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PACIFIC AND YUKON REGION

IMPACT OF COPPER SULPHATE MOLLUSCICIDE TREATMENTS ON CULTUS LAKE, B.C.

Regional Program Report: 82-08

by

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ABSTRACT

In March, 1978, studies were conducted at Cultus Lake, B.C., by the Department of Fisheries and Oceans (DFO) and the Environmental Protection Service (EPS) of Environment Canada. The objective of the studies was to determine the environmental impact of copper sulphate ($CuSO_4$) treatments used to kill the intermediate snail hosts of the Swimmer's Itch parasite (*Trichobilharzia* sp.). In addition, surveys of the incidence of Swimmer's Itch were conducted by DFO to assess the extent of the itch problem in the region.

Water, sediment, and fish samples were collected from copper sulphate treated and non-treated control areas. The post-treatment water column was contaminated with copper for a short time at levels close to the LC_{50} of fish (0.13 mg/l max. for dissolved copper). However, within 24 hours copper concentrations dropped to background levels (less than 0.01 mg/l). Copper residues in sediments peaked at 2830 mg/kg in treatment areas, and then declined to values averaging 839 mg/kg. Background sediment levels in non-treated areas averaged 19 mg/kg. Resident fish netted in treatment areas did not contain significantly higher copper concentrations than fish sampled in non-treated control areas.

A questionnaire survey of recreational users of Cultus Lake indicated no significant difference in the incidence of Swimmer's Itch between one $CuSO_4$ treatment and three non-treatment years. Incidence of itch varied at different locations in Cultus Lake, was more prevalent in young than old people, and some people appeared to show a greater susceptibility to the parasite. The study further showed that the itch had little effect in decreasing tourist demand on the lake system.

RÉSUMÉ

En mars 1978, le ministère des Pêches et des Océans (P et O) et le Service de la protection de l'environnement (SPE) du ministère de l'environnement (Canada) ont procédé à des études à Cultus Lake (C.-B.). Il s'agissait de déterminer l'incidence sur l'environnement des traitements au sulfate de cuivre ($CuSO_4$) pour tuer les hélices aquatiques, hôtes intermédiaires de la dermatite à schistomoses (trichobilharzia sp.). En outre, les P et O ont effectué des études sur l'incidence de la dermatite à schistomoses pour en évaluer l'ampleur dans la région.

On a pris des échantillons d'eau, de sédiments et de poissons à la fois dans des secteurs traités et des secteurs non traités au sulfate de cuivre. On a constaté que la collone d'eau traitée restait eontaminée par le cuivre pendant peu de temps, à des niveaux se rapprochant du niveau D.L. 50 des poissons (0.13 mg/l max de cuivre dissous). Cependant, en moins de vingtquatre heures on a constaté que la concentration de cuivre était redescendue au niveau normal (moins de 0.01 mg/l). La concentration de cuivre relevée dans les sédiments a atteint jusqu'à 2830 mg/kg dans les secteurs traités, pour redescendre ensuite à des niveaux avoisinant 839 mg/kg. La concentration de cuivre dans les sédiments des zones non traitées s'élevait à 19 mg/kg en moyenne. On a constaté que les poissons capturés dans les secteurs traités ne contenaient pas un pourcentage de cuivre notablement plus élevé que pour ceux qui étaient pris dans les secteurs non traités.

Un enquête faite sur les usagers du lac Cultus n'a révélé aucune différence notable en ce qui concerne la fréquence des cas de dermatite entre une année avec traitement au sulfate de cuivre et trois années sans traitement. On a constaté que la fréquence des cas variait selon les endroits du lac Cultus, était plus élevée dans la population jeune que chez les plus âgés et que certaines personnes étaient plus sujettes que d'autres à cette affection. L'étude a en outre révélé que la dermatite avait peu d'effets sur le taux de fréquentation du lac par les touristes.

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CONCLUSIONS

1. Elevated post-treatment dissolved copper levels were found in Cultus Lake surface and bottom waters (0.02-0.04 mg/l and 0.02-0.13 mg/l respectively) for several hours following the application of copper sulphate at the rate of 2 lbs/1000 ft^2 (96.5 kg/ha).

2. Dissolved copper concentrations approached the known LC_{50} of fish (0.02-0.516 mg/l), but their lethal or sub-lethal effects on fish were not determined in this study. Results from International Pacific Salmon Fisheries Commission monitoring of Cultus Lake indicate that salmon smolt mortalities have occurred from $CuSO_4$ applications in this lake.

3. Sediments in areas historically treated with copper sulphate were contaminated with copper to levels well above background levels. Consequently studies on the diversity of benthic communities would be desirable in both treated and non-treated control areas.

4. Resident fish netted in treatment areas did not contain significantly higher copper concentrations than fish sampled in non-treated control areas.

5. A questionnaire survey of recreational users of Cultus Lake indicated no significant difference in the incidence of Swimmer's Itch between one $CuSO_4$ treatment and three non-treatment years.

6. The same questionnaire survey showed that the itch had little effect in decreasing tourist demand in the Cultus Lake area.

1 INTRODUCTION

For more than two decades, copper sulphate ($CuSO_4$) has been used annually in Cultus Lake, B.C. to control snail hosts of Trichobilharzia sp., the causative agent of Swimmer's Itch, Schistosome dermatitis (Reid, 1975 and Boyd, 1976). It is estimated that an annual copper sulphate application of approximately 4000 lbs has resulted in a total deposit of 20 tons of elemental copper in the lake. Consequently, both federal and provincial environmental agencies were concerned about possible elevated lake and sediment copper levels and deleterious effects on aquatic biota.

From 1977 through 1980, a number of studies were conducted to determine the impacts of these annual molluscicide applications. The Environmental Protection Service (EPS) of Environment Canada determined the extent of contamination in Cultus Lake sediment and water, following copper sulphate applications to specific areas. The Habitat Protection Division (HPD) of Fisheries and Oceans Canada examined the effects of lake treatments on fish and the incidence of the Swimmer's Itch problem in the region.

1.1 Causal Agent of Swimmer's Itch

Schistosome dermatitis is a hypersensitive response by human skin to the penetration of the larval stage of an aquatic parasite, Trichobilharzia sp. (Shkurhan, 1971). This organism is a trematode worm which alternatively lives only in snail and waterfowl hosts. Adult male and female worms inhabit the blood vessels of ducks. The trematode eggs, which have sharp spines, pass through the duck blood vessel walls into the bladder or intestines and are discharged in urine or feces. The eggs hatch into free swimming ciliated larval forms called miracidia, (Hickman, 1961). Miracidia are viable for about 12 hours, during which time they must find a snail to penetrate in order to survive. When they find a snail susceptible to histolysis, they burrow into the soft flesh and transform into sporocysts, each of which in turn produces many daughter sporocysts that become cercariae. Each cercaria has suckers and a tail which provide it with mobility to escape from the snail and seek the skin of waterfowl to penetrate and enter. The cercariae are viable in open water for about 24 hours. If a human is encountered instead of waterfowl, they will indiscriminately invade the skin, but are always destroyed before further parasitization is accomplished.

If an allergic response occurs, it is detected as a prickling sensation soon after the bather leaves the water. After an hour or so the irritation subsides, only to return later as severe itching, possibly with edema and pustules. The reaction reaches its climax by the second or third day but on occasion will last longer. Infection is most common in July and August when people frequent the aquatic environment.

1.2 Attempts to Control Swimmer's Itch

At Cultus Lake a control program for *Schistosome dermatitis* attempted to destroy the intermediate snail hosts of the infectious agent. From the early 1950's through 1974, snail - infested areas were treated annually, prior to April 1, with the molluscicide copper sulphate. Applications were discontinued from 1975 through 1977, but were resumed in 1978 for one more summer (Harrison, 1979a).

This method of control has certain environmental implications. First, there was concern that repeated copper sulphate treatments would result in lethal and sub-lethal effects on fish and other pelagic biota in the water column. Secondly, concerns existed over the possible concentration of copper and its salts in lake sediments and concomitant negative impacts on the benthic invertebrate and fish communities.

1.3 Water Chemistry of Copper Sulphate

Copper sulphate ($CuSO_4$ and $CuSO_4 \cdot 5H_2O$) is highly soluble in water (i.e. it dissociates into its ionic states very readily):

$$CuSO_4 \rightleftharpoons Cu^{++} + SO_4^{=}$$

In natural waters with pH of 7.0 or above, cupric ions (Cu^{++}) will quickly precipitate as hydroxides or basic copper carbonate (McKee and Wolf, 1963):

$$H_2O + Cu^{++} + 2OH^{-} \rightleftharpoons Cu(OH)_2 \cdot 2H_2O$$

$$H_2O + Cu^{++} + CO_3 \rightleftharpoons CuCO_3 \cdot Cu(OH)_2 \cdot 2H_2O$$

These compounds are removed from the water column by adsorption to bottom mud or by sedimentation; as a result, the substrate becomes a reservoir of copper salts which, through slow dissolution, can release copper ions into the water.

The concentration of copper ions in natural waters depends on such factors as water hardness, temperature, dissolved oxygen, and pH (Pagenkopf et al., 1974; O'Shea and Mancy, 1978). Of these, hardness is considered to be of primary importance in complexing of ions such as Cu^{++} and $CuOH^{+}$. Howard et al. (1963) found that concentrations of ionic copper varied inversely with hardness. Pagenkopf et al. (1974) explained that increasing water hardness is accompanied by an increase in alkalinity providing carbonate ions for copper complexation, and this in turn affects the concentration of free Cu^{++} and $CuOH^{+}$. To illustrate this, relevant chemical equilibria all of which are dependent on pH and temperature, are outlined below; this assumes no contributions to system chemistry from sodium or potassium:

$$H^{+} + OH^{-} \rightleftharpoons H_2O$$

$$H^{+} + CO_3^{=} \rightleftharpoons HCO_3^{-}$$

$$2H^{+} + CO_3^{=} \rightleftharpoons H_2CO_3$$

$$Mg^{++} + CO_3^{=} \rightleftharpoons MgCO_3$$

$$Ca^{++} + CO_3^{=} \rightleftharpoons CaCO_3$$

$$Ca^{++} + CO_3^{=} + H^{+} \rightleftharpoons CaHCO_3^{+}$$

$$Cu^{++} + CO_3^{=} \rightleftharpoons CuCO_3$$
$$Cu^{++} + 2CO_3^{=} \rightleftharpoons Cu(CO_3)_2^{=}$$
$$Cu^{++} + CO_3^{=} + H^{+} \rightleftharpoons CuHCO_3^{+}$$
$$Cu^{++} + H_2O \rightleftharpoons CuOH^{+}\downarrow + H^{+}$$
$$2Cu^{++} + 2H_2O \rightleftharpoons Cu_2(OH)_2^{++}\downarrow + 2H^{+}$$
$$Cu^{++} + Cl^{-} \rightleftharpoons CuCl^{+}$$
$$Cu^{++} + SO_4^{=} \rightleftharpoons CuSO_4$$

From these equations it is obvious that Cu^{++} ions in water can form a number of complexes with carbonate and hydroxide ions. In certain cases, however, organic compounds such as humic and fluvic acids can also complex copper ions and affect their toxicity (Wildish, 1971; Carson and Carson, 1972; Sylva, 1976).

1.4 Mode of Action of Copper Sulphate on Aquatic Snails

The biochemical mechanism of copper sulphate toxicity to aquatic organisms is not clearly understood; however, Jones (1938) largely implicates dissolved copper in its ionic form (Cu^{++}) as the toxic agent. Copper salts kill aquatic snails because the metal precipitates as bicarbonate on the lake bottom, forming a reservoir of gradually redissolving cupric ions (Pagenkopf et al., 1974 and Howard et al., 1963). Therefore, water hardness, measured as mg/l of carbonate, is a major determinant of copper sulphate molluscicidal effectiveness, because it regulates how much free Cu^{++} is in solution. In very hard waters, granular cupric carbonate dissolves too slowly to release levels of Cu^{++} toxic to snails.

In natural waters where hardness can vary from 10 to 50 mg/l, free ionic copper concentrations can range from 6.8 to 0.3 mg/l, respectively. These levels are highly toxic to a variety of organisms (U.S. EPA, 1972, p. 453). Excess copper ions can also form bicarbonate which is capable of remaining suspended in the water column, releasing free Cu^{++} ions as equilibrium conditions shift.

1.5 Impact of Copper Sulphate on Non-Target Invertebrates

Very little information is available concerning the effects of copper sulphate on aquatic invertebrates. Small crustacea such as *Daphnia* sp. seem to be extremely sensitive to this substance; they succumb to copper concentrations varying from 0.01 to 0.08 mg/l (Jones, 1938; Anderson, 1950). Most aquatic algae and protozoa are also quite sensitive, dying from dosages of 1.0 mg/l or less (Hale, 1930). However, insecta, such as *Chironomus* sp. and *Simulium* sp. larvae, are not harmed by concentrations of 5.0 to 100 mg/l (Buchmann, 1933; Brown, 1932, Turner, 1959). Toxicity in these cases undoubtedly is also influenced by pH, temperature and hardness.

1.6 Impact of Copper Sulphate on Fish

Addition of copper salts to water also affects fish variably according to the chemical characteristics of the environment. Unfortunately, most of the literature concerning effects of copper on fish does not include consideration of anionic effects.

The results of a number of fish bioassay studies shown in Table 1 indicate that the species tested were quite sensitive to copper.

Laboratory studies have demonstrated that ionic copper (Cu^{++}) and to a lesser extent the ionized hydroxides, $CuOH^{+}$ and $Cu_2 OH_2^{++}$, are the copper species most toxic to fish (Pagenkopf *et al*., 1974; Howarth and Sprague, 1978). Furthermore, concentrations of these species are largely determined by water pH, alkalinity, and hardness. Copper is more concentrated and more highly toxic to fish in soft water than in hard alkaline water where its ionic form is complexed and precipitated by carbonates and hydroxides. Further, complexes of copper ions with organic compounds can reduce copper toxicity to fish (Wildish, 1971; Carson and Carson, 1972; Sylva, 1976). Therefore assessments of copper toxicity must take into consideration the effects of copper complexes (Sylva, 1976; Howarth and Sprague, 1978).

TABLE 1 ACUTE TOXICITY OF COPPER (LC_{50}) TO DIFFERENT FISH IN WATERS OF DIFFERENT QUALITY

Species	Size/ Age	Toxicant	LC_{50} Cu Concentration (mg/l)	Exposure Period (hours)	Type of Bioassay*	Temp. C°	pH	Alkalinity	Hardness	Reference**
Rainbow trout (*Salmo gairdneri*)	1.4 g	$CuSO_4$	0.030	96	FT	15	8	unknown	31	1
	1.5 g	$CuSO_4$	0.048	96	FT	15	7	unknown	100	1
	6.6 g	$CuSO_4$	0.298	96	FT	15	7	unknown	361	1
	1.8 g	$CuSO_4$	0.516	96	FT	15	8	unknown	371	1
	1 year	$CuCl_2$	0.060	96	S	10	6.8-7.9	68-78	89-99	2
	7 g	copper	0.020	96	FT	11.6-12.4	6.8-7.0	17-26	20-25	3
	juveniles	$CuSO_4$	1.250	96	S	15.0-15.6	7.3-7.4	200	290	3
	juveniles	$CuSO_4$	0.890	96	S	15	7.3-7.4	200	290	3
	unknown	copper	0.4-0.5	96	S	15	7.6	200	320	3
Chinook salmon (*Oncorhynchus tshawytscha*)	alevins	copper	0.031	96	FT	11.1-12.0	6.8-7.0	17-26	20-25	3
	unknown	$Cu(NO_3)_2$	0.178	L96	S	9.5	7.75-8.85	unknown	80	3
Coho salmon (*Oncorhynchus kisutch*)	unknown	$CuSO_4$	0.450	96	S	10	7.75-8.85	unknown	40	3
Brook trout (*Salvelinus fontinalis*)	14 months	copper	0. 100	96	FT	12±1	7.5	41.6	45	4

* (FT) Flow through; (S) Static

** (1) Howarth and Sprague, 1978; (2) Lorz and McPherson, 1976; (3) U.S. Environmental Protection Agency, 1976; (4) McKim and Benoit, 1971

2 STUDY AREAS

Cultus Lake is located in the Fraser Valley near Chilliwack, B.C, (Figures 1 and 2). Its outlet, Sweltzer Creek, discharges to the Chilliwack River, which is a tributary of the Fraser River. The Lake is oblong in shape, approximately 4.8 km long, 1.3 km wide and 6.3 km^2 in area.

Chilliwack Lake (Figure 3) was used as a control in this study. It is located only 19 km east of Cultus Lake, and is slightly larger in size.

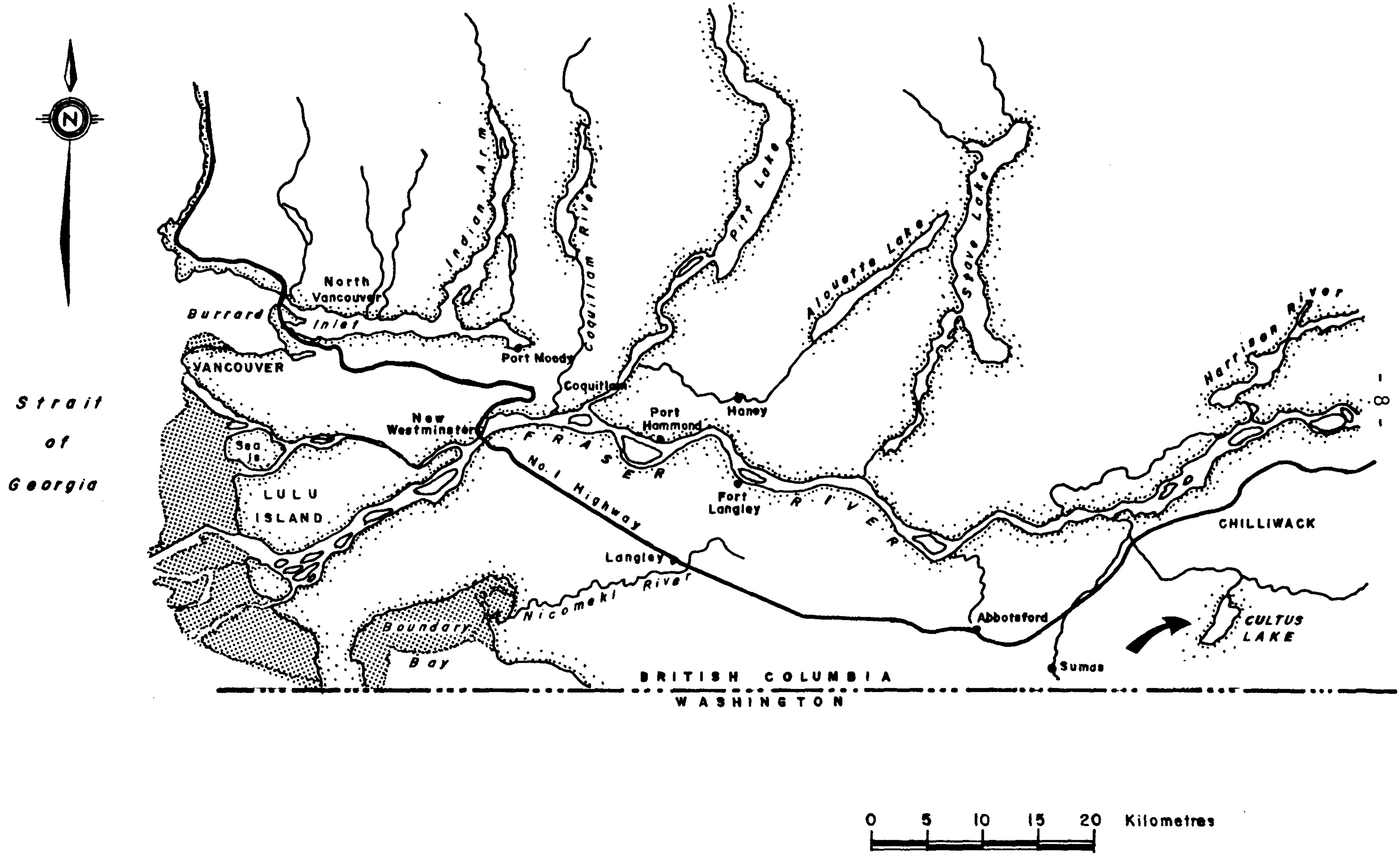

FIGURE I CULTUS LAKE LOCATION MAP

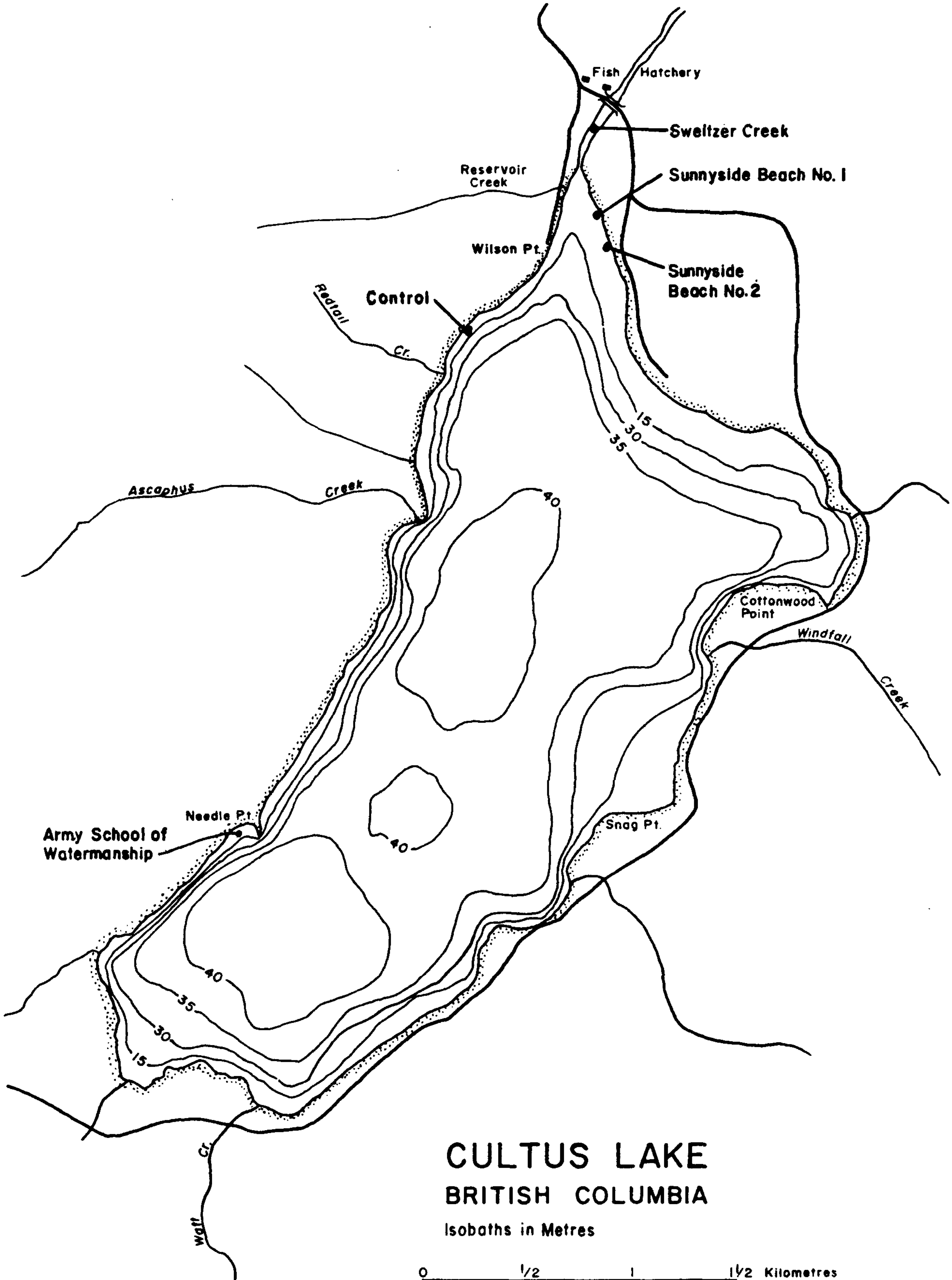

FIGURE 2 CULTUS LAKE SEDIMENT AND WATER SAMPLING STATIONS

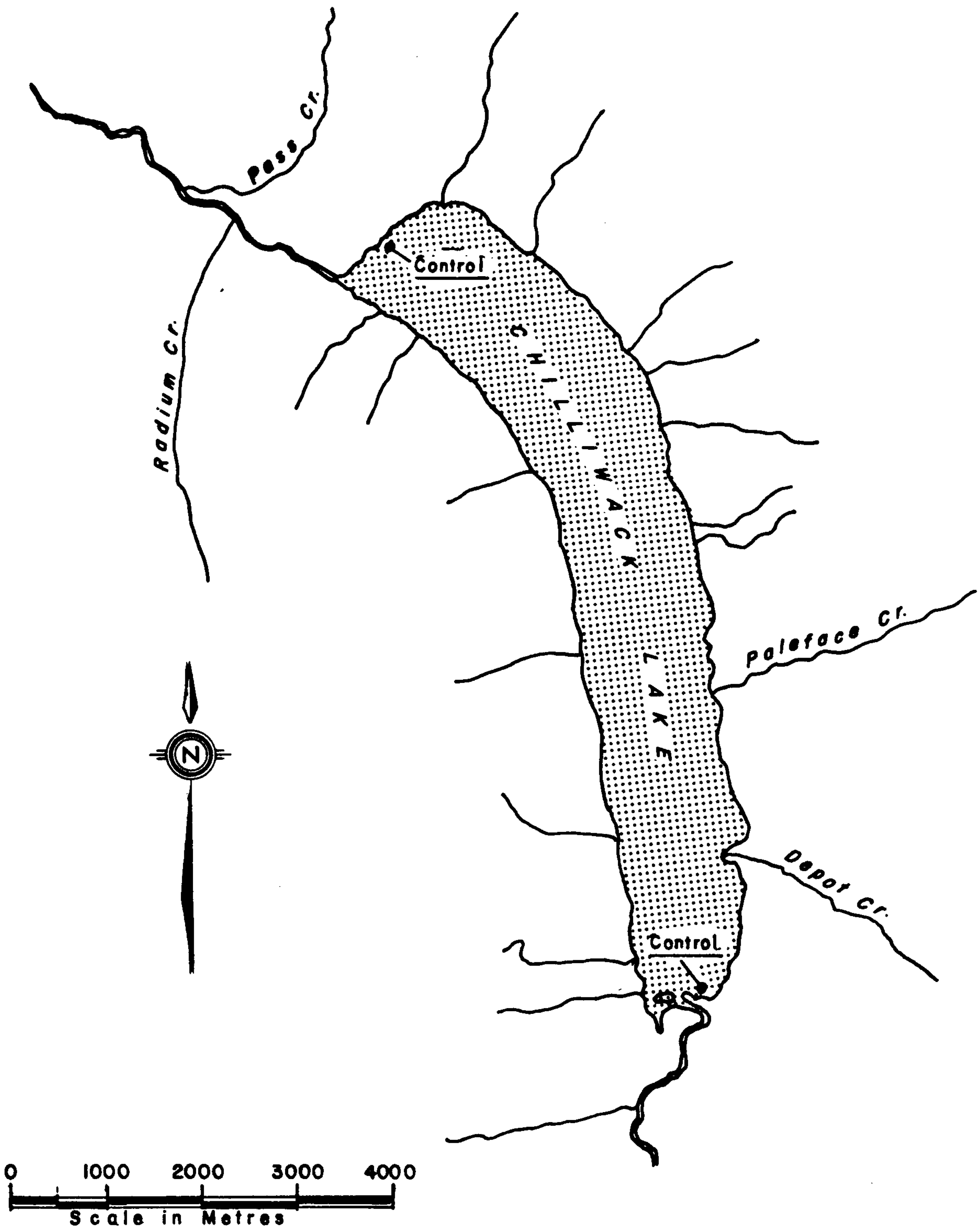

FIGURE 3 CHILLIWACK LAKE SEDIMENT AND WATER SAMPLING STATIONS

3 METHODS AND MATERIALS

3.1 Application of Copper Sulphate

Personnel of the Cultus Lake Park Board, under direction of Dr. T.E. Howard of B.C. Research, were responsible for the lake treatments. They applied hydrated crystal copper sulfate ($CuSO_4 \cdot 5H_2O$) with a manual scoop at a rate of approximately 2 lbs per 1000 ft^2 from a powered raft. The areas treated were Sunnyside Beach, Snail Bay, Entrance Bay, Jade Bay, Needle Point, and the Army School of Watermanship. Dispersal began on 20 March, 1978, and proceeded for 5 days; a different beach area was covered each day.

3.2 Water Sampling

Water samples for total and dissolved copper were collected at four stations on Cultus Lake (Figure 2) and at two stations on Chilliwack Lake (Figure 3). At each station a three-liter Van Dorne sampler was used to collect duplicate water samples from 1 meter below the surface and also 1 meter above the sediment. Water depths varied between 4 and 5 meters at each location. Samples were taken at different times relative to the copper sulphate treatments. The following sampling regime was used: pre-treatment and post-treatment at 2, 3, 8, 22, 26 hours, and 3, 8, 30, and 98 days. Dissolved copper samples were filtered through 0.45 micron cellulose nitrate membrame filters in the field prior to preservation. Each sample was preserved with 0.5 ml concentrated nitric acid in a 100 ml acid-washed plastic bottle. Bottles were then shipped with ice packs to the EPS-DFO laboratory where analyses for total and dissolved copper were performed.

Chilliwack Lake stations were only sampled once to check background copper levels in nearby natural waters. Temperature, dissolved oxygen and pH were also measured at the time of all water collections; for these data, a YSI telethermometer, YSI dissolved oxygen meter and Radiometer model 29 pH meter were used, respectively.

3.3 Sediment Sampling

Duplicate sediment samples were collected concurrently with water samples at the water chemistry stations (Figures 2 and 3). Except for the Sweltzer Creek station, all sediments were collected using SCUBA gear by scooping sediment directly from the bottom into a labelled Whirl-pak TM plastic bag. Care was taken to ensure that each sample was taken from a new spot on the bottom. The samples were transported with ice packs to the EPS-DFO West Vancouver laboratory where total copper analyses were performed.

3.4 Fish Sampling

3.4.1 In-Situ Juvenile Sockeye Salmon Experiments. Ten juvenile sockeye salmon (*Oncorhynchus nerka*) were placed in each of two cages at several *in-situ* bioassay sites (Figure 4). These fish ranged in weight from 0.9 to 4.6 g (mean= 2.6g) and fork length from 47 to 76 mm (mean= 61.4mm). The cages (30x30x45 cm) were constructed of expanded aluminum mesh and fitted with clear plexiglass lids to facilitate observation of the fish.

The cages at sites 1 to 5 were suspended in the water column by floats: one at a depth of 1.0 m and the other at 2.5 m. At the Sweltzer Creek sites (6 and 7) they were placed along the east bank on the bottom at a depth of about 30 cm and held by ropes tied to trees on the bank.

The fish were observed just prior to the copper sulphate treatments and daily thereafter until termination of the experiment (192 hours). At the termination of the experiment 10 fish were removed from each 2.5 m depth cage, five fish from each of the Sweltzer Creek cages, and were retained for histological examination.

The retained fish were killed and their ventral surfaces incised to allow rapid penetration of the fixative solution into which they were placed (Bouin Hollande Sublimate).

After soaking in the fixative solution for 24 hours, the fish were removed and kidney, liver, pancreas, gonad, and alimentary tract tissue samples excised; these tissues were embedded in paraplast and sectioned to thicknesses of 5 micrometers. Several of the smaller fish were totally blocked and serially sectioned for complete histological analysis. Sections were stained with Mayers' hematoxylin and eosin as well as using Massons' trichrome method (Culling, 1975) and then examined microscopically.

3.4.2 Gill Netted Fish Studies. Floating and sinking, multi-mesh-size gill nets were used to capture a variety of fish from Cultus and Chilliwack lakes (Figures 3 and 4). The weight and fork length of each fish caught was recorded and scale samples were taken for age determination. In addition, a portion of dorsal muscle just posterior to each fish head was excised, frozen on dry ice and later analyzed for total copper at the EPS-DFO laboratory.

3.5 Laboratory Procedures.

Water samples were analyzed for copper using a Jarrel-Ash atomic absorption spectrophotometer (AAS). The sediment samples which had been frozen upon arrival at the laboratory were freeze dried and passed through a 100 mesh stainless steel sieve; the fine materials were then subjected to an extraction using concentrated HCl and HNO_3 in a volumetric ratio of 3:1. The clear supernatant was subsequently analyzed for total copper using the AAS.

The fish muscle samples were macerated in a blender, freeze dried, weighed to calculate wet:dry weight ratios, ashed in a low temperature asher, and dissolved in a 1:50 solution of 0.1N HNO_3. A known volume of distilled water was then added to each sample which was next analyzed for total copper using an inductive coupled argon plasma spectrometer. Dry and wet weights were calculated from initial dry:wet weight ratios and analysis results were reported as mg copper per kg dry weight.

3.6 Analysis of Swimmer's Itch Incidence

The Department of Fisheries and Oceans conducted questionnaire surveys during the summers from 1976 through 1979 at Cultus Lake to

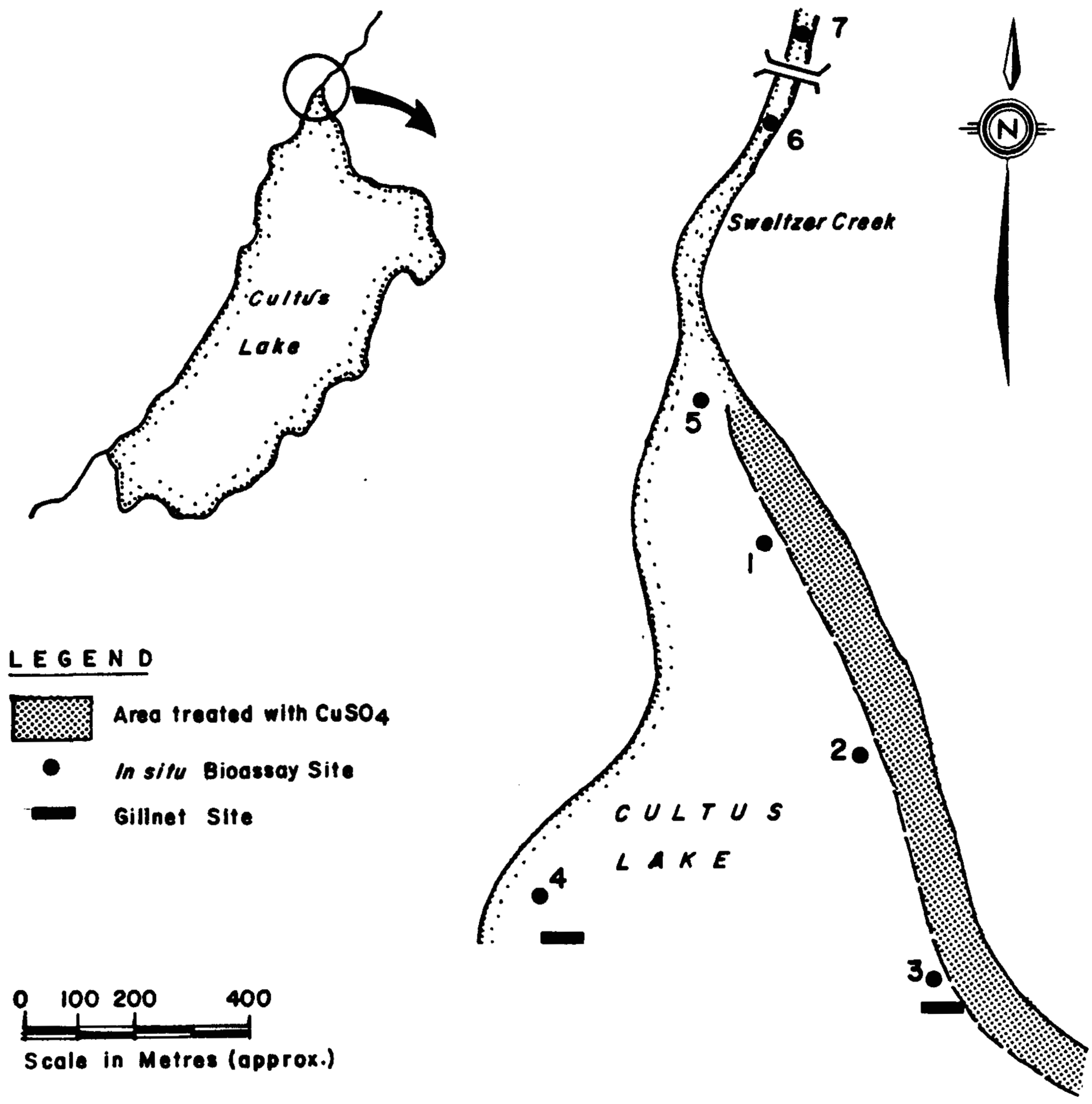

FIGURE 4 *IN SITU* FISH BIOASSAY AND GILLNET SITES IN CULTUS LAKE (1978)

determine incidence of Swimmer's Itch. (Harrison, 1979a, 1979b). Since the studies are published, the reader is referred to them for a description of the methodologies used. The results, however, will be summarized below as they are pertinent to the overall conclusions concerning copper sulphate impacts.

4 RESULTS

4.1 Copper Contamination of Cultus Lake Water and Sediments

4.1.1 Water Column Copper Levels. Elevated copper levels in post-treatment waters generally persisted for only very short periods. During the four hours immediately after the treatments at Sweltzer Creek and Sunnyside Beach, bottom water levels of both total and dissolved copper increased markedly from less than 0.01 mg/l to peaks of 0.37 and 0.13 mg/l, respectively (Figures 5 and 6). However, within 12 hours at Cultus Lake stations and 24 hours at the Sweltzer Creek station, bottom water concentrations dropped to background levels equivalent to those found in Chilliwack Lake (less than 0.01 mg/l). During the same four hours, Sunnyside Beach surface water copper levels at station 1 increased fourfold to 0.04 mg/l from background values (0.01 mg/l) and Sweltzer Creek samples indicated an eightfold increase to 0.08 mg/l (Table 2). By the eighth hour these surface water concentrations had also reached background levels.

4.1.2 Cultus Lake and Sweltzer Creek Sediment Copper. Like the water column values, sediment copper data showed increased levels immediately after treatment, followed by a sharp decrease (Figure 7). Copper residues peaked at 2830 mg/kg (ppm) at station Sunnyside Beach #2 and then declined to values averaging 839 mg/kg. At the control and Sweltzer Creek stations, concentrations were much lower, averaging 46 and 59 mg/kg respectively. These were at least twice the background levels found in Chilliwack Lake which averaged 19 mg/kg.

4.2 Copper Contamination of and Effects on Fish

4.2.1 Acute Fish Toxicity Studies. No deaths, abnormal behaviour, or histopathological effects were recorded for any of the fish used in the cage experiments after 192 hours. This was not surprising in the case of the Cultus Lake studies, because it was learned after the experiment

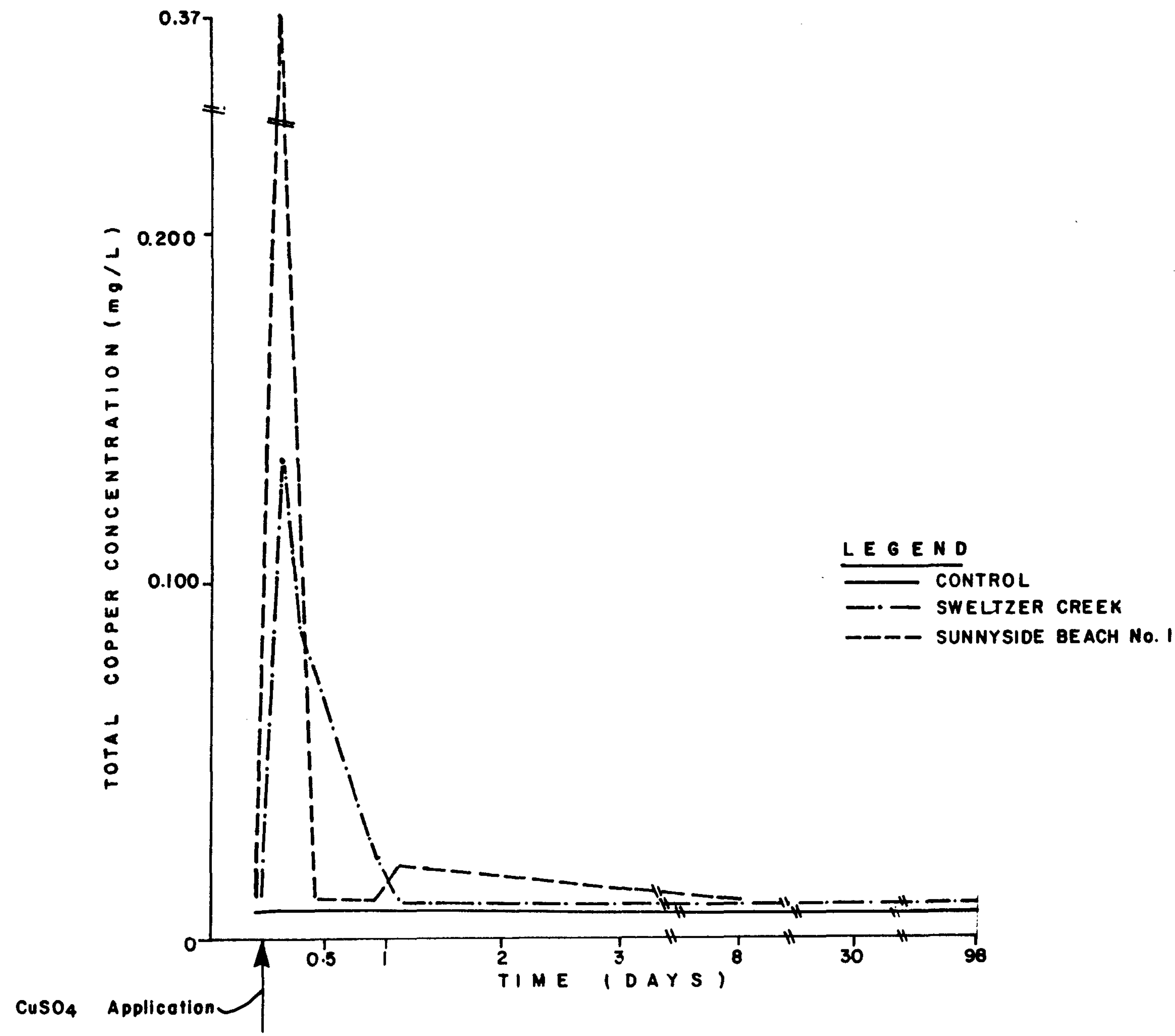

FIGURE 5 TOTAL COPPER IN BOTTOM WATER OF CULTUS LAKE AND SWELTZER CREEK (1978)

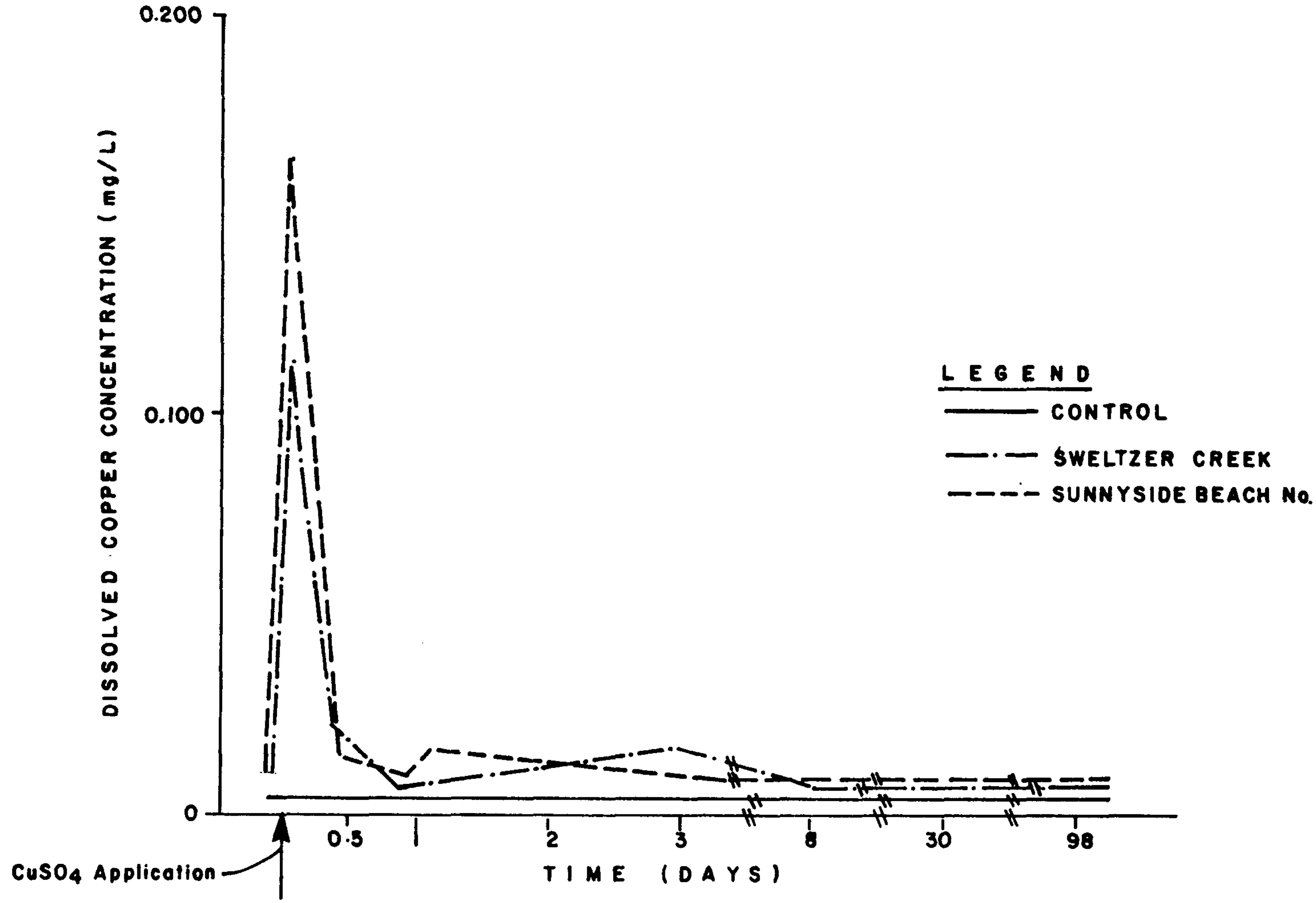

FIGURE 6 DISSOLVED COPPER IN BOTTOM WATER OF CULTUS LAKE AND SWELTZER CREEK (1978)

TABLE 2 TOTAL AND DISSOLVED COPPER IN SURFACE WATER OF CULTUS LAKE AND SWELTZER CREEK[1]

Time of Sampling	Sunnyside Beach #1		Sunnyside Beach #2		Sweltzer Creek		Control Cultus Lake	
Pre-treatment	L0.01	(L0.01)	L0.01	(L0.01)	L0.01	(L0.01)	L0.01	(L0.01)
Post-treatment								
2 (hours)	0.02	(L0.01)	L0.01	(L0.01)	0.14	(0.12)	L0.01	(L0.01)
4	0.04	(0.04)	0.01	(L0.01)	0.08	(0.06)	0.01	(L0.01)
8	0.01	(L0.01)	L0.01	(0.03)	0.02	(0.02)	L0.01	(L0.01)
22	L0.01	(L0.01)	L0.01	(L0.01)	0.01	(L0.01)	L0.01	(L0.01)
26	L0.01	(0.01)	L0.02	(0.02)	L0.01	(L0.01)	L0.01	(L0.01)
3 (days)	L0.02	(0.01)	0.02	(0.01)	0.02	(0.02)	L0.01	(L0.01)
8	0.01	(L0.01)	0.02	(L0.01)	0.01	(L0.01)	L0.01	(L0.01)
30	L0.01	(L0.01)	0.01	(L0.01)	L0.01	(L0.01)	L0.01	(L0.01)
98	L0.01	(L0.01)	L0.01	(L0.01)	L0.01	(L0.01)	L0.01	(L0.01)

[1]Concentrations in ppm (mg/L). Dissolved copper concentrations are shown in brackets

L = less than

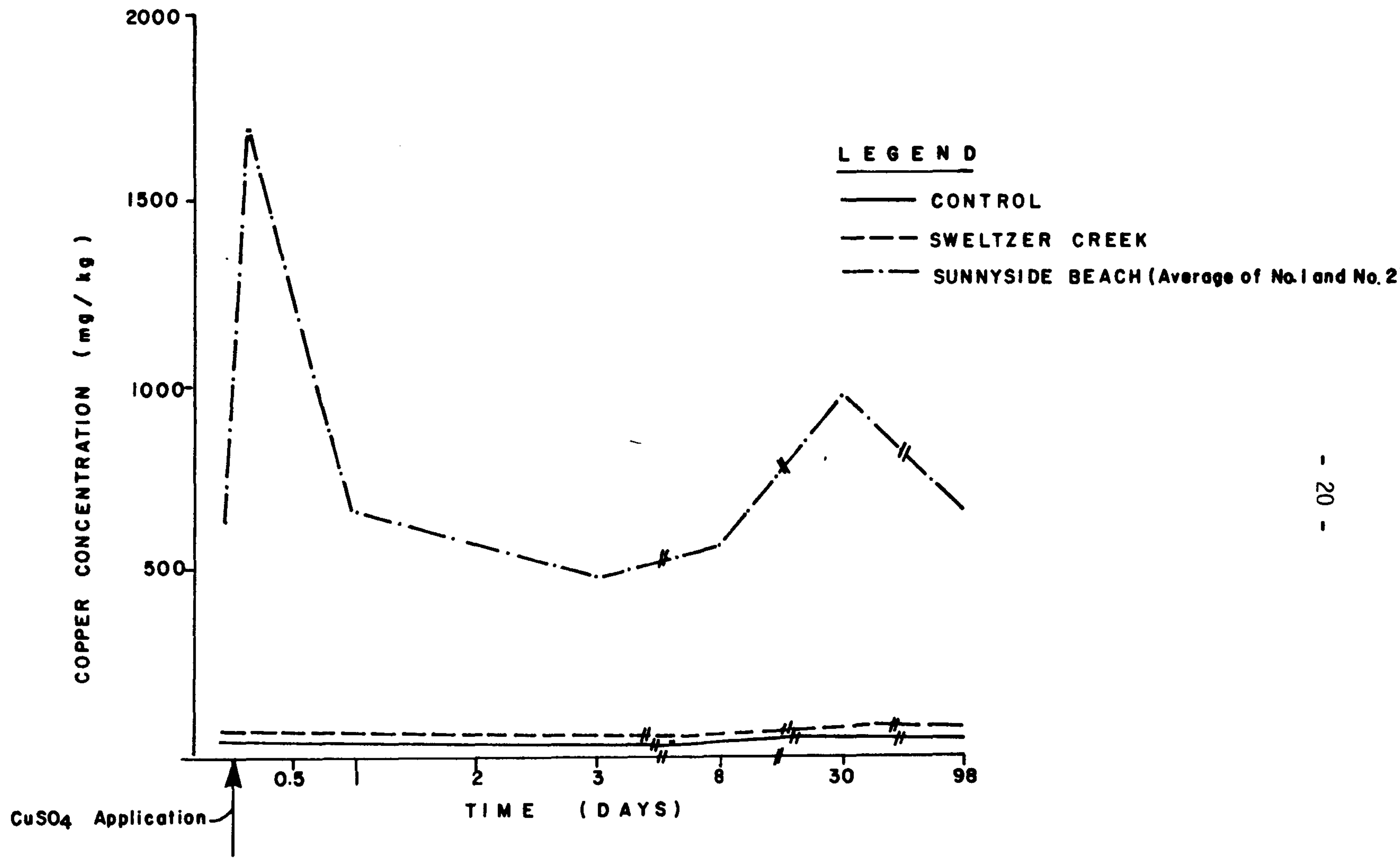

FIGURE 7 COPPER IN SEDIMENTS OF CULTUS LAKE AND SWELTZER CREEK (1978)

that the treatment areas did not extend outward from the beach as far as the bioassay cages. Therefore, little import was attached to the in-lake experiments; however, the Sweltzer Creek data were considered more valid because some contaminated water would have passed through this area after the lake treatments and could have affected fish there. However this was not substantiated by the experiment.

4.2.2 Netted Fish Tissue Copper Levels. Tissue data indicated that no significant copper accumulation had occurred in the resident fish species sampled (Tables 3 and 4). Analysis of variance demonstrated no significant difference between mean copper levels in different Cultus Lake fish species. Further, a Student's t-test indicated no difference between mean tissue copper concentrations in the same species found in both Cultus and Chilliwack Lakes, or between levels found in all Cultus Lake species compared to all Chilliwack Lake species. Linear regression analysis produced no significant correlations between tissue copper concentrations and fish weight, length or age. However, it may be inappropriate to use muscle tissue from fish as an indicator of pollution by trace metals other than mercury. For example, Phillips (1977) reported no significant difference in metal content of fish muscle collected from polluted and non polluted waters and furthermore he stated that no clear correlation has been demonstrated between metal concentrations in the soft-organs of fish and those of the ambient surroundings.

4.3 Trend Studies of Swimmer's Itch Incidence

Hobbs (1980) summarized temporally comparable results from her earlier studies (Harrison 1979a, b) and included more recent 1979 unpublished data to see if there was any variation in Swimmer's Itch incidence between study years. Presumably itch incidence would have been lower in the treatment year (1978) than in non-treatment years (1976, 77, 79).

As shown in Table 5, 1978 incidence levels did not differ significantly from those of the non-treatment years. However there was a difference between the 1979 and 1976 samples, but this was inconclusive because both were non-treatment years.

TABLE 3 SUMMARY OF WEIGHT, LENGTH, AGE AND COPPER CONTENT OF FISH COLLECTED FROM CHILLIWACK LAKE[1]

	Weight (g)	Length (cm)	Age (years)	Copper mg kg^{-1} Wet Weight	Copper mg kg^{-1} Dry Weight
Steelhead trout (n=1)	6500	81.6	6	1.12	4.61
Rainbow trout (n=4)	103.00±74.91 (11.70-29.0)	20.50±7.07 (18-200)	2.50±0.58 (2-3)	0.39±0.12 (0.284-0.564)	1.97±0.76 (1.43-3.07)
Kokanee (n=6)	108.83±5.71 (100-115)	22.2±0.51 (21.3-22.9)	3.71±0.41 (3-4)	0.37±0.11[3] (1.17-1.65)	1.41±0.34[3] (0.293-0.444)
Coho (n=7)	18.29±1.60 (15-20)	11.14±0.37 (10.6-11.7)	2[2]	0.73±0.28[5] (0.401-1.19)	3.24±1.21[d5] (2.16-5.28)
Dolly Varden (n=11)	327.91±473.40 (121-1750)	30.85±8.15 (23.1-53.4)	4.56±1.01 (3-6)	0.36±0.09[6] (0.234-0.497)	1.76±0.46[6] (1.29-2.35)
Whitefish (n=6)	71.17±78.69 (20-225)	17.58±5.16 (13-26.4)	3.0±1.26 (2-5)	0.55±0.38 (0.313-1.31)	2.72±2.01 (1.6-6.78)
Largescale sucker (n=4)	825.00±306.19 (500-1175)	40.50±4.88 (34.9-45.8)	7.67±1.15 (7-9)	0.36±0.10[4] (0.283-0.475)	2.02±0.71 (1.6-2.84)
Longnose sucker (n=2)	145±42.43 (115-175)	24.45±2.90 (22.4-26.5)	4.5±0.71 (4-5)	0.41±0.13 (0.324-0.503)	2.13±0.67 (1.64-2.6)

[1] Data are reported as a mean and standard deviation. Ranges are shown in brackets. Data reported by laboratory as "less than" ( ) were not included in the calculation of means.

[2] n=1

[3] n=2

[4] n=3

[5] n=5

[6] n=8

TABLE 4 SUMMARY OF WEIGHT, LENGTH, AGE AND COPPER CONTENT OF FISH COLLECTED FROM CULTUS LAKE[1]

	Weight (g)	Length (cm)	Age (years)	Copper mg kg^{-1} Wet Weight	Copper mg kg^{-1} Dry Weight
Squawfish	288.79±155.64	28.23±5.02	7.08±1.5[5]	0.53±0.48[6]	2.62±2.3[6]
(n=19)	(10-500)	(12-35)	(4-9)	(0.233-2.03)	(1.19-9.66)
Largescale	188.75±90.59	24.95±4.47	4.25±0.5[2]	0.47±0.27[2]	2.51±1.49[2]
sucker	(110-300)	(20.6-30.3)	(4-5)	(0.241-0.861)	(1.27-4.66)
(n=4)					
Rocky Mountain	332.50±118.73	31.83±4.52	6.2±1.3[4]	0.30±0.03[4]	1.27±0.14[4]
whitefish	(160-510)	(25.4-37.8)	(5-8)	(0.277-0.341)	(1.11-1.39)
(n=6)					
Peamouth chub	128.55±104.39	20.16±6.34	6±0[3]	0.44±0.17[3]	2.21±0.84[3]
(n=11)	(19-300)	(12-28.1)		(0.238-0.716)	(1.19-3.71)
Dolly Varden	650	41.6	N.T.[7]	0.296	1.37
(n=1)					
Redside shiner	15.55±3.24	8.62±2.05	2.5±0.71	0.57±0.25[d]	3.04±1.37
(n=11)	(10-20)	(8.6-10.4)	(2-3)	(0.323-1.05)	(1.61-6.04)

[1]Data are reported as a mean and standard deviation. Ranges are shown in brackets. Data reported by the laboratory as "less than" ( ) were not included in the calculation of the means.
[2]n=1
[3]n=4
[4]n=5
[5]n=13
[6]n=15
[7]N.T. - not taken

TABLE 5 INCIDENCE OF SWIMMER'S ITCH 1976-1979

WEEKENDS		YEAR	TOTAL INTERVIEWED	INCIDENCE LEVEL
28-30 July;	4-6 Aug.	1979	180	27.7% ± 6.5%
29-31 July;	5-7 Aug.	1978	100	19.0% ± 7.7%
30 July-1 Aug;	6-8 Aug.	1977	88	17.0% ± 7.8%
23-25 July;	30 July-1 Aug.	1976	84	16.6% ± 8.0%

These data were tested for "significance of difference between two proportions" and the following results obtained:

	Z	SIGNIFICANT DIFFERENCE
1979 data vs 1978 data	1.63	NO
1979 data vs 1977 data	1.93	NO
1979 data vs 1976 data	1.96	YES
1978 data vs 1977 data	0.356	NO
1978 data vs 1976 data	0.410	NO
1977 data vs 1976 data	0.161	NO

where

$$Z = \frac{P_1 - P_2}{\sqrt{\frac{P(1-P)}{N_1} + \frac{P(1-P)}{N_2}}}$$

$$P = \frac{N_1P_1 + N_2P_2}{N_1 + N_2} = \text{Proportion Contracting Itch}$$

N = Sample Population

0.05 Significance: $1.96 \leq Z \leq -1.96$

Harrison (1979a, b) also made a number of other observations. First, Main and Sunnyside Beaches were sites of higher itch incidence than other areas. Secondly, higher proportions of young than old people contracted the condition, and there appeared to be a positive correlation between incidence and length of holiday at the lake. Thirdly, some respondents appeared to show a greater susceptibility to the parasite; perhaps this is more indicative of some persons elliciting greater sensitivity to broadcast skin invasions than a selectivity on the part of *Trichobilharzia* sp. Finally, and possibly most important from an economic perspective, 92-100% of the respondents who had experienced Swimmer's Itch were willing to re-visit the lake despite the Swimmer's Itch problem.

5 DISCUSSION

5.1 Cultus Lake Water Contamination

Ricker (1937) found weakly alkaline (pH = 7.4 ± 0.02) and moderately hard ([$MgCO_3$] = 79.1 ± 0.6 mg/l) winter conditions in Cultus Lake; these data combined with similar spring data from this study (Appendix I) suggest a relatively rapid attenuation of elevated copper concentrations in the post-treatment water column. Chemistry results verified this theory, showing less than 0.01 mg/l total copper in bottom waters eight hours after a relatively high application rate of 96.5 kg of copper sulphate per hectare.

The rapid drop in dissolved copper following initial post-treatment peaks could possibly be explained by the complexation of Cu^{++} into forms such as tenorite (CuO), malachite ($Cu_2(OH)_2CO_3$) or azurite ($Cu_3(OH)_2(CO_3)_2$) which are relatively insoluble at pH levels found in this lake (Wagemann and Barica, 1978). In addition, high densities of the rooted weed Eurasian Watermilfoil (*Myriophyllum spicatum*) grow in summer at a number of locations and could possibly have provided enough organic fragment material in the water for further complexation of copper ions.

Finally, the large volume of lake water, and constant outflow through Sweltzer Creek, probably diluted free copper ions present in the water. All of these factors could have acted together to reduce free copper or other toxic species of ions in solution.

5.2 Cultus Lake Sediment Contamination

Unlike water, where elevated copper concentrations are decreased by complexation and dilution, sediment copper residues could persist for a long time. Some copper can redissolve in water as seasonal changes in temperature and pH alter the solubility products of complexes, or as chemical equilibria shift to the left when copper gets flushed from the system. However, such releases are usually not very significant as compared to releases when copper sulphate is regularly applied to the lake. Annual application of copper sulphate would invariably result in the accumulation of copper residues in the sediments.

Packman (1977) found that sediments in untreated areas of Cultus Lake contained 87.5 ± 1.7 mg/kg of copper - about three and one-half times the levels found in Chilliwack Lake, which has never been treated with copper sulphate. Historically treated Cultus Lake beach areas had an average sediment copper value of 236 ± 52 mg/kg. In 1978, sediment levels at Sunnyside Beach were 839 ± 208 mg/kg, three months following the last treatment; this is eight times the background level of 100 mg/kg as described by Thompson (1978). Therefore, sediments in treated areas of Cultus Lake are clearly contaminated, whereas those in untreated areas are well within acceptable background levels.

5.3 Impact of Copper Sulphate Applications on Fish

There was no conclusive evidence from this study that molluscicide treatments had a negative effect on Cultus Lake fish. The absence of fish mortality or copper accumulation in tissues was probably due to the fact that the fish bioassay cages were outside the treatment areas, and resident species were not contaminated because dissolved copper concentrations declined rapidly after the application.

Other information does indicate, however, that additions of copper sulphate to the lake could result in lethal or sublethal effects on Cultus Lake fish. Many of the LC_{50} values reported in Table 1 are similar to concentrations of copper found in Cultus Lake during this study. Resident fish might be able to adjust to sub-lethal copper concentrations (Drummond et al., 1973; Donaldson and Dye, 1975) but seaward migrating anadromous species could be affected (Lorz and McPherson, 1976). The latter authors, using water similar in quality to that of Cultus Lake (pH 7.2-7.5 and hardness 84-99 mg/l $CaCO_3$), found that yearling coho salmon (*Oncorhynchus kisutch*) exposed to sub-lethal copper concentrations (5-20 ug/l) were less successful in migration to the sea or in adapting to salt water. The same effects could be experienced by sockeye and chum stocks which migrate through the treatment area in the spring or by coho and steelhead that overwinter in Sweltzer Creek prior to smolting.

The International Pacific Salmon Fisheries Commission (unpublished data) reported that dead sockeye salmon smolts have been found in Cultus Lake when copper sulphate applications occurred with smolts in treatment areas. Because of this mortality, $CuSO_4$ applications have been restricted to the period before April 1 to avoid killing migrating fish. Unfortunately, some smolts migrate as early as late March and therefore could still be affected if the molluscicide additions occurred at that time.

5.4 Implications of Contaminated Bottom Sediments on Benthic Invertebrate Ecology.

Although high sediment copper residues are not acutely toxic to fish, they could affect the composition of the benthic invertebrate community (McKee and Wolf, 1963). Because these benthos spend part of their life cycle as fish food organisms, a change in their composition or numbers could be detrimental to fish.

One-third of the littoral area of Cultus Lake had been receiving annual copper sulphate treatment. Therefore, one-third of the most productive benthic invertebrate habitat was under pressure for ecological change from sediment copper contamination. In addition, the Cultus Lake areas most heavily infested with snails are the ones most heavily grazed by fish: Entrance Bay, Hatchery Bay, Needle Point, and the Army School of Watermanship (Howard, 1978).

5.5 Swimmer's Itch as a Problem

Schistosome dermatitis in Cultus Lake has been well documented over the years. However, other sources of itch must also exist, such as mosquitos or other blood ingesting insects; the extent of these contributions unfortunately has not been determined.

S. dermatitis usually is relatively short-term in duration but on occasions causes sever dermatitis and public health officials do consider it a public health problem. The problem may also have an economic impact with concern expressed about loss of tourist revenue to the area because of itch induced avoidance. However, the questionnaire survey of recreational users of Cultus Lake indicated that tourists are generally willing to use the area regardless of the itch problem.

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APPENDIX I WATER CHEMISTRY OF CULTUS LAKE, SWELTZER CREEK AND CHILLIWACK LAKE[1]

Time of Sampling	Sunnyside Beach #1			Sunnyside Beach #2			Sweltzer Creek			Control (Cultus Lake)		
	T°C	DO (ppm)	pH[2]	T°C	DO (ppm)	pH[2]	T°C	DO (ppm)	pH[2]	T°C	DO (ppm)	pH[2]
Pre-treatment (20-03-78)	-	14.0	7.6	-	13.5	7.3	-	-	7.6	-	-	7.6
Post-treatment												
2 (hours)	6.0	13.2	7.6	6.0	13.1	7.7	-	13.1	7.8	5.5	13.2	7.6
4	6.0	13.3	7.6	6.0	13.2	7.8	-	13.0	7.1	-	13.3	7.6
8	5.5	13.1	8.0	5.0	13.1	7.1	-	13.1	7.9	5.5	13.2	7.8
22	5.2	13.1	7.5	5.5	13.3	7.5	-	13.0	7.9	6.0	12.9	7.6
26	6.2	13.2	7.8	6.2	13.0	7.8	-	12.8	7.1	6.5	12.9	7.6
3 (days)	5.5	12.8	7.6	5.2	12.8	7.4	-	12.5	7.4	5.5	12.6	7.3
8	6.2	12.4	7.7	6.2	12.8	7.7	-	12.3	7.7	6.5	12.4	7.6
30 (20-04-78)	8.0	8.0	7.8	8.0	8.1	8.1	-	11.9	8.1	8.5	7.2	7.4
98	19.5	9.1	8.5	20.0	9.0	8.4	22.0	9.1	8.4	-	9.2	8.6

[1] Chilliwack Lake, June 30, 1978:

T°C = 15 C

DO = 9.6

pH = 7.3

[2] Mean of two readings