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RECURRENT COHO SALMON MORTALITY AT MARITIME HERITAGE FISH HATCHERY, BELLINGHAM: A SYNTHESIS OF DATA COLLECTED FROM 1987-1989

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ABSTRACT

Recurrent mortality of coho salmon (*Oncorhynchus kisutch*) at Maritime Heritage Fish Hatchery was studied from 1987-1989. Hatchery water is supplied by Whatcom Creek, an urban stream which drains downtown Bellingham. Mortality typically coincides with first-flush storm events, suggesting that toxicants in runoff to Whatcom Creek may be responsible. Conventional and priority pollutant scans of hatchery water, taken during kill episodes, showed that copper, lead, and zinc were the only substances detected in amounts above federal toxicity criteria. Metals concentrations were below LC_{50} values, possibly due to late sampling during storm events. However, additive or synergistic metals toxicity cannot be discounted. Histopathological examination of moribund coho revealed no evidence of infection or disease, but a proliferation of chloride cells in gill tissue may have been induced by metals contamination. We recommend confirmatory sampling for metals in water and further pathological study.

INTRODUCTION

Maritime Heritage Fish Hatchery (MHFH) in Bellingham has endured recurrent fish kills for much of the past decade. The kills usually accompany the first heavy rainfall of autumn, although vernal kills have occurred when major rain events succeeded prolonged dry spells. Several salmonid species are reared at the hatchery, but only coho salmon (*Oncorhynchus kisutch*) are affected during kill episodes.

Both juveniles and adults suffer mortality, primarily the former. Affected fish spiral and gasp at the water surface; gill bleeding is common. Coho die for up to one week after symptoms of stress are first noted. Hatchery losses are usually low, but have exceeded 20 percent of coho present. Cursory inspections by fish pathologists appeared to rule out disease and dietary causes.

The hatchery draws its water from Whatcom Creek at river mile (RM) 0.2, which is just above a falls and the zone of tidal influence. The creek originates 3.8 miles upstream at Lake Whatcom (Figure 1). Whatcom Creek has several small tributaries, but during the wet season much of its flow is contributed by storm sewers which drain downtown Bellingham. This, coupled with the timing of the kills, suggests that a "first-flush" of urban contaminants may be the source of toxicity.

In 1987, the Surface Water Investigations Section of Ecology studied the recurrent kills from a water quality perspective (Kendra 1988). Significant findings are summarized below:

- A literature review of bioassays which paired coho salmon with two species unaffected during kill events (chinook salmon *O. tshawytscha* and rainbow trout *O. mykiss*) showed coho were generally more pollution-tolerant than chinook or rainbow.

- During rain events, water quality in Whatcom Creek resembled that of tributary storm sewers. Federal toxicity criteria for several metals were exceeded in Whatcom Creek during summer and winter, but levels were below actual LC_{50} toxicity thresholds reported for coho.

- Whatcom Creek had trace quantities of the wood preservative pentachlorophenol (PCP). Fever Creek, a major tributary, had a PCP concentration which exceeded the federal acute toxicity criterion for the protection of aquatic life (EPA 1986), but was below the LC_{50} for coho. Surface runoff and/or ground water seepage from Brooks Lumber Company was the suspected source.

- Whatcom Creek sediments were contaminated with metals, chlorinated phenols (including PCP), and polycyclic aromatic hydrocarbons. The latter are common constituents of roadway runoff.

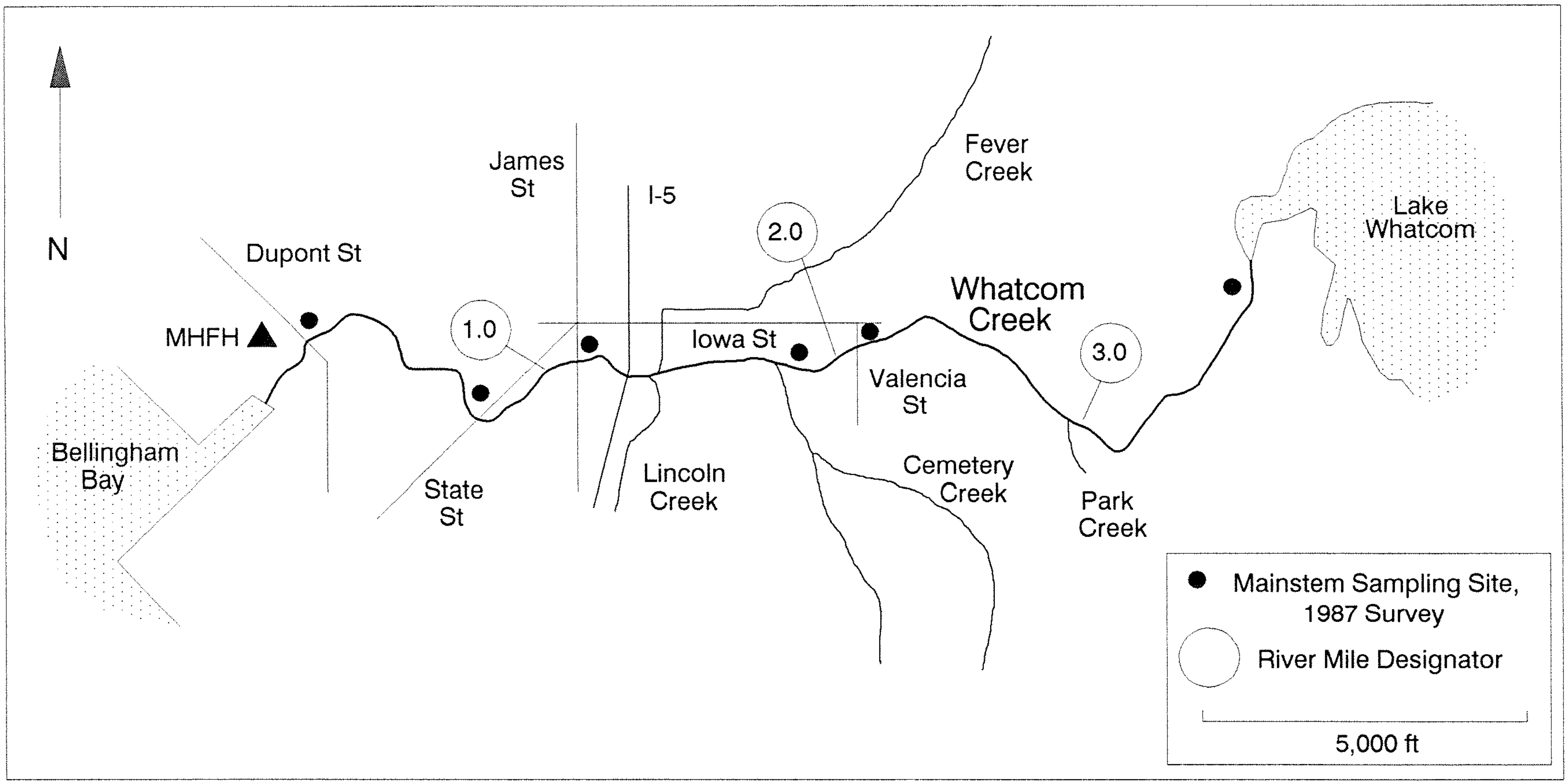

Figure 1. Map of Whatcom Creek showing location of Maritime Heritage Fish Hatchery.

- Benthic macroinvertebrate community structure failed to evidence toxicant entry points, which suggests that: 1) a waterborne toxicant was not involved in the recurrent kills; 2) all sites were equally affected by the toxicant(s); or 3) stream invertebrates were more tolerant than coho to the toxicant(s). A literature review showed metals and PCP were generally more toxic to fish than invertebrates.

- Hatchery water collected during the autumn 1987 kill contained metals, PCP, and several other organic compounds, but levels were below toxicity thresholds reported for coho salmon. Sample size was insufficient to allow a broad scan for priority pollutants.

The 1987 study concluded that the recurrent kills were probably associated with shock loading of metals and/or PCP during first-flush storm events. However, the possibility of disease could not be ruled out. Three recommendations were made:

1. Sample hatchery water during the next autumn kill and conduct comprehensive analyses for conventional and priority pollutants.

2. Subject moribund coho to histopathological study to determine if mortality was caused by infection.

3. Further investigate the nature and source of metal and PCP contamination in Whatcom Creek.

The present report documents findings of these follow-up activities and synthesizes data collected from 1987 through 1989.

METHODS

Hatchery water was sampled by Earl Steele (MHFH manager) during the kills of October 14, 1988 and November 3, 1989. Samples were iced and shipped to the Ecology/EPA Laboratory in Manchester, Washington. Sample containers, processing, and analysis conformed to EPA (1983), APHA *et al.* (1985), and Huntamer (1986).

Healthy and moribund coho were collected by the manager during the 1989 kill. Fish were preserved using fixation procedures outlined in Yasutake (1987). Specimens were sent to John Morrison of the U.S. Fish and Wildlife Service (USFWS) in Olympia, Washington for histopathological examination.

An Ecology fish kill response team (Lew Kittle, David Davidson, Lori LeVander-Pflug, and Bob Newman) inspected MHFH and Whatcom Creek on November 7, 1989. Samples for metals and PCP analysis were taken in Whatcom Creek (RM 0.2 and 1.5), Fever Creek (up- and downstream of Brooks Lumber), and at Brooks Lumber (treated-log storage area runoff and parking lot drain sump). Samples were shipped to the Ecology/EPA Laboratory and processed as described above.

RESULTS

Hatchery losses during the autumn kills of 1988 and 1989 totaled 3,000 and 6,000 juvenile coho respectively, or 10-20 percent of juvenile coho present (E. Steele, MHFH, personal communication). About 30 of 50 returning adults at MHFH in 1989 were killed also. Adult coho in the creek displayed spiraling behavior and several carcasses were observed. Yearling steelhead (anadromous rainbow) trout at MHFH were unaffected. The hatchery manager reported that the 1989 kill was the worst yet, and noted that the severity of the kills appeared to be increasing annually.

Histopathological examination of dying coho from MHFH revealed no evidence of infection or disease (J. Morrison, USFWS, personal communication). However, gills showed thickening of the epithelium, a typical response to an environmental irritant. Gill tissue also exhibited a proliferation of chloride cells, which play a role in ionic regulation. The histopathologist reported that the abundance of chloride cells in the gills of dying fish was among the highest he had ever seen.

Results of conventional and priority pollutant scans on hatchery water sampled during the 1988 and 1989 kills are tabulated in Appendix A. Quality assurance checks (blanks, spikes, surrogates, and internal standards) were generally acceptable. The only substances detected in water samples in potentially toxic quantities were copper, lead, and zinc. PCP was detected in hatchery water during both kills, but levels were one order of magnitude below federal toxicity criteria and two orders of magnitude below concentrations considered toxic to coho (Appendix B). Sampling by Ecology's kill response team in 1989 demonstrated that the source of PCP contamination in Whatcom Creek was surface runoff and/or ground water seepage from Brooks Lumber to Fever Creek. Ecology's Northwest Regional Office (NWRO) is currently working with Brooks Lumber to monitor and control site runoff.

Copper, lead, and zinc data collected between 1987 and 1989 are tabulated in Appendix C. Federal toxicity criteria and coho salmon LC_{50} values are provided for reference; both are dependent on water hardness. EPA (1986) recommends determination of total recoverable metals for comparison to federal toxicity criteria. Since most of our samples to date have been analyzed for total metals, comparisons of our data to federal toxicity criteria may be conservative (i.e., may err on the side of caution). The salient features of Appendix C are illustrated in Figures 2 through 5.

Figure 2 shows copper, lead, and zinc concentrations at the hatchery during the last three autumn kill events. Metals were relatively low in 1987, but samples were taken a day after the first-flush and onset of the kill (Table 1). Since rearing pond detention time is about four hours, considerable dilution of more-concentrated urban runoff may have occurred. In 1988 and 1989, samples were collected much nearer the onset of the first-flush and kill (in fact, 1989 samples were collected as soon as the fish began to spiral). Chronic toxicity criteria for all three metals were exceeded both years, as was the acute toxicity criterion for copper. The acute criterion for zinc was also exceeded in 1989. Still, concentrations were well below LC_{50}s for coho salmon (Appendix C).

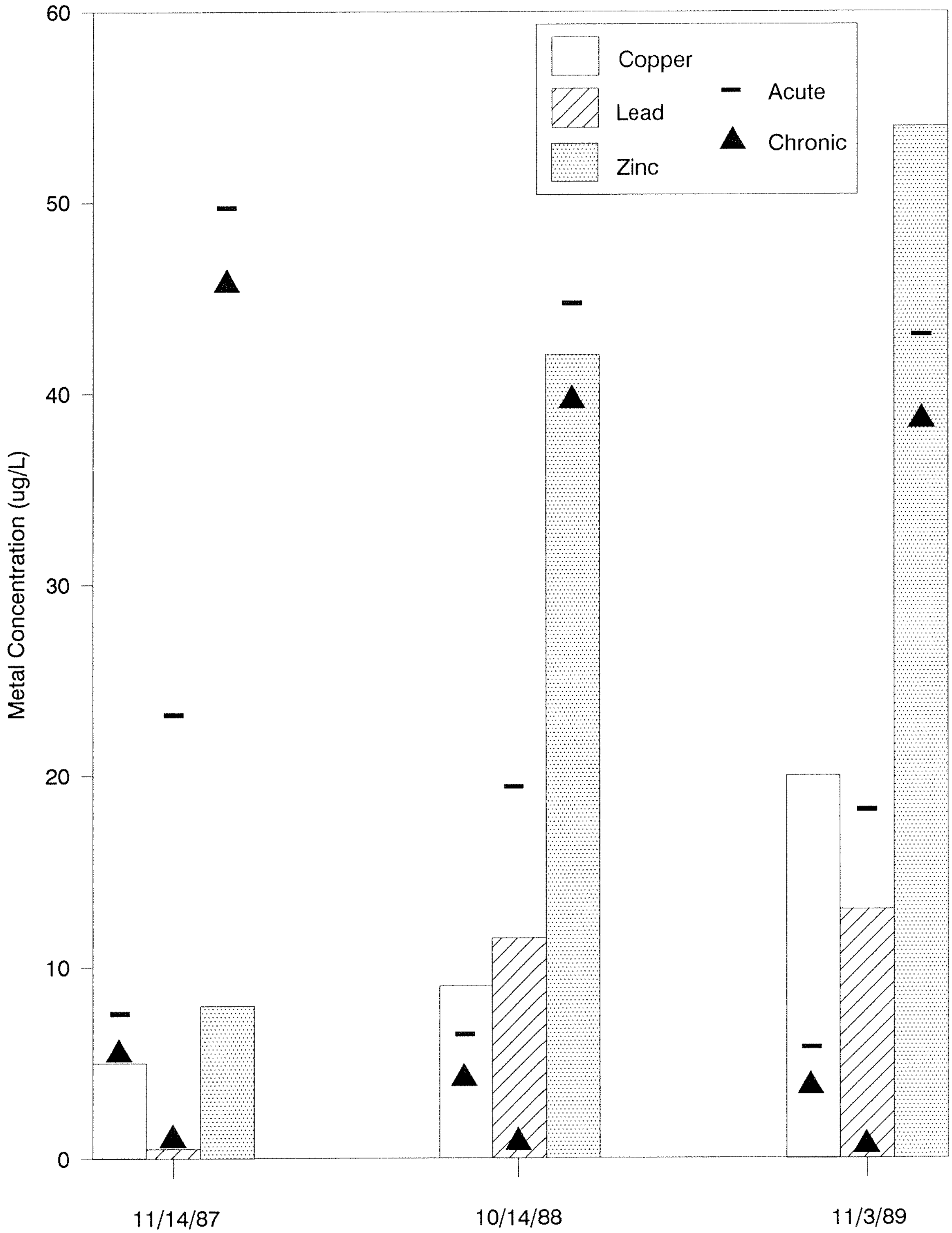

Figure 2. Total copper, lead, and zinc measured during kills at MHFH, 1987-1989. Acute and chronic toxicity criteria (based on total recoverable metals) are shown for reference.

Table 1. Rainfall accumulations (inches) in Bellingham before, during, and after autumn coho kills at MHFH (NOAA 1987-89).

	1987	1988	1989
Rainfall 2 days before kill	0.43	--	--
Rainfall 1 day before kill	0.02	0.73	0.02
Rainfall on day of kill	0.45	1.51*	1.15*
Rainfall 1 day after kill	0.02*	0.51	1.07

* Sampling dates at MHFH (11/14/87, 10/14/88, and 11/03/89).

Figure 3 displays levels of copper, lead, and zinc along mainstem Whatcom Creek during summer 1987. The chronic toxicity criterion for lead was exceeded at four of six sampling sites. Lead was highest at RM 0.7, where the acute toxicity criterion was matched. Tributary and storm sewer inflows to Whatcom Creek were negligible on the day of sampling, thus no source of contamination was evident.

Figure 4 shows mainstem concentrations of the same metals three weeks after the autumn 1987 kill episode. The four sites sampled on December 8 had relatively low lead and zinc, but high copper. Acute and chronic toxicity criteria for copper were exceeded at all four sites. Sampling was repeated at RM 0.2 on December 9 after heavy rainfall had tripled streamflow. Copper had declined, but lead and zinc had increased; all three exceeded chronic toxicity criteria. Since RM 1.8 is essentially the upstream boundary of storm sewer inflows, our 1987 findings suggest that background copper levels in the basin are elevated in winter and that mainstem concentrations of lead and zinc increase in proportion to urban runoff.

Figure 5 confirms that copper concentrations in urban runoff were modest compared to lead and zinc. All tributaries and storm sewers sampled during the December 9 storm event exceeded the chronic toxicity criterion for lead. Acute and chronic criteria for zinc were exceeded in five of the eight inflows. Exceedances of copper criteria were also noted, but copper concentrations in urban runoff were comparable to levels measured in mainstem Whatcom Creek on the previous day.

The hypothesis of elevated background copper in winter is difficult to substantiate without additional upstream data. The two miles of stream between RM 1.8 and Lake Whatcom flow mostly through steep, forested terrain within Whatcom Falls Park. There are several discharges to the creek in this reach, including two outfalls from the Washington Department of Wildlife's (WDW) Bellingham Trout Hatchery and a screen-house overflow from the municipal drinking water supply. Both the hatchery and city use Lake Whatcom as a water source. None of these discharges were sampled for metals, nor was the lake outflow. However, we did sample the hatchery influent as part of a WDW experiment in winter 1989. Total recoverable copper was present at about 10 ug/L, which exceeds acute and chronic toxicity criteria (Appendix C).

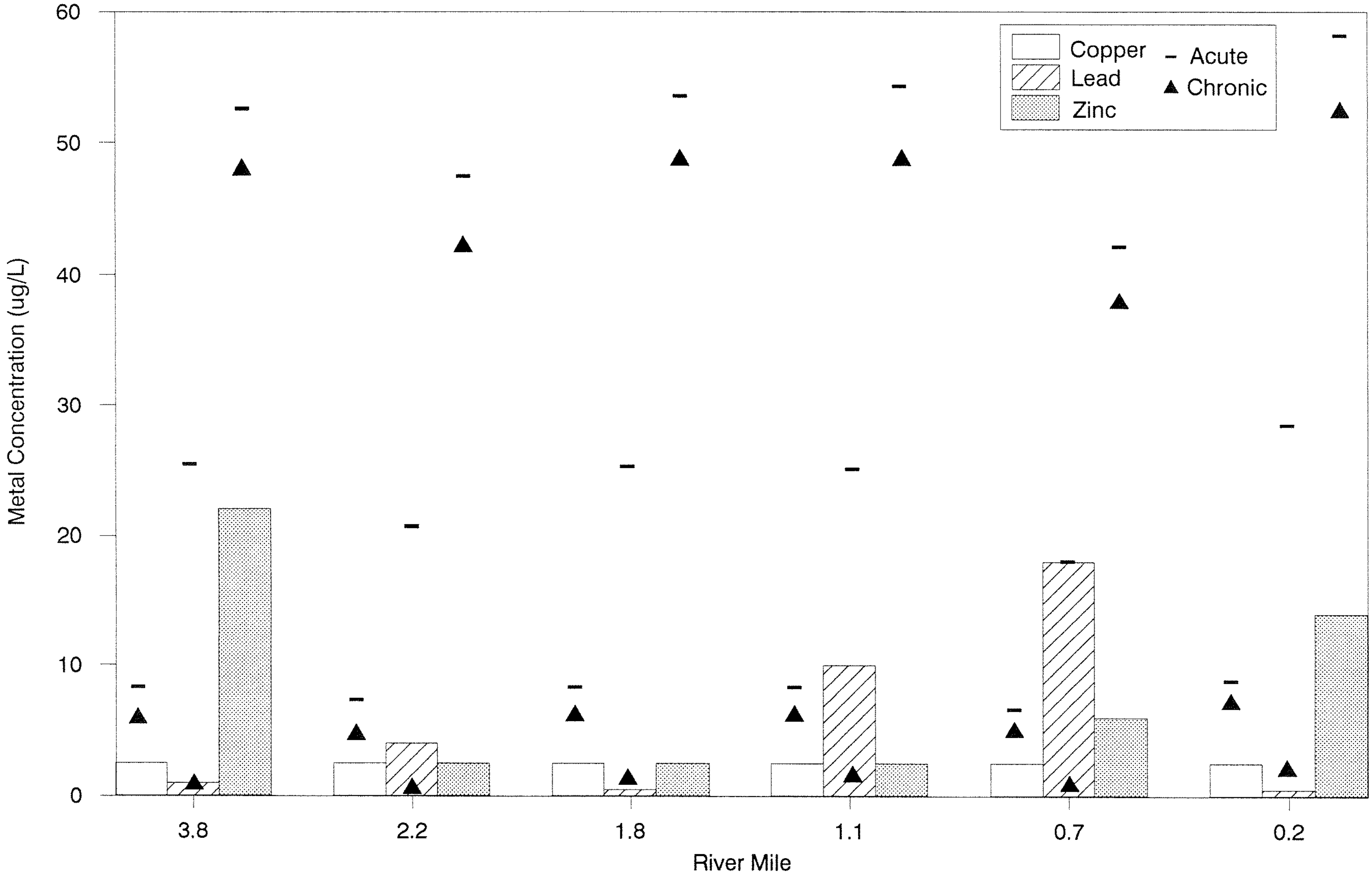

Figure 3. Total copper, lead, and zinc in mainstem Whatcom Creek on July 14, 1987. Acute and chronic toxicity criteria (based on total recoverable metals) are shown for reference.

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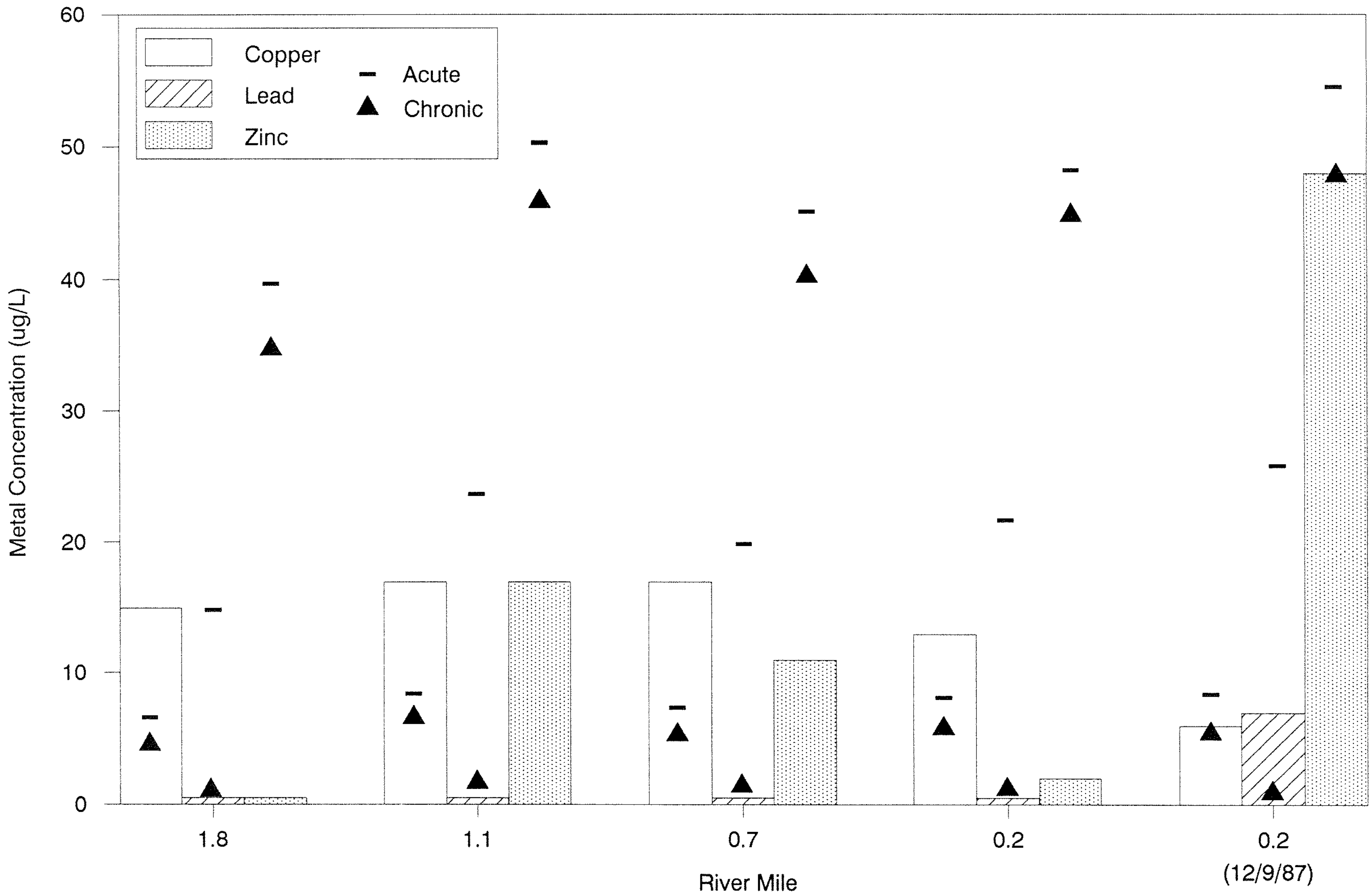

Figure 4. Total copper, lead, and zinc in mainstem Whatcom Creek on December 8, 1987 (RM 0.2 also sampled 12/9/87). Acute and chronic toxicity criteria (based on total recoverable metals) are shown for reference.

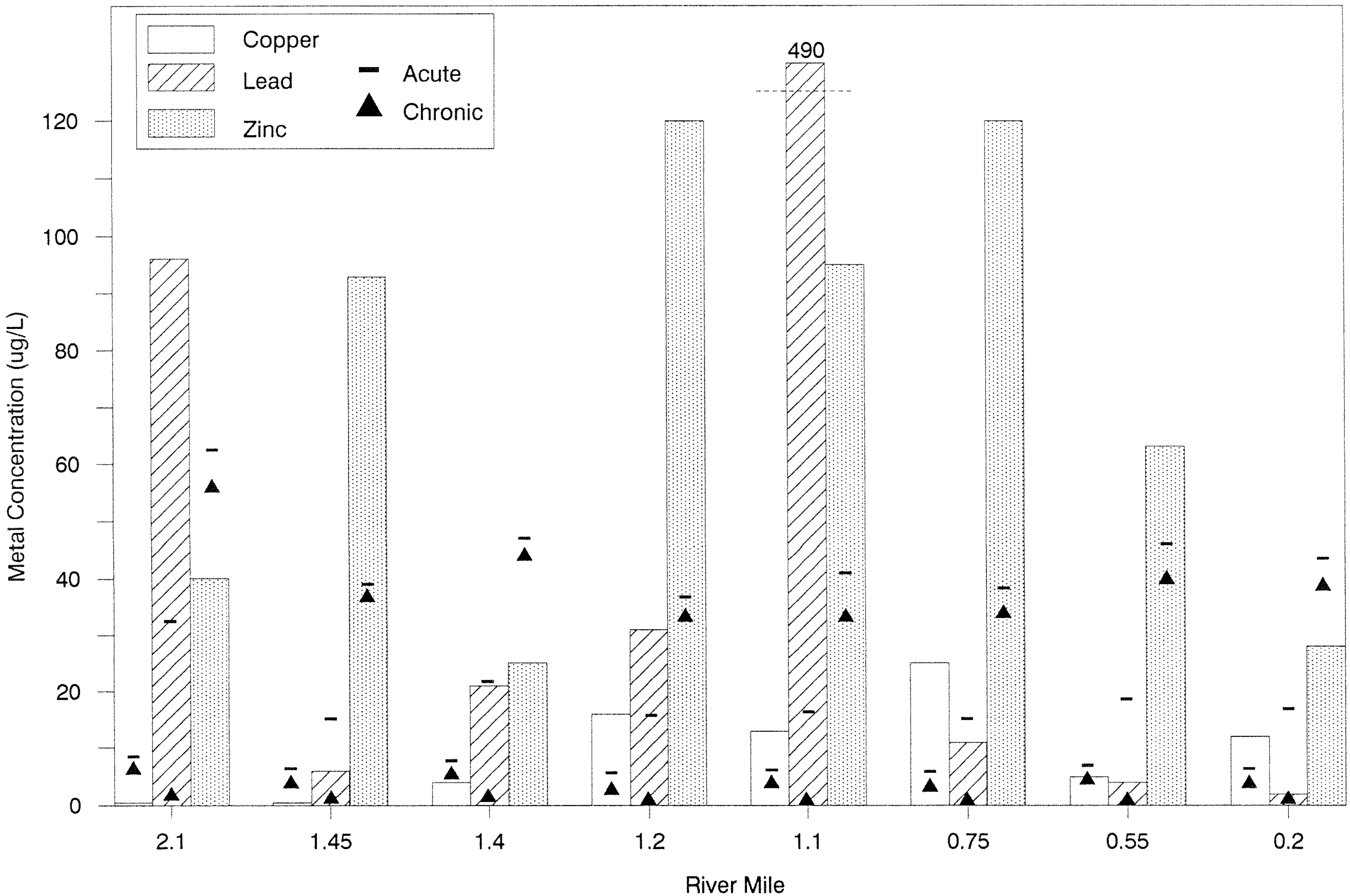

Figure 5. Total copper, lead, and zinc in tributaries and storm sewers flowing into Whatcom Creek on December 9, 1987. Acute and chronic toxicity criteria (based on total recoverable metals) are shown for reference.

DISCUSSION

The Nationwide Urban Runoff Program (NURP) was conducted by EPA from 1978-1982 to evaluate the quality of urban stormwater runoff. Priority pollutant monitoring performed under NURP revealed that copper, lead, and zinc were the most prevalent toxicants in urban runoff (Cole *et al.* 1984). All three metals were detected in at least 95 percent of samples collected. Potential sources were identified as fossil fuel combustion, metal alloy corrosion, and other automobile-related activities.

Copper, lead, and zinc were also the most prevalent toxicants in urban runoff to Whatcom Creek. Hall and Anderson (1988) found that these three metals showed a strong linear correlation with buildup time (i.e., antecedent dry days) in the urban watershed. Our fish kill data are inconsistent with this finding. Mortality at MHFH became successively worse from 1987 through 1989, but buildup time decreased over the same period. For example, in 1987 the time interval between the first-flush event and the previous moderate rainfall (0.5 inch) was about four months; in 1988 and 1989, moderate rainfall occurred within three weeks and one week of the kill events, respectively (NOAA 1987-89).

Fish kills apparently occur more often in Whatcom Creek than in other urban streams. For example, of 248 urban areas assessed in the United States, only 13 percent reported runoff-related fish kills during the period 1970-1979 (Heaney and Huber 1984). One possible reason is that stormwater runoff from Bellingham may have relatively high copper, lead, and zinc. Figure 6 compares water quality criteria exceedances in stormwater collected from Bellingham to exceedances in 15 cities participating in NURP. In general, metals criteria exceedances in stormwater discharges to Whatcom Creek were not unlike exceedances in urban runoff from other municipalities. The exception was the acute toxicity criterion for zinc, which was exceeded more often in stormwater discharges to Whatcom Creek.

An alternate explanation of the frequent kills may be that the hardness of Whatcom Creek is relatively low (30 mg/L). However, many streams in western Washington have equally low hardness, yet urban fish kills during first-flush events are uncommon. Another possibility is that metals concentrations in the creek may be relatively high. Figure 7 compares copper and zinc in Whatcom Creek to levels in four urban streams in Bellevue, a city of similar size to Bellingham. These data suggest that metals concentrations in Whatcom Creek are not atypical compared to other urban streams in western Washington. Instead, the prevalence of kills in Whatcom Creek may simply be a consequence of MHFH providing a continuous "bioassay" of fish health throughout the year. If fish populations in other urban streams were monitored with equal scrutiny, they may well show similar patterns of mortality in response to stormwater runoff.

The weathering and solution of natural copper minerals usually produces background surface water concentrations of 1-10 ug-Cu/L (EPA 1980). Copper levels in Whatcom Creek exceeded this range in winter, and our limited data indicate that copper levels in Lake Whatcom were high also. One possible explanation may lie in the mineralogy of the watershed. Moen (1969) sampled stream sediments statewide as part of a geochemical

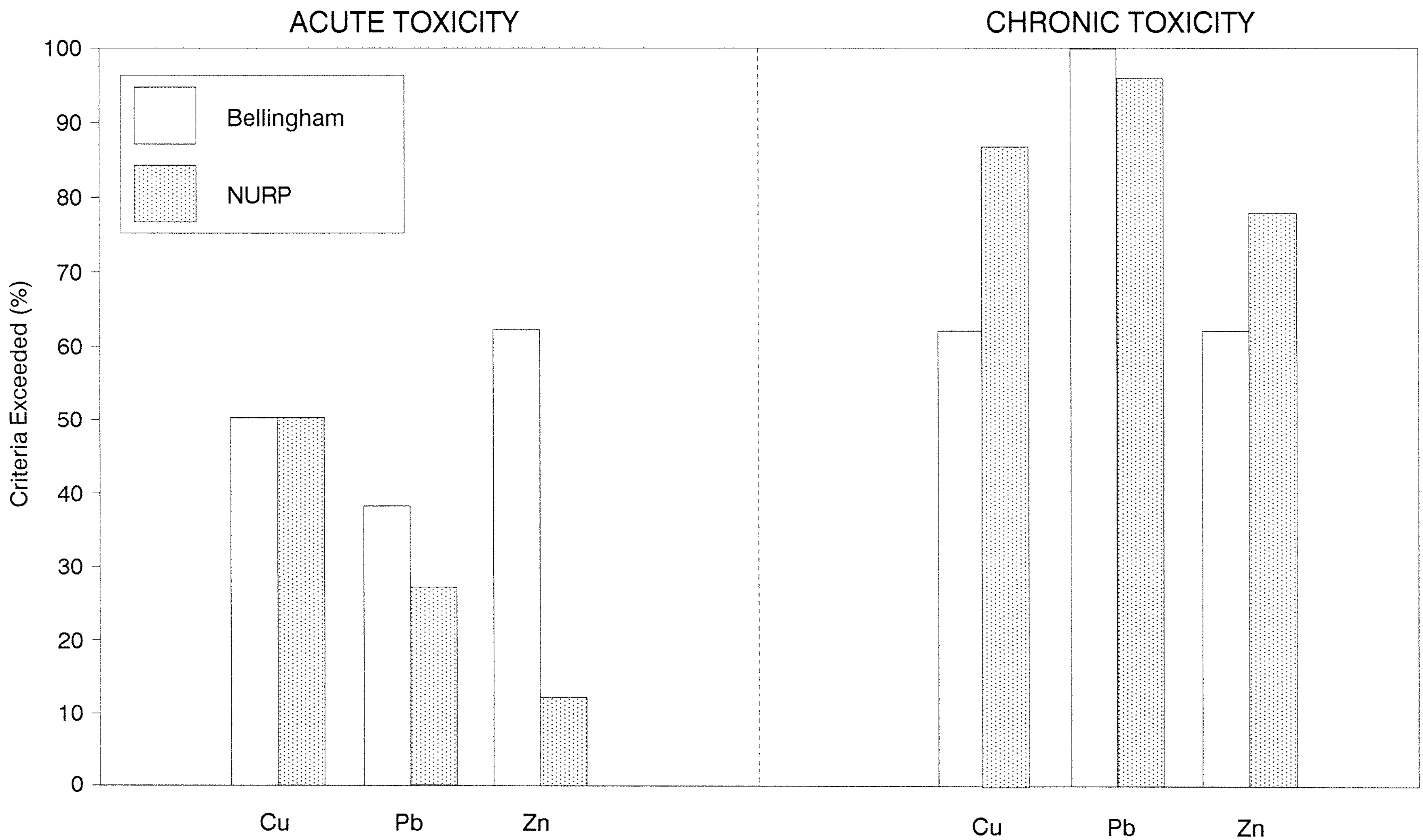

Figure 6. Proportions of water quality criteria exceedances in stormwater samples from Bellingham (n = 8) and 15 cities participating in NURP (n = 86). The Bellingham data are the samples represented in Figure 5; Fever and Lincoln Creeks were included as stormwater samples because most of their flow is urban runoff. NURP data are from Cole et al. (1984).

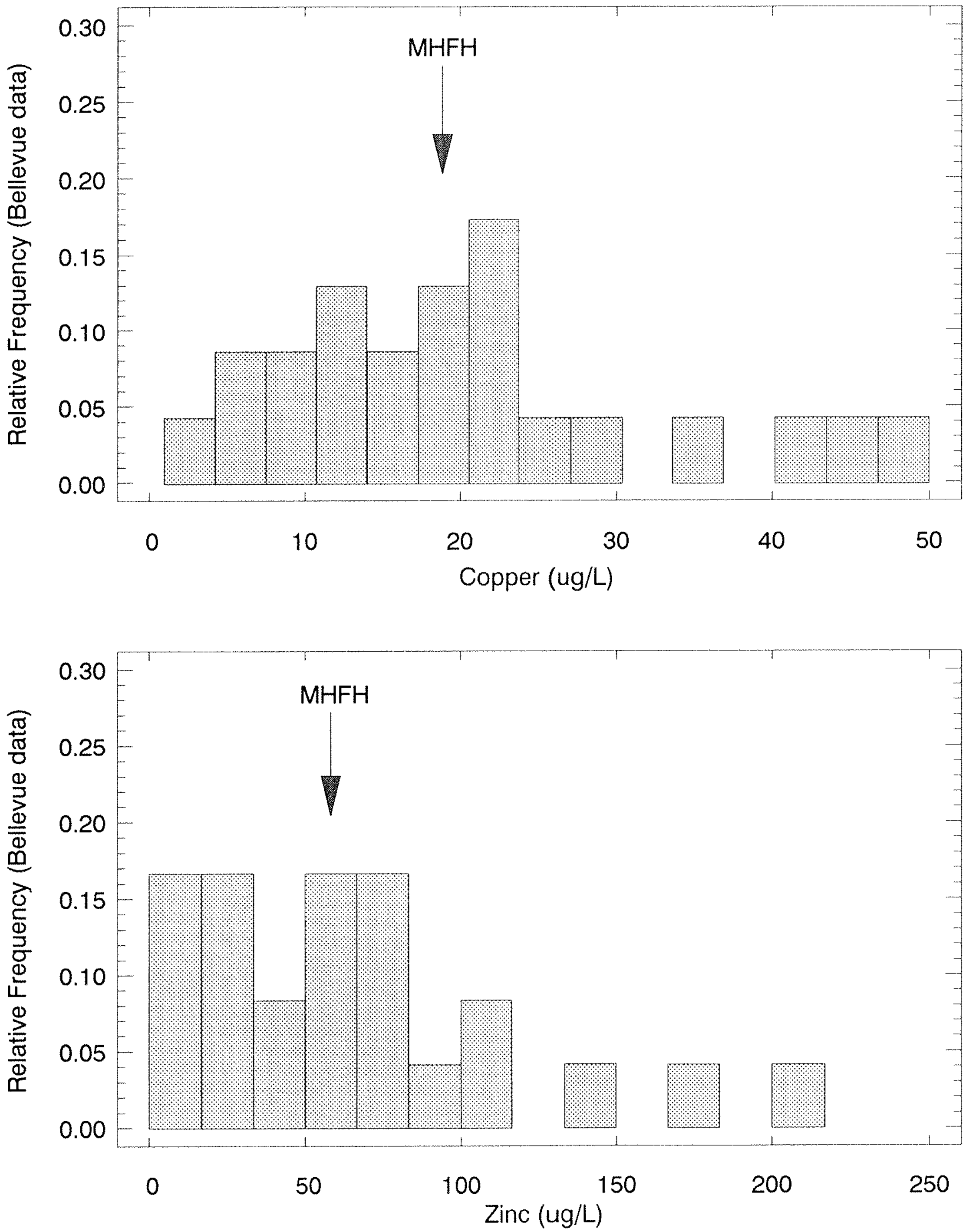

Figure 7. Comparison of metals concentrations in Whatcom Creek to four urban streams in Bellevue, Washington. The Whatcom Creek data are from the sample collected at MHFH during the autumn coho kill of 1989. Bellevue data, depicted as frequency histograms, were collected during several storm events from October through December 1989 (unpublished data provided by D. Funke, Bellevue Storm and Surface Water Utility). The frequency histogram for lead was omitted because most values from Bellevue were below a detection limit of 20 ug/L (MHFH = 13 ug/L).

prospecting survey. Of 14 counties sampled, Whatcom had the highest proportion of sediment samples with a copper content in excess of 75 mg/kg. This finding suggests that copper-bearing minerals could be relatively abundant in the Whatcom Creek basin. If so, accelerated leaching of these minerals during periods of runoff may account for elevated instream copper levels in winter. However, seasonal variations in tributary copper loading would likely be dampened or even eliminated by mixing and retention in Lake Whatcom. Clearly, more data are needed to better define the sources of copper loading to Whatcom Creek.

Metals concentrations at MHFH have not exceeded reported LC_{50} values for coho salmon during kill episodes. The copper concentration in autumn 1989 was 57 percent lower than the LC_{50}, while lead and zinc were more than 90 percent below their respective LC_{50}s (Appendix C). However, the LC_{50} for copper (46 ug/L) was developed using adult coho, which had similar or higher LC_{50}s than juvenile coho tested at the same lab (Chapman and Stevens 1978). Hence copper levels in Whatcom Creek may actually be closer to the LC_{50} when comparisons are restricted to juvenile fish. Still, concentrations of the individual metals do not appear high enough to explain the recurrent kills at MHFH.

There is limited evidence in the literature that combinations of copper, lead, and zinc may be additive or synergistic (i.e., the toxicity of the mixture is equal to or greater than the sum of component toxicities). Hall and Anderson (1988) tested the toxicity of combinations of the three metals to the water flea *Daphnia*. They found that copper-lead and lead-zinc mixtures were synergistic, copper-lead-zinc mixtures were roughly additive, and copper-zinc mixtures were antagonistic (less than additive). Finlayson and Verrue (1982) determined that the toxicity of copper and zinc combined was generally antagonistic to chinook salmon, but they noted that earlier studies had reported conflicting results for copper-zinc mixtures. We were unable to locate any literature on the toxicity of copper-lead and lead-zinc mixtures to fish, but the findings of Hall and Anderson lead us to speculate that lead may increase the toxicity of copper and zinc to fish. If so, additive or synergistic metal toxicity could account for the recurrent kills at MHFH.

Histopathological study of moribund coho from MHFH revealed a proliferation of chloride cells in gill tissue. Several investigators have reported an increased abundance of chloride cells in fish exposed to copper or zinc (Baker 1969; Matthiessen and Brafield 1973; Crespo *et al.* 1981), which suggests that: 1) chloride cells may play an important role in metal detoxification; and 2) chloride cell proliferation may be a toxicant-specific response to metal poisoning. The latter hypothesis was addressed by Mallatt (1985) during an extensive review of gill histopathology literature. He identified 11 studies which documented chloride cell proliferation, seven of which involved metals toxicity. He also identified five studies which explicitly reported the absence of chloride cell proliferation, yet three of these involved metals. Mallatt concluded that the various gill structural changes caused by environmental irritants are largely nonspecific; that is, a wide range of irritants can produce similar gill lesions. Thus chloride cell proliferation in the gills of dying coho may or may not have been induced by metals contamination.

The histopathological examination of gills and other tissues failed to evidence signs of disease. However, this result is inconsistent with the species-specific nature of mortality, which usually implicates infection. A literature review by Kendra (1988) identified only one study which paired coho and chinook or steelhead in a metals toxicity bioassay. Study findings were complicated by variable hardness levels, but steelhead appeared to be slightly more susceptible than coho to copper and zinc toxicity (Chapman and Stevens 1978). Our continued uncertainty regarding the species-specific nature of mortality at MHFH dictates the need for further study of this issue.

CONCLUSIONS AND RECOMMENDATIONS

The first-flush timing of the recurrent kills strongly implicates the presence of one or more toxicants in the water supply, Whatcom Creek. The most prevalent contaminants in hatchery water collected during kill episodes were copper, lead, and zinc. Federal toxicity criteria for all three were exceeded, but concentrations did not approach LC_{50} values for coho salmon. The latter finding may be an artifact of sampling; that is, samples may have been taken late during storm events. Another possibility is that the combination of the metals produced additive or synergistic toxicity. We propose several activities to address the unresolved issues identified in this report:

- Resample copper, lead, and zinc at MHFH during the next autumn kill, but have the manager take samples in advance of mortality as well. This will involve some guess work, but careful attention to weather forecasts would increase the probability of correctly anticipating the first-flush. Sampling results may show higher metals concentrations than previously observed.

- Resample copper, lead, and zinc in Whatcom Creek in summer and winter to identify possible sources of metals loading. The sampling effort should move beyond broad screening measures by incorporating appropriate quality assurance protocols. Samples should be tested for both total metals and total recoverable metals to quantify the relationship between the two methods and enable direct comparisons to federal toxicity criteria.

- Ecology's NWRO should issue a stormwater discharge permit to Brooks Lumber Company to control runoff of PCP to Fever Creek. Additional sampling may be required to characterize background PCP contamination and quantify PCP loads in site runoff.

Despite the finding of no evidence of infection, the histopathologist was reluctant to unequivocally rule out disease as a possible cause of the recurrent mortality (J. Morrison, USFWS, personal communication). His reluctance stemmed in part from the species-specific nature of the kills. Mortality by infection is not necessarily inconsistent with first-flush timing, as the stress imparted by contaminants in urban runoff could trigger disease outbreaks.

Due to this uncertainty, we recommend that the histopathology work be repeated during the next kill event. Sampling should be more systematic, with both coho and steelhead being collected before, during, and after the kill. We also propose that a fish pathologist conduct a formal on-site inspection during the next kill, including collection of samples for bacteriological, virological, and related studies.

If these additional efforts successfully discount infection as a source of mortality, a definitive test of metals toxicity should be performed. The test should subject juvenile coho and steelhead from MHFH to bioassay in Whatcom Creek water spiked with proportionate amounts of copper, lead, and zinc. The purpose of the test would be to confirm that coho are less tolerant of metals toxicity than steelhead.

Regardless of the bioassay outcome, our findings to date indicate that copper, lead, and zinc in Whatcom Creek exceed federal toxicity criteria during storm events. The duration and frequency of these exceedances may constitute state water quality standards violations (this issue would be addressed as part of our proposed follow-up activities). The ultimate solution to this problem lies in stormwater pollution control in the watershed. The Puget Sound Water Quality Management Plan called for the city of Bellingham to begin developing a stormwater control program by December 1989 (PSWQA 1988). This target date has been extended to June 1991 (J. Anderson, Ecology, personal communication). Program goals will include achievement of water quality standards and protection of beneficial uses, one of which is the rearing of salmonids.

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APPENDICES

Appendix A. Results of pollutant scans on hatchery water sampled during the 1988 and 1989 kills. Results above detection limits are highlighted.

Parameter	Units	10/14/88 Hatchery Water	10/14/88 Lab Blank 1	10/14/88 Lab Blank 2	11/03/89 Hatchery Water	11/03/89 Lab Blank 1	11/03/89 Lab Blank 2
BASE-NEUTRAL/ACID EXTRACTABLES							
Acenaphthene	ug/L	<5	<2	--	<0.8	<0.8	<0.8
Acenaphthylene	"	<5	<2	--	<0.8	<0.8	<0.8
Amine, n-nitrosodiphenyl-	"	<5 B	**0.2BJ**	--	<0.8	**0.09J**	**0.09J**
Amine, n-nitroso-di-n-propyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Aniline, 2-nitro-	"	<24	<10	--	<4 J	<4J	<4J
Aniline, 3-nitro-	"	<24	<10	--	--	--	--
Aniline, 4-nitro-	"	<24	<10	--	--	--	--
Aniline, 4-chloro-	"	<5	<2	--	<0.8J	<0.8J	<0.8J
Anthracene	"	<5	<2	--	<0.8	<0.8	<0.8
Anthracene, benzo(a)-	"	<5	<2	--	<0.8	<0.8	<0.8
Anthracene, dibenzo(a,h)-	"	<5	<2	--	<0.8	<0.8	<0.8
Benzene, 1,2-dichloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Benzene, 1,3-dichloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Benzene, 1,4-dichloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Benzene, 1,2,4-trichloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Benzene, hexachloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Benzene, nitro-	"	<5	<2	--	<0.8	<0.8	<0.8
Benzidine, 3,3'-dichloro-	"	<10	<4	--	<0.8	<0.8	<0.8
Benzoic acid	"	<24	<10	--	<4	<4	<4
Benzyl alcohol	"	<5	<2	--	<0.8	<0.8	<0.8
Butadiene, hexachloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Butanoic acid, 2,5-dibenzene-	"	--	--	--	**0.58JN**	--	--
Carbazole	"	<5	<2	--	<0.8J	<0.8J	<0.8J
Chrysene	"	**0.6J**	<2	--	<0.8	<0.8	<0.8
Decanoic acid, hexa-	"	**4.6J**	--	--	--	--	--
Ethane, hexachloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Ether, bis(2-chloroethyl)	"	<5	<2	--	<0.8	<0.8	<0.8
Ether, bis(2-chloroisopropyl)	"	<5	<2	--	<0.8	<0.8	<0.8
Ether, 4-bromophenyl-phenyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Ether, 4-chlorophenyl-phenyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Fluoranthene	"	**0.4J**	<2	--	**0.2J**	<0.8	<0.8
Fluoranthene, benzo(b)-	"	<5	<2	--	<0.8	<0.8	<0.8
Fluoranthene, benzo(k)-	"	<5	<2	--	<0.8	<0.8	<0.8
Fluorene	"	<5	<2	--	<0.8	<0.8	<0.8
Furan, dibenzo-	"	<5	<2	--	<0.8	<0.8	<0.8
Hexane, trans-1,2-dichlorocyclo-	"	--	**0.10J**	--	--	--	--
Hexanone, 5-methyl-2-	"	-- --	**0.79J**	--	--	--	--
Isophorone	"	<5	<2	--	<0.8	<0.8	<0.8
Methane, bis(2-chloroethoxy)	"	<5	<2	--	<0.8	<0.8	<0.8
Naphthalene	"	**0.2J**	<2	--	**0.1J**	<0.8	<0.8
Naphthalene, 2-chloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Naphthalene, 1-methyl-	"	<5	<2	--	**0.08J**	<0.8	<0.8
Naphthalene, 2-methyl-	"	<5	<2	--	**0.06J**	<0.8	<0.8

		10/14/88			11/03/89		
Parameter	Units	Hatchery Water	Lab Blank 1	Lab Blank 2	Hatchery Water	Lab Blank 1	Lab Blank 2
Pentadiene, hexachlorocyclo-	"	<5	<2	--	<2	<2	<2
Perylene, benzo(g,h,i)-	"	<5	<2	--	<0.8	<0.8	<0.8
Phenanthrene	"	**0.3J**	<2	--	**0.1J**	<0.8	<0.8
Phenol	"	<5	<2	--	<0.8	<0.8	<0.8
Phenol, o-chloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Phenol, 2,4-dichloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Phenol, 2,4,5-trichloro-	"	<24	<10	--	<4	<4	<4
Phenol, 2,4,6-trichloro-	"	<5	<2	--	<0.8	<0.8	<0.8
Phenol, pentachloro-	"	**2J**	<10	--	**1 J**	<4	<4
Phenol, 4-chloro-3-methyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Phenol, 2-methyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Phenol, 4-methyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Phenol, 2,4-dimethyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Phenol, 2,6-bis(1,1-dimethyl-ethyl)-4-methyl-	"	--	**0.36J**	--	--	--	--
Phenol, 2-nitro-	"	<5	<2	--	<0.8	<0.8	<0.8
Phenol, 4-nitro-	"	<24	<10	--	<4	<4	<4
Phenol, 2,4-dinitro-	"	<24	<10	--	<4 J	<4J	<4J
Phenol, 4,6-dinitro-2-methyl-	"	<24	<10	--	<4	<4	<4
Phthalate, bis(2-ethylhexyl)	"	**4BJ**	**0.2BJ**	--	<1	**0.09J**	<0.8
Phthalate, diethyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Phthalate, dimethyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Phthalate, di-n-butyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Phthalate, di-n-octyl-	"	**0.6J**	<2	--	<0.8	<0.8	<0.8
Phthalate, butylbenzyl-	"	<5	<2	--	<0.8	<0.8	<0.8
Pyrene	"	**0.5J**	<2	--	**0.2J**	<0.8	<0.8
Pyrene, benzo(a)-	"	<5	<2	--	<0.8	<0.8	<0.8
Pyrene, indeno(1,2,3-c,d)-	"	<5	<2	--	<0.8	<0.8	<0.8
Retene	"	<5	<2	--	--	--	--
Toluene, 2,4-dinitro-	"	<5	<2	--	<0.8	<0.8	<0.8
Toluene, 2,6-dinitro-	"	<5	<2	--	<0.8	<0.8	<0.8
Xylene, m	"	--	--	--	**0.33JN**	--	--
Xylene, p-	"	--	--	--	**0.49JN**	--	--
Surrog: Benzene, D5-nitro-	% recov.	69	80	--	56	80	85
Surrog: Biphenyl, 2-fluoro-	"	72	83	--	60	69	78
Surrog: Phenol, D5-	"	41	84	--	22	55	62
Surrog: Phenol, 2-fluoro-	"	61	97	--	47	87	94
Surrog: Pyrene, D10-	"	110	144	--	112	140	134
Surrog: Terphenyl, D14-	"	118	144	--	106	132	121
GENERAL CHEMISTRY							
Ammonia	mg-N/L	**0.07**	--	--	**0.05**	--	--
Chemical oxygen demand	mg/L	**24**	--	--	**29.9**	--	--
Cyanide	ug/L	<2	--	--	<2	--	--

Appendix A. Continued.

Parameter	Units	10/14/88 Hatchery Water	10/14/88 Lab Blank 1	10/14/88 Lab Blank 2	11/03/89 Hatchery Water	11/03/89 Lab Blank 1	11/03/89 Lab Blank 2
Hardness	mg/L	**32**	--	--	**31**	--	--
Nitrate-plus-nitrite	mg-N/L	**0.54**	--	--	**0.48**	--	--
Oil and grease	mg/L	--	--	--	<2	--	--
Specific conductance	umhos/cm	**99**	--	--	**89**	--	--
Total organic carbon	mg/L	**23**	--	--	**13.2**	--	--
Total phosphorus	mg-P/L	**0.09**	--	--	**0.13**	--	--
Turbidity	NTU	12	--	--	**35**	--	--
HERBICIDES							
2,4-D	ug/L	<0.15	<0.01	--	<0.04	<0.04	<0.04
2,4-DB	"	<0.60	<0.04	--	<0.16	<0.16	<0.16
2,4,5-T	"	<0.07	<0.005	--	<0.01	<0.01	<0.01
2,4,5-TB	"	<0.07	<0.005	--	<0.01	<0.01	<0.01
2,4,5-TP (Silvex)	"	<0.07	<0.005	--	<0.01	<0.01	<0.01
Bromoxynil	"	<0.07	<0.005	--	<0.01	<0.01	<0.01
Dicamba	"	<0.07	<0.005	--	<0.01	<0.01	<0.01
Dinoseb	"	<0.07	<0.005	--	<0.01	<0.01	<0.01
Ioxynil	"	<0.07	<0.005	--	<0.01	<0.01	<0.01
MCPA	"	--	--	--	<1	<1	<1
MCPB	"	--	--	--	<1	<1	<1
MCPP	"	--	--	--	<1	<1	<1
Phenol, pentachloro-	"	**0.77**	<0.005	--	**0.52**	<0.01	<0.01
Phenol, 2,3,4,5-tetrachloro-	"	<0.07	<0.005	--	**0.037**	<0.01	<0.01
Picloram	"	<0.07	<0.005	--	<0.01	<0.01	<0.01
IntStd: Phenol, 2,4,6-tribromo-	% recov.	--	--	--	39	51	36
METALS (TOTAL)							
Antimony	ug/L	<2	<2	<2	<1	<1	--
Arsenic	"	<1	<1	<1	**2**	<1	--
Beryllium	"	<1	<1	<1	<1	<1	--
Cadmium	"	<5	<5	<5	<2	<2	--
Chromium	"	<10	<10	<10	**10**	<5	--
Copper	"	**9**	<2	<2	**20**	**2**	--
Lead	"	**11.5**	**1.4**	<1	**13**	<1	--
Mercury	"	<0.08	--	--	<0.1	<0.1	--
Nickel	"	<20	<20	<20	**10**	<10	--
Selenium	"	<1	<1	<1	<1	<1	--
Silver	"	<0.2	<0.2	<0.2	<3	<3	--
Thallium	"	<1.0	<1.0	<1.0	<1	<1	--
Zinc	"	**42**	<4	<4	**54**	<4	--
Spike 1: Antimony	% recov.	109	--	--	--	--	--
Spike 1: Arsenic	"	87	--	--	--	--	--
Spike 1: Beryllium	"	100	--	--	--	--	--
Spike 1: Cadmium	"	90	--	--	--	--	--
Spike 1: Chromium	"	101	--	--	--	--	--

Appendix A. Continued.

Parameter	Units	10/14/88 Hatchery Water	10/14/88 Lab Blank 1	10/14/88 Lab Blank 2	11/03/89 Hatchery Water	11/03/89 Lab Blank 1	11/03/89 Lab Blank 2
Spike 1: Copper	"	101	--	--	--	--	--
Spike 1: Lead	"	79	--	--	--	--	--
Spike 1: Mercury	"	95	--	--	--	--	--
Spike 1: Nickel	"	97	--	--	--	--	--
Spike 1: Selenium	"	77	--	--	--	--	--
Spike 1: Silver	"	60	--	--	--	--	--
Spike 1: Thallium	"	100	--	--	--	--	--
Spike 1: Zinc	"	102	--	--	--	--	--
Spike 2: Antimony	"	107	--	--	--	--	--
Spike 2: Arsenic	"	86	--	--	--	--	--
Spike 2: Beryllium	"	100	--	--	--	--	--
Spike 2: Cadmium	"	97	--	--	--	--	--
Spike 2: Chromium	"	102	--	--	--	--	--
Spike 2: Copper	"	101	--	--	--	--	--
Spike 2: Lead	"	100	--	--	--	--	--
Spike 2: Mercury	"	112	--	--	--	--	--
Spike 2: Nickel	"	97	--	--	--	--	--
Spike 2: Selenium	"	81	--	--	--	--	--
Spike 2: Silver	"	61	--	--	--	--	--
Spike 2: Thallium	"	103	--	--	--	--	--
Spike 2: Zinc	"	102	--	--	--	--	--
ORGANOCHLORINE PESTICIDES							
Aldrin	ug/L	<0.005	<0.010	--	<0.003	<0.009	<0.01
BHC, alpha-	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
BHC, beta-	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
BHC, gamma- (Lindane)	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
BHC, delta-	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
Chlordane	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
DDT, 4,4'-	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
DDE, 4,4'-	"	**0.005M**	<0.010	--	<0.003	**0.009**	<0.01
DDD, 4,4'-	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
Dieldrin	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
Endosulfan, alpha-	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
Endosulfan, beta-	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
Endosulfan sulfate	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
Endrin	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
Endrin aldehyde	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
Heptachlor	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
Heptachlor epoxide	"	<0.005	<0.010	--	<0.003	<0.009	<0.01
Methoxychlor	"	--	--	--	<0.006	<0.02	<0.02
Toxaphene	"	<0.06	<0.15	--	<0.09	<0.27	<0.30
IntStd: Hexabromobenzene	% recov.	76	90	--	91	86	89

Appendix A. Continued.

Parameter	Units	10/14/88 Hatchery Water	10/14/88 Lab Blank 1	10/14/88 Lab Blank 2	11/03/89 Hatchery Water	11/03/89 Lab Blank 1	11/03/89 Lab Blank 2
ORGANOPHOSPHORUS PESTICIDES							
Azinphos, methyl (Guthion)	ug/L	<0.05	<0.10	--	<0.01	<0.03	<0.03
Azinphos, ethyl (Ethyl Guthion)	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Carbophenothion	"	**0.7**	<0.10	--	<0.01	<0.03	<0.03
Coumaphos	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
DEF	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Diazinon	"	**0.06**	<0.10	--	<0.01	<0.03	<0.03
Dichlorvos (DDVP)	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Dimethoate	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Dioxathion	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Disulfoton (Di-Syston)	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
EPN	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Ethion	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Fenthion	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Folex	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Imidan	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Malathion	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Mevinphos	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Monocrotophos	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Parathion, methyl	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Parathion, ethyl	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Phencapton	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Phorate	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
Ronnel	"	<0.05	<0.10	--	<0.01	<0.03	<0.03
POLYCHLORINATED BIPHENYLS							
PCB-1016	ug/L	<0.02	<0.05	--	<0.03	<0.09	<0.10
PCB-1221	"	<0.02	<0.05	--	<0.03	<0.09	<0.10
PCB-1232	"	<0.02	<0.05	--	<0.03	<0.09	<0.10
PCB-1242	"	<0.02	<0.05	--	<0.03	<0.09	<0.10
PCB-1248	"	<0.02	<0.05	--	<0.03	<0.09	<0.10
PCB-1254	"	<0.02	<0.05	--	<0.03	<0.09	<0.10
PCB-1260	"	<0.02	<0.05	--	<0.03	<0.09	<0.10
IntStd: 4,4-dibromooctafluoro-biphenyl	% recov.	--	--	--	49	30	43
VOLATILE ORGANICS							
Acetone	ug/L	<6.9	<6.9	--	<2	<2	--
Benzene	"	<1.0	<1.0	--	<1	<1	--
Benzene, chloro-	"	<0.9	<0.9	--	<1	<1	--
Benzene, ethyl-	"	<0.8	<0.8	--	<1	<1	--
Bromoform	"	<2.5	<2.5	--	<1	<1	--
Butanone, 2-	"	<6.2	<6.2	--	<2	<2	--
Carbon disulfide	"	<1.2	<1.2	--	<1	<1	--
Carbon tetrachloride	"	<0.9	<0.9	--	<1	<1	--

Appendix A. Continued.

Parameter	Units	10/14/88 Hatchery Water	10/14/88 Lab Blank 1	10/14/88 Lab Blank 2	11/03/89 Hatchery Water	11/03/89 Lab Blank 1	11/03/89 Lab Blank 2
Chloroform	"	<1.1	<1.1	--	<1	<1	--
Ethane, chloro-	"	<3.3	<3.3	--	<2	<2	--
Ethane, 1,1-dichloro-	"	<0.6	<0.6	--	<1	<1	--
Ethane, 1,2-dichloro-	"	<0.5	<0.5	--	<1	<1	--
Ethane, 1,1,1-trichloro-	"	<0.6	<0.6	--	<1	<1	--
Ethane, 1,1,2-trichloro-	"	<0.7	<0.7	--	<1	<1	--
Ethane, 1,1,2,2-tetrachloro-	"	<2.7	<2.7	--	<1	<1	--
Ethene, 1,1-dichloro-	"	<0.7	<0.7	--	<1	<1	--
Ethene, 1,2-dichloro-total	"	<0.8	<0.8	--	<1	<1	--
Ethene, trichloro-	"	<0.6	<0.6	--	<1	<1	--
Ethene, tetrachloro-	"	<0.5	<0.5	--	<1	<1	--
Ether, 2-chloroethylvinyl-	"	<2.7	<2.7	--	--	--	--
Hexanone, 2-	"	<3.2	<3.2	--	<2	<2	--
Methane, bromo-	"	<3.1	<3.1	--	<2	<2	--
Methane, chloro-	"	<3.8	<3.8	--	<2	<2	--
Methane, bromodichloro-	"	<0.3	<0.3	--	<1	<1	--
Methane, dibromochloro-	"	<0.7	<0.7	--	<1	<1	--
Methylene chloride	"	<3.3	<3.3	--	<1	<1	--
Pentanone, 4-methyl-2-	"	<3.5	<3.5	--	<2	<2	--
Propane, 1,2-dichloro-	"	<0.7	<0.7	--	<1	<1	--
Propene, cis-1,3-dichloro-	"	<1.9	<1.9	--	<1	<1	--
Propene, trans-1,3-dichloro-	"	<1.8	<1.8	--	<1	<1	--
Styrene	"	<1.1	<1.1	--	<1	<1	--
Toluene	"	<0.8	<0.8	--	<1	<1	--
Vinyl acetate	"	<3.1	<3.1	--	<2	<2	--
Vinyl chloride	"	<2.0	<2.0	--	<2	<2	--
Xylene, total	"	<1.8	<1.8	--	<1	<1	--
Surrog: Benzene, bromofluoro-	% recov.	95.7	96.3	--	101	109	--
Surrog: Ethane, D4-1,2-dichloro-	"	95.6	96.1	--	105	105	--
Surrog: Toluene, D8-	"	98.5	98.6	--	98	107	--

B = Blank contamination probable.
J = Estimated value; not accurate.
M = Presence of material verified but not quantified.
N = Presence of material probable, but not verified or quantified.

Appendix B. Pentachlorophenol (PCP) and 2,3,4,5-tetrachlorophenol (TCP) in and near Whatcom Creek, 1987-1989. Federal toxicity criteria for the protection of aquatic life (EPA 1986) and 96-hour LC_{50}s for coho salmon are provided for reference. Results above detection limits are highlighted.

Site	River Mile	Date	pH	PCP (ug/L)	TCP (ug/L)
Hatchery Kills					
MHFH	0.2	11/14/87	6.8	**0.14**	**0.02**
		11/16/87	6.8 J	**0.15**	**0.04**
		10/14/88	--	**0.77**	<0.07
		11/03/89	--	**0.52**	**0.04**
Summer 1987 Survey					
Whatcom Creek					
20 m above end of Racine St.	1.8	7/14/87	7.7	**0.02**	--
20 m above James St.	1.1	7/14/87	7.8	**0.01**	--
50 m above Dupont St.	0.2	7/14/87	8.0 J	**0.02**	--
Winter 1987 Survey					
Whatcom Creek					
20 m above end of Racine St.	1.8	12/08/87	6.6	**0.02**	<0.01
20 m above James St.	1.1	12/08/87	6.8	**0.06**	**0.01 M**
50 m below State St.	0.7	12/08/87	6.7	**0.05**	**0.02 M**
50 m above Dupont St.	0.2	12/08/87	6.6	**0.03**	**0.02 M**
Fever Creek at mouth	1.45	12/09/87	6.6	**10**	**0.16**
Ecology 1989 Kill Response*					
Fever Creek					
Above Brooks Lumber	--	11/07/89	--	**0.42**	0.04N
Below Brooks Lumber	--	11/07/89	--	**4.5**	**0.19**
Brooks Lumber					
Parking lot drain sump	--	11/07/89	--	**2.63**	--
Federal Toxicity Criteria					
Acute (1-hour average concentration not to be exceeded more than once every 3 years)			6.5	5.5	--
			7.0	9.1	--
			7.5	15	--
			8.0	25	--
Chronic (4-day average concentration not to be exceeded more than once every 3 years)			6.5	3.5	--
			7.0	5.7	--
			7.5	9.5	--
			8.0	16	--

Appendix B. Continued.

Site	River Mile	Date	pH	PCP (ug/L)	TCP (ug/L)
Coho Salmon 96-hour LC_{50}s					
Davis and Hoos (1975)			7.0	30	--
			7.0	85	--
Iwama and Greer (1980)			6.5-7.5	60	--

* = Data should be regarded as estimates due to possible use of improper sample containers.
J = Estimated; value not accurate.
M = Presence of material verified but not quantified.
N = Presence of material probable, but not verified or quantified.

Appendix C. Total metals in and near Whatcom Creek, 1987-1989. Federal toxicity criteria for the protection of aquatic life (EPA 1986) and 96-hour LC_{50}s for coho salmon are provided for reference. Results above detection limits are highlighted.

Site	River Mile	Date	Hardness (mg/L)	Copper (ug/L)	Lead (ug/L)	Zinc (ug/L)
Hatchery Kills						
MHFH	0.2	11/14/87	37J	**5**	<1	**8**
		11/16/87	37J	**1**	<1	**6**
		10/14/88	32	**9**	**11.5**	**42**
		11/03/89	31	**20**	**13**	**54**
Summer 1987 Survey						
Whatcom Creek						
10 m below Lake Whatcom Dam	3.8	7/14/87	39	<5	**1**	**22**
100 m above Valencia Street	2.2	7/14/87	34	<5	**4**	<5
20 m above end of Racine St.	1.8	7/14/87	40	<5	<1	<5
20 m above James St.	1.1	7/14/87	40	<5	**10**	<5
		7/15/87	42	**13**	<1	<5
50 m below State St.	0.7	7/14/87	30	<5	**18**	**6**
50 m above Dupont St.	0.2	7/14/87	44	<5	<1	**14**
		7/15/87	37	<5	<1	<5
Winter 1987 Survey						
Whatcom Creek						
20 m above end of Racine St.	1.8	12/08/87	27	**15**	<1	<1
20 m above James St.	1.1	12/08/87	37	**17**	<1	**17**
50 m below State St.	0.7	12/08/87	32	**17**	<1	**11**
50 m above Dupont St.	0.2	12/08/87	35	**13**	<1	**2**
		12/09/87	39	**6**	**7**	**48**
Tributaries						
Mouth of Fever Creek	1.45	12/09/87	26	<1	**6**	**93**
Mouth of Lincoln Creek	1.4	12/09/87	36	**4**	**21**	**25**
Pipes						
1 m below Valencia Street	2.1	12/09/87	48	<1	**96**	**40**
Between King St. and I-5	1.2	12/09/87	25	**16**	**31**	**120**
2 m below James Street	1.1	12/09/87	28	**13**	**490**	**95**
Under State Street	0.75	12/09/87	27	**24**	**11**	**120**

Appendix C. Continued.

Site	Mile	Date	Hardness (mg/L)	Copper (ug/L)	Lead (ug/L)	Zinc (ug/L)
Under Cornwall Avenue	0.55	12/09/87	31	**5**	**4**	**63**
40 m above Dupont Street	0.2	12/09/87	29	**12**	**2**	**28**
Lake Whatcom						
Bellingham Hatchery (WDW)	3.8	1/19/89	33	<8 *	**1.6 ***	**3.6***
		2/14/89	35	**9.9***	<1 *	**27.9***
		2/15/89	28	<8 *	<1 *	**7.3***
Ecology 1989 Kill Response**						
Whatcom Creek	1.5	11/07/89	30J	<10 *	<2 *	<10 *
	0.2	11/07/89	30J	<10 *	<2 *	<10 *
Fever Creek						
Above Brooks Lumber	--	11/07/89	--	**10 ***	**4 ***	**60 ***
Below Brooks Lumber	--	11/07/89	--	<10 *	**8 ***	**80 ***
Brooks Lumber						
Treated log storage area runoff to Fever Creek	--	11/07/89	--	<10 *	**4 ***	**2,580 ***
Parking lot drain sump	--	11/07/89	--	**20 ***	**34 ***	**240 ***
Federal Toxicity Criteria						
Acute (1-hour average concentration not to be exceeded more than once every three years)			25	4.8	14	36
			35	6.6	21	48
			45	8.4	30	59
Chronic (4-day average concentration not to be exceeded more than once every 3 years)			25	3.6	0.54	33
			35	4.8	0.84	44
			45	6.0	1.20	54
Coho Salmon 96-hour LC_{50}s						
Chapman (unpublished data cited in EPA 1976)			17-26	--	520-800	--
Lorz and McPherson (1976)			89-99	60-74	--	4600
Chapman and Stevens (1978)			19-26	46	--	905

* = Total recoverable metals.
** = Data should be regarded as estimates due to possible use of improper sample containers.
J = Estimated; value not accurate.