out that when fewer than 30 samples are analyzed, "there are reasons for distrusting the reliability of the difference that is indicated by the graphical method, since the values of the standard deviation are calculated on the assumption of normal distribution, not likely to be realized in small samples".

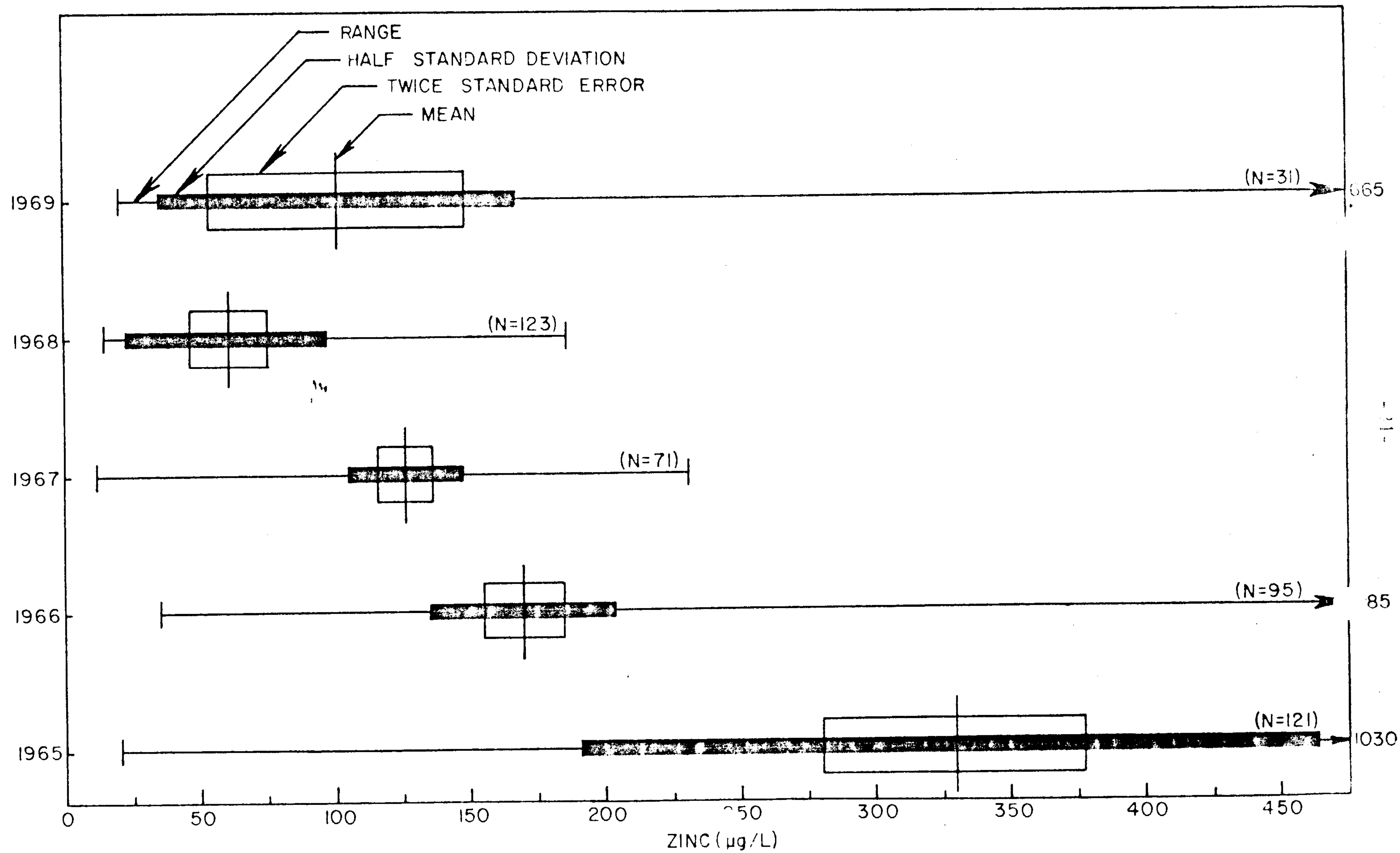

FIGURE 2 VARIATION OF ZINC CONCENTRATIONS IN THE EXPLOITS RIVER 1965-69

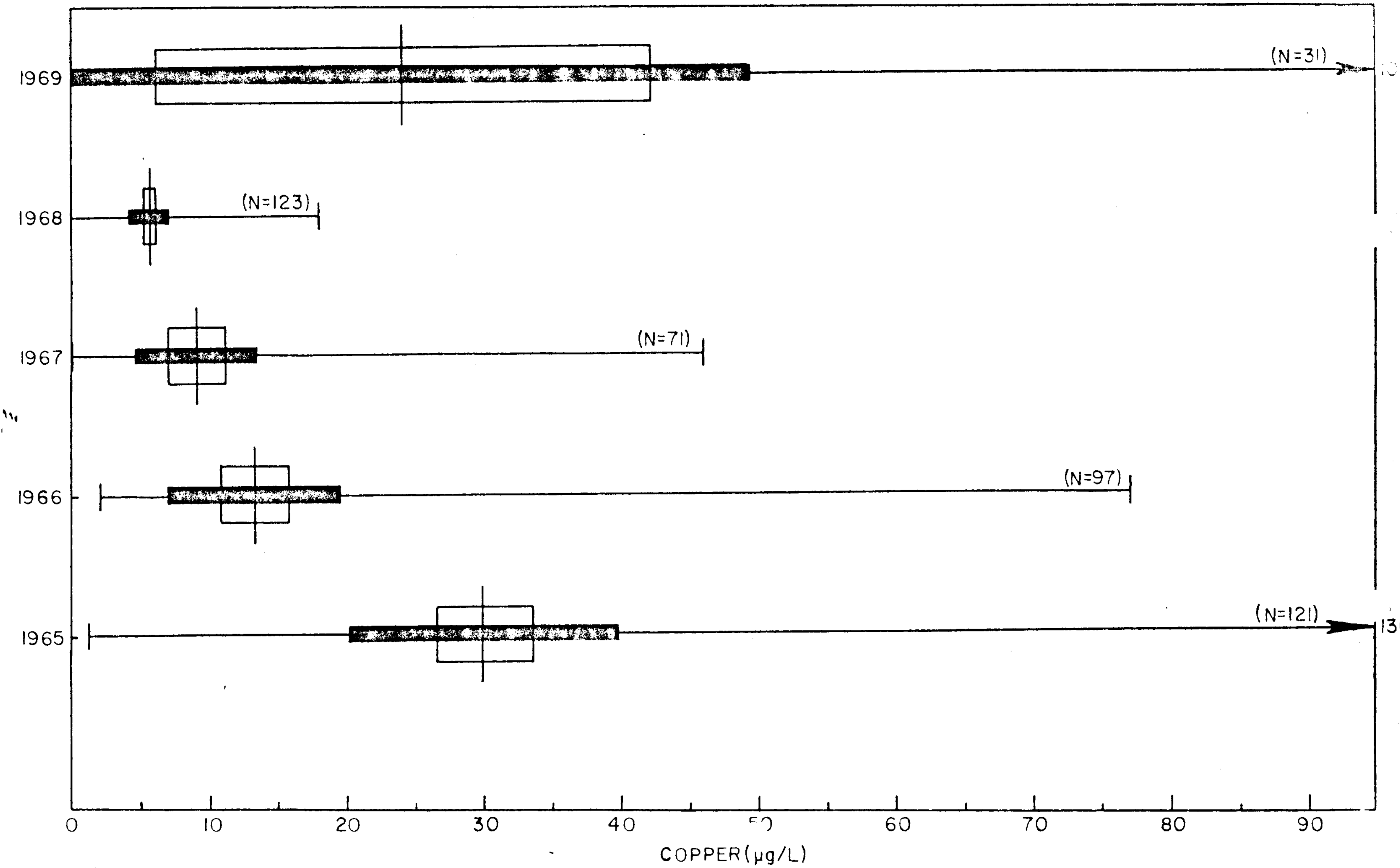

FIGURE 3 VARIATION OF COPPER CONCENTRATIONS IN THE EXPLOITS RIVER 1965—69

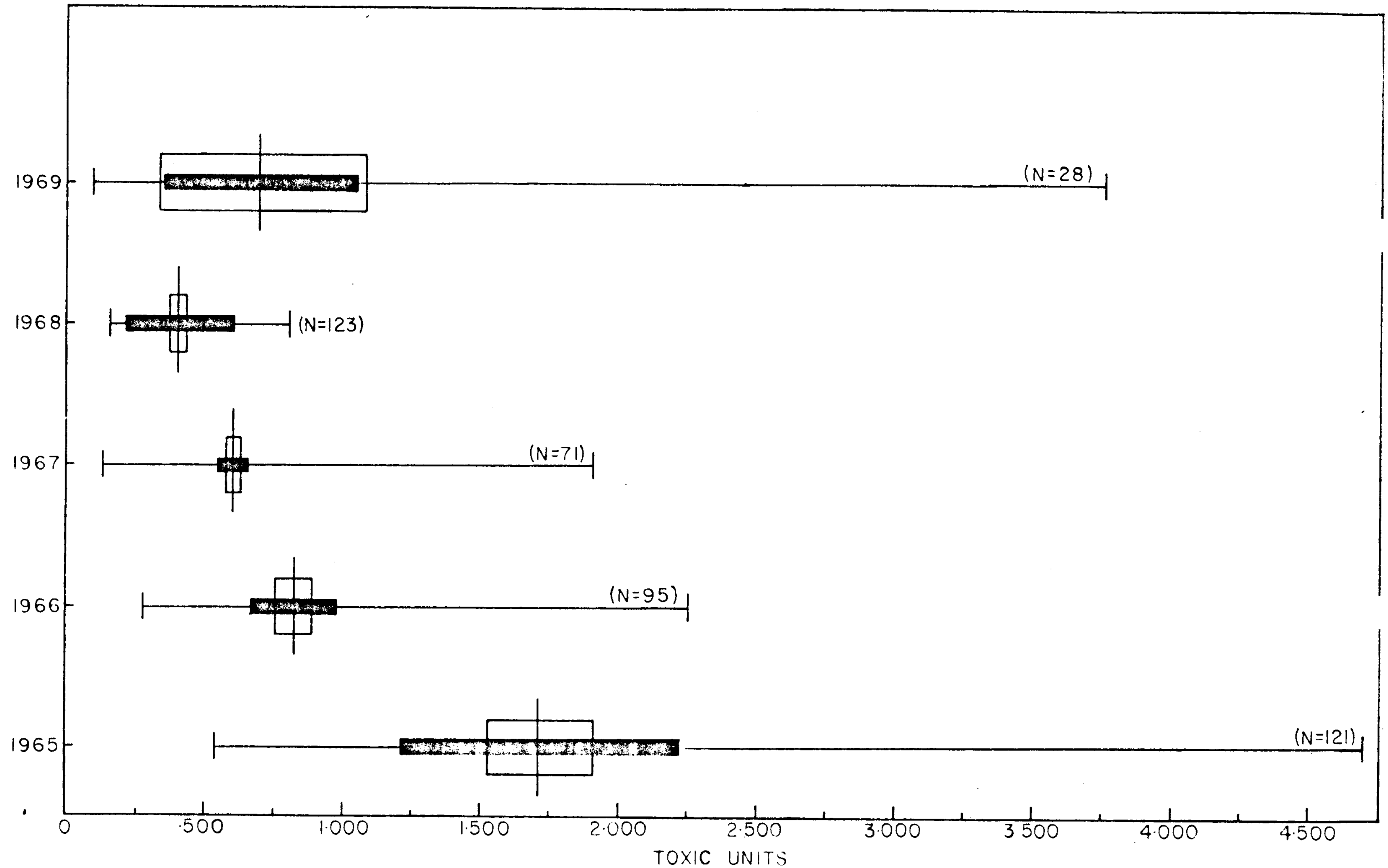

FIGURE 4 VARIATION OF TOXIC UNITS (DERIVED FROM Cu-Zn CONCENTRATIONS IN THE EXPLOITS RIVER) FROM 1965–69

The monitoring of heavy metals will continue throughout 1970. These samples, hopefully will establish whether the reversal in 1969 of the trend to decreased levels of copper and zinc was temporary, or a reflection of decreased water flow in the river.

At present, ASARCO is planning to construct a new tailings pond at Buchans during 1970. This Department has few details yet, but it is anticipated that this will further reduce the pollutants entering Red Indian Lake.

Extent of tailings deposits in Red Indian Lake

No sampling of bottom deposits in Red Indian Lake was carried out during 1969. The levels of total copper, zinc, and lead were analyzed by Cowley in 1962 and 1967. Results from the 1962 survey are presented in Table X (see figure 5 for location of sampling sites).

Table X. Total heavy metal concentrations in Red Indian Lake bottom sediments (Cowley, 1963).

Station	Total copper (mg/1)	Total zinc (mg/1)	Total lead (mg/1)
C	300	1,200	3,000
F	1,000	2,000	4,700
I	350	2,100	5,000
J	300	5,000	2,000
K	400	2,200	4,000
L	0.00	0.00	0.00
P	250	10,000	5,000
Q	700	2,100	4,500
Range	250 - 1,000	1,200 - 10,000	2,000 - 5,000

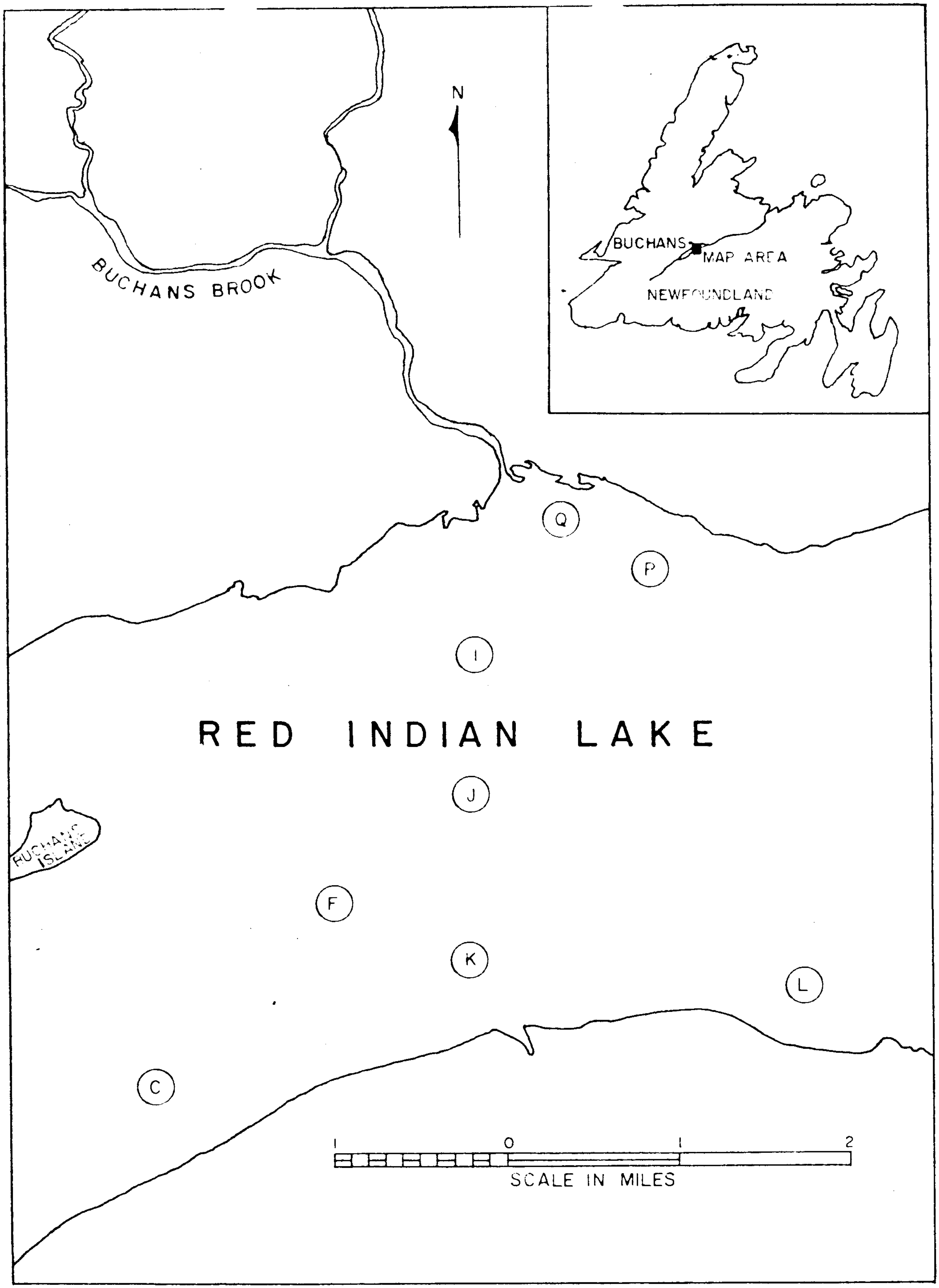

FIGURE 5. DREDGING OPERATIONS—RED INDIAN LAKE

In a similar survey carried out in 1967, Cowley found that the ranges of total copper, zinc and lead were 100-880, 220 - 14,600 and 250 - 1,250 mg/l respectively.

Present tailings deposits in the lake were built up over a period of 40 years. The concentrations of copper, zinc and lead are very high and undoubtedly leach out slowly, adding to heavy metal levels in the river. This leaching process is enhanced by the acidic pH of the lake.

Using the average river flows of Buchans Brook, and the Exploits River at Millertown, and average 1969 concentrations of dissolved Cu, Zn and Pb at stations 2 and 3, a rough estimation was made of the contribution of heavy metals in the Exploits River from Buchans Brook and the bottom of Red Indian Lake (see Appendix 2 for detailed method of calculation). Buchans Brook, with a drainage area of 75 sq. mi. and a mean run-off of 2.5-3.0 cubic feet per second (cfs.) per square mile of watershed area, has an estimated flow of between 186-225 cfs. (Shawinigan Engineering Co. Rept. 1968). During 1969, mean concentrations of Cu, Zn and Pb at station 2 were 29.64, 532.58 and 96.23 ug/l respectively. The mean water flow at the Millertown dam for the period July-November 1969, was estimated to be 3386 cfs. (Shawinigan Engineering Co. Rept., 1966), and average Cu, Zn and Pb concentrations were 65.28, 170.28, and 57.60 ug/l respectively.

Table XI presents the mean weight of copper, zinc and lead per day entering Red Indian Lake from Buchans Brook and entering the Exploits River from Red Indian Lake.

Table XI. Contributions of Buchans Brook and other sources to heavy metal concentrations in the Exploits River.

Metal	Contribution of Buchans Brook kg/day	Amount entering Exploits River kg/day	Bottom heavy metal contribution kg/day	% of total derived from bottom
Copper	13.01-16.31	540.72	524.41-527.71	96.9-97.6%
Zinc	234.51-293.13	1410.61	1117.48-1176.10	79.2-83.4%
Lead	42.37-52.96	477.10	424.14-434.73	88.9-91.1%

Although these results may in no way be regarded as conclusive, they do indicate that a considerable percentage of the heavy metals entering the Exploits River are derived from Red Indian Lake, which acts as a reservoir of heavy metals.

With adequate tailings impoundment, it is not likely that there will be a continuing build-up of heavy metal sediments on the bottom of Red Indian Lake. Present concentrations however are high enough to maintain dissolved heavy metals in the lake and Exploits River at undesirable levels for a number of years.

Effect of river flows on heavy metal levels in the Exploits River

Saunders and Sprague (1967) found that high levels of dissolved copper and zinc were correlated with periods of high flow in the Miramichi River in New Brunswick. This also occurs to some extent in the Exploits River. Figures 6 and 7 illustrate the variation of copper and zinc (expressed as total toxic units) in relation to river flow during June and August, 1965. It can be seen that generally, as flows decreased, heavy metal concentrations increased. Conversely, higher volumes of flow often

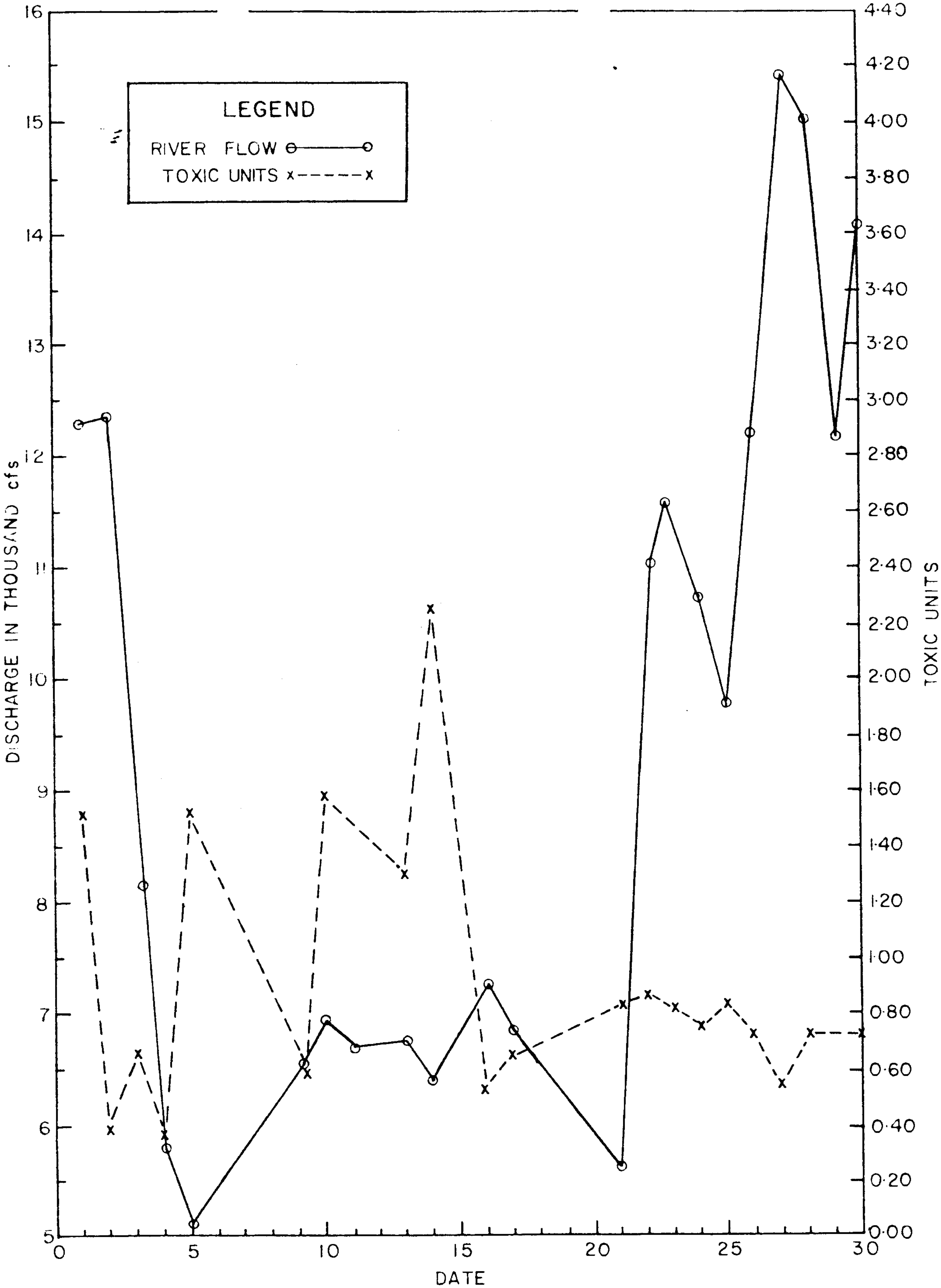

FIGURE 6 VARIATION OF TOXIC UNITS (Zn & Cu) IN RELATION TO RIVER FLOW AT BOND BRIDGE, JUNE 1966

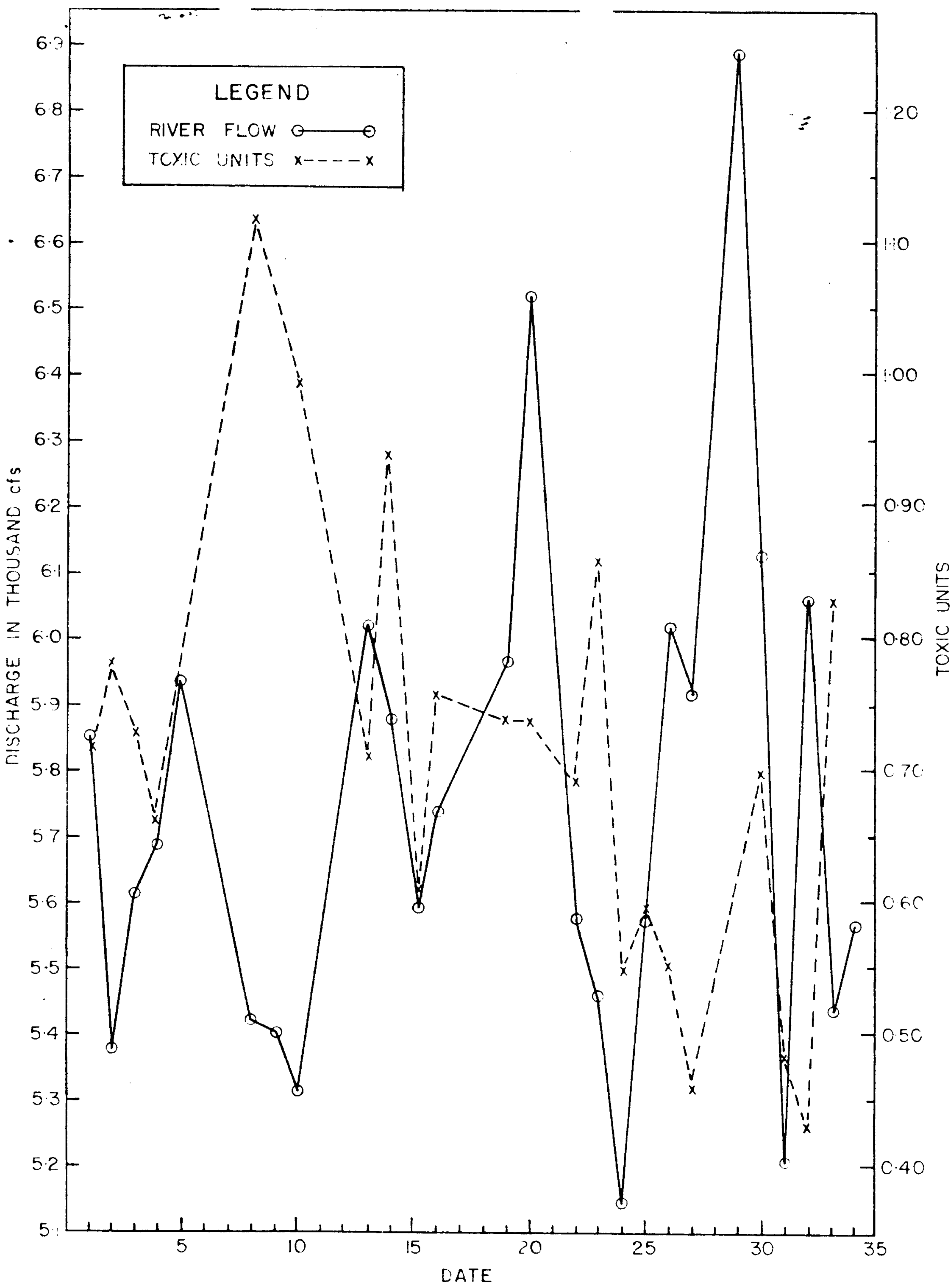

FIGURE 7 VARIATION OF TOXIC UNITS (Zn & Cu) IN RELATION TO RIVER FLOW AT BOND BRIDGE, AUGUST 1966.

are accompanied by reduced levels of heavy metals. This is not always the case however, as freshets sometimes have a flushing effect on dissolved metals in the lake, and as flows increase rapidly, they tend to bring increased amounts of copper and zinc into the river.

The diversion of some of the water which drains into Red Indian Lake will probably have an undesirable effect on heavy metal levels in the Exploits River, especially during the summer when flows are often low. The higher values of dissolved metals in the river during 1969 may be partially accounted for by the reduced dilution capabilities of the river. During June - November 1969, the average flow in the river decreased to 5583 cfs. the lowest average recorded for a similar period during five previous years.

Apart from the reduced dilution ability of the river as a result of the Victoria Lake diversion scheme, the increased retention time of water in Red Indian Lake may increase levels of metals entering the river during the dry months. Water is stored in the lake during the Spring, and during the summer the flow is regulated at the Millertown dam so that at least 5,000 cfs. flows past the Price Nfld. powerhouse below Grand Falls. As water levels decline in the lake during July, August and September, the possibility exists that water which has been in contact with bottom tailings deposits may flow into the river. This water would likely have higher concentrations of dissolved copper and zinc.

Since there has been no work carried out in Red Indian Lake since the completion of the Victoria Lake diversion, any conclusions regarding its effect on heavy metal concentrations can only be speculative. Hopefully, information collected in 1970 will clarify the problem.

Results of the *in situ* bioassays

Live fish experiments were carried out in the Exploits River by Cowley in 1961 and 1962. In 1961, three Atlantic salmon and three mud trout were placed in cages at two stations in the river. One station was located 1.6 miles upstream from the Price Nfld. Mill sewers, and the second station was 350 yards downstream from the South sewer. These fish were held in cages for 20 days during August and early September. During this period, dissolved copper ranged from 20-30 ug/l and dissolved zinc ranged from 140-330 ug/l. Results showed no mortality or observable chronic effects on the caged fish. In a similar study in 1962, caged salmon were unaffected by mine wastes and pulp mill wastes when held for a period of 96 hours. Total copper concentrations were 20 and 30 ug/l and zinc concentrations were 110 and 130 ug/l during this experiment.

From the results of these two studies, Cowley concluded that though heavy metals may be present at borderline levels, they are not at lethal levels and apparently do not deter migration.

Cowley also investigated the possibility that the salmon population of the Exploits River might have developed a resistance to dissolved copper and zinc. At Cowley's request, Sprague carried out bioassays on juvenile Exploits River salmon and found no such resistance or acclimation was present (Rept. of Res. Dev. Branch, 1964).

These results with caged fish are difficult to explain. According to literature values, levels of copper and zinc should have been high enough to cause at least an abnormal reaction in the caged fish, if not mortality. To clarify this problem, more results from studies with caged fish, and from laboratory bioassays are necessary to determine the real effect of present heavy metal levels on the Exploits River salmon.

CONCLUSIONS

1) Dissolved copper and zinc in the Exploits River exist at undesirably high levels. Values reportedly toxic to salmon are often exceexed and some mortalities or sublethal effects could be expected. Results from past experiments with caged fish however, indicated that heavy metals had no noticeable effect on fish. This is possibly because occasional high concentrations of dissolved copper and zinc are of short duration.

2) Concentrations of dissolved lead, although occasionally at undesirable levels, are not a serious problem.

3) Bottom deposits of tailings in Red Indian Lake contain high concentrations of copper, zinc and lead, and probably add appreciably to levels of dissolved Cu, Zn and Pb in the Exploits River.

4) The system of tailings impoundment at Buchans effectively lowered heavy metal concentrations in the Exploits River during the years 1965 - 1968.

5) An increase in mean levels of dissolved Cu and Zn in the river during 1969 could be attributable to the reduced flow in the river as a result

of the Victoria Lake diversion. If this is the case, concentrations during 1970 will likely remain at undiminished levels.

6) During low flow in the river, values of dissolved oxygen in the river below Grand Falls reach critical levels. These low values of D.O. have the secondary effect of increasing the toxicity of copper and zinc to fish.

RECOMMENDATIONS

1) Weekly sampling in Buchans Brook and on the Exploits River be conducted in 1970 to determine general water conditions and concentrations of heavy metals.

2) Daily sampling of heavy metals be carried out at Bond Bridge. Occasionally, hourly samples over a 24 hour period be collected to determine the fluctuations of heavy metals at Bond Bridge.

3) Sampling of the water of Red Indian Lake for dissolved Cu, Zn and Pb should be carried out when possible. In addition, bottom samples should be taken to determine the existing levels of heavy metals.

4) If possible, experiments with caged fish in the river or laboratory bioassay studies should be carried out to determine the effect of extant concentrations of Cu and Zn on fish in the Exploits River.

REFERENCES

ANON. 1960. Report of the Water Pollution Research Board, with the report of the director of the Water Pollution Research Laboratory for the year 1959. Department of Scientific and Industrial Research. H. M. Stationery Office, London.

BAKER, J.T.P. 1969. Histological and Electron Microscopal Observations on Copper Poisoning in the Winter Flounder (Pseudopleuronectes americanus). J. Fish. Res. Bd. Canada, 26(11): 2785-2793.

BALL, I.R. 1967. The relative susceptibilities of some species of freshwater fish to poisons. Water Research, 1: 777-783.

BISHAI, H.M. 1962. Reactions of larval and young salmonids to water of low oxygen concentration. J. du Consiel, 27: 167-180.

BROWN, V.M. 1968. The calculation of the acute toxicity of mixtures of poisons to rainbow trout. Water Research, 2: 723-733.

BRUNGS, W.A. 1969. Chronic toxicity of zinc to the fathead minnow, Pimephales promelas Rafinesque. Trans. Am. Fish. Soc., 98(2): 273-279.

CARPENTER, K.E. 1927. The lethal action of soluble metal salts on fishes. Brit. J. Exp. Biol., 4: 378-390.

COWLEY, L.J. 1963. Exploits River Investigations - 1962. Pollution Surveys - Red Indian Lake and Exploits River. Report of the Fish Culture Development Branch, Dept. of Fisheries of Canada, St. John's, Nfld.

CRANDALL, C.A. and C.J. GOODNIGHT. 1962. Effects of sublethal concentrations of several toxicants on growth of the common guppy, Lebistes reticulatus. Limnol. Oc., 7(2): 233-239.

______________________________ 1963. The effects of sublethal concentrations of several toxicants to the common guppy, Lebistes reticulatus. Trans. Am. Mic. Soc., 82(1): 59-73.

DAWSON, A.B. 1935. The hemopoietic response in the catfish, Ameirus nebulosis, to chronic lead poisoning. Biol. Bull., 68(3): 335-346.

DORFMAN, D. and W.R. WHITWORTH. 1969. Effects of fluctuations of lead, temperature, and dissolved oxygen on the growth of brook trout. J. Fish. Res. Bd. Canada, 26(9): 2493-2501.

DOUDOROFF, P. 1957. Water quality requirements of fishes and effects of toxic substances. In The Physiology of Fishes. M.E. Brown (ed.). Vol. 2, Behaviour. Academic Press Inc., New York. P403-430.

DOUDOROFF, P. and M. KATZ. 1950. Critical review of literature on the toxicity of industrial wastes and their components to fish. I Alkalies, acids and inorganic gases. Sewage Ind. Wastes, 22(11): 1432-1458.

__________________________ 1953. Critical review of literature on the toxicity of industrial wastes and their components to fish. II The metals, as salts. Sewage Ind. Wastes, 25(7): 802-839.

____________ and C. E. WARREN. 1962. Dissolved oxygen requirements of fishes. In Biological problems in water pollution. U.S. Dept. of Health, Education and Welfare. 145-155.

EIFAC Working Party Report. 1965. Water quality criteria for European freshwater fish. Report on finely divided solids and inland fisheries. Int. J. Air Wat. Poll., 9: 151-168.

__________________________ 1969a. Water quality criteria for European freshwater fish - extreme pH values and inland fisheries. Water Research, 3: 593-611.

__________________________ 1969b. Water quality criteria for European freshwater fish - water temperature and inland fisheries. Water Research, 3(9): 645-662.

GILL, J.M., J.H. HUGUET and E.A. PEARSON. 1960. Submarine dispersal system for treated chemical wastes. J. Wat. Poll. Contr. Fed., 32: 858-867.

GRANDE, M. 1966. Effect of copper and zinc in salmonid fishes. In Advances in Water Pollution Research, Jaag, O., and H. Liebmann (ed.), Vol. I: 97-111.

HERBERT, D.W.M., D.H.M. JORDAN, and R. LLOYD. 1965. A study of some fishless rivers in the industrial midlands. J. Proc. of Inst. of Sew. Purif. 6: 569-579.

______________ and D.S. SHURBEN. 1964. The toxicity to fish of mixtures of poisons. Ann. Appl. Biol., 53(1): 33-41.

______________ and J.M. VANDYKE. 1964. The toxicity to fish of mixtures of poisons. II. Copper-ammonia and zinc-phenol mixtures. Ann. Appl. Biol., 53(3): 415-421.

HERRMANN, R.B., C.E. WARREN, and P. DOUDOROFF. 1962. Influence of oxygen concentration on the growth of juvenile coho salmon. Trans. Am. Fish. Soc., 91(2): 155-167.

HUBBS, C.L. and C. HUBBS. 1953. An improved graphical analysis and comparison of series of samples. Syst. Zool., 2: 49-56.

HUBBS, C.L. and A. PERLMUTTER. 1942. Biometric comparison of several samples, with particular reference to racial investigations. Am. Natur., 76: 582-592.

JONES, A.N. and W.R. HOWELLS. 1969. Recovery of the river Rheidol. Effluent Wat. Treat. J., 9(11): 605-610.

JONES, J.R.E. 1935. The toxic action of heavy metal salts on the threespined stickleback (Gasterosteus aculeatus). J. Exp. Biol., 12(2): 165-173.

__________ 1938. The relative toxicity of salts of lead, zinc and copper to the stickleback (Gasterosteus aculeatus) and the effect of calcium on the toxicity of lead and zinc salts. J. Exp. Biol., 15(3): 394-407.

LLOYD, R. 1960. The toxicity of zinc sulphate to rainbow trout. Ann. Appl. Biol., 48: 84-94.

__________ 1961a. The toxicity of mixtures of zinc and copper sulphates to rainbow trout (Salmo gairdnerii Richardson). Ann. Appl. Biol., 49: 535-538.

__________ 1961b. Effect of dissolved oxygen concentrations on the toxicity of several poisons to rainbow trout (Salmo gairdnerii Richardson). J. Exp. Biol., 38: 447-455.

__________ 1965. Factors that affect the tolerance of fish to heavy metal poisoning. 181-187. In Biological problems in water pollution. Trans. of the 1962 seminar. Public Health Service Publication No. 999-Wp-25.

MOUNT, D.I. 1966. The effect of total hardness and pH on acute toxicity of zinc to fish. Int. J. Air Wat. Poll., 10: 49-56.

__________ 1968. Chronic toxicity of copper to fathead minnows (Pimephales promelas, Rafinesque). Water Research, 2: 215-223.

__________ and C.E. STEPHEN. 1969. Chronic toxicity of copper to the fathead minnow (Pimephales promelas) in soft water. J. Fish. Res. Bd. Canada, 26(9): 2449-2457.

PICKERING, Q.H. 1968. Some effects of dissolved oxygen concentrations upon the toxicity of zinc to the bluegill, Lepomis macrochirus Raf. Water Research, 2: 187-194.

__________ and W.N. VIGOR. 1965. The acute toxicity of zinc to eggs and fry of the fathead minnow. Prog. Fish-Cult., 27(3): 153-157.

PIPPY, J.H.C. and G.M. HARE. 1969. Relationship of river pollution to bacterial infection in salmon (Salmo salar) and suckers (Catostomus commersonii). Trans. Am. Fish. Soc., 98(4): 685-690.

REPORT of the Res. Dev. Branch, Nfld. Region. 1964. Dept. of Fisheries and Forestry of Canada.

REIMER D.N. and S.J. TOTH. 1970. Adsorption of copper by clay minerals, Humic acid and bottom muds. J. American Water Works Ass. 62(3): 195-197.

SAUNDERS, R.L. and J.B. SPRAGUE. 1967. Effects of copper-zinc mining pollution on a spawning migration of Atlantic salmon. Water Research 1: 419-432.

SHAWINIGAN ENGINEERING CO. LTD. 1966. Effect on Energy production at Grand Falls and Bishop's Falls. Report for Newfoundland and Labrador Power Commission on Bay D'Espoir Power Project - Stage II. Victoria Lake and Lloyds River Diversions. 10 pp. + appendices.

______________________________ 1968. Water Resources Study of the Province of Newfoundland and Labrador for the Atlantic Development Board. Vol. 6A - River Basins. Report No. 3591-1-68.

SKIDMORE, J.F. 1964. Toxicity of zinc compounds to aquatic animals, with special reference to fish. Quart. Rev. Biol., 39(3): 227-248.

_____________ 1965. Resistance to zinc sulphate of the zebrafish (Brachydanio rerio) at different phases of its life history. Ann. Appl. Biol., 56(1): 47-53.

_____________ 1966. Resistance to zinc sulphate of Zebrafish (Brachydanio rerio) embryos after removal or rupture of the outer egg membrane. J. Fish. Res. Bd. Canada, 23(7): 1037-1041.

_____________ 1967. Oxygen uptake by Zebrafish of different ages in relation to zinc sulphate resistance. J. Fish. Res. Bd. Canada, 24(6): 1253-1267.

SPRAGUE, J.B. 1964. Lethal concentrations of copper and zinc for young Atlantic salmon. J. Fish. Res. Bd. Canada, 21(1): 17-26.

____________ 1968. Avoidance reactions of rainbow trout to zinc sulphate solutions. Water Research, 2: 367-372.

____________ and W.V. CARSON. 1963. Chemical conditions in the northwest Miramichi River during 1960, 1961 and 1962, including heavy metal concentrations. Manuscript report. Fish. Res. Bd. Canada. Biological Station, St. Andrews, N.B.

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 and Wat. Poll., 9: 531-543.

____________ and B.A. RAMSAY. 1965. Lethal levels of mixed copper-zinc solutions for juvenile salmon. J. Fish. Res. Bd. Canada, 22(2): 425-432.

WATER and WASTEWATER analysis procedures. 1966. Hach Chemical Co., Catalogue No. 9.

____________________________ 1967. Hach Chemical Co., Catalogue No. 10: 28-31, 47-48.

WEDEMEYER, G. 1968. Uptake and distribution of Zn^{65} in the Coho salmon egg. Comp. Biochem. Physiol., 26(1): 271-279.

APPENDIX 1

List of Tables

		Page
Table 1	Chemical and Physical Determinations, Station No. 1, Buchans Culvert - 1969	49
Table 2	Chemical and Physical Determinations, Station No. 2, Buchans Brook - 1969	50
Table 3	Chemical and Physical Determinations, Station 3, Millertown Dam - 1969	51
Table 4	Chemical and Physical Determinations, Station 4, 16 miles above Badger - 1969	51
Table 5	Chemical and Physical Determinations, Station No. 5, Above Grand Falls - 1969	52
Table 6	Chemical and Physical Determinations, Station No. 6, Bishop's Falls Trestle - 1969 .	52
Table 7	Chemical and Physical Determinations, Station No. 7, Bond Bridge - 1969	53
Table 8	Dissolved Oxygen Values in the Exploits River Below Grand Falls - July 25, 1969. River Flow - 4,000 cfs.	54
Table 9	Dissolved Oxygen Values in the Exploits River Below Grand Falls - Aug. 8, 1969. River Flow - 4,332 cfs.	55
Table 10	Dissolved Oxygen Values in the Exploits River Below Grand Falls - Sept. 30, 1969. River Flow - 6,110 cfs.	56
Table 11	Dissolved Oxygen Values in the Exploits River Below Grand Falls - Oct. 2, 1969. River Flow - 5,335 cfs.	57

Table 1 - Chemical and Physical Determinations, Station No. 1, Buchans Culvert - 1969

Date	Temp. °C	pH	Hardness mg/1	Spec. Cond.	Turb. J.T.U.	Ttl. Alk. mg/1	Cu. µg/1	ILL.	Zn-µg/1	ILL.	Pb-µg/1	ILL.	Total ILL.	River Flow cfs.
July 24	18.6	6.73	184.0	315.0	4.1	10.0	40.0	0.832	370.0	0.618	-	-	1.450	-
Aug. 5	20.8	7.40	140.0	260.0	12.0	10.0	12.0	0.250	448.0	0.744	-	-	0.994	-
Aug. 18	18.9	6.70	132.0	225.0	5.4	13.0	36.0	0.750	4200.0	7.000	133.0	0.391	7.883	-
Aug. 25	12.8	7.02	182.0	290.0	5.6	18.0	25.0	0.521	660.0	1.100	133.0	0.391	2.012	-
Sept. 9	22.0	6.90	134.0	220.0	7.3	20.0	52.0	1.081	750.0	1.250	12.0	0.035	2.366	-
Sept 1	-	6.92	170.0	280.0	17.0	27.0	70.0	1.459	270.0	0.450	120.0	0.353	2.262	-
Sept.26	-	6.62	100.0	188.0	125.0	8.0	32.0	0.667	410.0	0.682	120.0	0.353	1.702	-
Oct. 1	7.8	6.78	106.0	190.0	25.0	16.0	33.0	0.687	620.0	1.033	150.0	0.441	2.101	-
Oct. 10	-	6.77	106.0	178.0	64.0	18.0	30.0	0.625	218.0	0.364	150.0	0.441	1.430	-
Oct. 17	-	7.28	110.0	192.0	37.0	18.0	5.0	0.104	325.0	0.542	120.0	0.353	0.999	-
Oct. 24	-	6.60	102.0	-	-	-	18.0	0.375	336.0	0.560	100.0	0.294	1.229	-
Nov. 7	-	6.55	122.0	220.0	21.0	16.0	38.0	0.791	470.0	0.782	22.0	0.065	1.638	-
Nov. 13	-	6.15	100.0	165.0	320.0	10.0	33.0	0.687	125.0	0.208	22.0	0.065	0.960	-
Nov. 21	-	6.38	221.0	220.0	53.0	16.0	43.0	0.895	580.0	0.965	22.0	0.065	1.925	-
Nov. 28	-	6.66	80.0	137.0	65.0	12.0	5.0	0.104	66.0	0.110	22.0	0.065	0.279	-
Dec. 12	-	6.63	80.0	142.0	85.0	12.0	45.0	0.937	880.0	1.468	-	-	2.405	-
Dec. -9	-	6.09	110.0	166.0	175.0	8.0	61.0	1.270	760.0	1.264	22.0	0.065	2.599	-
Average	-	6.71	128.17	211.75	63.8	14.5	34.0	0.708	675.76	1.126	82.0	0.241	2.075	-

Table 2 - Chemical and Physical Determinations, Station No. 2, Buchans Brook - 1969

Date	Temp. °C.	pH	Hardness mg/l	Spec. Cond.	Turb. J.T.U.	Ttl. Alk. mg/l	Cu. µg/l	ILL.	Zn-µg/l	ILL.	Pb-µg/l	ILL.	Total ILL.	River Flow cfs.
July 24	18.6	6.90	18.0	19.0	-	6.0	93.0	2.910	475.0	1.130	-	-	4.040	-
Aug. 5	20.8	7.14	22.0	47.0	2.7	8.0	12.0	0.250	372.0	0.626	-	-	0.870	-
Aug. 18	19.5	6.80	14.0	28.0	5.8	8.0	9.0	0.272	115.0	0.273	12.0	0.035	0.580	-
Aug. 25	13.3	6.95	26.0	50.0	2.4	8.0	25.0	0.520	840.0	1.400	290.0	0.850	2.770	-
Sept. 9	-	7.10	30.0	61.0	6.1	8.0	30.0	0.625	1096.0	1.820	12.0	0.035	2.480	-
Sept. 11	-	6.73	38.0	49.0	2.7	12.0	22.0	0.457	975.0	1.623	12.0	0.035	2.115	-
Sept. 26	-	6.13	8.0	15.0	1.9	6.0	38.0	1.190	161.0	0.372	120.0	0.353	1.925	-
Oct. 1	8.4	6.56	12.0	25.0	2.5	8.0	18.0	0.561	290.0	0.690	290.0	0.850	2.101	-
Oct. 10	-	7.13	14.0	29.0	2.9	8.0	42.0	1.318	415.0	0.987	255.0	0.750	3.055	-
Oct. 17	-	7.21	16.0	31.0	4.7	9.0	5.0	0.156	353.0	0.840	150.0	0.441	1.437	-
Oct. 24	-	6.62	16.0	39.0	4.2	8.0	21.0	0.656	500.0	1.190	-	-	1.846	-
Nov. 7	-	5.83	11.0	25.0	3.2	3.0	10.0	0.314	258.0	0.613	-	-	0.927	-
Nov. 13	-	6.22	15.0	32.0	30.0	5.0	23.0	0.718	605.0	1.440	22.0	0.065	2.223	-
Nov. 21	-	6.40	16.0	37.0	3.5	6.0	22.0	0.687	760.0	1.805	22.0	0.065	2.557	-
Nov. 28	-	5.85	15.0	36.0	4.0	3.0	34.0	1.082	650.0	1.700	22.0	0.065	2.847	-
Dec. 12	-	6.41	13.0	27.5	2.0	6.0	54.0	1.684	662.0	1.580	22.0	0.065	3.329	-
Dec. 19	-	6.43	20.0	28.0	3.8	7.0	46.0	1.440	525.0	1.250	22.0	0.065	2.755	-
Average	-	6.61	17.88	34.03	5.15	7.00	29.64	0.873	532.58	1.138	96.23	.283	2.226	-

Table 3 - Chemical and Physical Determinations, Station 3, Millertown Dam - 1969

Date	Temp. °C	pH	Hardness Mg/1	Spec. Cond.	Turb. J.T.U.	Ttl. Alk. mg.1	Cu. µg/1	ILL.	Zn-µg/1	ILL.	Pb-µg/1	ILL.	Combined ILL.	River Flow cfs
July 24	15.3	6.90	8.0	18.0	0.70	8.0	82.0	2.560	160.0	0.380	-	-	2.940	4590
Aug. 5	16.1	6.80	9.0	29.0	0.80	6.0	13.0	0.405	125.0	0.297	-	-	0.702	4330
Aug. 18	16.1	6.70	9.0	17.0	0.70	6.0	4.0	0.138	91.0	0.216	12.0	0.035	0.389	5290
Aug. 25	15.0	6.85	8.0	18.0	0.60	6.0	4.0	0.138	61.0	0.145	120.0	0.353	0.636	4140
Sept. 25	12.5	6.80	12.0	20.0	0.85	8.0	257.0	8.050	428.0	1.020	14.0	0.041	9.111	4840
Oct. 1	10.6	6.75	9.0	18.0	0.80	6.0	85.0	2.660	280.0	0.642	120.0	0.353	3.655	5880
Nov. 26	-	6.34	10.0	22.0	0.50	6.0	12.0	0.375	47.0	0.112	22.0	0.065	0.552	6670
Average	-	6.73	9.28	20.28	0.71	6.57	65.28	2.040	170.28	0.405	57.60	0.169	2.569	5105

Table 4 - Chemical and Physical Determinations, Station 4, 16 miles above Badger - 1969

Date	Temp. °C	pH	Hardness mg/1	Spec. Cond.	Turb. J.T.U.	Ttl. Alk. mg/1	Cu. µg/1	ILL	Zn-µg/1	ILL.	Pb-µg/1	ILL.	Combined ILL.	River Flow cfs
July 24	15.8	6.95	8.0	17.0	0.8	6.0	48.0	1.470	96.0	0.229	-	-	1.699	4590
Aug. 5	16.7	6.80	7.0	18.0	1.0	6.0	7.0	0.219	96.0	0.229	-	-	0.448	4470
Aug. 18	18.9	6.65	11.0	19.0	0.8	7.0	trace	-	36.0	0.085	12.0	0.035	0.120	5290
Aug. 25	13.9	6.90	8.0	18.0	0.7	7.0	5.0	0.156	58.0	0.138	12.0	0.035	0.329	4140
Sept.25	12.0	6.80	10.0	23.0	0.9	12.0	7.0	0.219	58.0	0.138	120.0	0.353	0.710	4840
Oct. 1	8.9	6.41	10.0	18.0	0.75	8.0	10.0	0.314	58.0	0.138	12.0	0.035	0.487	5880
Nov. 26	-	6.17	9.0	20.0	0.90	6.0	0	-	39.0	0.093	22.0	0.065	0.158	6670
Average	-	6.67	9.0	19.0	0.84	7.4	11.0	0.339	63.0	0.150	35.60	0.104	0.565	5105

Table 5 - Chemical and Physical Determinations, Station No. 5, Above Grand Falls - 1969

Date	Temp. °C	pH	Hardness mg/l	Spec. Cond.	Turb. J.T.U.	Ttl. Alk. mg/l	Cu µg/l	ILL.	Zn-µg/l	ILL.	Pb-µg/l	ILL.	Combined ILL.	River Flow cfs
July 24	16.1	6.82	8.0	17.5	0.7	6.0	14.0	0.438	88.0	0.210	-	-	0.648	4590
Aug. 5	17.5	6.80	7.0	18.0	1.0	6.0	7.0	0.219	96.0	0.229	-	-	0.448	4470
Aug. 18	19.5	6.50	9.0	17.0	1.3	8.0	2.0	0.063	55.0	0.131	12.0	0.035	0.229	5290
Aug. 25	15.0	7.09	8.0	18.0	0.7	6.0	trace	-	36.0	0.085	12.0	0.035	0.120	4140
Sept. 25	13.0	6.75	8.0	18.0	0.5	8.0	14.0	0.438	55.0	0.131	12.0	0.035	0.604	4840
Oct 1	9.5	6.73	14.0	18.0	0.66	8.0	33.0	1.030	62.0	0.147	12.0	0.035	1.212	5880
Nov. 26	-	6.22	9.0	19.0	0.8	6.5	0	0	21.0	0.050	22.0	0.065	0.119	6670
Average	-	6.70	9.0	17.9	0.80	6.9	10.0	0.313	59.00	0.140	14.0	0.041	0.482	5105

Table 6 - Chemical and Physical Determinations, Station No. 6, Bishop's Falls Trestle - 1969

Date	Temp. °C	pH	Hardness mg/l	Spec. Cond.	Turb. J.T.U.	Ttl. Alk. mg/l	Cu µg/l	ILL.	Zn-µg/l	ILL.	Pb-µg/l	ILL.	Combined ILL.	River Flow cfs
July 25	14.5	6.60	10.0	26.0	1.60	9.0	101.0	3.160	665.0	1.580	27.0	0.079	4.819	4000
Oct. 1	10.0	6.45	12.0	26.0	1.40	7.0	9.0	0.281	58.0	0.138	12.0	0.035	0.454	5880
Nov 26	-	6.22	9.0	19.0	0.80	6.5	2.0	0.0625	10.0	0.0238	0.0	-	0.0863	6670
Average	-	6.42	10.33	23.7	1.27	7.50	37.3	1.165	244.3	0.580	13.0	0.038	1.786	5516

Table 7 - Chemical and Physical Determinations, Station No. 7, Bond Bridge - 1969

Date	Temp. °C	pH	Hardness mg/l	Spec. Cond.	Turb. J.T.U.	Ttl. Alk. mg/l	Cu µg/l	ILL.	Zn-µg/l	ILL.	Pb-µg/l	ILL.	Combined ILL.	River Flow cfs
July 24	16.1	6.40	8.0	23.0	1.20	4.0	trace	-	88.0	0.210	-	-	0.210	4590
Aug. 5	18.3	6.32	8.0	25.0	1.70	6.0	4.0	0.125	80.0	0.190	-	-	0.315	4470
Aug. 18	18.9	6.40	10.0	26.0	1.50	8.0	trace	-	33.0	0.079	12.0	0.035	0.114	5290
Aug. 25	15.1	6.95	10.0	25.0	1.40	6.0	trace	-	33.0	0.079	12.0	0.035	0.114	4140
Se[illegible] 25	14.2	6.30	10.0	28.0	1.15	8.0	9.0	0.281	52.0	0.124	12.0	0.035	0.440	4840
Oct. 1	10.5	6.35	12.0	25.0	1.80	10.0	11.0	0.344	52.0	0.124	120.0	0.353	0.821	5880
Nov. 26	-	5.87	10.0	25.0	1.70	7.0	13.0	0.406	13.0	0.031	22.0	.065	0.502	6670
Average	-	6.37	9.71	25.2	1.49	7.0	5.28	0.165	50.14	0.119	35.60	0.105	0.375	5105

Table 8 - Dissolved Oxygen values in the Exploits River below Grand Falls - July 25, 1969.

River Flow - 4000 cfs.

Station	Depth	Morning			Afternoon			Evening		
		Temp. °C	D.O. mg/1	Percent Saturation	Temp. °C	D.O. mg/1	Percent Saturation	Temp. °C	D.O. mg.1	Percent Saturation
Price Bridge (0 miles)	S	18.5	9.4	100.0	21.0	8.2	94.5	22.0 21.2	8.0 8.0	93.8 92.8
Du (1.8 miles)	S	16.5	9.2	97.0	21.1	8.7	100.0	21.0	7.5	86.7
	B	16.5	9.2	97.0	-	-	-	-	-	-
Fox Farm (7.1 miles)	S	18.2	8.2	90.0	20.9	6.7	77.0	21.1	7.2	83.1
	B	18.0	7.8	85.0	21.0	7.3	84.0	22.2	6.6	77.8
Trestle (10.6 miles)	S	21.5	8.0	93.0	22.0	6.7	78.0	21.2	7.2	83.3
	B	21.2	7.2	83.0	22.0	6.7	78.0	21.0	7.0	80.9
Bond Bridge (11.7 miles)	S-right	21.5	7.5	83.3	20.9	5.4	62.0	21.5	7.1	82.3
	S-left	-	-	-	-	-	-	21.0	7.0	80.9

Table 9 - Dissolved Oxygen values in the Exploits River below Grand Falls - Aug. 8, 1969

River Flow - 4332 cfs.

Station	Depth	Morning			Afternoon			Evening		
		Temp. °C	D.O. mg/1	Percent Saturation	Temp. °C	D.O. mg/1	Percent Saturation	Temp. °C	D.O. mg/1	Percent Saturation
Price Bridge (0 miles)	S	16.7	8.2	87.0	17.2	8.5	91.0	19.4	8.4	94.0
Dump (1.8 miles)	S	16.1	6.0	63.0	16.7	8.5	90.0	20.6	8.7	99.0
Fox Farm (7.1 miles)	S	17.2	7.7	82.5	17.8	7.7	83.0	21.1	8.2	94.5
	B	16.7	7.2	76.0	17.2	7.6	82.0	18.9	7.5	83.0
Bishop's Falls Trestle (10.6 miles)	S	17.8	7.0	76.0	19.7	7.1	80.0	21.4	7.1	82.5
	B	18.6	5.05	56.5	17.5	7.2	78.5	20.9	6.9	79.0
Bond Bridge	S-right	21.5	7.5	83.3	20.9	5.4	62.0	21.5	7.1	82.3
	S-left	-	-	-	-	-	-	21.0	7.0	80.9

Table 10 - Dissolved Oxygen values in the Exploits River below Grand Falls - Sept. 30, 1969

River Flow - 6110 cfs.

Station	Depth	Morning			Afternoon			Evening		
		Temp. °C	D.O. mg/l	Percent Saturation	Temp. °C	D.O. mg/l	Percent Saturation	Temp. °C	D.O. mg/l	Percent Saturation
Price Bridge (0 miles)	S-left	11.1	10.4	97.5	10.5	10.6	98.4	10.5	10.1	93.6
	S-right	11.1	10.5	98.5	10.5	10.85	100	11.1	10.1	94.6
Dur[illegible] (1.[illegible] miles)	S	10.8	10.2	95.0	11.1	10.3	96.6	10.5	10.0	92.9
Fox Farm (7.1 miles)	S	11.1	9.35	87.7	10.8	9.45	87.1	10.5	10.0	92.9
Bishop's Falls Trestle (10.6 miles)	S	10.5	9.9	92.0	11.1	9.65	90.6	11.65	9.4	89.3
	B	10.3	9.1	84.0	11.1	9.95	93.2	11.40	8.5	80.5
Bond Bridge (11.7 miles)	S-right	10.5	9.4	87.3	10.5	9.8	91.0	11.1	10.2	95.8
	S-left	10.5	9.9	91.8	10.5	8.6	79.8	11.1	9.5	89.3

Table 11 - Dissolved Oxygen values in the Exploits River below Grand Falls - Oct. 2, 1969

River Flow - 5335 cfs.

Station	Depth	Morning			Afternoon			Evening		
		Temp. °C	D.O. mg/1	Percent Saturation	Temp. °C.	D.O. mg/1	Percent Saturation	Temp. °C	D.O. mg/1	Percent Saturation
Prince Bridge	S-left	10.0	9.30	85.0	9.45	10.20	92.5	9.45	10.5	95.3
(0 miles)	S-right	10.0	9.35	85.5	9.45	10.20	92.5	9.45	10.1	91.6
Dump (1.8 miles)	S	9.45	9.80	89.0	9.45	9.90	89.9	9.45	9.9	89.8
Fox Farm (7.1 miles)	S	9.45	8.40	76.3	9.45	8.85	80.4	9.45	8.55	77.5
Bishop's Falls Trestle	S	9.45	9.50	86.2	9.45	9.60	87.1	9.45	9.60	87.0
(10.6 miles)	B	9.45	9.55	86.6	9.45	8.55	77.6	9.45	9.33	84.9
Bond Bridge	S-right	9.45	9.70	88.0	9.45	9.75	88.5	9.45	9.80	89.0
(11.7 miles)	S-left	9.45	9.60	87.0	9.45	9.60	87.1	9.45	9.70	88.0

Appendix 2

The calculation of the amount of heavy metals entering Red Indian Lake and the Exploits River was carried out by converting the mean flow of Buchans Brook and the Exploits River at Millertown from cubic feet per second to liters per day. This figure was then multiplied by the average metal concentration in ug/liter to obtain the kilograms per day of metal.

1) Conversion of cubic feet per second to liters per day for Buchans Brook.

   a) 1 cubic ft. per second = 7.4804 U.S. gals. per second

   b) Average daily outflow at Buchans Brook = 186 x 7.4804 x 3600 x 24 = 116,335,008 U.S. gals. per day.

   c) 116,335,008 x 3.785 = 440,327,975 liters per day.

2) Calculations of average amount of dissolved copper entering Red Indian Lake via Buchans Brook during 1969.

   a) Average flow of Buchans Brook per day = 440,327,975 liters per day

   b) Average copper concentration = 29.64 ug/1

   c) Average daily discharge of dissolved copper = 29.64 x 440,327,975 = 13.01 kg/day.