ASSESSMENT OF FEDERAL-PROVINCIAL WATER QUALITY DATA FOR THE FLATHEAD AND SIMILKAMEEN RIVERS

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ABSTRACT

B.C. Environment and Environment Canada have jointly monitored water quality on the Similkameen and Flathead Rivers near the International Boundary since 1984 or 1985. The Similkameen River has been sampled every two weeks and 35 variables have been routinely measured; the Flathead River has been sampled once per week for 27 variables. The 1984/85 to 1989/90 water quality data from these two sites were analyzed statistically to detect the frequency and timing of non-attainment of criteria and objectives, and the presence of any long-term trends. Based on the results of this analysis, the efficiency of the monitoring program was assessed, and possible refinements suggested.

Levels of most variables in both rivers either attained the water quality objectives and criteria or only occasionally did not attain them. Non-attainment of water hardness (exceeding 100 mg/L but not 200 mg/L) resulted from naturally high concentrations of calcium and magnesium. Most other variables not attaining the objectives were associated with particulate matter (turbidity, non-filterable residue, total phosphorus, apparent colour, iron, manganese, zinc), reflecting sediment erosion and transport, especially during periods of high discharge (spring freshet). Levels of zinc and copper were probably exaggerated by historical problems of sample contamination, and non-attainment of objectives for mercury were overestimated by the previously high detection limit. Chromium exceeded the monthly average criterion (0.002 mg/L) in almost every month it was measured (possibly an artifact), but the maximum objective (0.02 mg/L) was never exceeded. Most metals were probably in inert, particulate forms rather than biologically available dissolved forms, and thus were not a hazard to aquatic life. Similarly, the high levels of total phosphorus in both rivers during spring runoff resulted from transport of phosphorus-bearing mineral particles, and do not pose a threat of enrichment of the ecosystem. Non-attainment of criteria for fecal coliform bacteria in the Similkameen River arose from cattle, as there are no direct sewage discharges to the river. Cyanide criteria were rarely exceeded in the Similkameen River except in 1987-1990; Several sources, particularly measurement error, may have caused the elevated cyanide levels.

Although most variables on both rivers showed strong seasonal differences, there were few long-term trends. On both rivers, water temperatures increased in concert with average air temperature over the five-year sampling period. On the Flathead River, trends of increasing conductivity and decreasing iron, manganese, total phosphorus and turbidity were all linked to decreasing river discharge. A weak trend of declining concentrations of nitrate-nitrite-nitrogen (and hence dissolved nitrogen) in both rivers may be natural if net nitrogen assimilation by biota has increased, but laboratory contamination of samples may also be significant. High concentrations of zinc in 1986-1987 probably reflect a known problem of sample contamination. In the Similkameen River, abrupt increases in concentrations of lead, copper and cyanide in 1988-1989 correspond with the opening of two mining projects, but sample contamination or natural sources are more likely causes.

The present sampling scheme detected trends on either river as small as 2-5% yr^{-1}; the goals of the program could probably be achieved with monthly sampling. Measurement of water and air temperature, (true) colour, non-filterable residue, conductance, pH, alkalinity and hardness should continue on both rivers, along with ammonia, fecal coliform bacteria and cyanide (simple and total) in the Similkameen River. Turbidity, filterable residue, major ions, reactive silica and fluoride should be deleted. Total phosphorus should be measured along with dissolved phosphorus, and dissolved nitrogen and nitrate-nitrite-nitrogen should be replaced with total nitrogen. Key metals to monitor are cadmium, copper, chromium, iron, lead, manganese, mercury, molybdenum, nickel, selenium and zinc. Metals should be measured as totals until a reliable method of field filtration can be devised.

Water column sampling should be supplemented with twice-yearly sampling of sediments for metals (except iron and manganese) plus cyanide and representative pesticides in the Similkameen River. Alternatively, toxicity of sediment pore water could be assessed in the spring and fall, using a battery of simple toxicity tests. Spring and fall sampling of benthic invertebrates and periphyton is recommended as a means of early detection of ecosystem changes. Sampling should concentrate on obtaining reliable, quantitative density estimates of common species. Analysis of biotic data would rely on relative abundances of sensitive taxa or changes in proportions of functional groups, rather than absolute measures of abundance or production.

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1. INTRODUCTION

B.C. Environment and Environment Canada have jointly operated a network of 27 water quality monitoring stations on major rivers and lakes in British Columbia since 1985. The monitoring program is intended to allow assessment of the present status of the waterbodies, and especially of any trends in water quality at these sites. Sufficient data have now been collected at two sites, on the Flathead and Similkameen Rivers, for trend assessment to begin.

The Flathead River (known as the North Fork Flathead River in the U.S.) arises in the extreme southeast corner of British Columbia, just west of Waterton Lakes National Park, and flows 90 km directly southward into Montana. Its drainage basin is sparsely populated, mountainous and heavily forested. The Similkameen River arises in the Cascade Mountains and flows north, and then southeast along the edge of the Interior Plateau, eventually crossing into Washington State near Osoyoos. In contrast to the Flathead River, the Similkameen River flows through a broad, open valley where mining, forestry and irrigated agriculture are significant activities. The Similkameen River near the U.S. border has been sampled every two weeks since March, 1984, and 35 variables have been measured routinely. On the Flathead River at Flathead (an unoccupied location on the U.S. Border) weekly sampling for 27 variables began in 1985. The relatively frequent sampling of the Flathead River was intended to capture possible short-term variations or cycles in water quality with periods of one to a few months. Data collected through 1989 are now available for analysis.

This report presents a statistical and ecological analysis of the water quality data from these two sites, as well as of the sampling program from which the data were derived. The data analysis had two precise goals: first, comparison of the data against established water quality objectives and criteria, and second, assessment of the data for any long-term trends, and exposition of the sources, whether hydrological, meteorological, ecological or anthropogenic, of those trends.

The Similkameen River does not presently receive large municipal or industrial effluent loads and the Flathead River basin is nearly pristine. Consequently water quality in both rivers is high, and water quality criteria or objectives for protection of all water uses (aquatic life, drinking, recreation, irrigation) are applicable. Some objectives have been established specifically for the Similkameen (Swain, 1985, 1990) and Flathead (Valiela et al., 1987) Rivers; others are intended to be more general (Pommen, 1989; CCREM, 1987), but should still be applicable here.

For this report, trends were defined as consistent increases or declines in mean concentration or level over time. Trends in any water quality variable may arise from a number of sources. An increase in discharge from one season or year to the next may lead to a parallel increase in concentrations of suspended materials that are eroded or scoured from the river bed, or a decline in concentration of dissolved material, if the added water dilutes a constant solute source. Other trends may arise from ecological processes (an increase or decrease in production, for example), from natural cycles or fluctuations in local climate, from random events, and of course from human activity within the river basin. Detection of a trend over several years that has no obvious natural antecedent or that corresponds temporally with a change in land use acts as an early warning signal that human activity may be impinging on the river's behaviour.

Based on the results of the water quality data analysis, the efficiency of the sampling program for trend detection is assessed. The assessment draws on the data now collected to further optimize the sampling regime according to the kind and magnitude of trends actually being encountered. The central objective of the refinement is, while considering compromises between cost and comprehensiveness, to ensure that if a real trend should appear in the chemistry or biology of the rivers, the sampling program would be adequate to detect it.

The review considered all aspects of the sampling program, including timing and frequency of sampling, variables to be measured, and the medium (water, sediments, plants or animals) in which to measure each variable. The sampling frequency that will ensure detection of a trend of given magnitude within a specified time depends on the variability of the variable in question, the dynamics of the river, and the strength of obfuscating factors such as seasonality and autocorrelation. The variable list itself was modified by examining the data and trend analysis to determine which variables produced clear trends or temporal patterns and which provided only ambiguous results. Both exclusion of presently sampled variables and addition of new ones were considered.

All variables presently are measured in the water column, but for some (e.g., metals) the sediments may be the larger and more biologically active pool, and living organisms are the best monitors of which chemicals are actually entering the food chain. Sampling aquatic organisms may be further extended to ecological monitors or "bioindicators". Ecological monitors hold considerable promise as sensitive early signals of subtle or long-term changes in status of river ecosystems, if the advantages and disadvantages of each are considered for a particular aquatic system. Finally, all these considerations are incorporated into a recommended revised sampling program for continued monitoring of the Flathead and Similkameen Rivers.

2. RIVER BASIN OVERVIEW

2.1 Flathead River

The Flathead River arises from a network of small mountain streams in the extreme southeast corner of British Columbia, just west of Waterton Lakes National Park, and flows 90 km almost due south into Montana. Figure 1 shows the location of the Flathead River, and Martin et al. (1987) describe the river and its basin in detail. In Canada, the river and its tributaries occupy a relatively narrow, flat-bottomed valley, bounded on the east by the Flathead and Clark Ranges, rising to form the Great Divide, and on the west by the MacDonald Range, with a total drainage area of 1580 km^2. The upper river lies in a narrow, steep-walled valley between tall mountain ranges, and even 40 km downstream the valley is only about 2 km in width. At the International Boundary, the valley has widened to 13 km (Martin et al., 1987).

Geology of the area is complex. Roughly half the basin is mountains, including peaks in the MacDonald Range up to 2100 m high. The remainder of the basin is relatively flat-bottomed valleys underlain by a thick layer of unsorted and unconsolidated glacial till, ranging from silt and sand through gravel and boulders (Wardell et al., 1987), combined with recent alluvium from the surrounding mountains. Where the Flathead River valley is wider, lateral and terminal moraines from retreating glaciers have formed ranks of low, rounded hills between the valley floor and the mountains.

The mountains themselves are composed mostly of sandstone, siltstone, limestone (including dolomite) and argillite, a rock formed from clay or silt that is intermediate in hardness between shale and slate. The limestone and argillite resist weathering and erosion, and hence form the mountain peaks and steep, rocky buttresses prominent in the area (Martin et al., 1987). The entire basin was covered with glacial ice during the Pleistocene period, from which upland scouring and the moraines and till in the valley bottoms arose, and alpine glaciers are still present throughout the higher mountain ranges. Most of the mountain strata are of Paleozoic or Precambrian age, but the

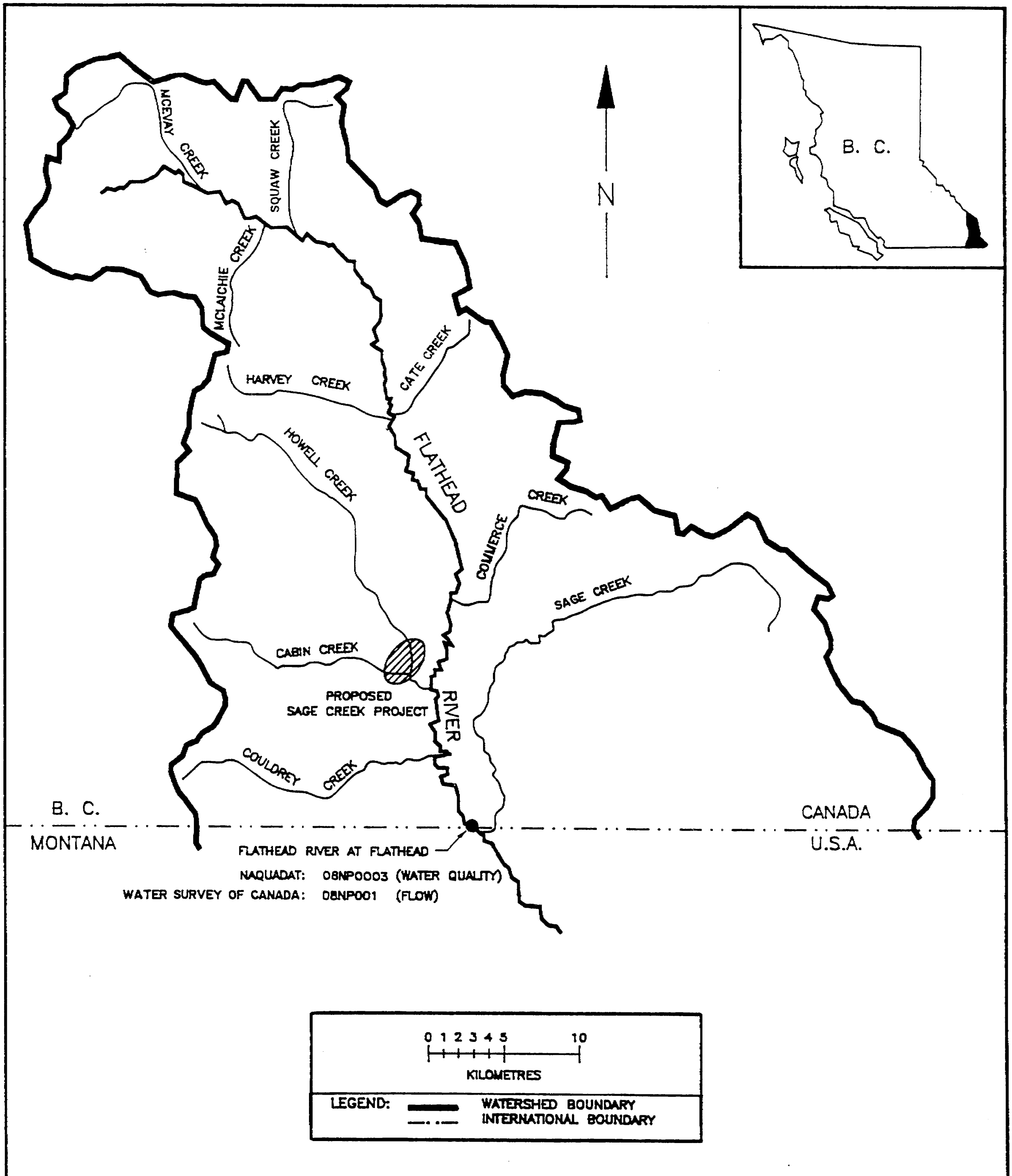

FIGURE 1	FLATHEAD RIVER BASIN	Environmental Management Associates

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western and northern portions of the basin have small areas of Mesozoic rock, which contains coal. In the area near Cabin Creek where commercial coal mining has been proposed (Figure 1), total coal reserves are estimated at 152 million tonnes (Martin et al., 1987).

The mountains create a local, humid continental climate of long, cold, snowy winters and short, cool, moist summers. The greater part of precipitation falls as snow, and snowpack accumulations may exceed 2-3 m. Seasonal changes are well-defined, and the relatively sudden onset of spring snowmelt creates peak spring flows in the Flathead River.

Soils in the basin tend to be immature and incompletely developed because of the relatively recent disturbance by glacial ice, and the short growing season at higher elevations. Soils on mountain slopes are usually rocky, thin, and nutrient-poor, especially for nitrogen and phosphorus (Martin et al., 1987). Nevertheless, the area supports a dense coniferous forest, except at high elevations or on slopes too steep to maintain soil; on steeper slopes, vegetation significantly enhances soil stability, which otherwise is prone to slip downslope. The basin falls into the Engelman Spruce-Subalpine Fir biogeoclimatic zone according to the schema of Krajina (1973). In addition to the dominant species, western red cedar and interior Douglas-fir are common, and lodgepole pine is abundant at lower elevations.

The upper Flathead River is essentially a parallel drainage system, with east- and west-flowing streams draining successive mountain valleys on each side into the south-flowing Flathead River (Figure 1). In all there are about 50 streams, of which the largest are named on Figure 1. The Flathead River has a mean gradient of 1.8% and long-term average discharge at the International Boundary is about 27 m^3/s (Martin et al., 1987). The river is unregulated, and so shows the dramatic seasonal variation in discharge that is typical of mountain rivers (Figure 2). Lowest discharge (4-10 m^3/s) usually occurs in winter, when precipitation accumulates as snow, and in late summer (August-September) when rainfall is lowest. Discharge increases abruptly with the onset of spring melt, and

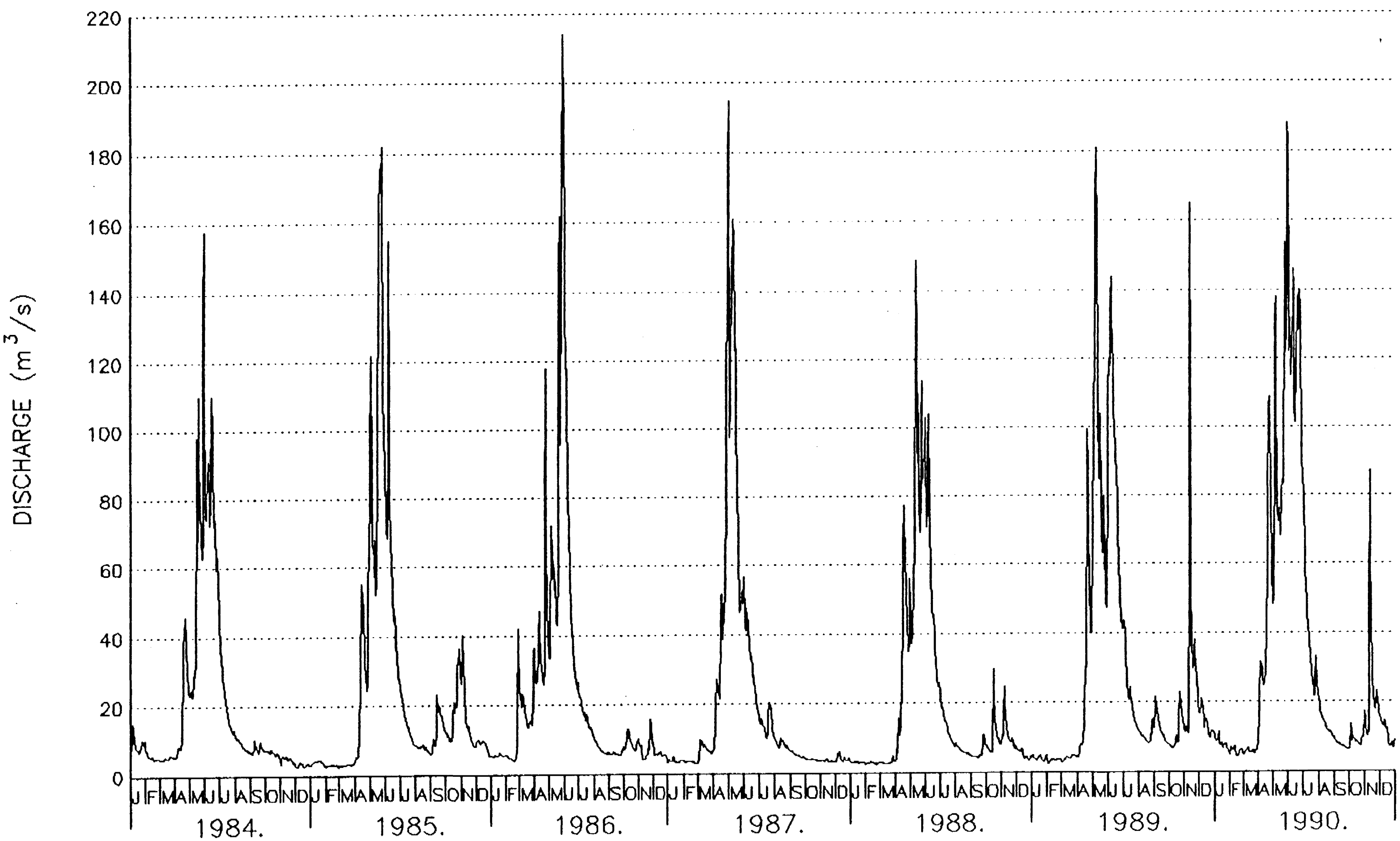

Figure 2

FLATHEAD RIVER AT FLATHEAD
FLOWS (1984 – 1990)

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peak flows in May and June exceed base flows by an order of magnitude or more (Figure 2). More gradual melt of snow at high elevations and spring rains cause a slow decline in discharge toward the late summer minimum. A second peak may occur in late autumn, but its magnitude varies greatly from one year to the next, probably as a function of seasonal rainfall and temperature, which determine the proportion of snow. In 1989 and 1990, the autumn discharge peaks briefly rivalled the magnitude of spring flows (Figure 2).

Inflows to the Flathead River are dominated by surface runoff, delivered quickly because of the steep slopes and thin soils. The valley bottoms, however, because of their deep accumulation of coarse till and alluvium, have a considerable potential to store groundwater, which feeds into the river after much longer exposure to mineral rock, and hence carries a greater solute load. There may also be some deep groundwater delivery through fissures in Precambrian rocks (Martin et al., 1987).

Land use in the basin is presently restricted to salvage logging of bark-beetle-infested lodgepole pine. There may be very local sedimentation from construction of logging roads, and removal of trees tends to increase spring runoff and decrease base flow, but these effects are limited to the immediate area being cut. Stream sedimentation has resulted from logging in Couldrey, Howell and Sage Creeks, and the lower Flathead River itself, but the effect has not been quantified and is considered transitory (Wardell et al., 1987). Logged areas are more prone to erosion and stream sedimentation during spring melt, when overland flow is greatest. Other effects of logging, such as effects on stream temperature or dissolved solute concentrations, have not been studied in this basin. The total logged area in the Flathead River basin, including areas planned for future logging, constitutes <5% of the basin area (Wardell et al., 1987).

Other activities within the basin are recreational: hiking, camping, hunting, fishing, canoeing and rafting. Their effects on the Flathead River are minimal. A gas pipeline, built in the late 1970s, transects the extreme northwest headwaters of the river, but evidently has no measurable effect on water quality (Wardell et al., 1987). There are no resident settlements along the Flathead River, and the basin has a permanent population of <12.

Water quality in the Flathead River is excellent. The river is clear and clean (except during spring freshet) and has been characterized as oligotrophic. Flathead River water is basic (pH 8.2-8.6) and well-buffered (alkalinity 60-130 mg/L), with calcium and bicarbonate as dominant ions (Martin et al., 1987). Total dissolved solids range from 100-200 mg/L at the International Boundary. Water tends to be cool (0-19°C), well-oxygenated, and low in nutrients and most metals. Valiela et al. (1987) and Sheehan et al. (1980, 1985) have exhaustively described historical water quality in the basin. The river supports a diversity of fish species, including several salmonids, both native (westslope cutthroat trout, mountain whitefish, dolly varden) and introduced (kokanee). Tributary streams to the Flathead River in Canada are important spawning and rearing habitats for mountain whitefish and dolly varden. Martin et al. (1987) discuss the biota of the Flathead River system in detail.

2.2 Similkameen River

The Similkameen River arises from mountain-fed streams in the Cascade Mountains and flows northward out of Manning Provincial Park. About 60 km downriver, at the town of Princeton, the river swings eastward, and continues south and east, eventually crossing the International Boundary about 15 km west of Osoyoos (Figure 3). A short distance thereafter the Similkameen River enters the Okanogan River, just south of Osoyoos Lake in Washington. The Canadian portion of the river basin is 9190 km^2 in area (Zeman and Slaymaker, 1987).

The Similkameen River system constitutes a typical dendritic drainage, with a network of small headwater streams coalescing relatively quickly into a few major tributaries of the Similkameen mainstem. The river is formed from several mountain streams draining most of Manning Provincial Park and an equivalent area south of the International Boundary. The headwaters are steep and fast-flowing, but an abrupt elevation change (Similkameen

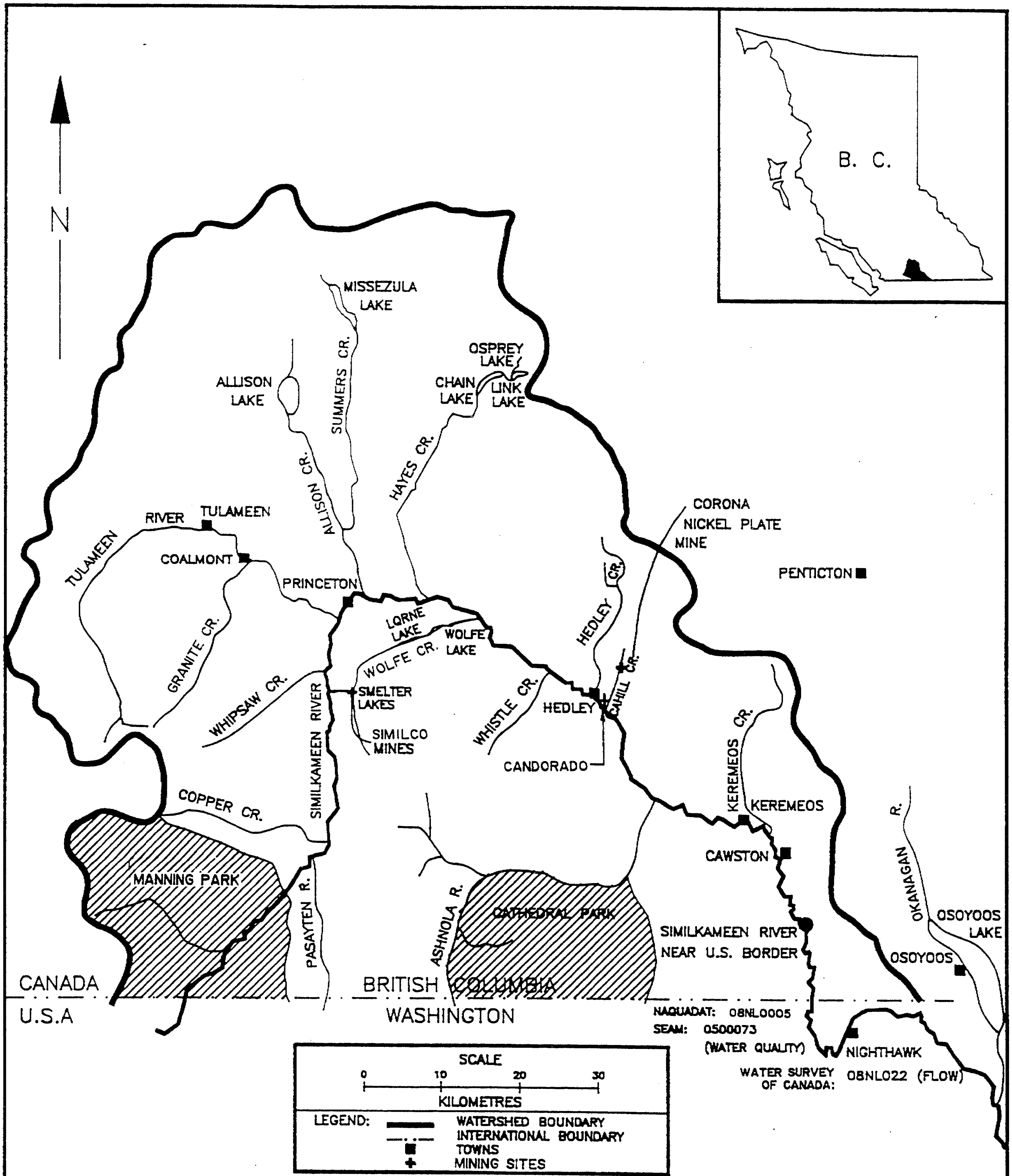

FIGURE 3	SIMILKAMEEN RIVER BASIN	Environmental Management Associates

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Falls) near the park boundary marks a transition to a broader, less turbulent river. The entire river has a mean gradient of roughly 1%. The north-flowing segment of the Similkameen River, from Manning Park to Princeton, drains the Hozameen Range of the Cascade Mountains on the west and the Okanagan Range on the east. The river receives a number of small tributaries, including Copper Creek and Whipsaw Creek from the west and the Pasayten River from the south. (The Pasayten River also arises in the U.S.). At Princeton the river receives a major tributary, the Tulameen River, flowing east off the Hozameen Range, as well as smaller Allison and Summers Creeks from the north (Figure 3).

The southeast-flowing portion of the river, from Princeton to Nighthawk (near the U.S. Border) essentially defines the boundary between the Okanagan Range and the Interior Plateau. Unconfined by steep mountains, the river runs through a broad, open valley for most of its length. In addition to numerous small streams, this section of the Similkameen River receives three tributaries from the north (Hayes, Hedley and Keremeos Creeks) and one from the south (Ashnola River) (Swain, 1985).

The Interior Plateau is a broad glacial outwash consisting of a deep layer of sorted or unsorted alluvium that forms a broadly undulating upland, patterned with ridges, hummocks and hollows. The upland is broken by higher plateaus and rounded, low morainal hills, and is deeply dissected by small streams and rivers. Water may collect in depressional areas, forming small lakes at the heads of drainage systems. Such "headwater" lakes are found along many of the north tributaries to the Similkameen River, and include Allison Lake, Missezula Lake and Chain Lake (Figure 3).

Climate in the mountains is cool and wet, with most precipitation falling as snow. Over most of the basin, however, the climate is semiarid, cool temperate, with hot, dry summers and cold, moist winters (Zeman and Slaymaker, 1987). There is a steep gradient in annual precipitation from 150 cm/yr in the western mountains to <30 cm/yr at Osoyoos. The high mountains, such as in Manning Park, support dense coniferous forests of Engelmann spruce, subalpine fir, and at lower elevations, ponderosa and lodgepole pine. Open woodland of ponderosa pine and interior Douglas-fir borders the Similkameen River from Manning Park to near Princeton, where bunchgrass begins to appear (Swain, 1985). The remainder of the river's length winds through dry grassland, and open parkland of Douglas-fir, ponderosa pine and aspen. Denser forests rise on the mountains to the south.

Soils of the area are immature because of recent glaciation, and in the mountains they may be thin and nutrient-poor. Soils of the Interior Plateau are more fertile; they have developed from fine glacial and fluvial sediments supplemented with windblown material. Soil profiles are deep and usually well-drained (Zeman and Slaymaker, 1987).

Despite the fact that the river flows largely through open grassland, precipitation, especially snowmelt, in the mountains is the principal source of water for the Similkameen River. Consequently, river discharge evinces the same strong seasonal pattern as the Flathead River (Figure 4). Mean monthly flows are least in winter (18-20 m^3/s at Nighthawk) and in late summer and fall. Flows increase sharply in March-April, and then again in May or June to peak in the range of 300-400 m^3/s (long-term monthly means 224 m^3/s and 253 m^3/s). The smaller increase in flow in March and April, before the main peak in June, probably reflects snowmelt on the plateau and foothills preceding melt in the high mountains. Flows decline quickly in July to reach the baseflow level by mid-August. Late autumn rains may bring a second discharge peak, usually <50 m^3/s, but in 1990 the autumn peak was >350 m^3/s, equivalent to peak spring discharge.

Discharge in the Similkameen River increases progressively downstream as tributaries and ground water are received. Mean baseflow and peak flow are only 6 m^3/s and 130 m^3/s, respectively above the Tulameen River confluence, but increase to 10.5 m^3/s and 260 m^3/s at the town of Hedley, and 20 m^3/s and >300 m^3/s at Nighthawk (Swain, 1990). In terms of flow, the major tributaries to the Similkameen River are the Pasayten and Tulameen Rivers (Swain, 1990); although there are numerous other tributaries, discharge in streams draining the Interior Plateau is small, with annual means on the order of 1 m^3/s (Swain, 1985).

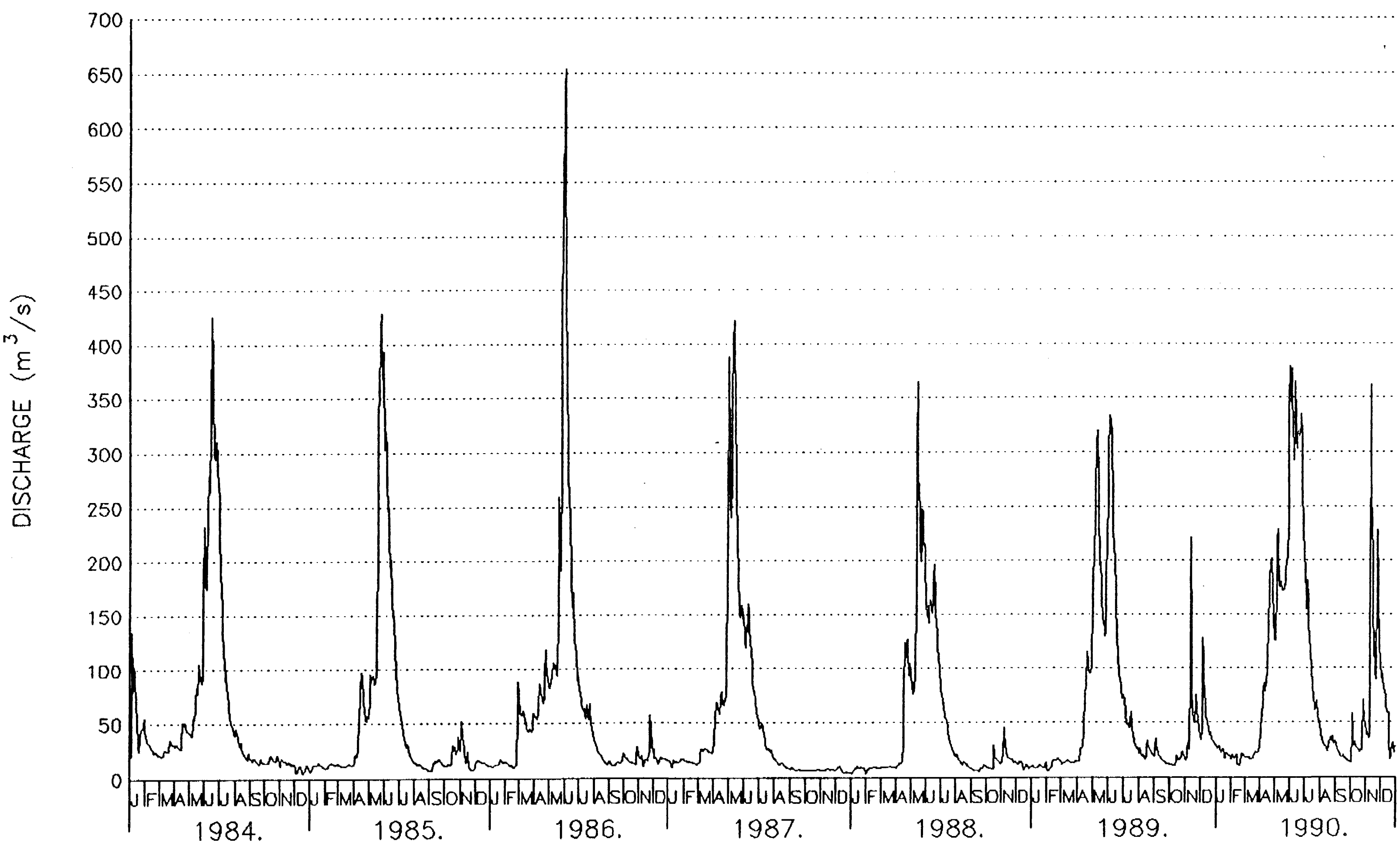

Figure 4	SIMILKAMEEN RIVER AT NIGHTHAWK FLOWS (1984 – 1990)	Environmental Management Associates

The Similkameen River basin had a population of 8550 in 1981, projected to increase at a rate of 100 people per year through 2005 (Swain, 1985). Major human activities within the basin are metal mining, agriculture (fruit farming and cattle ranching), forestry and recreation (Zeman and Slaymaker, 1987, 1988). Princeton (1981 population 3050) is the largest town in the basin; other communities are Hedley (450), Keremeos (830) and Cawston (800) (Swain, 1985). Coalmont and Tulameen are located along the Tulameen River (Figure 3).

Agriculture is found throughout the basin, except in mountainous and forested areas, but is concentrated in the area downstream from Hedley (Swain, 1990). There are approximately 3500 cattle in the basin, most of which have direct access to the river or its tributaries; consequently cattle are considered the largest single source of wastes, particularly nutrients and fecal coliforms, to the river (Swain, 1990). Agriculture in the basin depends heavily on irrigation; there are approximately 140 licensed irrigation withdrawals in the basin, which withdraw a total of 20×10^6 m^3/year from the Similkameen River and its tributaries (Swain, 1985, 1990). Most of the water is applied to pasture or tame hay to feed cattle, but in the eastern side of the basin there is substantial fruit production. Approximately 1000 tonnes of fertilizer are applied annually to >3000 ha of farmland in the basin, but Swain (1990) calculates that the effect of the fertilizer on river nitrogen and phosphorus levels is insignificant compared with that from cattle.

As of 1982, forestry permits had been issued for 19 000 ha of land in the Similkameen basin (0.2% of basin area), all of it in the west of the basin, upstream from Hedley Creek, and in the Okanagan Range to the south (Swain, 1985). However, only a small part of this area has actually been logged, and its effect on stream hydrology and solute loads is unknown. In some areas selective logging, rather than clearcutting, is practised, which tends to reduce impacts on surface waters.

Active mining for gold and other metals continues at a number of locations along the river. The largest operation is Similco Mines (formerly Newmont Mines), which operates a 20 000 tonne/day copper mine and mill between the Similkameen River and Wolfe

Creek. Tailings are discharged to Smelter lake; the pond is dammed at both ends, and most leachate is recovered. Nevertheless, increased levels of dissolved zinc have been noted in the Similkameen River and elevated levels of Cu, Fe, Mn, Mo, Zn, and dissolved solids have occurred in Wolfe Creek, downstream from Smelter Lake (Swain, 1985).

Some 11 placer gold mines operate along the upper Similkameen and Tulameen Rivers, but these do not normally discharge waste water to the rivers. The Dankoe silver/gold mine near the International Boundary also does not discharge waste water. A large mine operation (Corona Nickel Plate Mine) has recently (1987) begun to mine and mill ore for gold in the headwaters of Cahill Creek near Hedley. Earlier mining operations in this area deposited tailings along the Similkameen River and Hedley Creek near Hedley (Swain, 1990). Some of these tailings are being reprocessed by Candorado Mines Ltd. using hydrogen cyanide to leach gold out of the tailings, which is then recovered electrolytically. No surface discharge is allowed from the latter operation, but seepage from tailings ponds and disturbance of old tailings piles could be sources of dissolved metals, nutrients, suspended solids, and cyanide.

A second operation to rework old tailings near Hedley has been proposed, also based on cyanide leaching (Sumac Ventures Inc.) and new exploration of an old shaft mine near Hedley has also been proposed (Banbury Mines). Neither of these operations would be permitted to discharge to surface waters, but the possibility still exists of contamination with metals, nitrates, cyanide, and suspended solids from seepage, explosives, or disturbance of tailings piles (Swain, 1990). An open-pit coal mine has been proposed for a site near the Tulameen River, but it is unlikely to proceed in the foreseeable future (Swain, 1985). More recently, a metal mine (Huldra Silver) south of Tulameen on a tributary of the Tulameen River has also been proposed (L. Swain, personal communication, 1991).

Other sources of wastes are treated sewage from towns along the river, and individual septic tanks, but these are not seen as significant pollutant sources. The Town of Princeton disposes of sewage by land irrigation or infiltration, and other towns along the river have tertiary sewage treatment, or infiltration basins, or both. Water-based recreation in the Similkameen River basin includes swimming, boating, canoeing and fishing. There are two large provincial parks in the basin (Manning and Cathedral Parks) and several small parks (Stemwinder, Bromley Rock) and campgrounds along the river. Fishing and swimming are concentrated almost entirely along lakes (Swain, 1985).

Water quality throughout the Similkameen River system is good. River water is alkaline (pH 7.9-8.3), well-buffered (alkalinity 60-100 mg/L) and, despite the numerous active and abandoned mines, mostly low in metals. Turbidity and suspended solids vary widely through the year because of the scouring effect of high flows, with suspended solids ranging from <10 mg/L to >100 mg/L. Dissolved solids show a reverse pattern because spring runoff has little contact with rocks or soil and therefore carries a lower solute load.

The Similkameen River and its tributaries are cool (0-22°C) and dissolved oxygen levels are usually near saturation (Swain, 1985). The river supports healthy populations of salmonids (rainbow trout, mountain whitefish), and a wide variety of other fish species: prickly sculpin, longnose dace, bridgelip sucker, northern mountain sucker, peamouth chub, northern squawfish, crappie and redside shiner (Swain, 1990). Many of the lakes are stocked, but trout and mountain whitefish reproduce throughout the basin.

3. METHODS

3.1 Overview of Monitoring Program

B.C. Environment and Environment Canada have maintained water quality monitoring stations on the Flathead and Similkameen Rivers since the mid-1980's. Environment Canada commenced weekly sampling on 21 May 1985 at the Flathead River near Flathead, and fortnightly sampling (i.e., once every two weeks, biweekly) on 4 April 1984 at the Similkameen River near the U.S. Border. B.C. Environment has also sampled the Similkameen River at fortnightly intervals since 16 March 1987.

Water samples have been analyzed for a number of physical, chemical, and biological variables. Twenty-nine different variables were analyzed routinely from the Flathead River and 33 from the Similkameen River (Table 1). All water quality data are stored in the B.C. Environment's and Environment Canada's data bases (SEAM and NAQUADAT, respectively). At the time of this study, records in SEAM were complete to 15 January 1991 and in NAQUADAT to 24 October 1989.

3.2 Data Review

Water quality data were transferred electronically to EMA's computer facility from the B.C. Environment's and Environment Canada's data bases. All water quality data were screened graphically to identify potential errors in analysis or data entry. Potential errors were discussed with federal and provincial personnel to determine possible causes.

Flow records from 1984-1988 for the Flathead and Similkameen rivers were transferred electronically to EMA's computer from the data base of the Water Resources Branch, Environment Canada. Flows for 1989-1990 were entered by hand. These data were also screened graphically for potential errors due to transferring or entering flow records.

Table 1. Variables Routinely Analyzed at the Flathead and Similkameen Rivers (1984-1990).

Variable	Code
ENVIRONMENT CANADA (Flathead and Similkameen Rivers)	
Water Temperature	02061S
pH	10301L
Specific Conductance	02041L
Turbidity	02073L
Colour (Apparent)	02011L
Alkalinity (Phenolphthalein)	10151L
Alkalinity (Total)	10101L
Calcium	20103L
Magnesium	12102L
Hardness	10603L
Potassium	19103L
Sodium	11103L
Chloride	17206L
Fluoride	09105L
Silica (Reactive)	14105L
Sulphate	16306L
$(NO_2^- + NO_3^-)$-N	07110L
Total Dissolved Nitrogen	07651L
Total Phosphorus	15406L
Cyanide (Total)[1]	06606P
Arsenic (Total)	33008L
Selenium (Total)	34008L
Mercury (Total)	80011P
Cadmium (Total)	48002P
Chromium (Total)[2]	24003P
Copper (Total)	29005P
Iron (Total)	26004P
Manganese (Total)	25004P
Nickel (Total)[2]	28002P
Lead (Total)	82002P
Zinc (Total)	30005P
B.C. ENVIRONMENT (Similkameen River)	
pH	0004
Non-Filterable Residue	0008
Specific Conductance	0011
Cyanide (S.A.D.)	0105
Fecal Coliforms	0450
Ammonia-Nitrogen	1180
Total Dissolved Phosphorus	P--D

[1] Not measured on Flathead River
[2] Measured from April 1987 to April 1988

3.3 Quality Assurance

Quality assurance information for the Flathead and Similkameen sampling programs consists of field blanks and field replicates. In addition, laboratory blanks were analyzed by both the Provincial and Federal laboratories. These data can provide useful information on sample contamination resulting from field and laboratory procedures and the random nature of water quality variables, i.e., small-scale variation in space and time.

Both laboratory and field blanks were prepared in regular sampling bottles from de-ionized water obtained from the Provincial and Federal laboratories. Prior to a sampling trip in June 1990, blanks were prepared in both laboratories, preserved and left in the laboratories for the duration of the trip. De-ionized water was also transported to the monitoring site, and field blanks were mock collected using the same procedures as for regular water samples. The bottles containing the de-ionized water were loaded into the sampling apparatus, their caps were removed, and the bottles were lowered to just above the river surface. The sampling apparatus was held above the water surface for the length of time that it takes to collect a regular sample. Blanks were preserved as for regular samples, and transported back to the laboratory. Both laboratory and field blanks were then submitted along with regular samples for analysis.

Field replicates were obtained on a number of occasions at both rivers. For the Flathead River, duplicate samples were collected a few minutes apart on 2 March 1988 and after an interval of nearly three hours on 25 August 1987. Those samples were analyzed for all variables regularly monitored at that site. In addition, on all sampling occasions, triplicate samples were obtained and analyzed for $(NO_2^- + NO_3^-)$-N, total dissolved nitrogen, and total phosphorus.

On the Similkameen River, six replicates were collected at 3-min intervals by the B.C. Environment on 11 June 1990, and 2-5 replicates were collected by Environment Canada on six different occasions. On 16 March 1987, 23 November 1987, and 10 July 1989, samples were collected a few minutes apart, while on 2 May 1984, 11 July 1984, and

4 July 1987 samples were collected at intervals of 1 to 2.5 hours. Field replicates were analyzed for the variables routinely monitored at those sites. In addition, triplicate samples were obtained during most sampling trips from April 1988 to October 1989, and were analyzed for $(NO_2^- + NO_3^-)$-N, total dissolved nitrogen, and total phosphorus.

3.4 Comparison with Objectives

River water quality was compared against the following objectives, criteria or guidelines in order of preference:

1. Site-specific criteria or objectives for the Flathead River, or the lower reach of the Similkameen River, as given in recent Water Quality Assessment and Objectives reports (Swain, 1985, 1990; Zeman, 1990) or provided by the Flathead River International Study (Valiela et al., 1987);

2. General criteria for the Province of B.C., as given in Pommen (1989);

3. Canadian Water Quality guidelines, as given in CCREM (1987);

4. General American Water Quality criteria, as given in USEPA (1986).

Each water quality variable was compared only against the single best applicable objective or criterion according to the above list. Comparisons were only made against numeric objectives; narrative objectives or those defined in terms of percentage change from the natural or upstream condition were not used.

Water pH was compared against both the upper limit (9.0) and the lower limit (6.5) taken to define the pH range suitable for aquatic life. Similarly, the criteria for water hardness define a range (80-100 mg/L) within which hardness is considered "acceptable" for domestic use; water of up to 200 mg/L total hardness is considered "poor but tolerable" for drinking (CCREM, 1987). The present evaluation used both limits.

Concentrations of cyanide, chromium, lead, mercury and zinc were compared against both the instantaneous maximum criterion and the monthly average criterion defined by B.C. Environment. The objective for fecal coliform bacteria in the Similkameen River strictly applies to the 90th percentile of >5 monthly samples, but was compared here with individual samples. Hence, the frequency of exceeding the objective will be overestimated.

Criteria for copper and lead varied for each sample according to formulae relating toxicity to water hardness (Pommen, 1989). For other metals, the criteria chosen were those applicable to the range of water hardness normally found in the Flathead and Similkameen Rivers. An agricultural objective for sodium in the Similkameen River is based on the Sodium Adsorption Ratio, the ratio of sodium to calcium plus magnesium. Assessment of water colour used the B.C. colour criterion, which is set for true colour (filtered samples), even though the data are for apparent colour (unfiltered samples); colour data are thus biased upward by particulate material. Similarly, cyanide concentrations in the Similkameen River were compared against B.C. Environment criteria for weak-acid-dissociable cyanide, although the data reported other, less toxic forms of cyanide.

There are no water quality criteria or objectives for total phosphorus in flowing waters. Criteria for lakes are not directly applicable to rivers, where the flow of water often limits production by algae or rooted aquatic plants, irrespective of nutrient load. If nutrient levels are very high, however, eutrophication of the river, as well as lakes or rivers downstream, is still possible. The USEPA (1986) has suggested a tentative limit of 100 μg/L total phosphorus (TP) to protect rivers against excess production. For completeness, that limit has been used here for the Flathead and Similkameen Rivers, but it must be stressed that exceeding the criterion does not at once imply that phosphorus levels in the river are excessive. Much particulate phosphorus, especially mineral phosphorus contained in suspended particles, is chemically inert and unavailable to river biota. Further, high TP levels during spring freshet are of little concern because production during that period is severely limited by torrential flow. Hence, the ecological significance of high phosphorus concentrations must be assessed by considering the probable sources and chemical forms of the river load.

For each variable, the proportion of values that did not attain the applicable criterion were determined. The proportion of non-attainments was also determined for each month so that seasonal patterns could be identified. Time-series plots were also evaluated to elucidate potential changes over time with respect to attainment.

3.5 Trend Analysis

Analysis of long-term trends used simple methods. Initially, all variables were assessed graphically using time-series plots; only consistently increasing or decreasing trends in mean concentration or level over time were considered. A subset of variables was then selected for more detailed statistical analysis. The variables selected included those for which site-specific objectives exist, and those that are of particular ecological importance, or that exhibited a conspicuous trend in the time-series plots:

Water Temperature	Arsenic
Turbidity	Cadmium
Specific Conductance	Chromium
pH	Copper
Cyanide	Iron
Total Phosphorus	Lead
Total Dissolved Phosphorus	Manganese
Ammonia-Nitrogen	Mercury
$(NO_2^- + NO_3^-)$-N	Nickel
Total Dissolved Nitrogen	Selenium
Fecal Coliforms	Zinc

Most parametric and non-parametric statistical tests for long-term trends require data that are independently distributed. However, water quality data are often time-dependent, because of seasonality, serial correlation, or both (Montgomery and Reckhow, 1984). Seasonality implies that the value of a variable exhibits fluctuations based on the time of the year. If seasonality is present, the data should be treated to remove seasonal effects before testing for trends, or statistical tests that account for seasonality should be used.

Seasonal trends were assessed graphically, by inspection of box-and-whisker plots of monthly data, and statistically, with the Kruskal-Wallis test (Loftis et al., 1989a).

Serial correlation arises when the value of a datum is dependent, to some degree, upon previous data (after seasonality and trend have been removed). Serial correlation was assessed with a correlogram (Loftis et al., 1989a). If serial correlation was present, then average monthly data rather than weekly or biweekly data were used to test for long-term trends.

Long-term trends were assessed graphically by inspection of time-series plots and statistically with the Kendall test (Hirsch et al., 1982; Berryman et al., 1988). If seasonality was present, the data were deseasonalized by subtracting the seasonal mean from each datum before testing for trend, e.g., for monthly values, the monthly mean (computed from all data collected for a particular month over the course of the study) was subtracted from each datum for that month. The Kendall test is non-parametric and therefore not dependent on normally distributed data. In addition, a limited number of missing values or censored data (e.g., values reported below the detection limit) present no problem for the Kendall tests.

It is well known that concentrations of some variables are related to river discharge (Harned et al., 1981; Hirsch et al., 1982; Smith et al., 1982). Therefore, for flow-dependent variables, the detection of long-term trends may be a result of changes in streamflow. For variables with significant long-term trends ($P < 0.05$), a residual analysis technique was used to determine flow-adjusted concentrations. First, for each variable, a best-fit regression of concentration against discharge was calculated. The regression model was used to compute an expected concentration for every flow, and the flow-adjusted concentration was taken as the actual concentration minus the expected concentration (i.e., residual). The flow-adjusted concentrations were then tested for long-term trends as outlined above. This method of flow adjustment has been used in the evaluation of long-term trends in river water quality in a number of different studies (e.g., Smith et al., 1982; Shaw et al., 1990).

Trend analysis was carried out with SYSTAT (weekly and fortnightly data) and WQSTAT (mean monthly data). Residual analysis was performed with a Lotus 1-2-3 macro developed specifically for quantifying relationships between water quality and flow. Water quality data reported as less than the detection limit were set to one-half the detection limit for use in statistical procedures.

3.6 Sampling Frequency

The original monitoring program was intended to detect trends primarily and attainment of objectives secondarily; the same priorities were retained here when assessing sampling frequency. It was anticipated that a linear trend of 10% could be detected with the original sampling design. To test whether that magnitude of trend was detectable, the seasonal Kendall slope estimate was computed for those variables for which significant ($P < 0.05$) long-term trends were detected. The seasonal Kendall slope estimate is the seasonal equivalent of the non-parametric Sen slope estimate (Gilbert, 1987). The percentage change per year was estimated as the slope divided by the median (as computed from the complete data set).

The adequacy of the monitoring frequency was assessed by repeating trend tests on subsets of data for those variables that exhibited significant ($P < 0.05$) long-term trends. For the Flathead River, trend tests were conducted on a subset of data collected every two weeks, monthly, and quarterly; for the Similkameen River, trend tests were conducted on a subset of data collected monthly and quarterly.

4. QUALITY ASSURANCE

Quality assurance information for the Flathead and Similkameen sampling programs consists of laboratory and field blanks and field replicates. Laboratory blanks are used to identify and quantify potential sources of contamination arising from bottles, preservatives, de-ionized water, and laboratory analysis, and field blanks are used to determine the level of contamination that may result from the above plus sampling, handling and transport. Field replicates provide information on the random nature of water quality variables (e.g., small-scale variations in time and space) and on the overall precision of the analytical measurements.

Laboratory blanks were near or below detection limits for all variables except $(NO_2^- + NO_3^-)$-N, total dissolved nitrogen, and total iron (Table 2). Relatively high $(NO_2^- + NO_3^-)$-N levels (and consequently dissolved nitrogen levels) in laboratory blanks may be a result of contamination from filter paper or ion-exchange resins in the de-ionizer (Goudey et al., 1987; Sparrow and Masiak, 1987). The cause of the high iron concentration is unknown; additional laboratory blanks need to be analyzed to determine whether this was a one-time occurrence or a common problem.

As for laboratory blanks, field blanks for most variables were near or below detection limits (Table 3). The relatively high levels of $(NO_2^- + NO_3^-)$-N and total iron are comparable with those recorded for laboratory blanks, and thus probably arise from sample preparation or analysis rather than field procedures. In addition, relatively high concentrations were also recorded for copper, lead, and zinc. These findings are consistent with those from other rivers sampled by Environment Canada in British Columbia (Environment Canada, unpublished data). The cause of these high field blanks is not known, but it appears to be related to the sampling procedure rather than laboratory analysis, since comparable values were not detected in laboratory blanks. However, additional laboratory and field blanks should be evaluated to isolate the causes of the sample contamination.

Table 2. Laboratory Blanks, June 1990.

Variable	Unit	Sample							
		1	2	3	4	5	6	7	8
B.C. ENVIRONMENT									
Fecal Coliforms	CFU	<2	<2	<2	<2	<2	<2	<2	<2
Ammonia-Nitrogen	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
pH		5.6	5.6	5.6	5.6	5.6	5.7	5.7	5.6
Total Dissolved Phosphorus	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Non-Filterable Residue	mg/L	<1	<1	<1	<1	1	1	<1	1
Specific Conductance	µS/cm	1	1	1	1	1	1	1	1
Cyanide (S.A.D.)	mg/L	<0.005	<0.005	<0.005	<0.005				
ENVIRONMENT CANADA									
Colour (Apparent)	ACU	<5							
Conductivity	µS/cm	1.9							
Turbidity	NTU	<0.1							
Alkalinity (Total)	mg/L	<1							
Fluoride	mg/L	<0.05							
Potassium	mg/L	<0.01							
Calcium	mg/L	<0.1							
Magnesium	mg/L	<0.1							
Sodium	mg/L	<0.1							
Reactive Silica	mg/L	<0.05							
Hardness	mg/L	<0.4							
Nitrate+Nitrite-Nitrogen	mg/L	0.01	0.034	0.017					
Total Dissolved Nitrogen	mg/L	0.02	0.05	0.03					
pH		5.8							
Total Phosphorus	mg/L	<0.02	<0.02	<0.02					
Sulphate	mg/L	0.8							
Arsenic (Total)	mg/L	<0.1							
Cadmium (Total	mg/L	<0.0001							
Copper (Total)	mg/L	<0.0002							
Iron (Total)	mg/L	0.0047							
Lead (Total)	mg/L	<0.0002							
Manganese (Total)	mg/L	<0.0001							
Mercury (Total)	µg/L	<0.1							
Selenium (Total	mg/L	<0.0002							
Zinc (Total)	mg/L	<0.0002							

Table 3. Field Blanks, June 1990.

Variable	Unit	Sample					
		1	2	3	4	5	6
B.C. ENVIRONMENT							
Fecal Coliforms	CFU	<2	<2	<2	<2	<2	<2
Ammonia-Nitrogen	mg/L	0.007	0.006	0.006	<0.005	0.005	0.007
pH		5.6	5.8	5.8	5.6	5.6	5.7
Total Dissolved Phosphorus	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Non-Filterable Residue	mg/L	<1	<1	<1	<1	1	1
Specific Conductance	µS/cm	1	2	1	1	1	1
Cyanide (S.A.D.)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
FEDERAL LABORATORY							
Colour (Apparent)	ACU	<5					
Conductivity	µS/cm	2.5					
Turbidity	NTU	<0.1					
Alkalinity (Total)	mg/L	1.3					
Fluoride	mg/L	<0.05					
Potassium	mg/L	<0.01					
Calcium	mg/L	<0.1					
Magnesium	mg/L	<0.1					
Sodium	mg/L	0.1					
Reactive Silica	mg/L	<0.05					
Hardness	mg/L	<0.4					
Nitrate+Nitrite-Nitrogen	mg/L	<0.002	0.023	0.029			
Total Dissolved Nitrogen	mg/L	<0.01	0.03	0.03			
pH		6.2					
Total Phosphorus	mg/L	0.002	<0.002	<0.002			
Sulphate	mg/L	1.1					
Arsenic (Total)	mg/L	<0.0001					
Cadmium (Total)	mg/L	<0.0001					
Copper (Total)	mg/L	0.0025					
Iron (Total)	mg/L	0.0059					
Lead (Total)	mg/L	0.0009					
Manganese (Total)	mg/L	0.0002					
Mercury (Total	µg/L	<0.01					
Selenium (Total)	mg/L	<0.0001					
Zinc (Total)	mg/L	0.0010					

Water quality variables are stochastic, so random variations in time and space are not unexpected, particularly for those variables associated with particulate matter (e.g., turbidity, total phosphorus, total metals). For most variables analyzed, there was little variation among replicate samples; in most cases, the coefficient of variation was less than 25% (Tables 4, 5). Notable exceptions were the dissolved nitrogen fractions from the Flathead River and total phosphorus and a number of metals from both rivers. The relatively high coefficients of variation associated with some variables (e.g. many metals) arise largely because the mean concentrations are close to the laboratory detection limit; thus, the smallest resolvable unit represents a large percentage of the mean. For other variables (e.g., nitrogen fractions, total phosphorus), information from split samples would be required to differentiate the variation due to natural stochastic processes from that arising from laboratory analyses.

Table 4. Field Replicates, Flathead River (1985-1989).

Variable	Units	Number of Cases	Number of Replicates	Overall (Average)		
				Mean	Standard Deviation	Coefficient of Variation (%)[1]
ENVIRONMENT CANADA						
Water Temperature	°C	2	2	8.4	1.2	10.5
Conductivity	µS/cm	2	2	248.8	4.6	1.8
Turbidity	NTU	2	2	0.7	0.3	30
Colour (Apparent)	ACU	2	2	5	0	0
Alkalinity (Phenolphthalein)	mg/L	2	2	0.8	0.7	113
Alkalinity (Total)	mg/L	2	2	133.8	2.5	1.9
Calcium	mg/L	2	2	42.4	0.4	0.9
Magnesium	mg/L	2	2	8.9	0.02	0.2
Hardness	mg/L	2	2	142.6	1.0	0.7
Potassium	mg/L	2	2	0.30	0.07	24
Sodium	mg/L	2	2	0.93	0.04	3.7
Chloride	mg/L	2	2	0.33	0.04	14
Fluoride	mg/L	2	2	0.06	0.01	14
Silica	mg/L	2	2	4.5	0	0
Sulphate	mg/L	2	2	5.4	0.1	2.0
$(NO_2^- + NO_3^-)$-N	mg/L	235	3	0.041	0.023	46
Total Dissolved Nitrogen	mg/L	234	3	0.098	0.044	33
Total Phosphorus	mg/L	230	3	0.027	0.009	39
Arsenic (Total)	mg/L	2	2	0.0003	0	0
Cadmium (Total)	mg/L	2	2	0.0002	0	0
Mercury (Total)	µg/L	1	2	0.02	0	0
Cadmium (Total)	mg/L	2	2	0.0001	0	0
Chromium (Total)	mg/L	1	2	0.0011	0.0009	77
Copper (Total)	mg/L	2	2	0.091	0.126	92
Iron (Total)	mg/L	2	2	0.033	0.013	36
Manganese (Total)	mg/L	2	2	0.0030	0.0007	18
Nickel (Total)	mg/L	1	2	0.00050	0	0
Lead (Total)	mg/L	2	2	0.0029	0.0031	61
Zinc (Total)	mg/L	2	2	0.0024	0.0027	94

[1] mean CV computed from all cases, not overall SD divided by overall mean.

Table 5. Field Replicates, Similkameen River.

Variable	Units	Number of Cases	Number of Replicates	Overall (Average)		
				Mean	Standard Deviation	Coefficient of Variation (%)[3]
B.C. ENVIRONMENT (June 1990)						
Fecal Coliforms	CFU	1	6	10.3	2.3	22
Ammonia-Nitrogen	mg/L	1	6	<0.005	--	--
pH		1	6	7.67	0.05	0.7
Total Dissolved Phosphorus	mg/L	1	6	0.0053	0.001	19
Non-Filterable Residue	mg/L	1	6	28.7	1.9	6.6
Cyanide (S.A.D.)	mg/L	1	6	0.0052	0.0004	7.7
Conductivity	µS/cm	1	6	72	0	0
ENVIRONMENT CANADA (1984-89)						
Water Temperature	°C	6	2-5	12.2	0.6	3.8
Conductivity	µS/cm	6	2-5	145	4	3.2
Turbidity	NTU	6	2-5	1.0	0.2	19
Colour (Apparent)	ACU	6	2-5	6.3	1.8	19
Alkalinity (Phenolphthalein)	mg/L	6	2-5	0	0	--
Alkalinity (Total)	mg/L	6	2-5	61.7	1.3	2.4
Calcium	mg/L	6	2-5	21.7	0.5	2.6
Magnesium	mg/L	6	2-5	3.6	0.2	6.2
Hardness	mg/L	6	2-5	69.0	1.9	3.1
Potassium	mg/L	6	2-5	0.72	0.02	4.0
Sodium	mg/L	6	2-5	3.2	0.3	19.4
Chloride	mg/L	6	2-5	1.4	0.04	3.0
Fluoride	mg/L	6	2-5	0.057	0.004	5.8
Silica	mg/L	6	2-5	10.7	0.1	1.0
Sulphate	mg/L	6	2-5	11.9	0.43	4.9
$(NO_2^- + NO_3^-)$-N	mg/L	43	3	0.020	0.002	18
Total Dissolved Nitrogen	mg/L	45	3	0.065	0.006	9
Total Phosphorus	mg/L	45	3	0.025	0.006	30
Cyanide (Total)	mg/L	3	2-5	0.00078	0.00006	7.3
Arsenic (Total)	mg/L	6	2-5	0.0015	0.0001	6.1
Cadmium (Total)[1]	mg/L	6	2-5	<0.0001	--	--
Chromium (Total)	mg/L	1	2	0.00074	0.00046	10
Copper (Total)	mg/L	6	2-5	0.044	0.035	47
Iron (Total)	mg/L	6	2-5	0.145	0.051	35
Lead (Total)[2]	mg/L	2	2-5	0.0027	0.00075	26
Manganese (Total)[2]	mg/L	3	2-5	0.0076	0.0010	12
Nickel (Total)	mg/L	1	2	0.0006	0.000	0
Selenium (Total)	mg/L	6	2-5	0.00021	0.00005	43
Zinc (Total)	mg/L	6	2-5	0.0067	0.0068	88

1 All values at or below detection limit, standard deviation not computed.
2 Computed for those dates when concentrations were greater than detection limit.
3 Mean CV computed from all cases, not overall SD divided by overall mean.

5. ATTAINMENT OF OBJECTIVES

5.1 Flathead River

Levels of most variables in the Flathead River either attained the water quality objectives or only occasionally did not attain them (Table 6). In general, non-attainment was restricted to water hardness and variables associated with particulate matter (turbidity, non-filterable residue, total phosphorus, some total metals). In many cases, non-attainment was a result of natural processes. For instance, the relatively high water hardness is related to the high natural levels of calcium and magnesium (Appendix I). The water quality guideline for hardness (80-100 mg/L) defines the ideal range for drinking and domestic use. Water with up to 200 mg/L total hardness, which would include all data from the Flathead River (maximum hardness 162 mg/L), is still suitable for drinking, although it may react poorly with detergents (CCREM, 1987).

Non-attainment for some variables related to particulate matter may be a result of natural processes such as sediment erosion and transport. For example, the highest number of excursions for turbidity was recorded in 1986 (Figure 5), a year with high river flows (Figure 2) and peak turbidity levels in other years tended to vary with flow. Similar patterns were noted for total phosphorus, total iron and possibly total manganese (Figures 6,7,10). In contrast, there were no obvious annual trends in the frequency of non-attainment of apparent colour or total copper (Figures 8-9). The colour criterion is for true colour, while apparent colour was measured; non-attainment may be exaggerated by the inclusion of particulate matter in the apparent colour measurement. Virtually all non-attaining samples of total zinc were collected in 1986 and 1987 (Figure 11). Annual patterns for non-attainment with the 0.002 mg/L total chromium criterion could not be assessed as it was only sampled over a 13-month period in 1987-88.

Chromium only once exceeded the 0.02 mg/L criterion for protection of fish, but all 13 monthly means exceeded the lower criterion (0.002 mg/L) intended for protection of

Table 6. Attainment Summary, Flathead River (1984-89).

Variable[1]	Units	Sample Period	Criterion[2]	Number of Samples		Percentage of Non-Attaining Samples
				Non-Attaining	Total	
Water Temperature	(°C)	1988-89	≤20[3]	0	233	0
pH		1988-89	≥6.5 - ≤9.0	0	79	0
Turbidity	NTU	1985-89	≤10[3]	16	235	7
Colour (Apparent)	ACU	1985-89	≤15 TCU	8	235	3
Alkalinity (Total)	mg/L	1985-89	>20	0	235	0
Calcium	mg/L	1985-89	>8	0	235	0
Magnesium	mg/L	1985-89	<100	0	235	0
Hardness	mg/L	1985-89	≥80 - ≤100	209	235	89
Hardness	mg/L	1985-89	<200	0	235	0
Chloride	mg/L	1985-89	<250[4]	0	235	0
Fluoride	mg/L	1985-89	<0.3	0	235	0
Sulphate	mg/L	1985-89	<150	0	235	0
$(NO_2^- + NO_3^-)$-N	mg/L	1985-89	<10	0	235	0
Total Phosphorus	mg/L	1985-89	≤0.1	10	231	4
NFR	mg/L	1985-89	≤25[3]	18	33	55
Arsenic (Total)	mg/L	1985-89	≤0.05	0	234	0
Cadmium (Total)[7]	mg/L	1986-89	≤0.0008 - 0.0013[6]	1	166	<1
Chromium (Total)	mg/L	1987-88	≤0.02	1	54	2
Chromium (Total)	mg/L	1987-88	≤0.002	13	13	100
Copper (Total)	mg/L	1985-89	Variable (maximum)[6]	2	230	1
Copper (Total)[5]	mg/L	1985-89	Variable (average)[5,6]	23	58	40
Iron (Total)	mg/L	1985-89	≤0.3	50	234	21
Lead (Total)	mg/L	1985-89	Variable (maximum)[6]	0	234	0
Lead (Total)[5]	mg/L	1985-89	Variable (average)[5,6]	0	58	0
Manganese (Total)	mg/L	1985-89	≤0.05	8	234	3
Mercury (Total)	µg/L	1985-89	≤0.1 (maximum)	1	231	<1
Mercury (Total)[5]	µg/L	1985-89	≤0.02 (average)[5,8]	3	43	7
Nickel (Total)	mg/L	1987-88	≤0.065[4]	0	53	0
Selenium (Total)	mg/L	1985-89	≤0.001	0	233	0
Zinc (Total)	mg/L	1985-89	≤0.03	25	234	11

[1] All variables analyzed by Environment Canada.
[2] Criteria are for individual samples as reported by Pommen (1989) unless indicated otherwise.
[3] Valiela et al. (1987).
[4] CCREM (1987)
[5] Monthly average based on ≥ 5 samples.
[6] Formula based on hardness
[7] Prior to 8/12/86, the detection limit (0.001 mg/L) was greater than the 0.0008 mg/L criterion but less than the 0.0013 mg/L criterion, and all values were <DL; those data were omitted.
[8] Most samples from August 1988 to October 1989 were contaminated and not included in analysis. Prior to October 1987, the detection limit (0.02 µg/L) was the same as criterion.

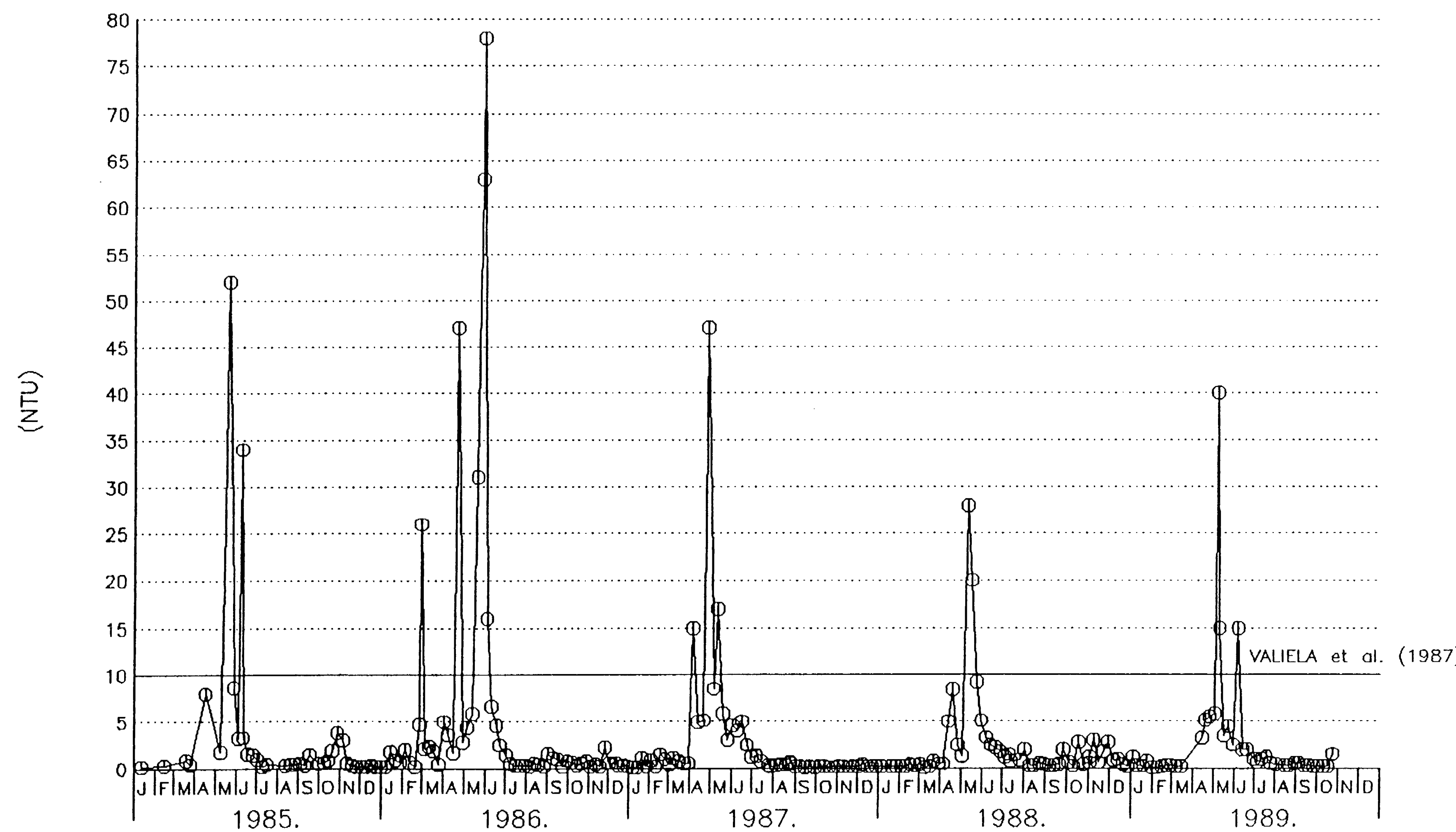

Figure 5	TURBIDITY FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

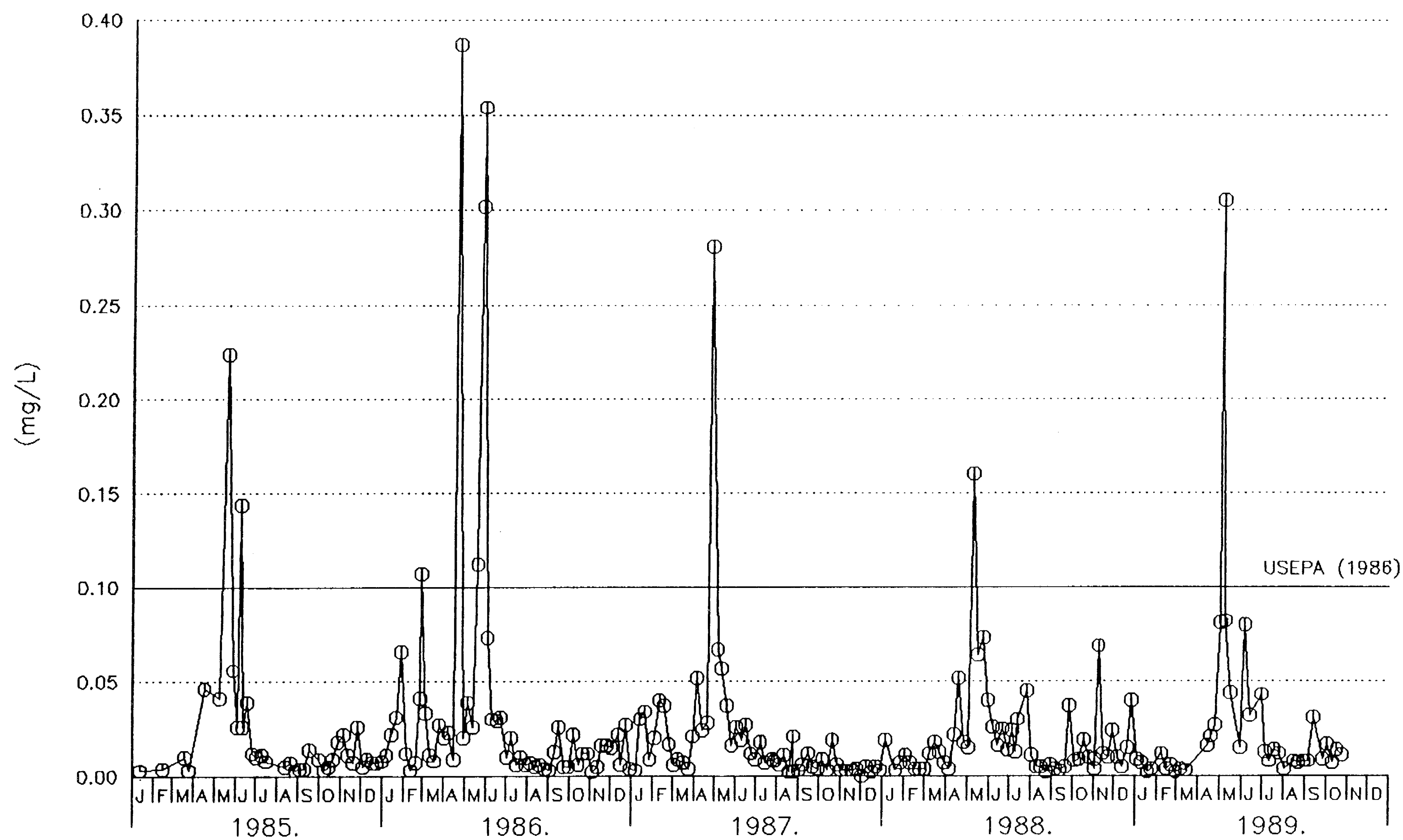

Figure 6	TOTAL PHOSPHORUS FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

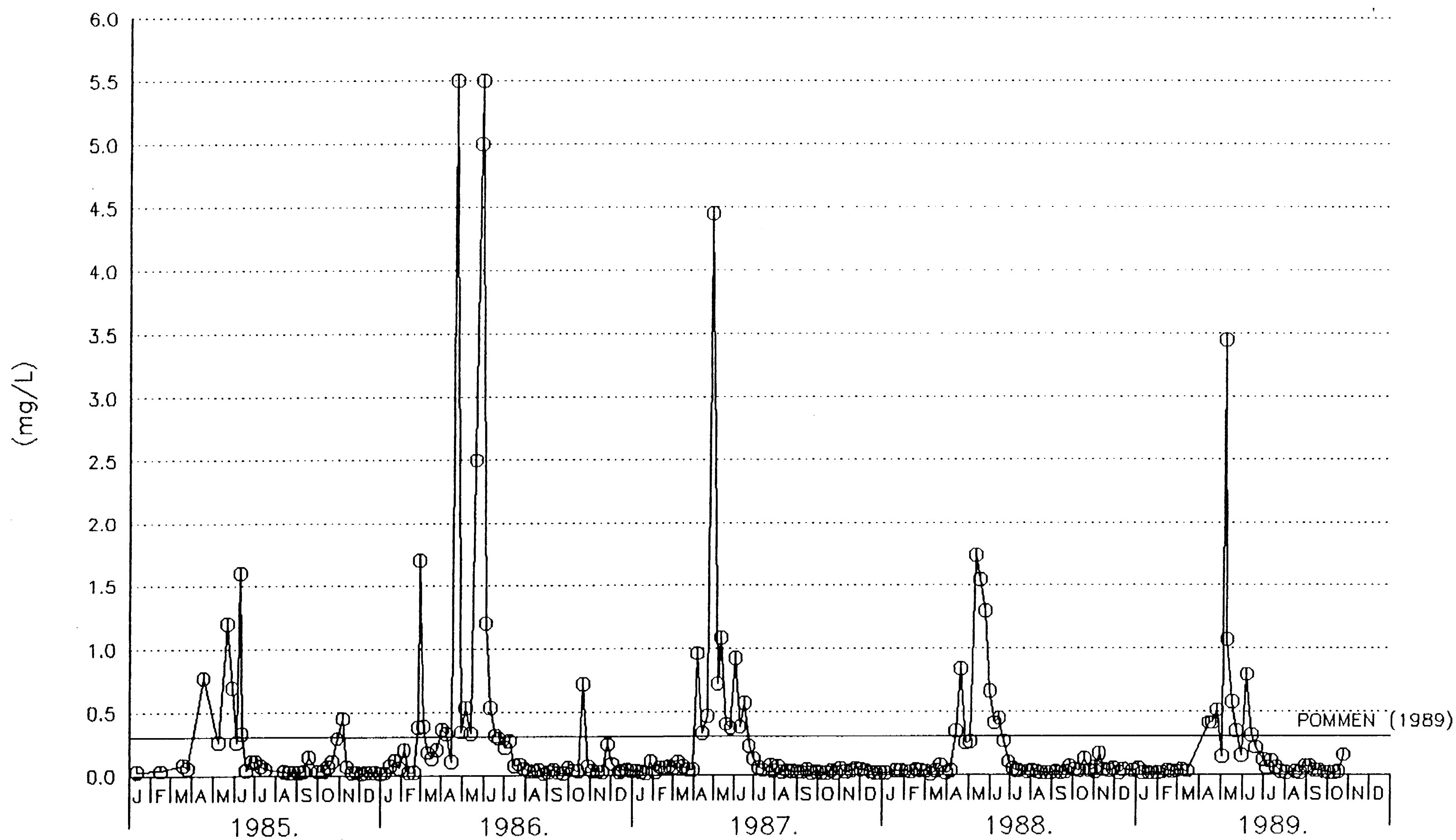

Figure 7	TOTAL IRON FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

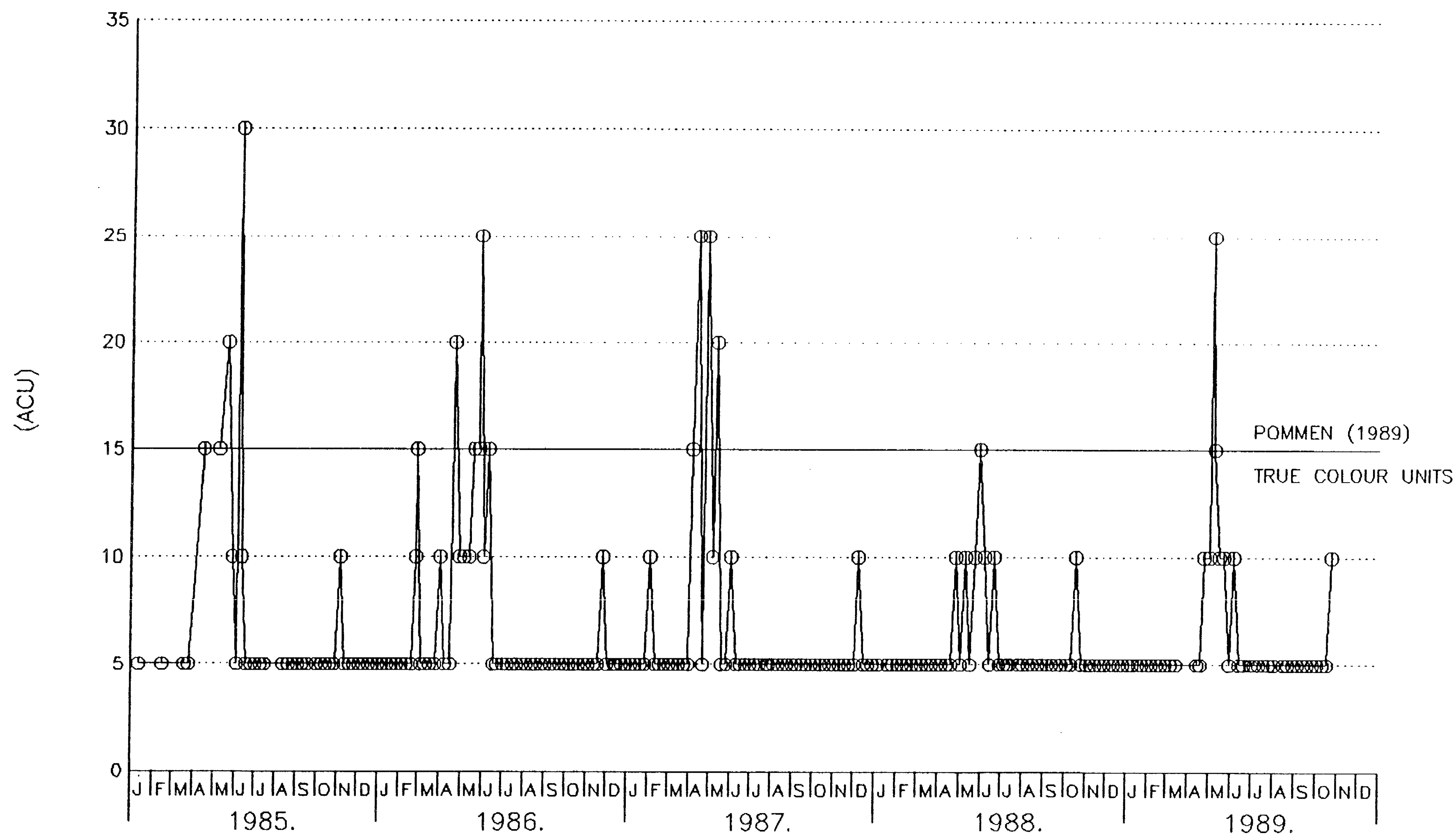

Figure 8	APPARENT COLOUR FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

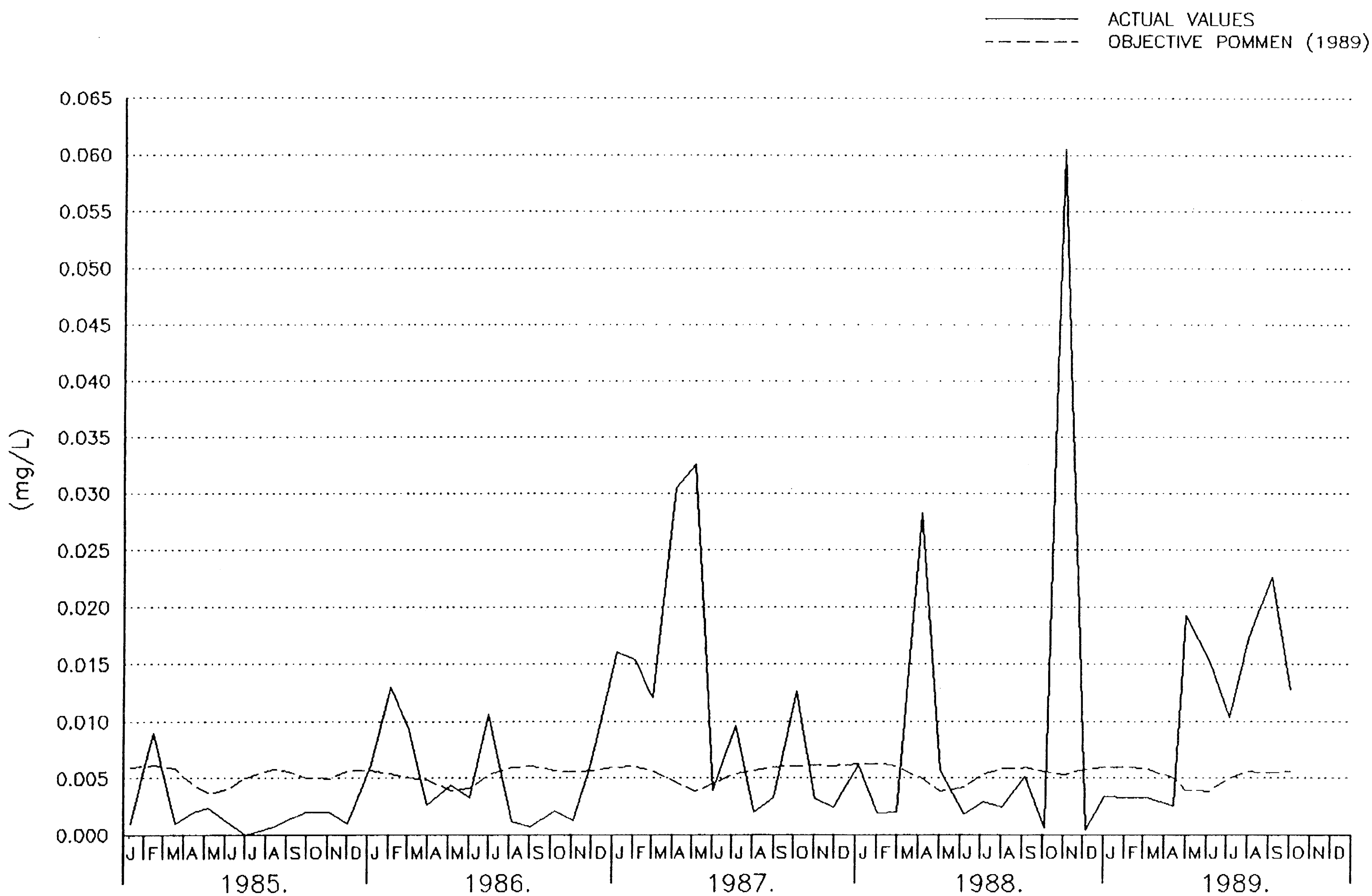

Figure 9	TOTAL COPPER (MONTHLY MEAN) FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

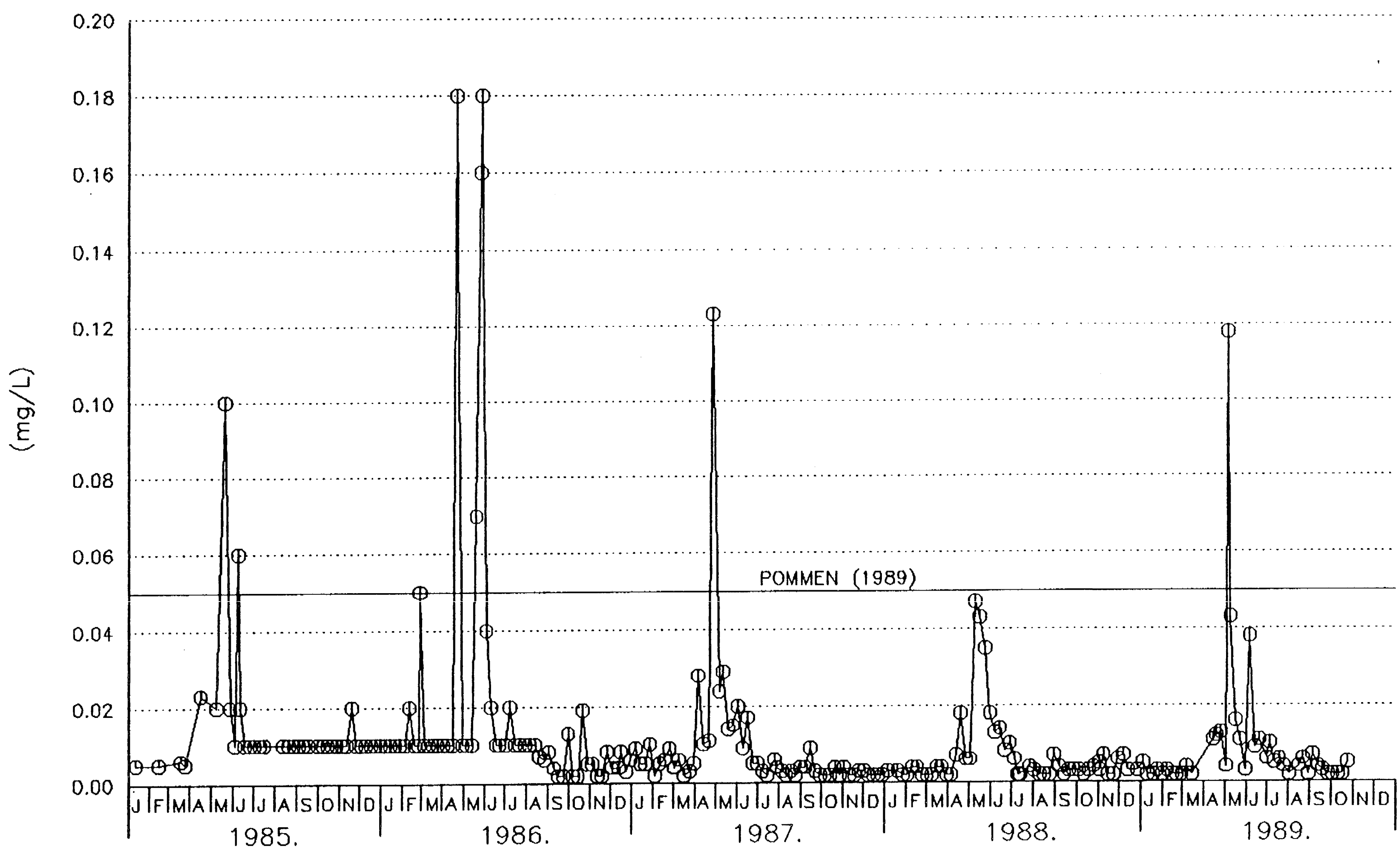

Figure 10	TOTAL MANGANESE FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

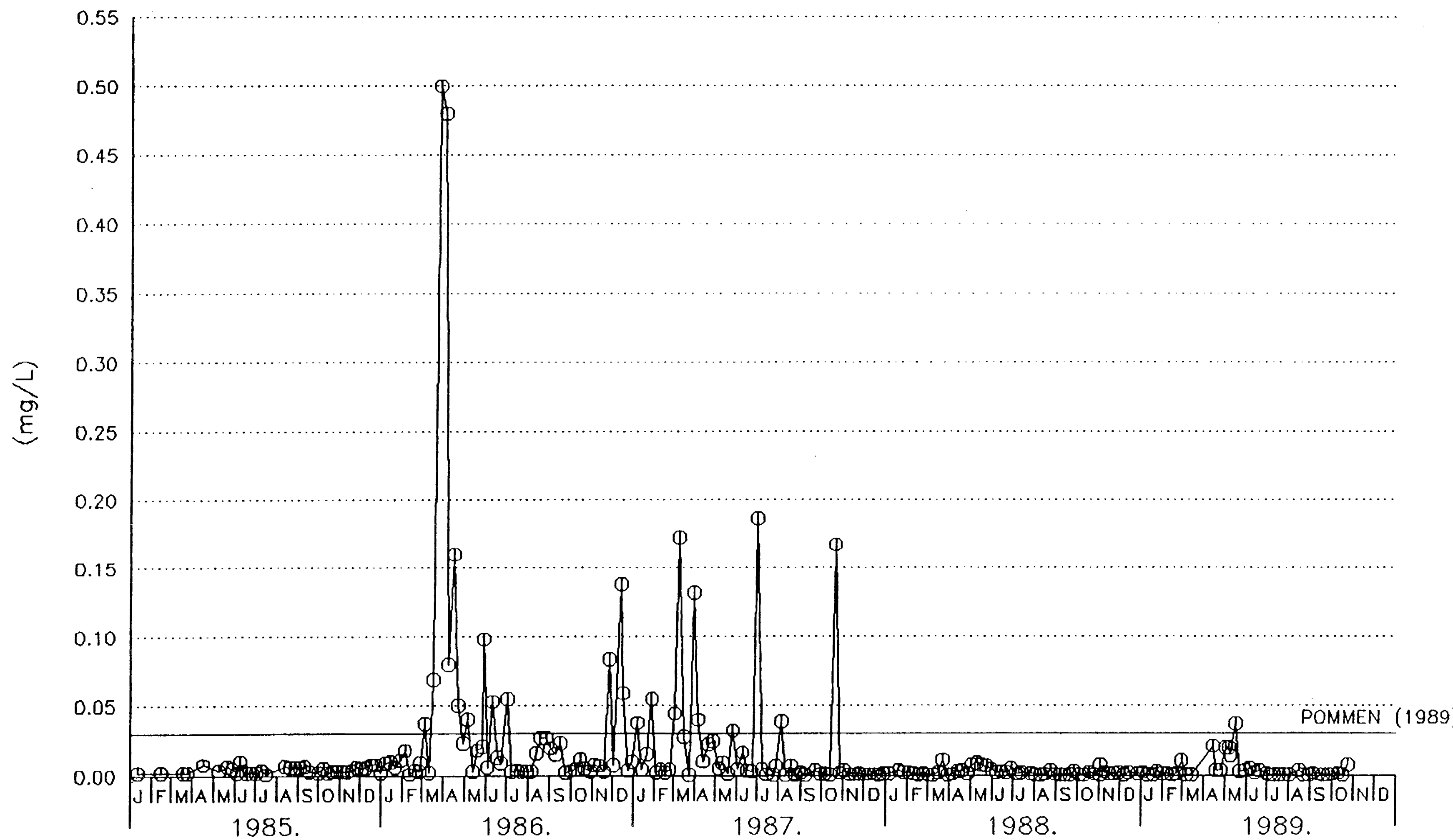

Figure 11	TOTAL ZINC FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

zooplankton and phytoplankton. (The lower criterion was applied here as a monthly mean to facilitate comparison with the site-specific objective for the Similkameen River).

In addition to annual trends, monthly patterns of non-attainment of water quality criteria were also investigated. As would be expected for those variables associated with particulate matter, the proportion of non-attaining samples of turbidity, total phosphorus, total iron, apparent colour, total manganese and total zinc was greatest from April to June (Figures 12 and 13) and was coincident with the spring freshet. There was no clear monthly pattern for total copper (Figure 13), and total chromium did not attain the 0.002 mg/L criterion in 13 of 13 months sampled in 1987-88.

Criteria exceedences for iron are largely artifacts. The iron of concern with respect to toxicity to aquatic life or staining and off-tastes in domestic water is dissolved iron or iron precipitates. Total iron is often high in turbid water because of the iron content of mineral particles, but iron in that form is of no concern (Pommen, 1989).

Exceedences of the average mercury criterion were largely an artifact of the data analysis. Prior to October 1987 the detection limit was 0.02 μg/L, the same as the criterion. For the excursion analysis, values reported below the detection limit were assumed to equal the detection limit; thus any detectable levels of mercury would automatically create an exceedence.

Non-attainment of copper and zinc criteria may also have been artifacts, possibly arising from contamination of sample bottles due to failure of lid liners in preservative vials. This problem has already been corrected. If the high Cu and Zn levels, or some part of them, were real, they were evidently natural, probably a result of erosion of metal-bearing rocks in the mountains, as there have been no human activities in the basin that could have produced metal contamination. If so, the metals would be in biologically inactive, particulate forms, as is consistent with the apparent health of populations of sensitive fish species in the river. Similarly, observed levels of total chromium probably arise from erosion, and evidently do not threaten the health of the river's biota. (There are no

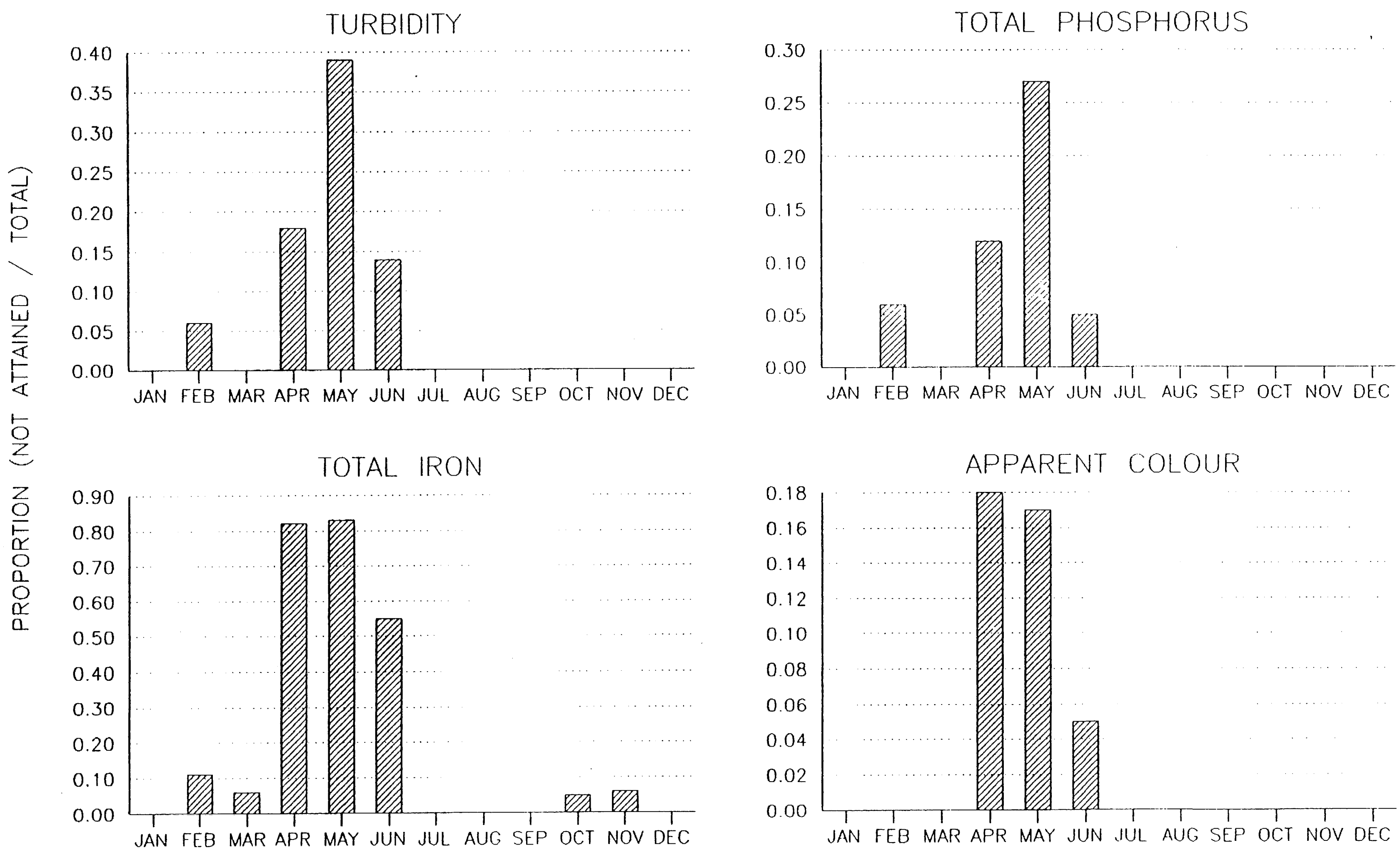

Figure 12	MONTHLY NON-ATTAINMENT SUMMARY FLATHEAD RIVER (1985 - 1989)	Environmental Management Associates

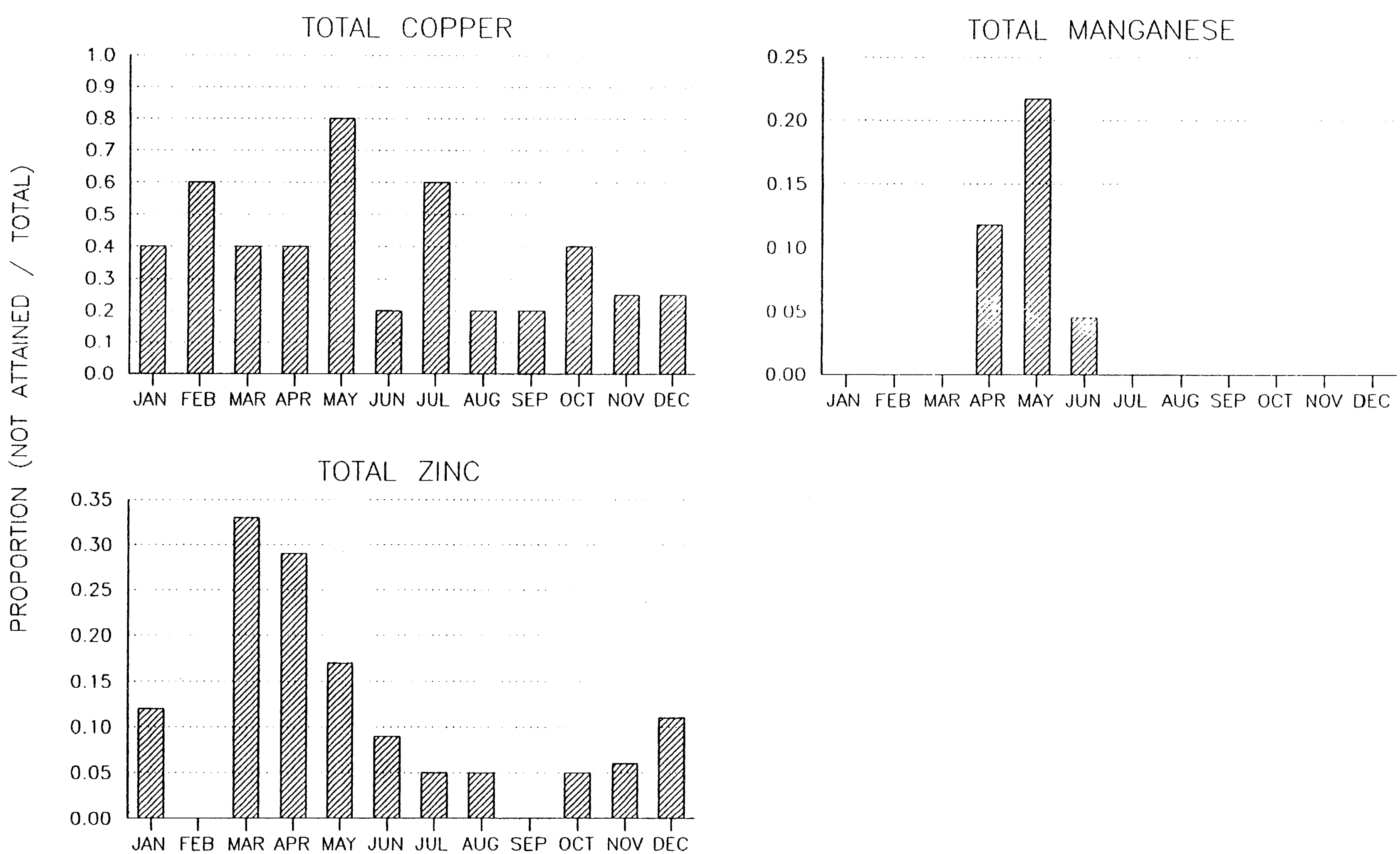

Figure 13

MONTHLY NON-ATTAINMENT SUMMARY
FLATHEAD RIVER (1985 – 1989)

Environmental
Management Associates

laboratory blanks for chromium to assess the possibility of sample contamination). The applicability of the lower Cr criterion, intended to protect (lake) plankton (CCREM, 1987), may be disputed, since these organisms are absent from fast-flowing rivers.

5.2 Similkameen River

Like the Flathead River, non-attainment of water quality objectives for the Similkameen River was generally restricted to water hardness and variables associated with particulate matter (Table 7). Patterns for total phosphorus, total iron, and total manganese (Figures 14-16) were related to the presence of particulate matter, which in turn was largely a function of river flows. There were no obvious annual patterns for non-attainment of apparent colour, total zinc, or fecal coliforms (Figures 17-19). The colour criterion is for true colour, while apparent colour was measured; non-attainment may be exaggerated by the inclusion of particulate matter in the apparent colour measurement. Non-attainment of total copper and cyanide occurred most frequently in 1987-89 (Figures 20-22, See Section 6.2). Annual patterns of non-attainment for total chromium could not be assessed as it was only sampled over a 13-month period in 1987-88.

As for the Flathead River, non-attainment for those variables associated with particulate matter (total phosphorus, total iron, total manganese, apparent colour) was most prevalent from April to June (Figure 23). There were no clear seasonal patterns for the other variables (Figures 24 and 25); total chromium that did not attain the 0.002 mg/L criterion in 11 of 13 months sampled in 1987-88. Again, while water hardness in the Similkameen River was often outside the purported ideal range (80-100 mg/L), water hardness in the river is typical of many other sources of domestic supply in Canada, and in no way limits use of this water for drinking or household use. Exceedences of criteria for iron and manganese (and probably phosphorus) are of no real significance because they reflect particulate forms found in suspended solids, not biologically active dissolved forms.

Table 7. Attainment Summary, Similkameen River (1985-89).

Variable	Units	Sample Period	Criterion[1]	Number of Samples		Percentage of Non-Attaining Samples
				Non-Attaining	Total	
B.C. ENVIRONMENT						
pH (Lab)	units	1987-91	≥6.5 - ≤8.5[2]	0	79	0
Conductivity (Lab)	μS/cm	1987-91	<1000	0	82	0
Cyanide (S.A.D.)	mg/L	1989-90	≤ 0.005 (avg)[5,10]	6	17	29
			≤ 0.01 (max)[5,10]	3	37	8
Fecal Coliforms	CFU	1987-91	≤10[2]	20	80	25[4]
Ammonia-N	mg/L	1987-91	Variable[2]	0	94	0
ENVIRONMENT CANADA						
pH (Lab)		1988-89	≥6.5 - ≤8.5[2]	0	41	0
Conductance (lab)	μS/cm	1984-89	<1000	0	199	0
Colour (Apparent)	ACU	1984-89	<15 TCU	23	199	12
Alkalinity	mg/L	1984-89	>20	0	197	0
Calcium	mg/L	1984-89	>8	1	197	<1
Magnesium	mg/L	1984-89	<100	0	197	0
Hardness	mg/L	1984-89	>80 - <100	120	197	61
Potassium	mg/L	1984-89	<20	0	197	0
Sodium	mg/L	1984-89	SAR <3[3]	0	197	0
Chloride	mg/L	1984-89	<100[3]	0	197	0
Fluoride	mg/L	1984-89	0.2 or 0.3[7]	0	197	0
Sulphate	mg/L	1984-89	<150	0	197	0

Table 7. (continued). Attainment Summary, Similkameen River (1985-89).

Variable	Units	Sample Period	Criterion[1]	Number of Samples		Percentage of Non-Attaining Samples
				Non-Attaining	Total	
ENVIRONMENT CANADA (continued)						
$(NO_2^- + NO_3^-)$-N	mg/L	1984-89	<10	0	197	0
Total Phosphorus	mg/L	1984-89	<0.1[6]	15	197	8
Cyanide	mg/L	1984-89	<0.005 (avg)[5,10]	3	67	4
			<0.01 (max)[5,10]	5	189	3
Arsenic	mg/L	1984-89	<0.05[5]	0	197	0
Cadmium[9]	mg/L	1986-89	<0.0002-0.0008[7]	5	96	5
				1	96	1
Chromium	mg/L	1987-88	<0.02 (max)[5]	0	32	0
			<0.002(avg)[5,8]	11	13	85
Copper	mg/L	1984-89	Variable (max)[5,7]	14	195	7
			Variable(avg)[5]	47	67	70
Iron	mg/L	1984-89	<0.3[5]	43	197	22
Lead	mg/L	1984-89	Variable (max)[5,7]	0	197	0
			Variable(avg)[5,7,8]	2	67	3
Manganese	mg/L	1984-89	<0.05[5]	13	197	7
Mercury[11]	µg/L	1984-89	<0.1[5] (max)	2	185	1
			<0.02(avg)[5,8]	7	54	13
Nickel	mg/L	1984-89	0.025 or 0.065[5,7]	0	33	0
Selenium	mg/L	1984-89	<0.001	0	197	0
Zinc	mg/L	1984-89	0.03[5]	29	197	15
			0.01(avg)[5,8]	10	45	22

1 Criteria are for individual samples as reported by Pommen (1989) unless indicated otherwise.
2 Swain (1985)
3 CCREM (1987)
4 Criterion is for 90th percentile of ≥ 5 samples, so this is likely an overestimate.
5 Swain (1990)
6 USEPA (1986)
7 Dependent upon hardness
8 Monthly averages based on ≥ 5 samples
9 Prior to 8/12/86, the detection limit (0.001 mg/L) was greater than criteria and all values were <DL.
10 Weak-acid-dissociable cyanide
11 Most samples from August 1988 to October 1989 were contaminated and not included in analysis. Prior to October 1987, the detection limit (0.02 µg/L) was the same as criterion.

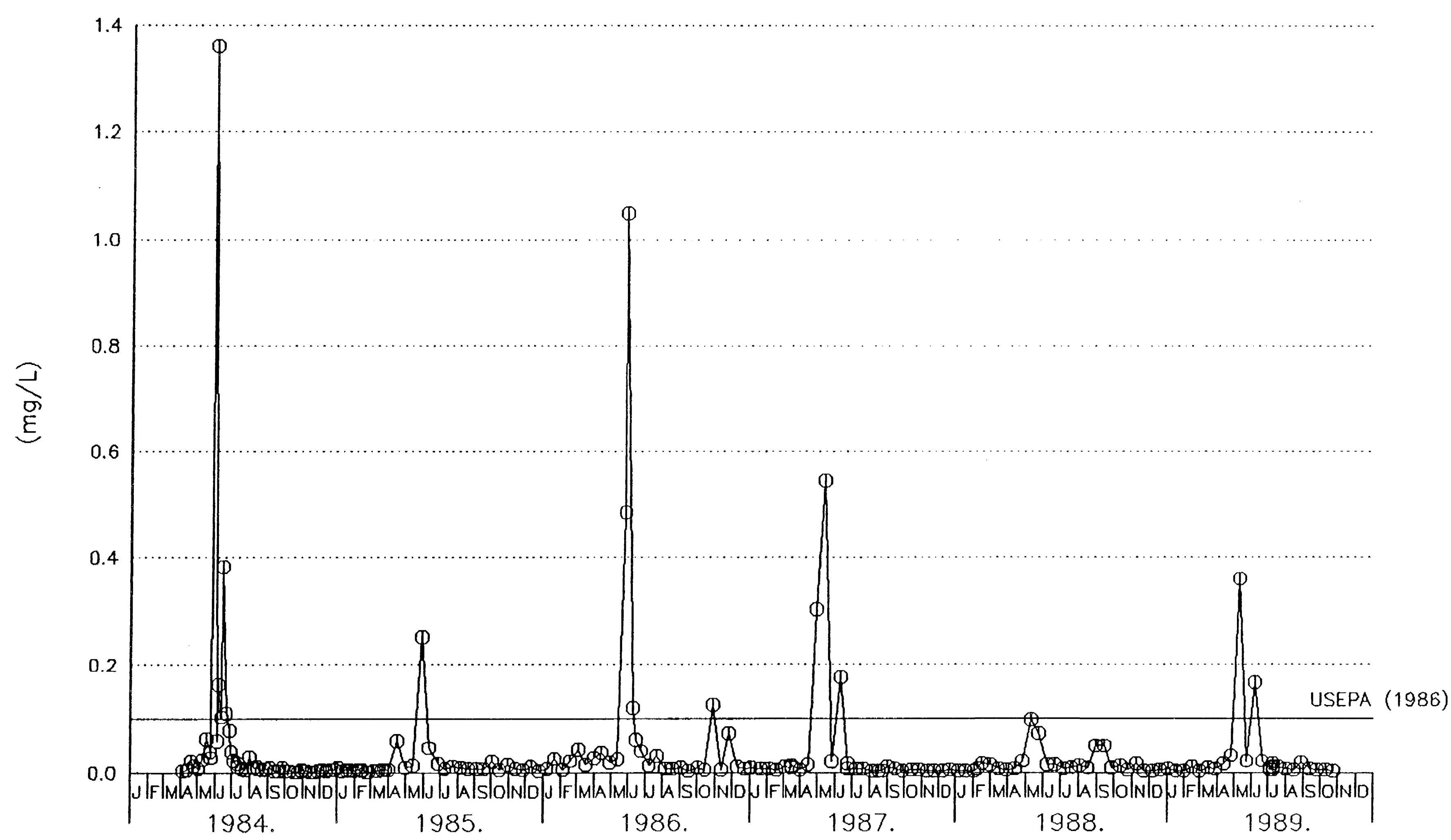

Figure 14	TOTAL PHOSPHORUS SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

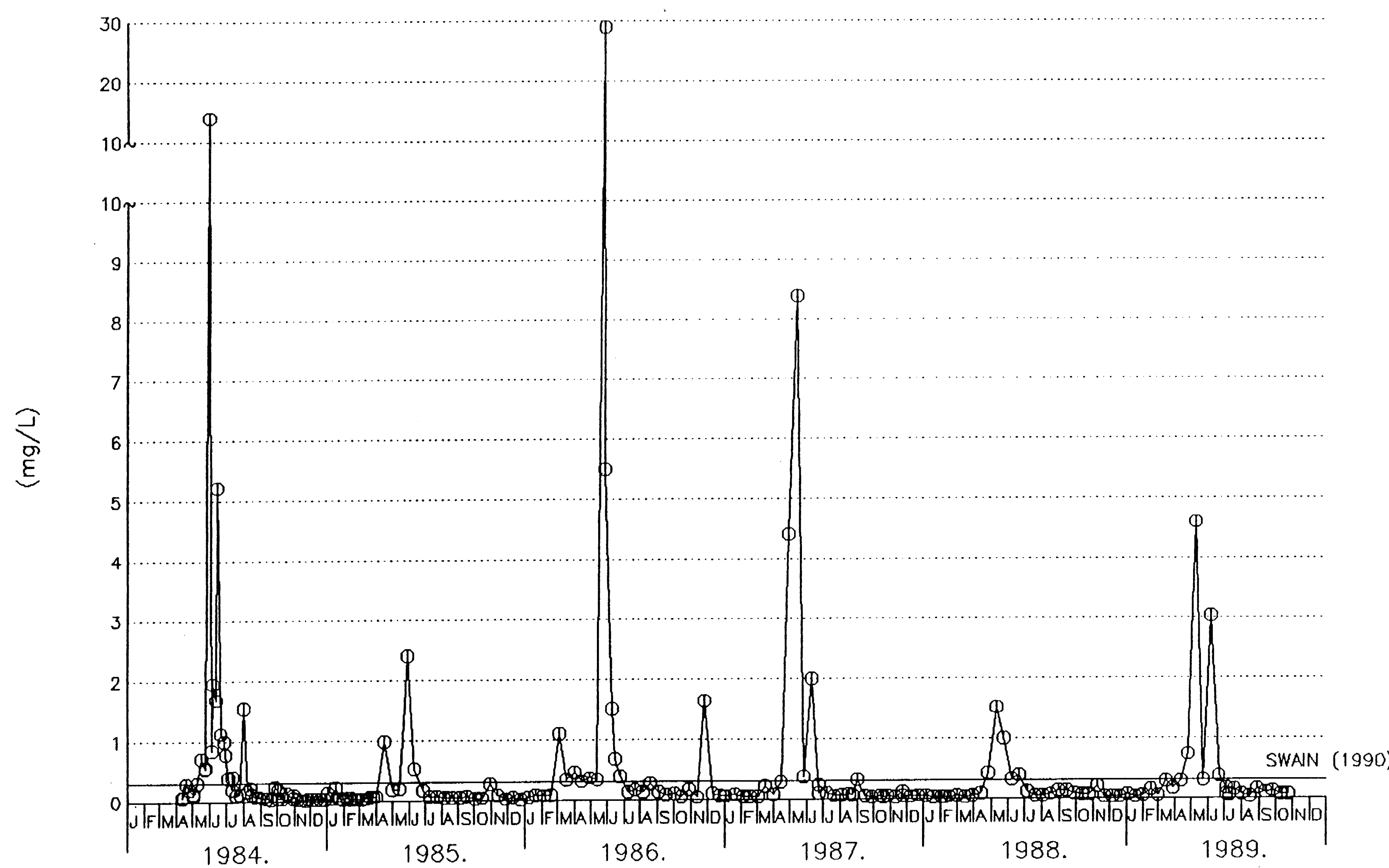

Figure 15

TOTAL IRON
SIMILKAMEEN RIVER (1984 – 1989)

Environmental Management Associates

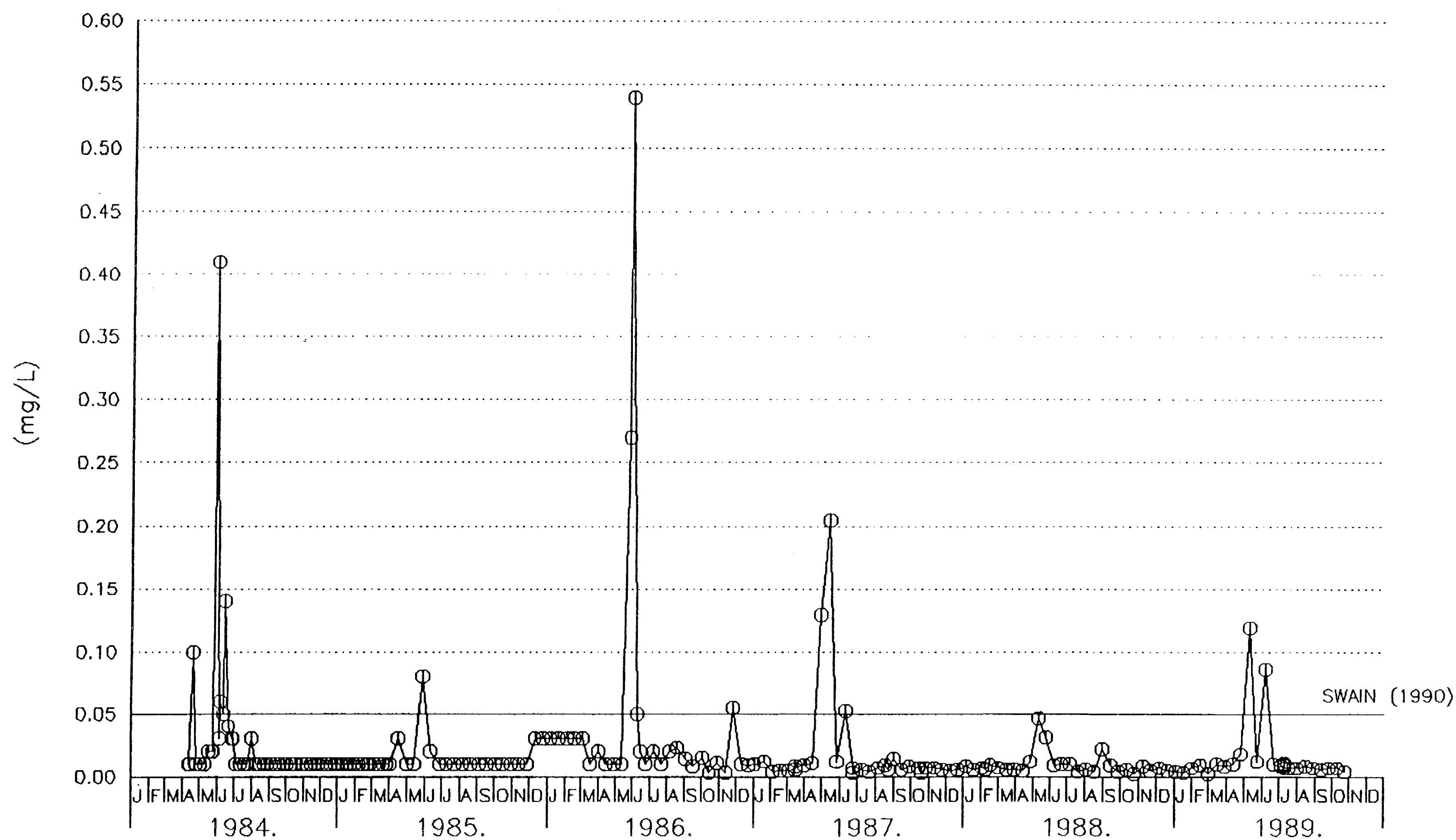

Figure 16	TOTAL MANGANESE SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

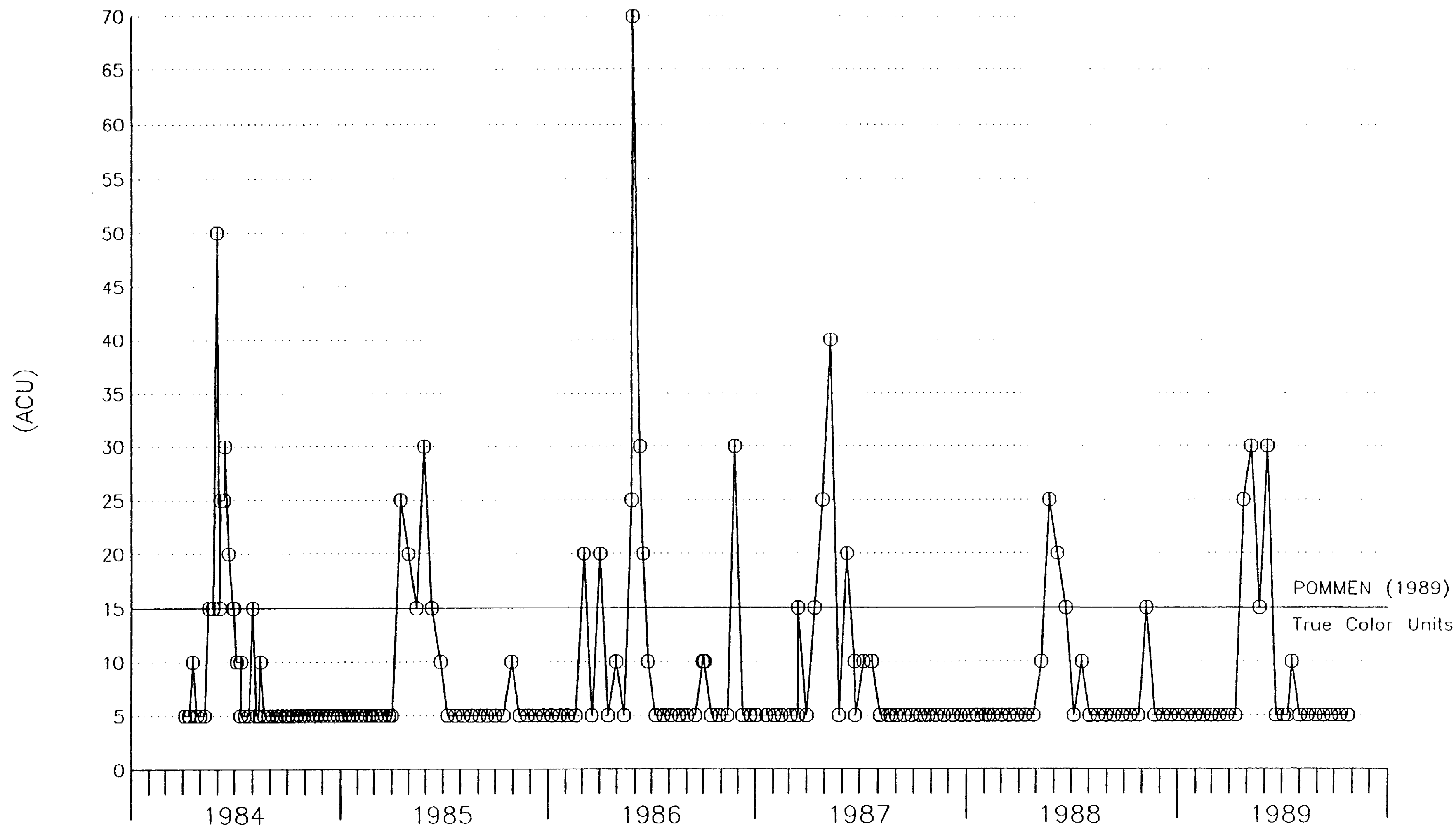

Figure 17

APPARENT COLOUR
SIMILKAMEEN RIVER (1984 – 1989)

Environmental
Management Associates

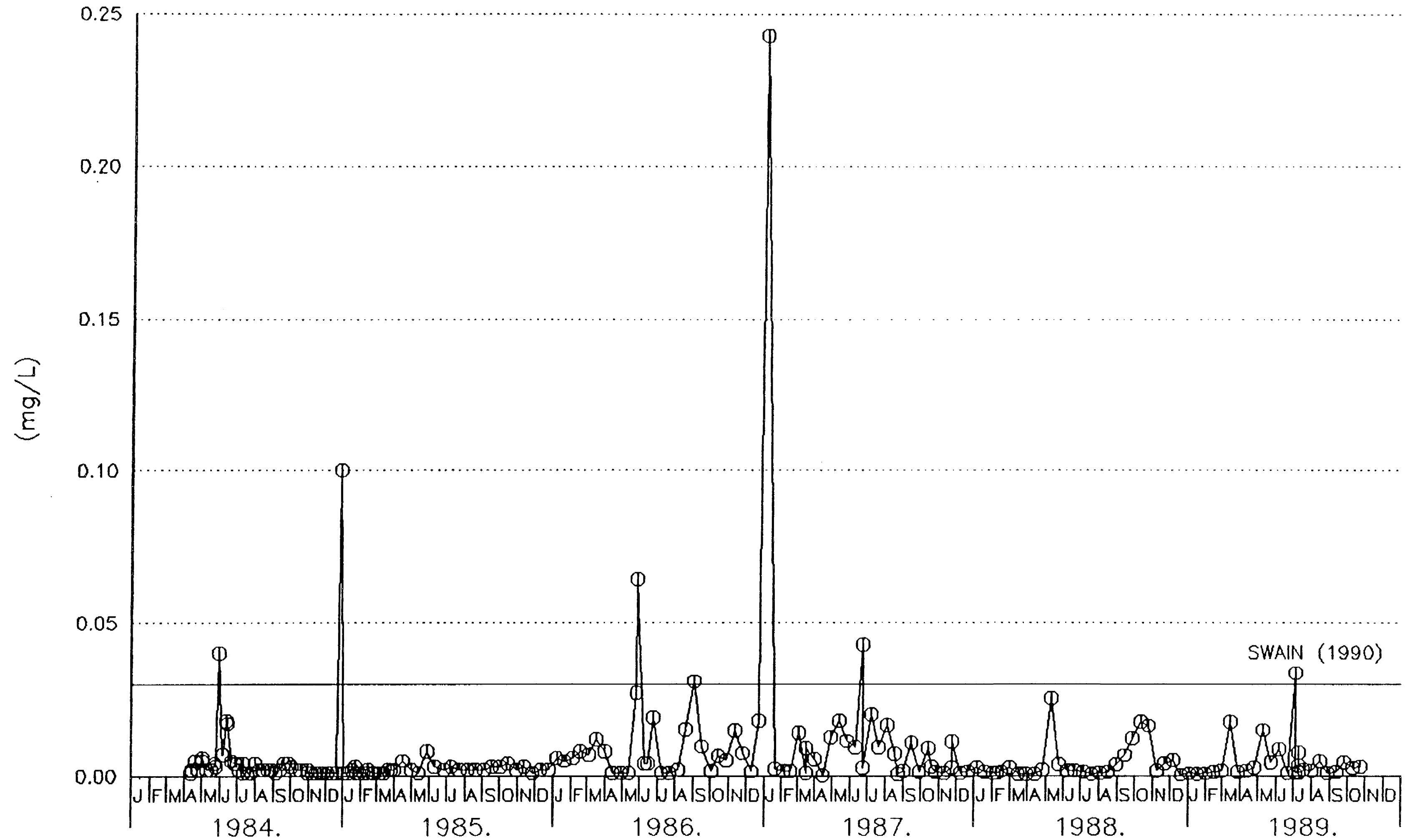

Figure 18	TOTAL ZINC SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

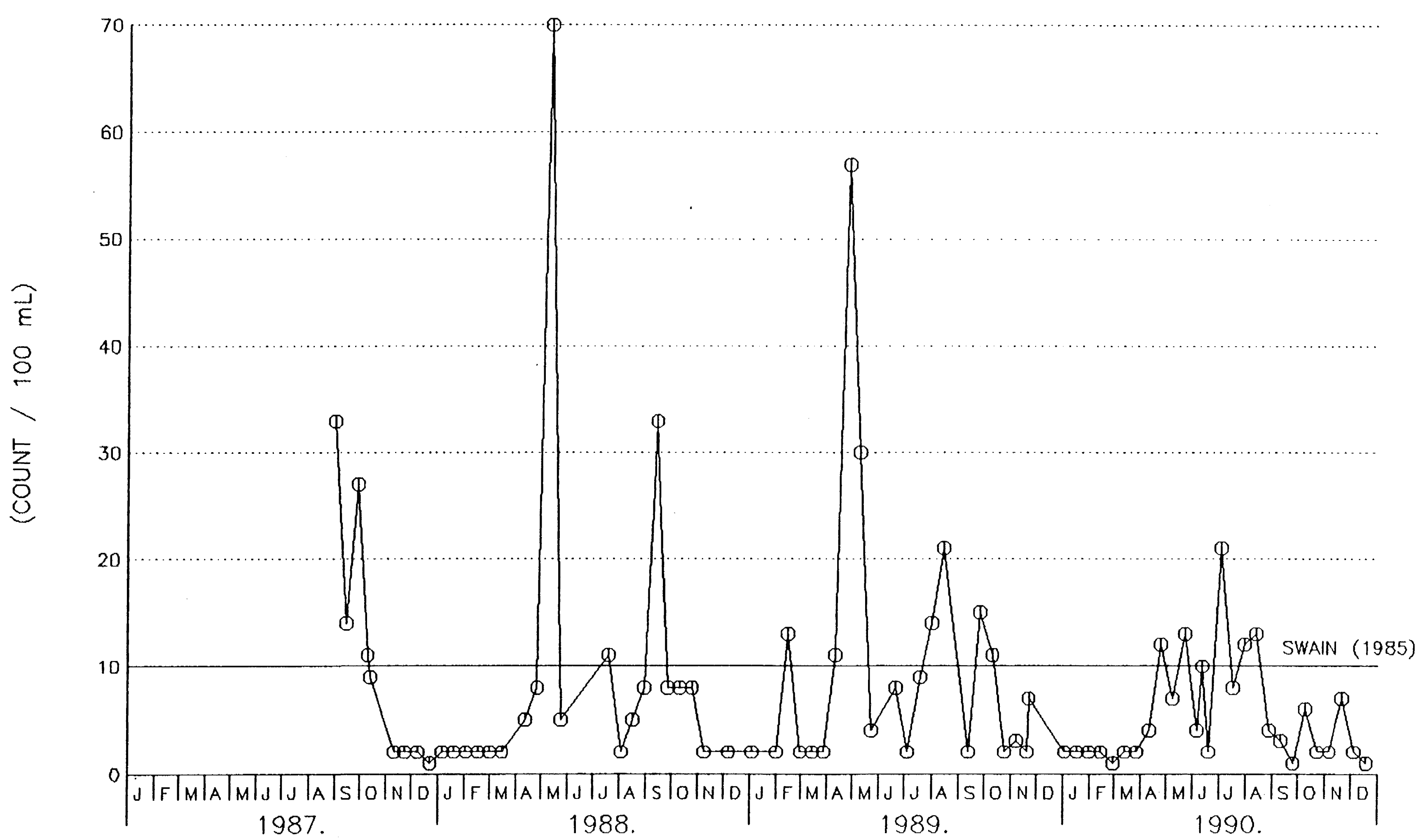

Figure 19	FECAL COLIFORMS SIMILKAMEEN RIVER (1987 – 1990)	Environmental Management Associates

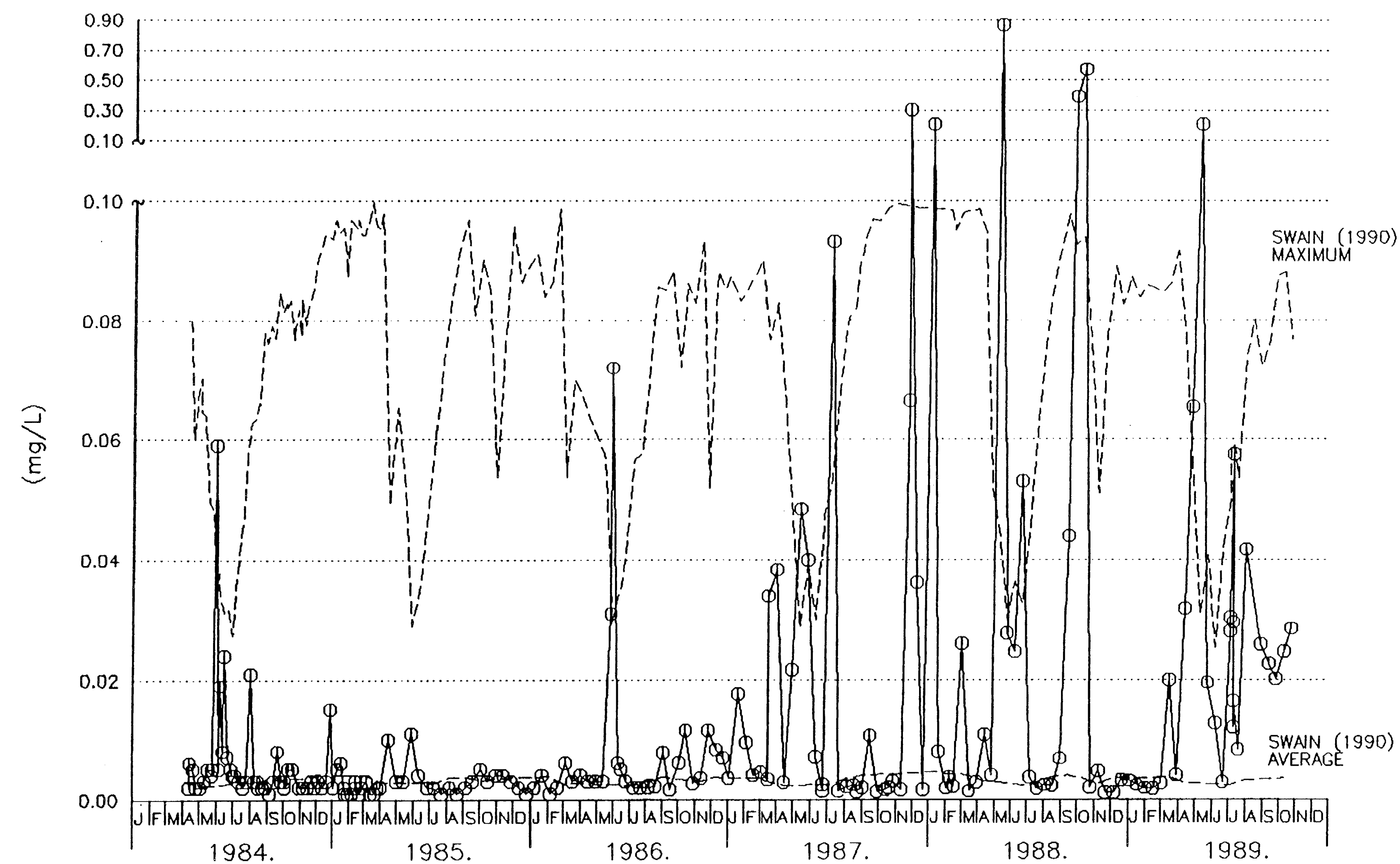

Figure 20	TOTAL COPPER SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

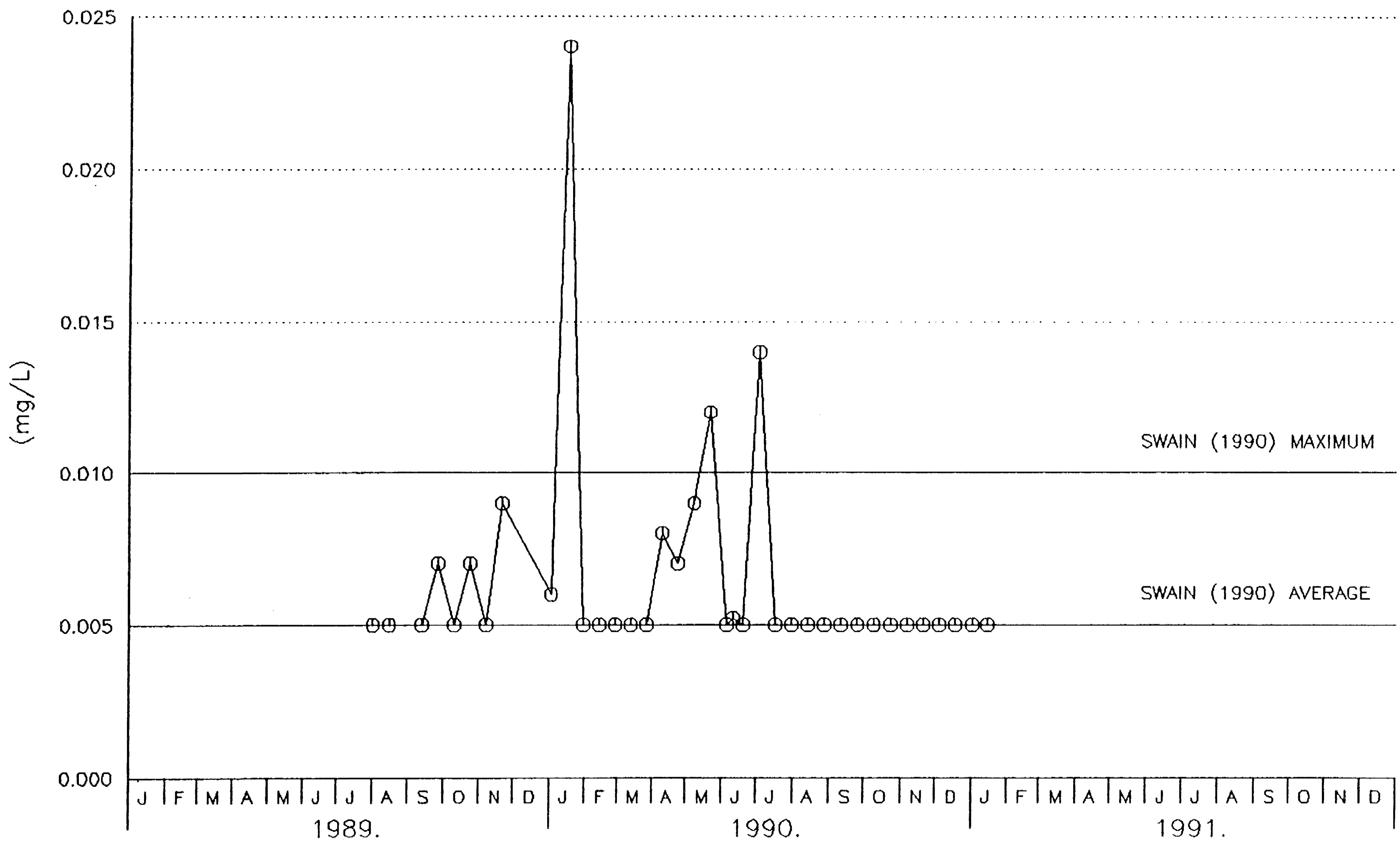

Figure 21	CYANIDE (S.A.D.) SIMILKAMEEN RIVER (1989 – 1991)	Environmental Management Associates

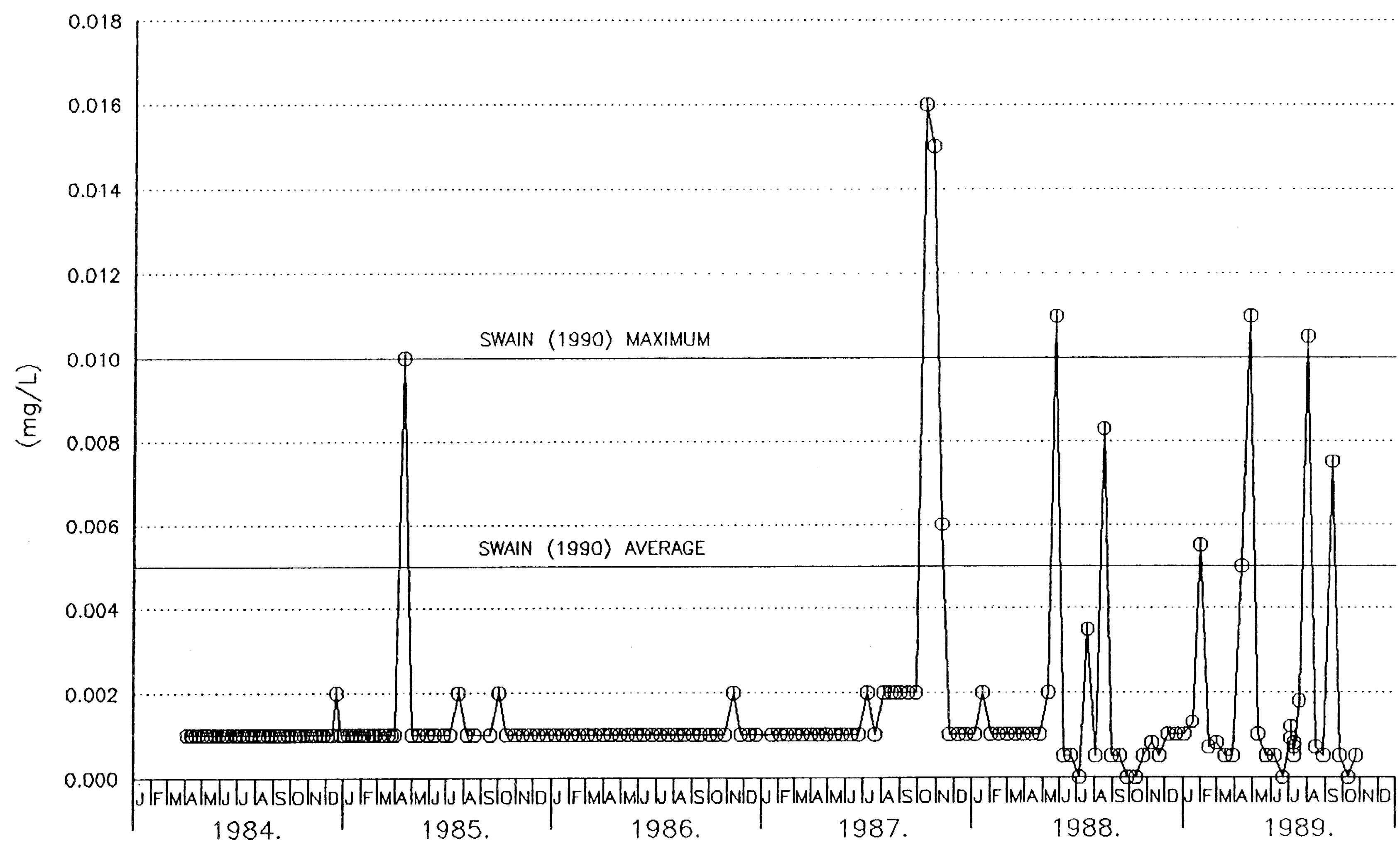

Figure 22	TOTAL CYANIDE – FEDERAL SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

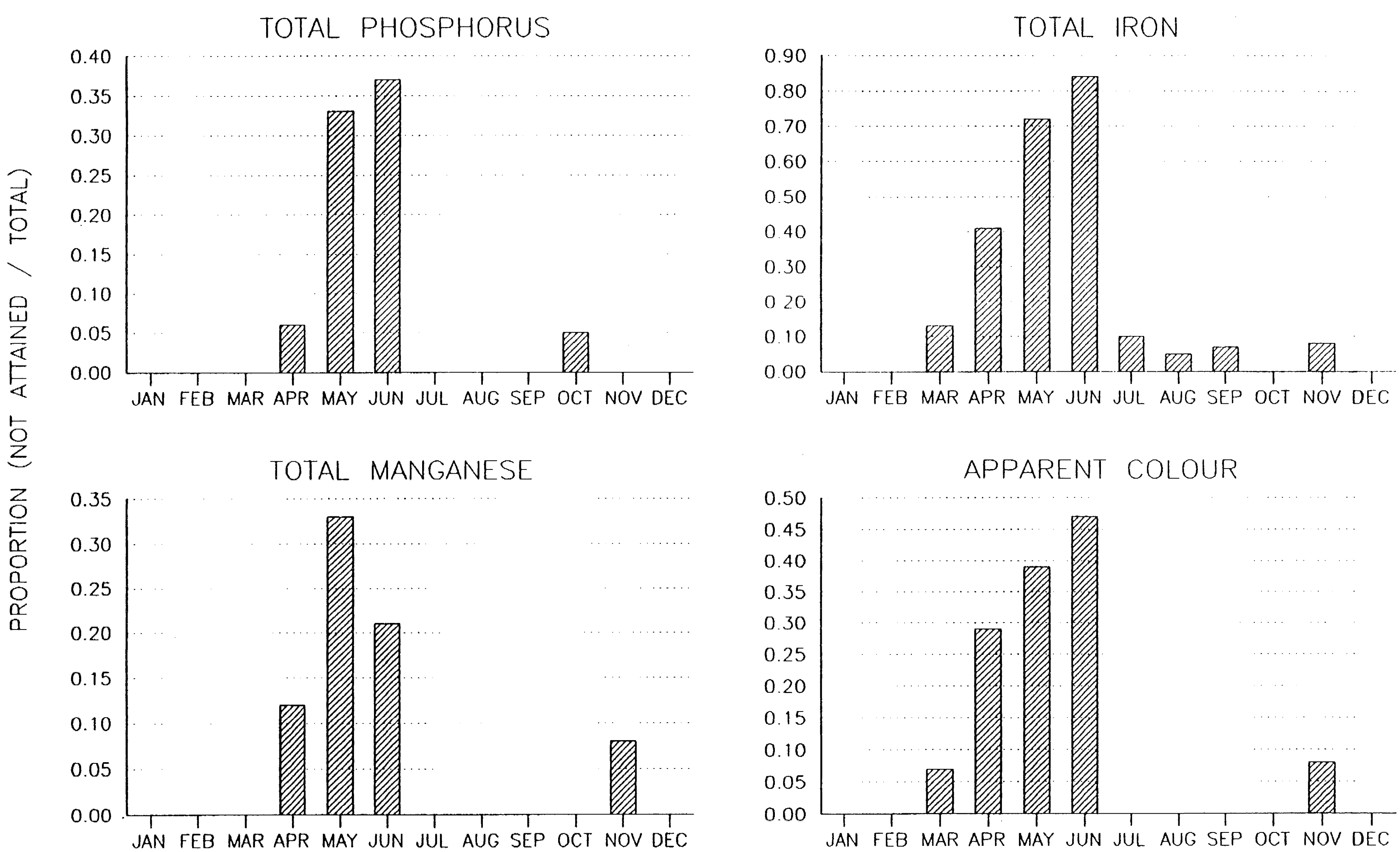

Figure 23	MONTHLY NON-ATTAINMENT SUMMARY SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

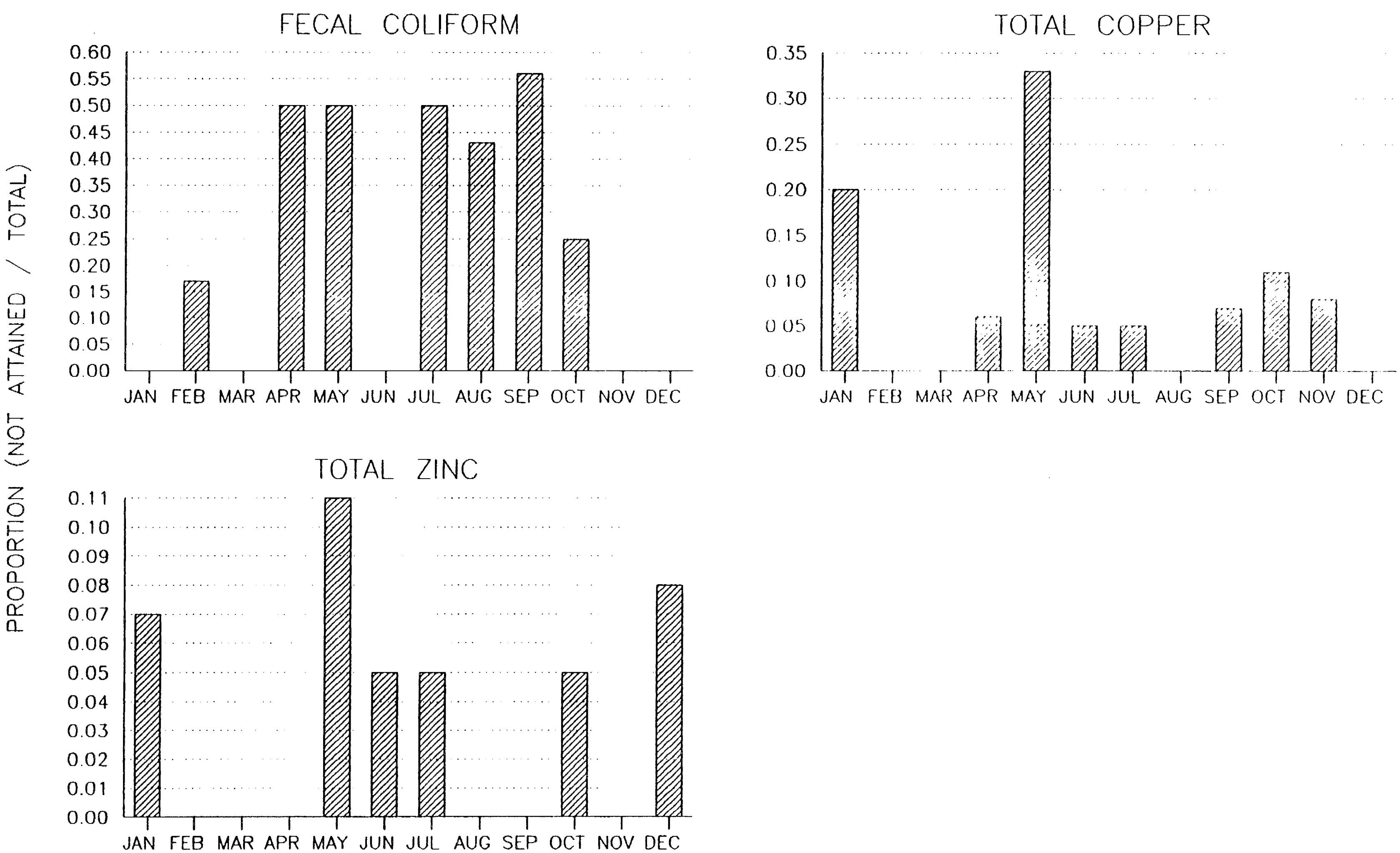

Figure 24

MONTHLY NON-ATTAINMENT SUMMARY
SIMILKAMEEN RIVER (1984 - 1989)

Environmental
Management Associates

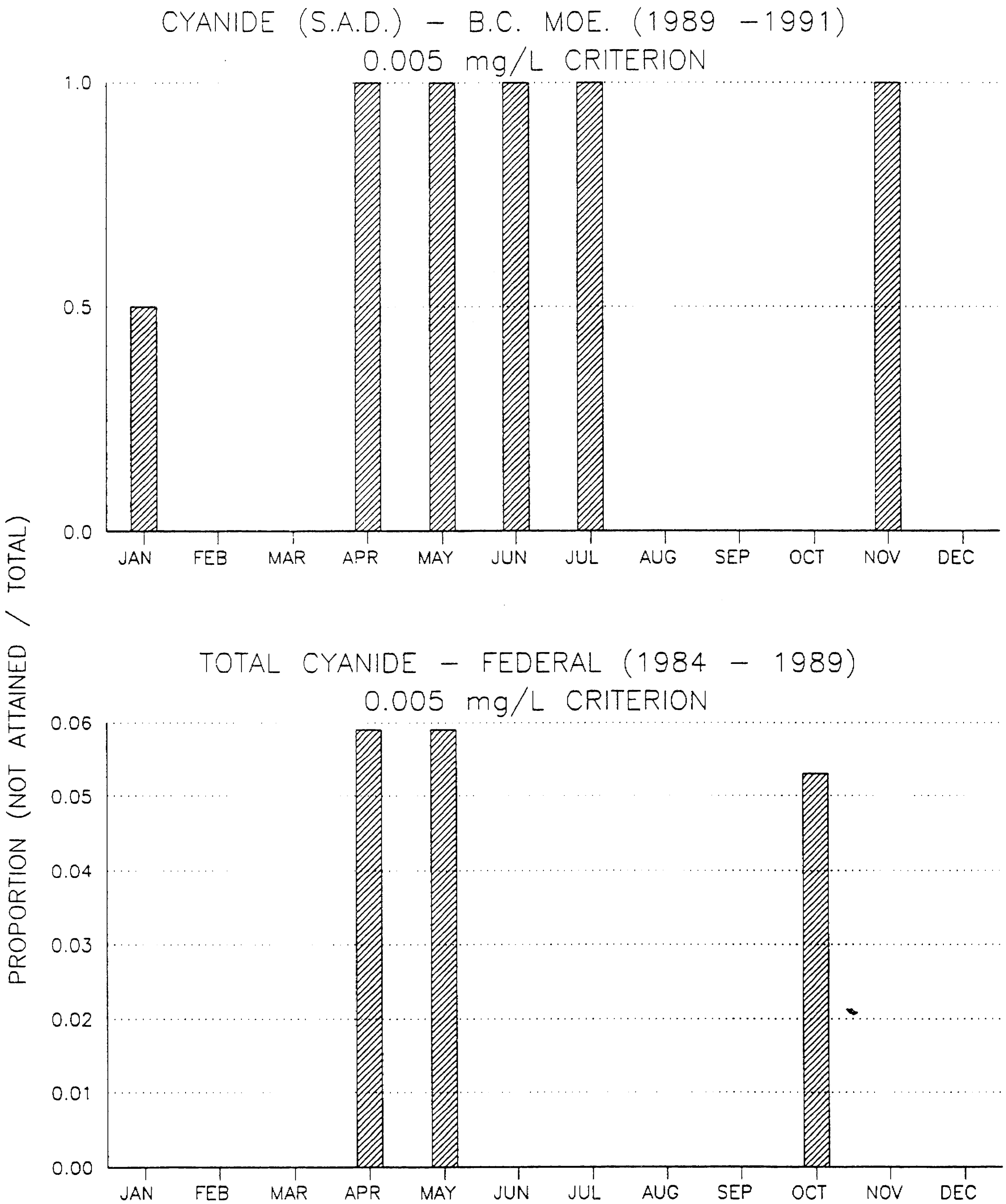

Figure 25	MONTHLY NON-ATTAINMENT SUMMARY FOR CYANIDE SIMILKAMEEN RIVER	Environmental Management Associates

As discussed for the Flathead River, exceedences of the average mercury criterion were an artifact of assumptions used in excursion analysis, and exceedences of zinc criteria are probably at least partly a reflection of historical problems of sample contamination. Although there are potential sources of Zn in the Similkameen Basin (metals mines) the occurrence of exceedences for the same metal in the pristine Flathead River implies a natural source. Similarly, the high frequency of exceedences for chromium, based on monthly means, reiterates the pattern found in the Flathead River, where there are no anthropogenic sources. Therefore, if the observed Cr level in the Similkameen River is real, it is probably particulate and of no concern for the river's biota. Sample contamination is also seen as the probable cause of exceedences in cyanide data (Pommen and Ryan 1992). The high levels of fecal coliform bacteria undoubtedly arise from cattle in or near the river, as has been noted in earlier surveys (Swain, 1985). Exceedences of the fecal coliform criterion tend to be more frequent in spring, when overland runoff is likely, and in the late summer - early autumn, when river flows are least and bacterial survival is longest due to warm temperatures.

6. TRENDS IN WATER QUALITY

6.1 Flathead River

Inspection of time-series plots for all variables routinely sampled on the Flathead River (Appendix A) indicates that concentrations of most variables are seasonally dependent. Levels of major ions, conductivity, and hardness were highest in winter and lowest in summer as a result of dilution. In contrast, levels of many variables related to particulate matter, e.g., turbidity, non-filterable residue, total phosphorus, and total metals peaked in spring and early summer, as a result of the spring freshet. Neither gradual nor incremental changes in river water quality were apparent for most variables. The only notable trends were the relatively high concentrations of phenolphthalein alkalinity (the result of an error in Federal pH data) and fluoride in 1988-89 and of total zinc in 1986-87.

In addition to inspection of time-series plots, a more detailed statistical analysis was carried out for the variables listed in Section 3.5. Preliminary analysis consisted of an evaluation of serial correlation and seasonality. Serial correlation was evaluated with autocorrelation function plots (correlograms). Except for the nitrogen fractions, serial correlation was evident in weekly samples for all variables tested from the Flathead River (Table 8). The presence of serial correlation violates the assumption of independence required by most parametric and non-parametric statistical tests. Therefore, mean monthly data were used to test for trend, although weekly data were also tested for those variables without significant serial correlation. The use of mean monthly data eliminated serial correlation in virtually all variables tested.

The results of the Kendall tests are summarized in Table 9. On the Flathead River, there were significant ($P < 0.05$) long-term trends in nine of the 13 variables tested. From 1985 to 1989, water temperature and conductivity increased while levels of iron, manganese, $(NO_2^- + NO_3^-)$-N, dissolved nitrogen, total phosphorus, turbidity, and zinc decreased. For $(NO_2^- + NO_3^-)$-N concentrations, a significant trend was detected with the weekly data but not with monthly means.

Table 8. Preliminary Analysis of Weekly Samples from Flathead River, May 1985 - October 1989.

Variable	Serial Correlation[1]	Seasonality
Water Temperature	Yes - Positive lags 1-8	Yes - peaks in late summer
Conductivity	Yes - Positive lags 1-6	Yes - peaks in autumn/winter
Turbidity	Yes - Positive lags 1-3	Yes - peaks in spring
$(NO_2^- + NO_3^-)$-N	No	Yes - peaks in spring/autumn
Dissolved Nitrogen	No	Yes - peaks in spring/autumn
Total Phosphorus	Yes - Positive lags, 1-2, 5-6	Yes - peaks in spring
Arsenic (Total)	Yes - Positive lags 1-2, 5-6	Yes - peaks in spring
Copper (Total)	Yes - Positive lags, 2,4	Yes - slight increases in spring/summer
Iron (Total)	Yes - Positive lags 1-2, 5-6	Yes - peaks in spring
Lead (Total)	Yes - Positive lags 1, 5	No
Manganese (Total)	Yes - Positive lags 1, 5-6	Yes - peaks in spring
Selenium (Total)	Yes - Positive lags 1-3	No
Zinc (Total)	Yes - Positive lags 1-2	Yes - peaks in spring

[1] Significant at $P < 0.05$.

Table 9. Kendall Tests on Deseasonalized Mean Monthly values - Flathead River, May 1985-October 1989.

Variable	t_s[1]	P	Slope[2]	Comments
Water Temperature	2.08	0.04	0.16°C/yr	Trend not obvious
Conductivity	3.521	<0.001	4.2 μS/cm/yr	Increase from 1985 to 1987
Turbidity	-3.16	0.002	-0.15 NTU/yr	Reduction in peak values from 1986 to 1989
$(NO_2^- + NO_3^-)$-N	-1.238	0.22		Slight decrease from 1985 to 1989
	-2.817	0.005	--[3]	Computed from weekly values
Dissolved N	-4.088	<0.001	-0.014 mg/L/yr	Decrease from 1985 to 1989
	-5.320	<0.001	--[3]	Computed from weekly values
Total Phosphorus	-2.16	0.03	-0.0007 mg/L/yr	Reduction in peak values from 1986 to 1989
Arsenic (Total)	-1.418	0.16		No trend
Copper (Total)	1.343	0.18		High values in 1987-1988
Iron (Total)	-4.073	<0.001	-0.013 mg/L/yr	Reduction in peak values from 1986 to 1989
Lead (Total)[4]	-0.579	0.56		No trend
Manganese (Total)	-4.446	<0.001	-0.0010 mg/L/yr	reduction in peak values from 1986 to 1989
Selenium (Total)[4]	-0.606	0.54		No trend
Zinc (Total)	-2.73	0.006	-0.017 mg/L/yr	Reduction in peak values from 1986 to 1989

[1] Test statistic $t_s = \dfrac{\text{Kendall tau}}{\sqrt{2(2n+5)/9n(n-1)}}$

[2] Seasonal Kendall slope estimate computed only for those variables with a significant (P <0.10) long-term trend, as computed from mean monthly values.

[3] Slope not computed for trends detected in weekly data because of statistical software limitations.

[4] Not deseasonalized before applying Kendall test.

For those variables with significant (P <0.05) long-term trends, 60-day moving average time-series plots are shown in Figures 27 to 34. These plots smooth the data by reducing random noise in the series, so that seasonal and long-term patterns are more readily apparent. In general, the trends detected by the statistical tests were apparent in these plots. Gradual increases in water temperature and conductivity and decreases in total dissolved nitrogen levels were obvious. Peak levels of turbidity, total phosphorus, total iron, and total manganese declined from 1985 to 1989. Relatively high concentrations of total zinc were recorded in 1986 and 1987.

Initially, investigation of the potential causes of the above trends focused on natural factors, such as changes in air temperature and river flows. The increase in water temperatures was a result of changes in air temperatures, which have increased by 1.1°C/yr at the Flathead River sampling sites (as recorded on the dates that the river was sampled; t_s = 2.72, P = 0.007; Figure 26). A significant trend in flows also occurred in the Flathead River over the course of the study; flows have decreased by 1.2 $m^3/s/yr$ (t_s = -2.85, P = 0.004). Since levels of many water quality variables are affected by river discharge, some of the trends detected for the Flathead River may be a result of changes in flow. Therefore, a residual method was used to test whether changes in flow could account for the observed water quality trends.

Levels of conductivity, turbidity, total phosphorus, total iron, and total manganese were significantly correlated with flow (Table 10). Residuals from the regression models were tested for trend with the Kendall test (Table 11). Flow-adjusted concentrations (i.e., residuals) of total phosphorus and turbidity from the Flathead River did not change significantly from 1985 to 1989 (Figures 35 and 36), indicating that trends in these variables were likely a result of changes in river flows.

In contrast, significant trends were detected for flow-adjusted values of conductivity, total iron, and total manganese (Table 11). Strong trends were not, however, obvious from inspection of time-series plots of the residuals (Figures 37-39), which indicates that changes in flow may at least partly account for the long-term trends detected for these

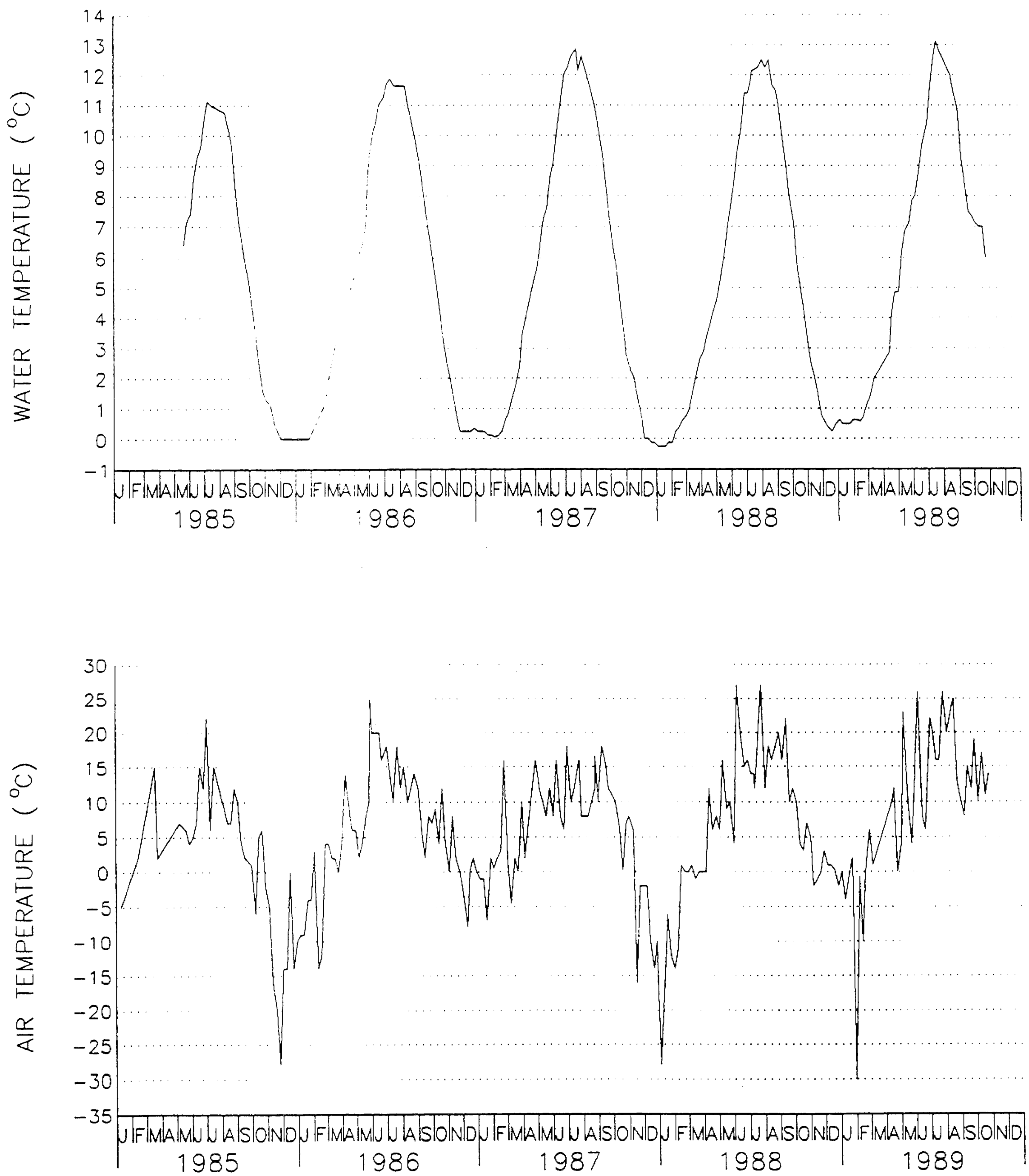

Figure 26	WATER AND AIR TEMPERATURES FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

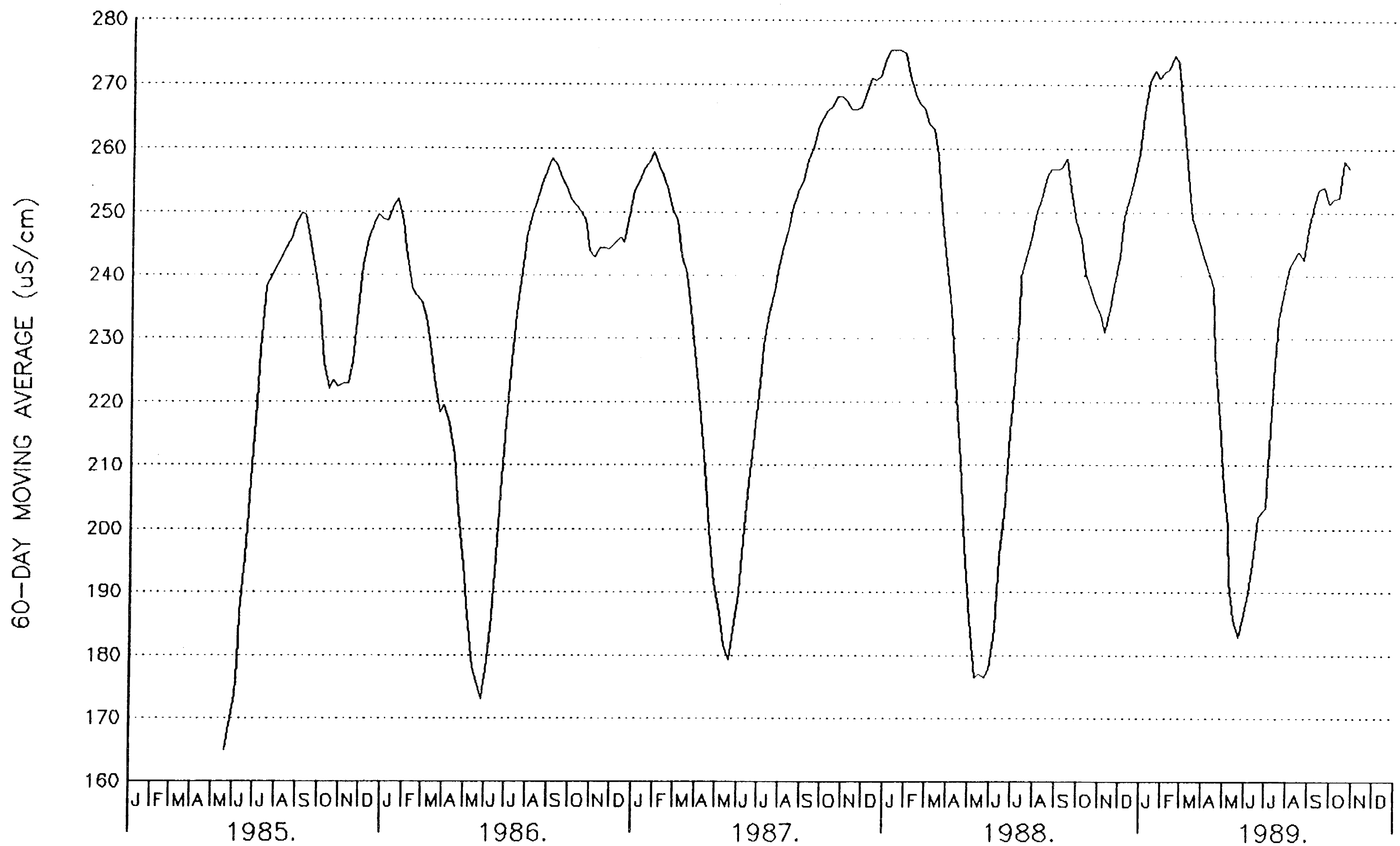

Figure 27	SPECIFIC CONDUCTANCE FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

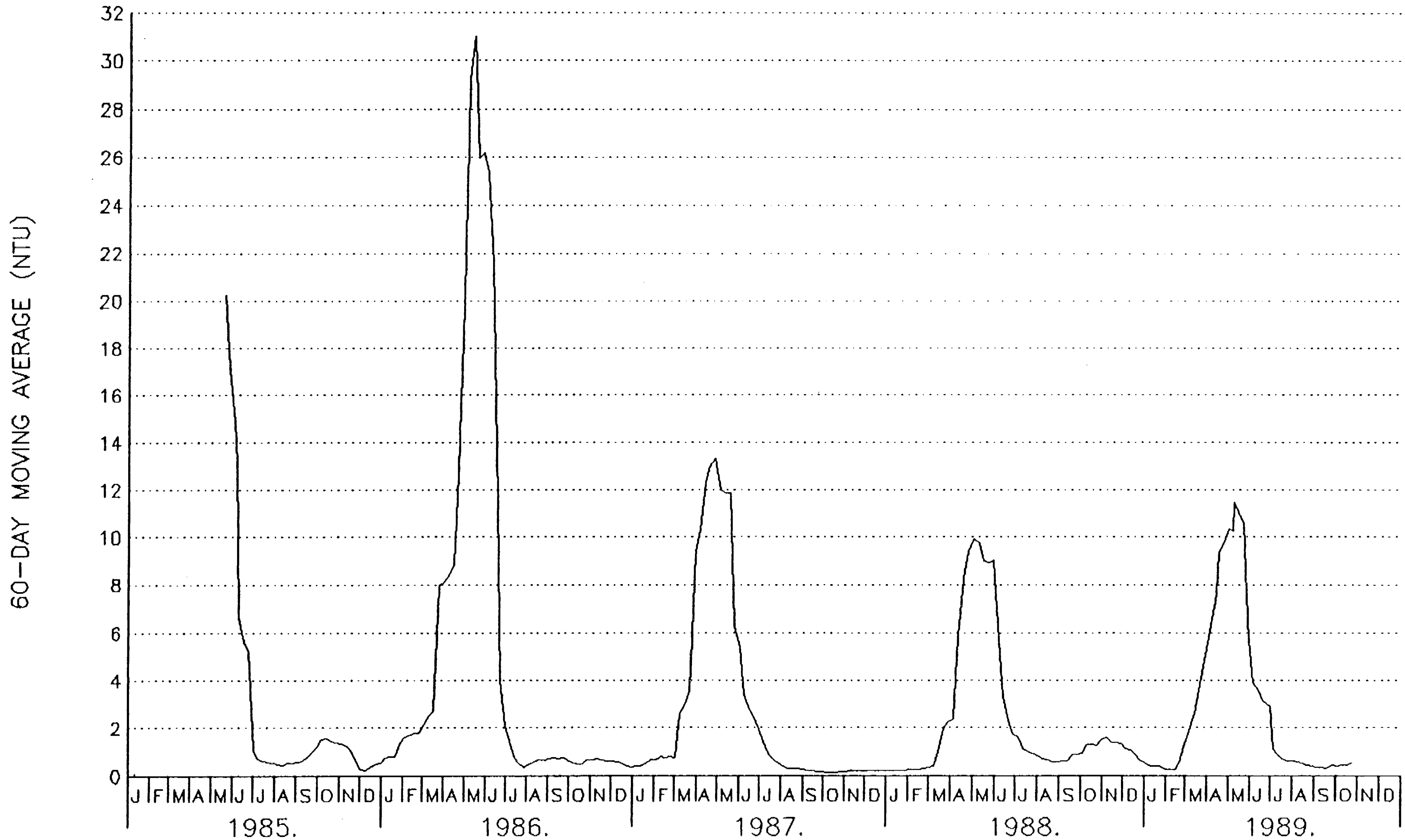

Figure 28	TURBIDITY FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

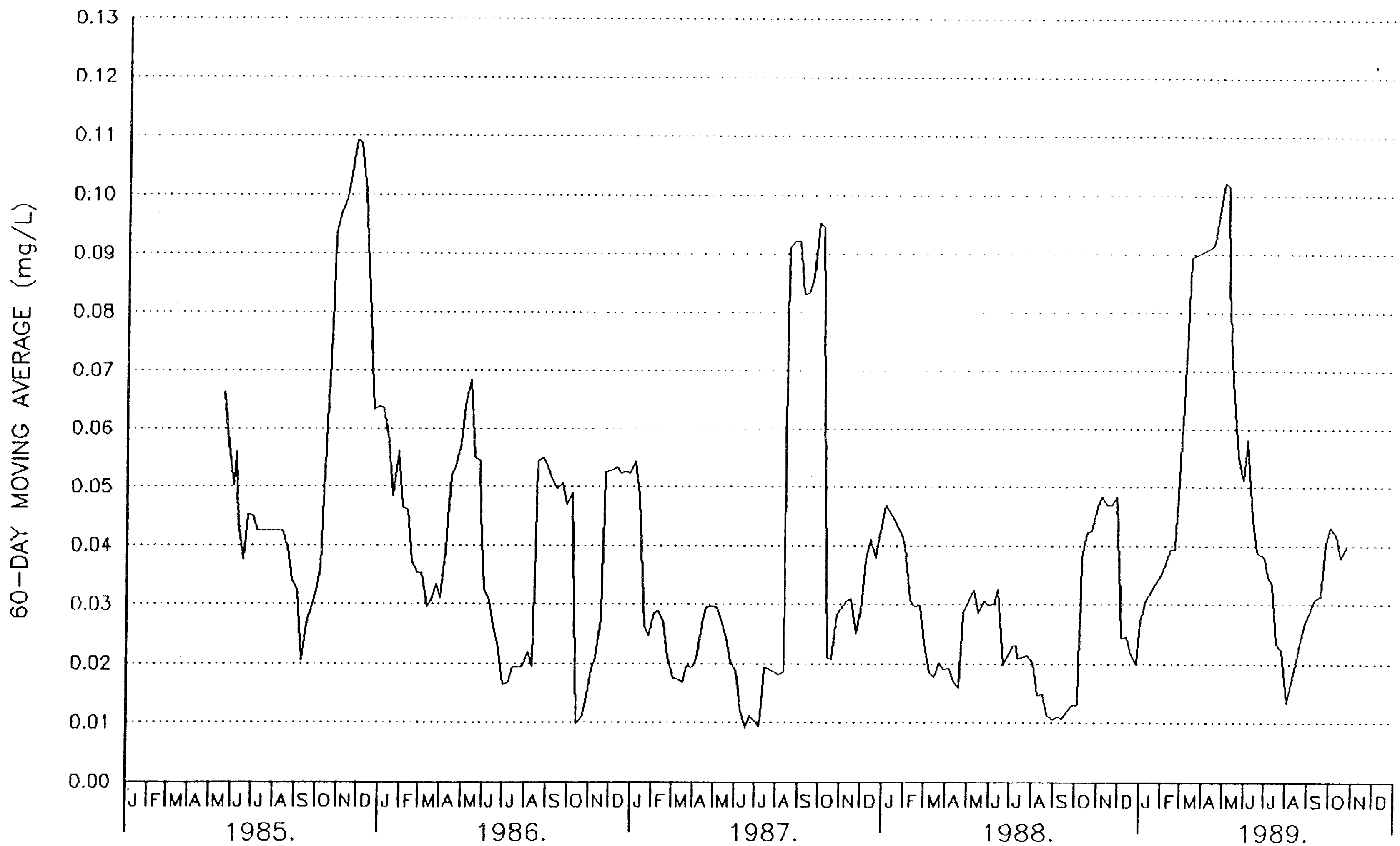

Figure 29	NITRATE+NITRITE–NITROGEN FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

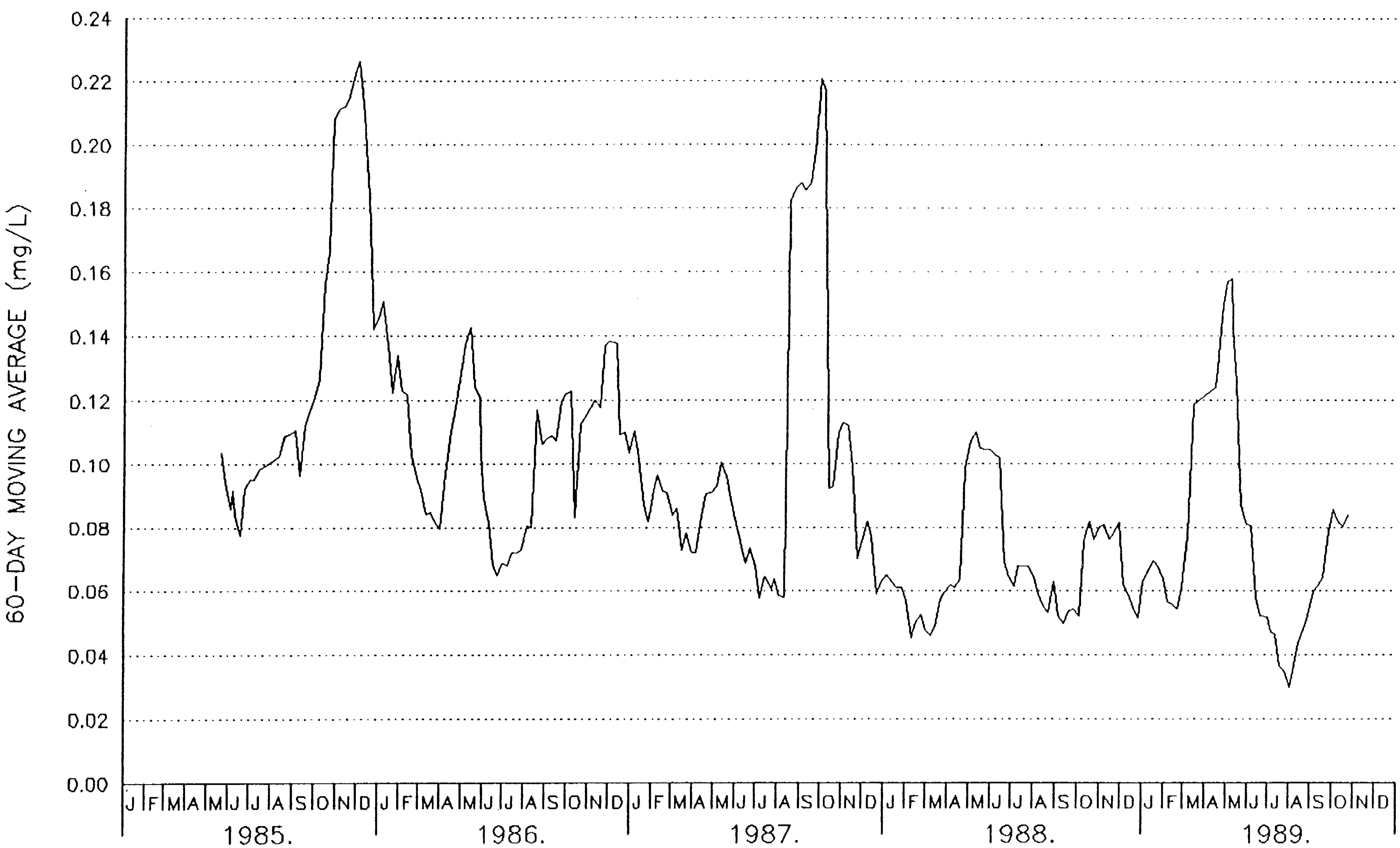

Figure 30	TOTAL DISSOLVED NITROGEN FLATHEAD RIVER (1985 - 1989)	Environmental Management Associates

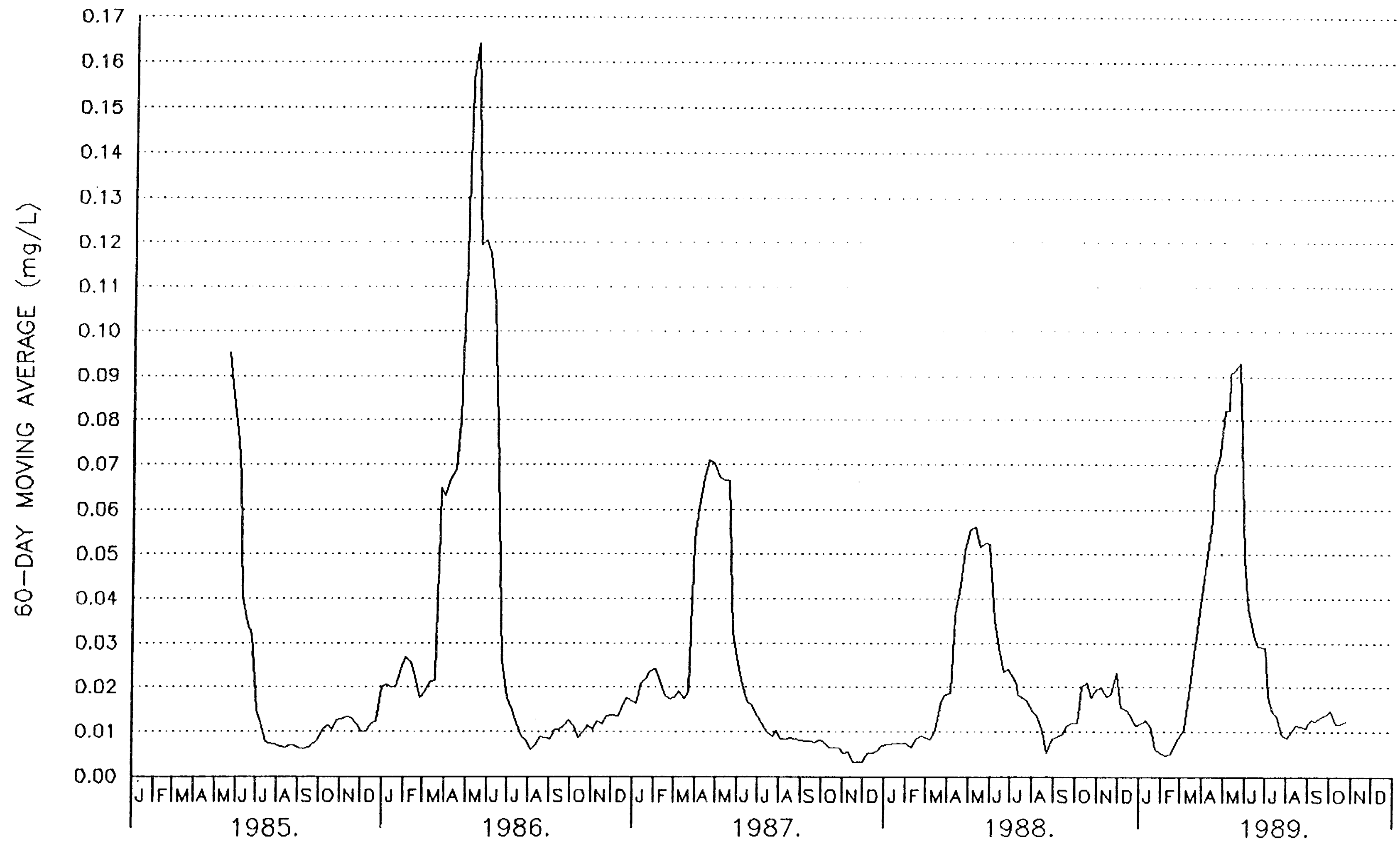

Figure 31	TOTAL PHOSPHORUS FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

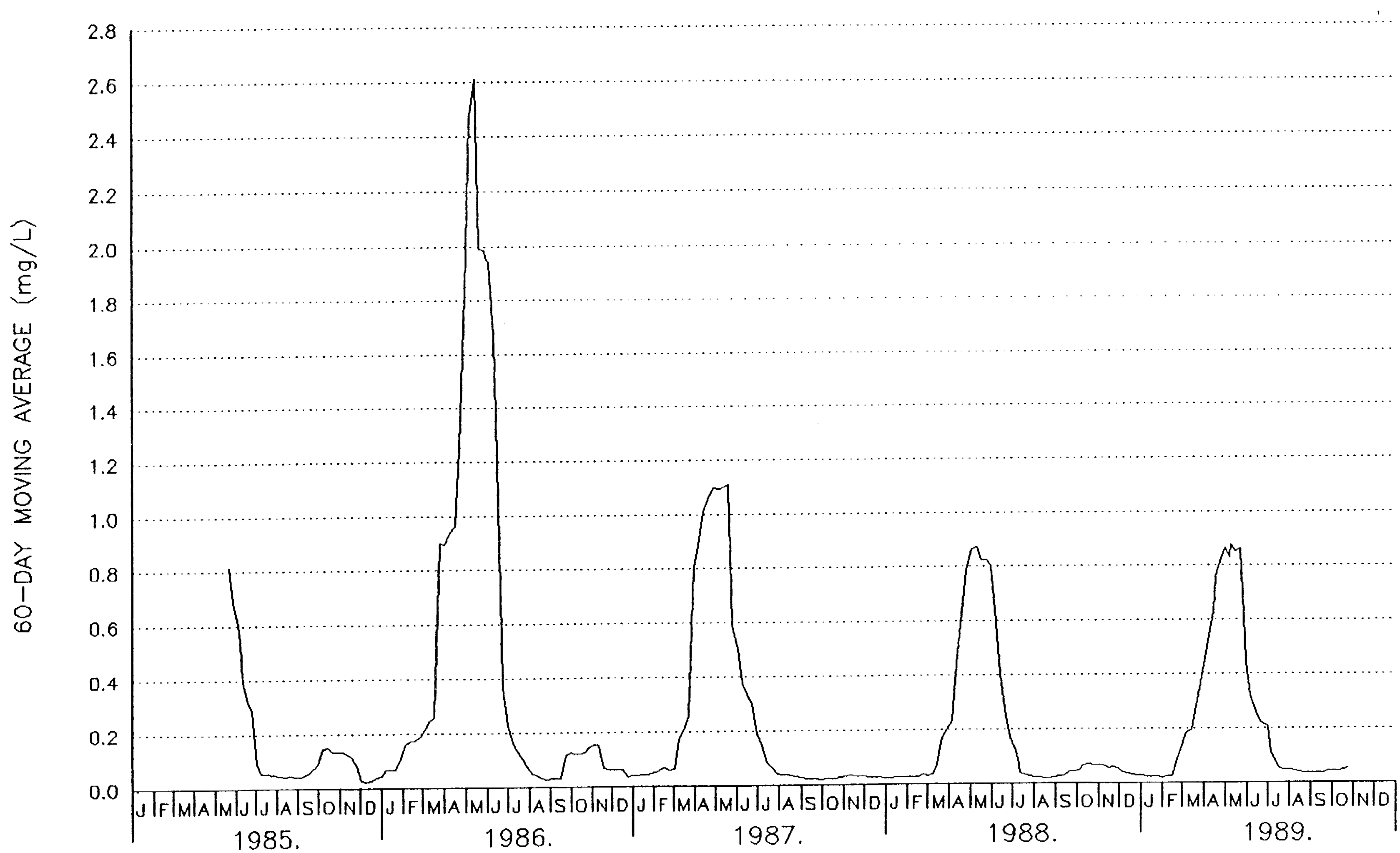

Figure 32	TOTAL IRON FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

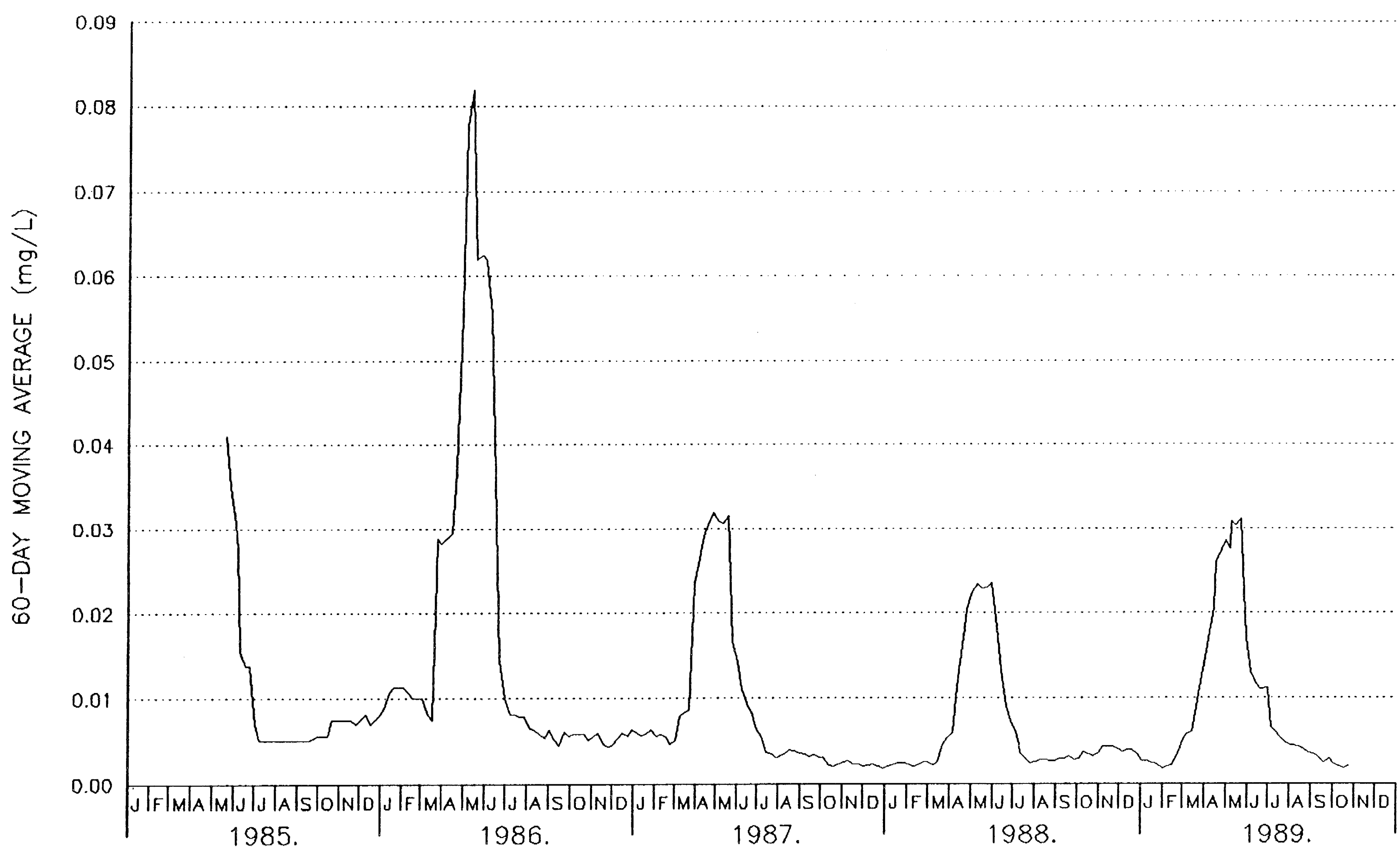

Figure 33	TOTAL MANGANESE FLATHEAD RIVER (1985 - 1989)	Environmental Management Associates

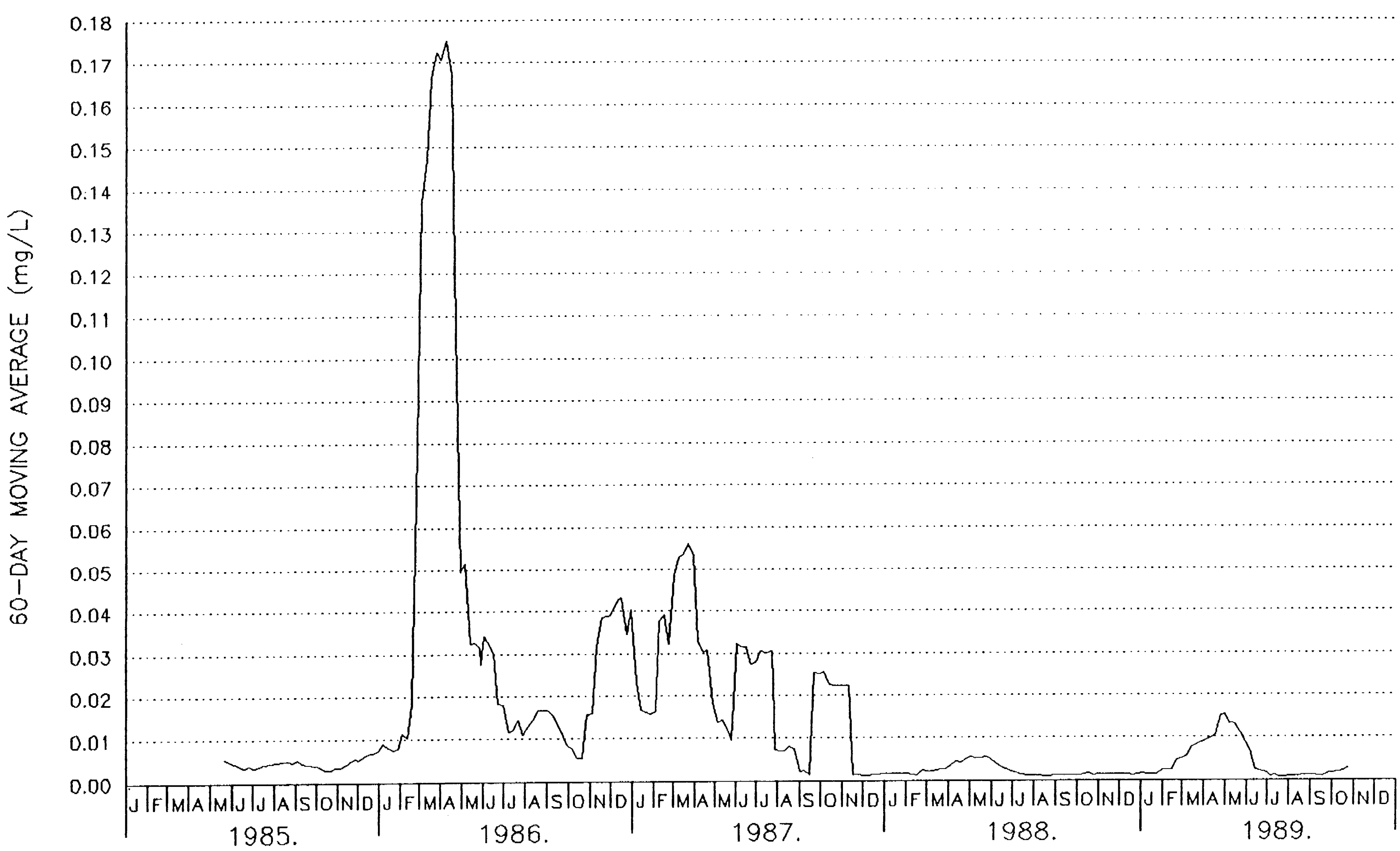

Figure 34

TOTAL ZINC
FLATHEAD RIVER (1985 – 1989)

Environmental Management Associates

Table 10. Regression Models - Concentration ([X]) Versus Flow (Q, m^3/s).

Variable	Unit	Model	*df*	r^2
FLATHEAD RIVER				
Conductivity	$\mu S/cm$	$\log[X] = 5.77 - 0.13\log Q$	224	0.90
Turbidity	NTU	$\log[X] = -2.97 + 1.12\log Q$	224	0.72
Total Phosphorus	mg/L	$[X] = 0.107 + 1.26 \times 10^{-4}Q + 5.90 \times 10^{-6}Q^2$	220	0.58
Total Iron	mg/L	$\log[X] = -5.37 + 1.10\log Q$	223	0.71
Total Manganese	mg/L	$[X] = 0.00499 - 4.44\times10^{-5}Q + 3.42\times10^{-6}Q^2$	223	0.61
$(NO_2^- + NO_3^-)$-N		No significant relationship (P >0.05)		
Total Dissolved Nitrogen		No significant relationship (P >0.05)		
Total Zinc		No significant relationship (P >0.05)		
SIMILKAMEEN RIVER[1]				
$(NO_2^- + NO_3^-)$-N	mg/L	$\log[X] = -1.75 - 0.62\log Q$	143	0.34
Total Dissolved Nitrogen		No significant relationship (P >0.05)		
Total Copper		No significant relationship (P >0.05)		

[1] Relationship with total lead not tested because of large number of non-detects for lead.

Table 11. Results of Kendall Tests on Mean Monthly Flow-Adjusted Concentrations.

Variable	t_s [1]	P	Comments
FLATHEAD RIVER			
Conductivity	2.24	0.025	Higher values in 1988-89
Turbidity	-1.09	0.28	No trend
Total Phosphorus	-0.91	0.37	No trend
Total Iron	-2.34	0.019	Gradual decrease from 1986 to 1989
Total Manganese	-2.98	0.003	Very slight decline from 1986 to 1989
SIMILKAMEEN RIVER			
$(NO_2^- + NO_3^-)$-N	-1.69	0.09	High values in 1985-86

[1] Test statistic $t_S = \dfrac{\text{Kendall tau}}{\sqrt{2(2n+5)/9n(n-1)}}$

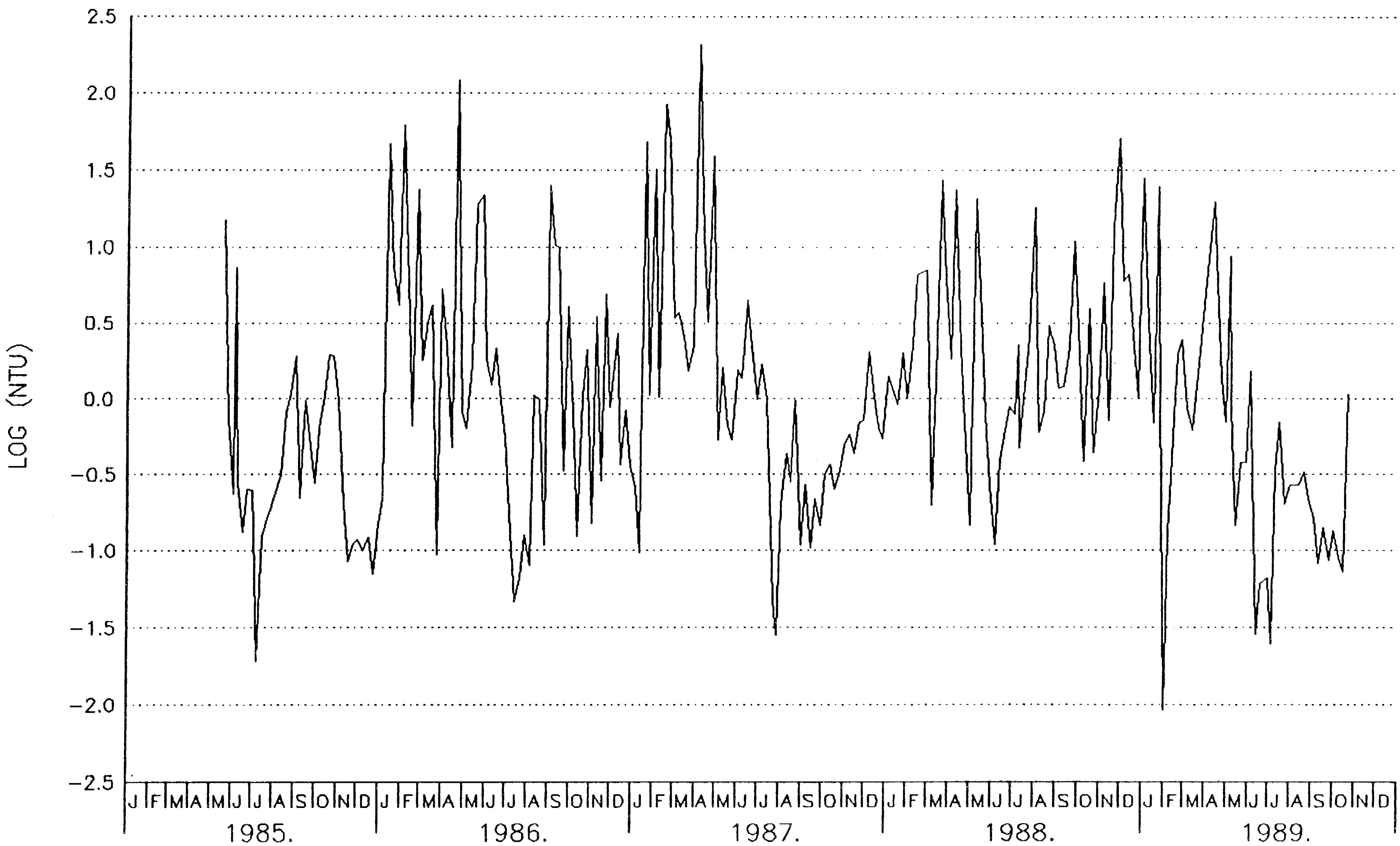

Figure 35	FLOW–ADJUSTED TURBIDITY FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

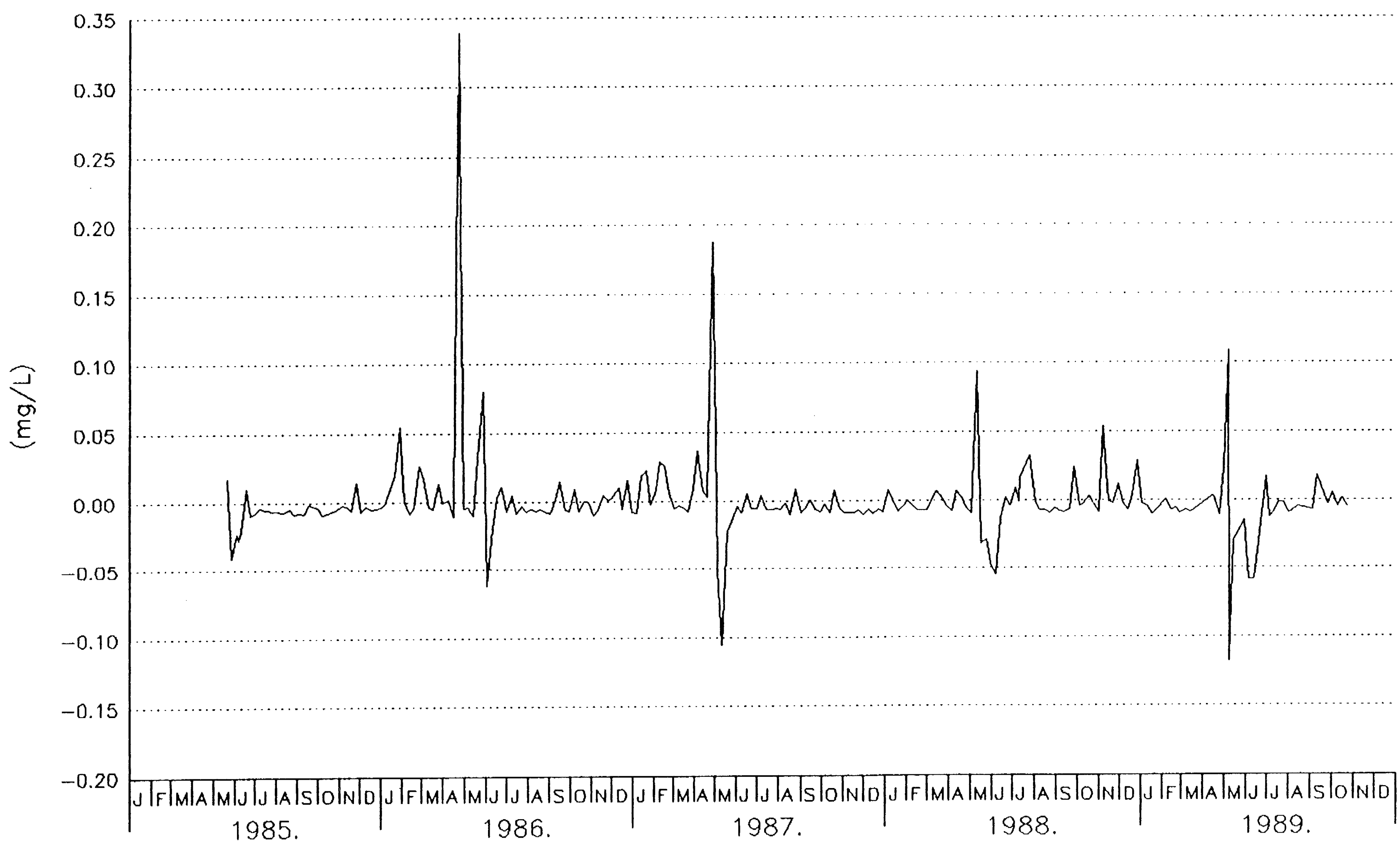

Figure 36

FLOW-ADJUSTED TOTAL PHOSPHORUS
FLATHEAD RIVER (1985 - 1989)

Environmental
Management Associates

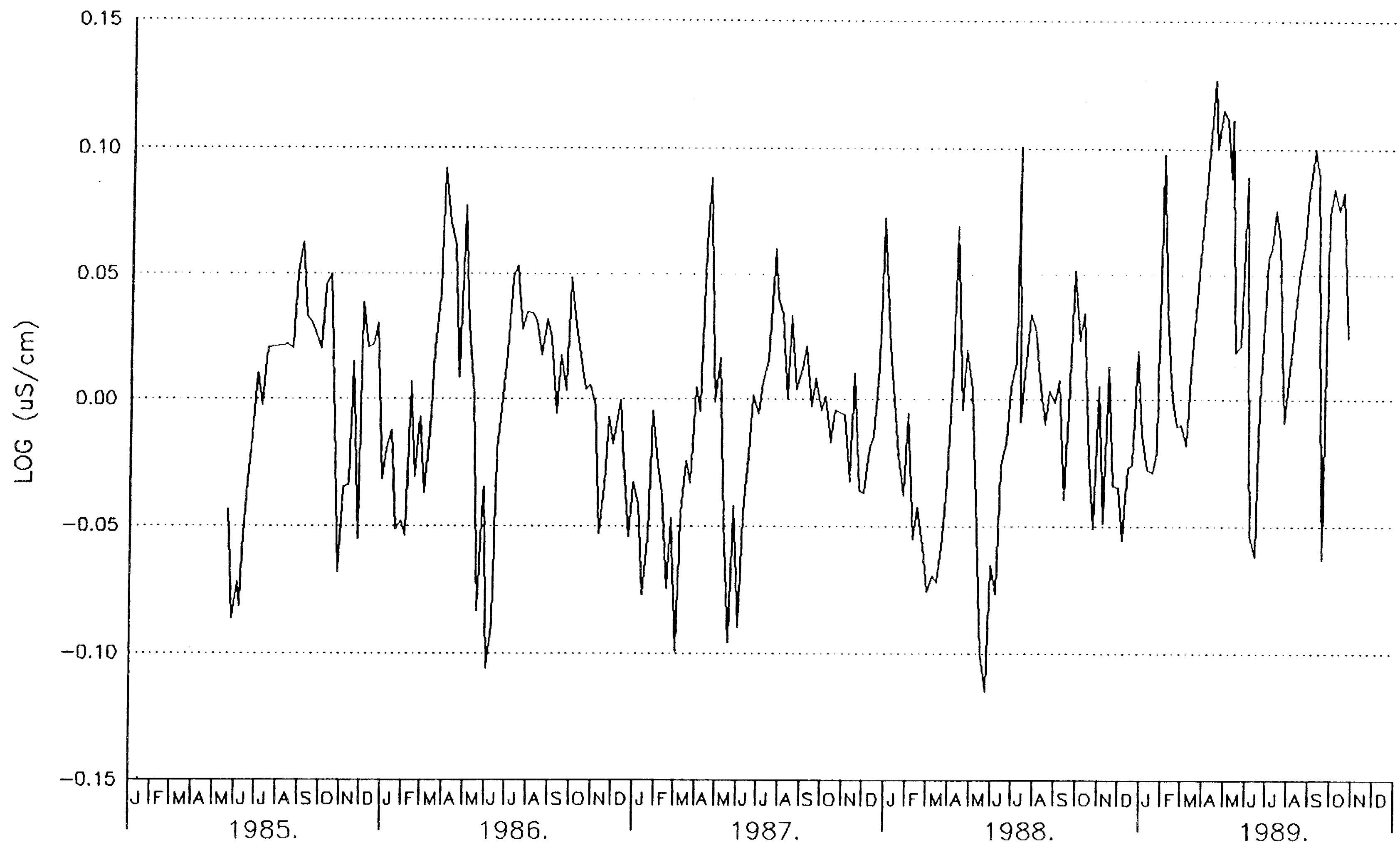

Figure 37

FLOW−ADJUSTED CONDUCTIVITY
FLATHEAD RIVER (1985 − 1989)

Environmental Management Associates

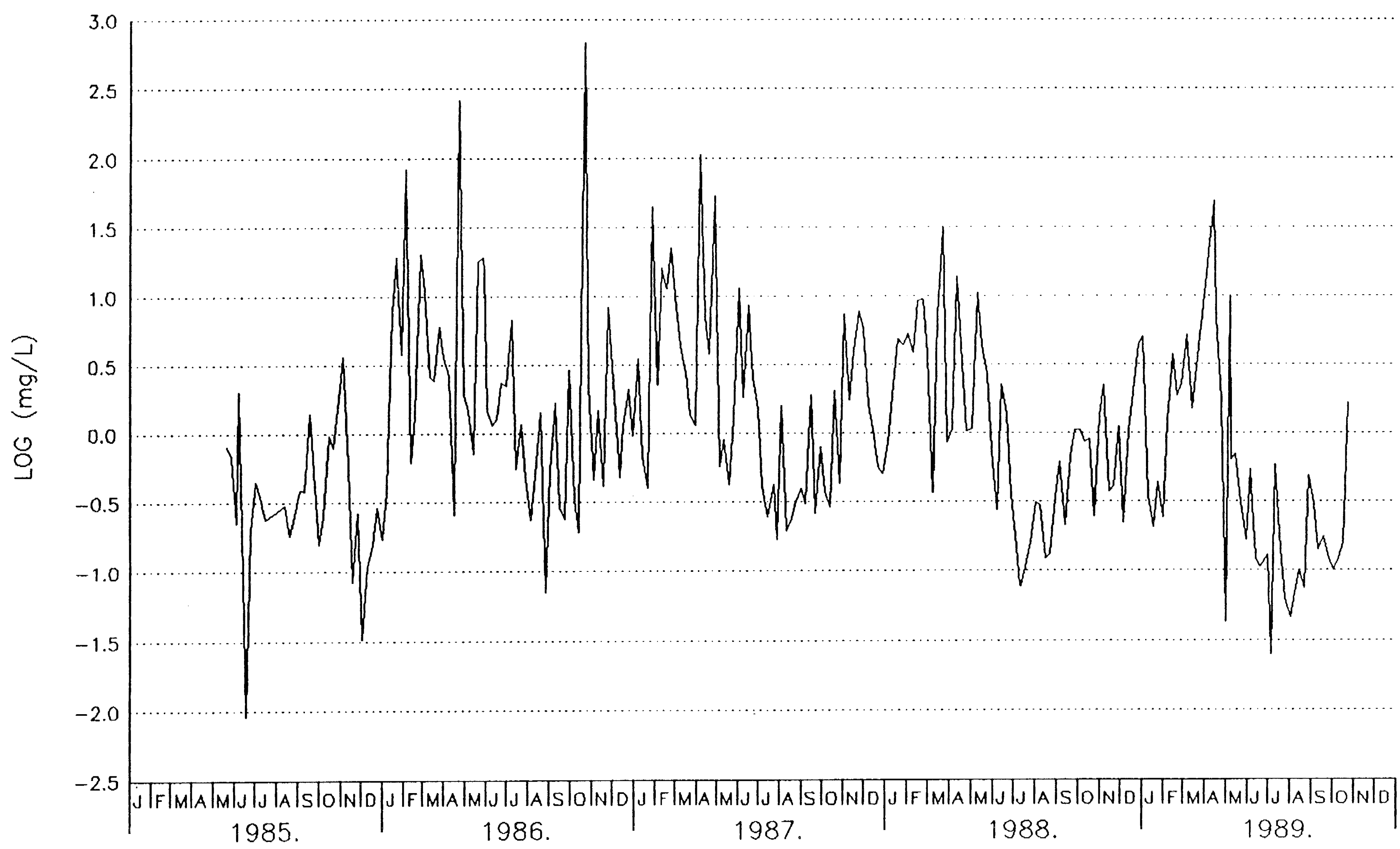

Figure 38	FLOW–ADJUSTED TOTAL IRON FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

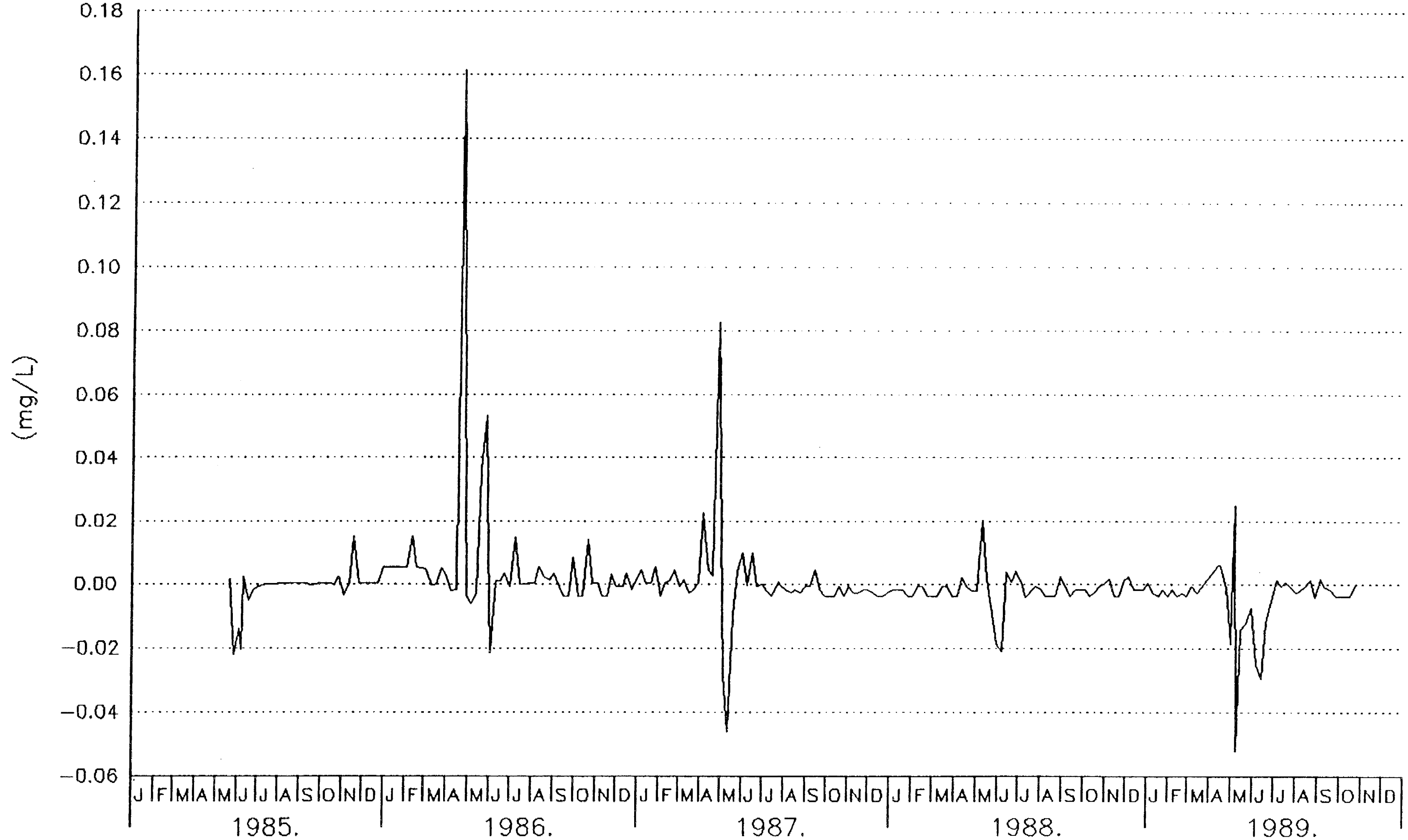

Figure 39	FLOW-ADJUSTED TOTAL MANGANESE FLATHEAD RIVER (1985 - 1989)	Environmental Management Associates

variables. Certainly, changes in river discharge would be the most probable cause of apparent trends in these three variables, given the strong dependence of iron and manganese concentrations on sediment transport, and the tendency of total solute loads to decrease in proportion with increasing flow because of dilution of ion-rich base flow with surface runoff. There have been no known interventions in the basin capable of producing this effect. The lack of statistical corroboration may be simply because of noise in the data (the trends are not strong) or because the discharge-concentration relationship has non-linear components.

It is suspicious that zinc concentrations remained uniformly low in 1985, and as well in 1988-1989, but abruptly became much greater (by a factor of 10-20 times) and more variable in 1986-1987 (Figure 34). There was a known problem of zinc contamination of water samples during this period, which has since been corrected. There has been no activity in the basin sufficient to account for the change, and the absence of similar patterns in other metals further argues against a natural source. The weight of evidence, therefore, suggests that the high zinc levels are an artifact, resulting from analytical problems.

Concentrations of nitrate-nitrite were highest in 1985, declined until 1987 and have remained fairly constant since then (Figure 29). While natural cycles in nutrient concentrations with a period of 5-10 years have been observed in other systems (Schindler, 1987), the data here are rendered dubious by the high values from laboratory and field blanks (Section 4), which could represent as much as a third of the mean nitrate-nitrite level in this river. The trend in total dissolved nitrogen is almost certainly reflecting the nitrate-nitrite data and thus is confounded as well.

6.2 Similkameen River

Inspection of time-series plots for all variables routinely sampled on the Similkameen River (Appendix B) indicates that, as in the Flathead River, concentrations of most variables are seasonally dependent. Levels of major ions, conductivity, and hardness were highest in winter and lowest in summer, while levels of variables related to particulate matter, e.g., turbidity, non-filterable residue, total phosphorus, and total metals peaked in spring and early summer, as a result of the spring freshet. Most variables showed no gradual or incremental trends. The only notable trends were relatively high concentrations of $(NO_2^- + NO_3^-)$-N and total dissolved nitrogen in 1985-86 and of total cyanide in 1988-89.

In addition to inspection of time-series plots, a more detailed statistical analysis was carried out for the variables listed in Section 3.5. Preliminary analysis consisted of an evaluation of serial correlation and seasonality. Significant serial correlation was evident in fortnightly samples for 11 of 17 variables tested (Table 12). Since serial correlation violates the assumption of independence required by most statistical tests, mean monthly data were used to test for trend, although fortnightly data were also used for those variables without significant serial correlation. The use of mean monthly data eliminated serial correlation in all variables tested.

Fewer trends were evident on the Similkameen River than on the Flathead River; long-term trends were detected in only five of 17 variables (Table 13). From 1984 to 1989, water temperature, total copper, and total lead levels increased, and $(NO_2^- + NO_3^-)$-N and dissolved N concentrations decreased. Comparable results were obtained from analysis of both fortnightly and monthly samples. The higher and more variable cyanide concentrations in 1987-1989 were not sufficient to create a significant trend over the whole sampling period.

For those variables with significant ($P < 0.05$) long-term trends, 60-day moving average time-series plots are shown in Figures 41 to 44. The trends detected by the statistical tests are readily apparent in these plots. Gradual increases in water temperature and decreases in $(NO_2^- + NO_3^-)$-N levels and total dissolved nitrogen levels are obvious. Concentrations of total copper and total lead increased sharply in 1988 and 1989.

Like the Flathead River, increases in water temperature in the Similkameen River were a result of increases in air temperature, which has increased by 0.5°C/yr at the river

Table 12. Preliminary Analysis of Fortnightly Samples from Similkameen River, April 1984 - October 1989.

Variable	Serial Correlation[1]	Seasonality
Water Temperature	Yes - Positive lags 1-4	Yes - peaks in late summer
Conductivity	Yes - Positive lags 1-3	Yes - peaks in autumn/winter
Turbidity	No	Yes - peaks in spring
$(NO_2^- + NO_3^-)$-N	Yes - Positive lags 1-4	Yes - peaks in winter
Dissolved Nitrogen	Yes - Positive lags 1-4	Yes - peaks in winter
pH	Yes - Positive lags 1-4	Yes - peaks in autumn
Total Phosphorus	Yes - Positive lag 1	Yes - peaks in spring
Total Dissolved Phosphorus	Yes - Positive lag 1	Yes - peaks in spring
Cyanide (Total)	Yes - Positive lag 1	Yes - peaks in spring, autumn
Arsenic (Total)	No	Yes - peaks in spring
Copper (Total)	No	No
Iron (Total)	No	Yes - peaks in spring
Lead (Total)	Yes - Positive lag 1	No
Manganese (Total)	Yes - Positive lag 1	Yes - peaks in spring
Selenium (Total)	Yes - Positive lag 1	No
Zinc (Total)	No	Yes - peaks in spring

[1] Significant at $P < 0.05$.

Table 13. Kendall Tests on Deseasonalized Mean Monthly Values - Similkameen River, April 1984-October 1989.

Variable	t_s[1]	P	Slope[2]	Comments
Water Temperature	4.968	<0.001	0.50°C/yr	Increase from 1985 to 1989
Conductivity	0.146	0.89		No trend
Fecal Coliforms	-1.525	0.13		No trend
Turbidity	-0.503	0.62		No trend
	-0.500	0.62		Computed from fornightly samples
$(NO_2^- + NO_3^-)$-N	-1.964	0.05	-0.001 mg/L/yr	High values in 1986-87
Dissolved N	-3.647	<0.001	-0.0086 mg/L/yr	Decrease from 1985 to 1989
pH	-1.531	0.13		No trend
Total Phosphorus	0.574	0.57		No trend
TDP	-0.370	0.71		No trend
Cyanide (Total)	1.646	0.10		Increased variance in 1987-89
Arsenic (Total)	0.530	0.60		No trend
	0.393	0.70		Computed from fortnightly samples
Copper (Total)[4]	4.005	<0.001	0.0024 mg/L/yr	Increased variance in 1987-89
	4.058	<0.001	--[3]	Computed from fortnightly samples
Iron (Total)	-0.022	0.98		No trend
	-0.020	0.98		Computed from fortnightly samples
Lead (Total)[4]	1.916	0.06	0.00006 mg/L/yr	High values in 1988-89
Manganese (Total)	-0.357	0.59		High values in 1986-87
Selenium (Total)	-0.397	0.69		No trend
Zinc (Total)	1.716	0.085		High values in 1986-87
	0.782	0.44		Computed from fortnightly samples

[1] Test statistic $t_s = \frac{\text{Kendall tau}}{\sqrt{2(2n+5)/9n(n-1)}}$

[2] Seasonal Kendall slope estimate computed only for those variables with a significant (P <0.10) long-term trend, as computed from mean monthly values.

[3] Slope not computed for trends detected in weekly data because of statistical software limitations.

[4] Not deseasonalized before applying Kendall test.

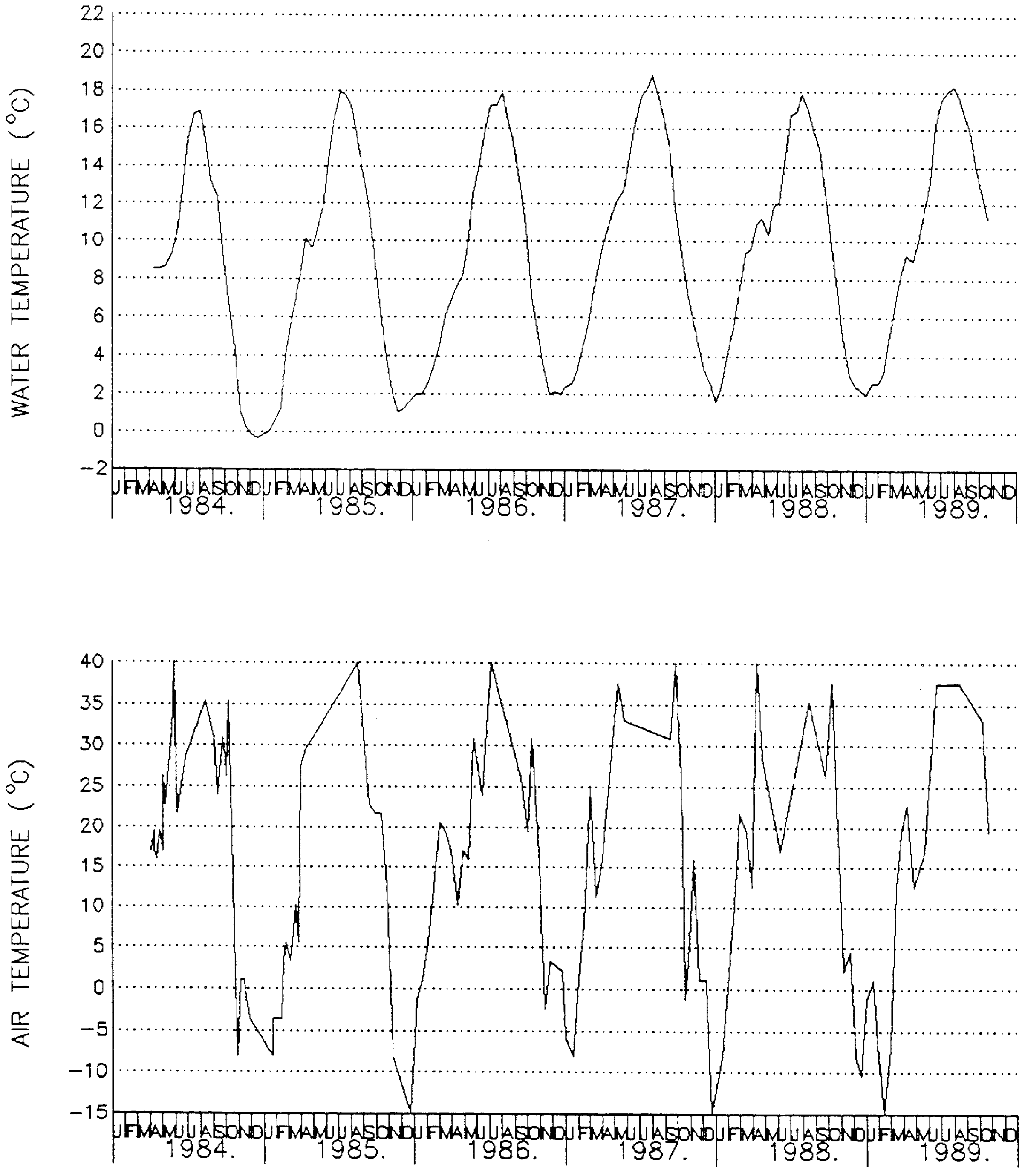

Figure 40	WATER AND AIR TEMPERATURES SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

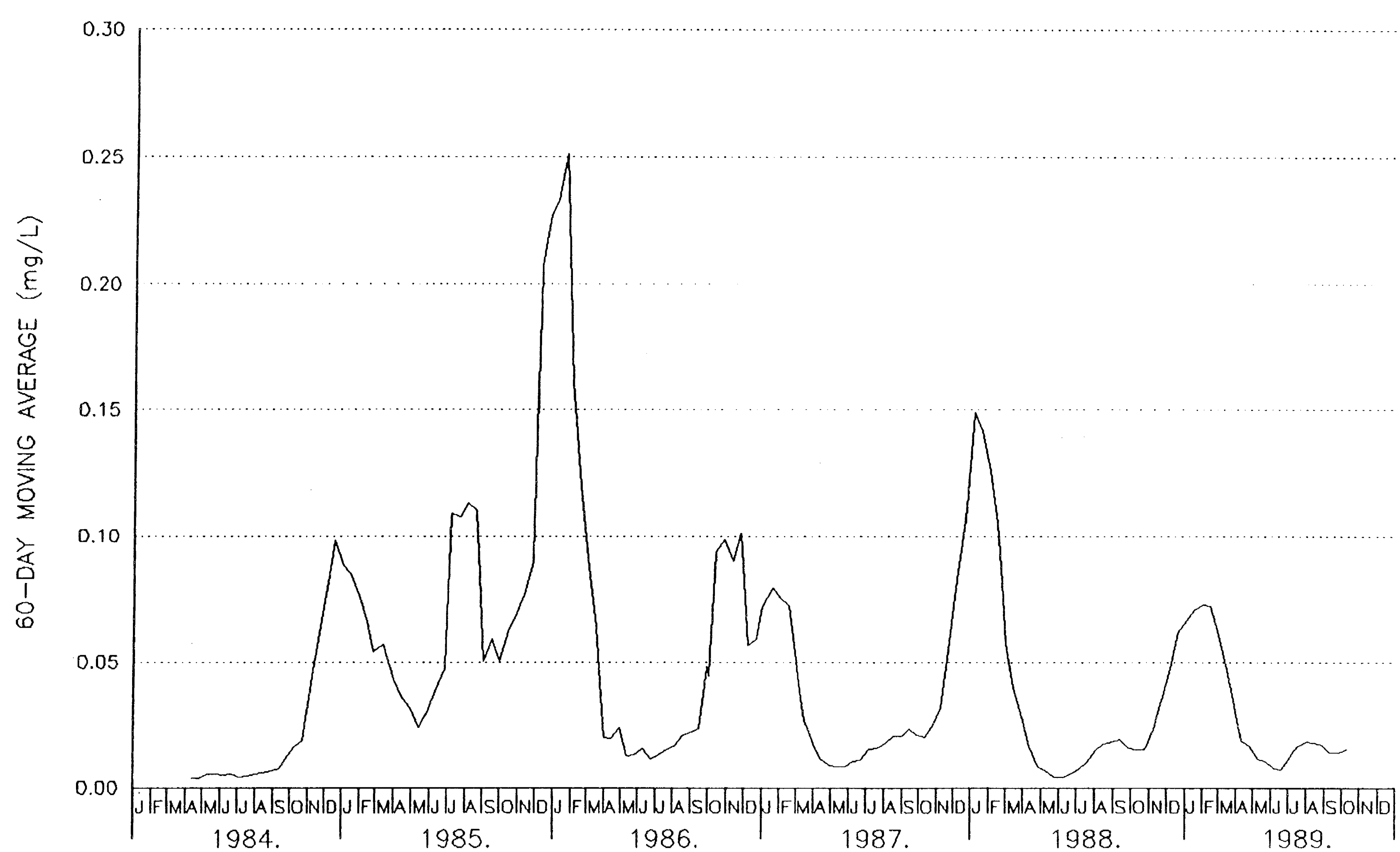

Figure 41 | NITRATE+NITRITE–NITROGEN SIMILKAMEEN RIVER (1984 – 1989) | Environmental Management Associates

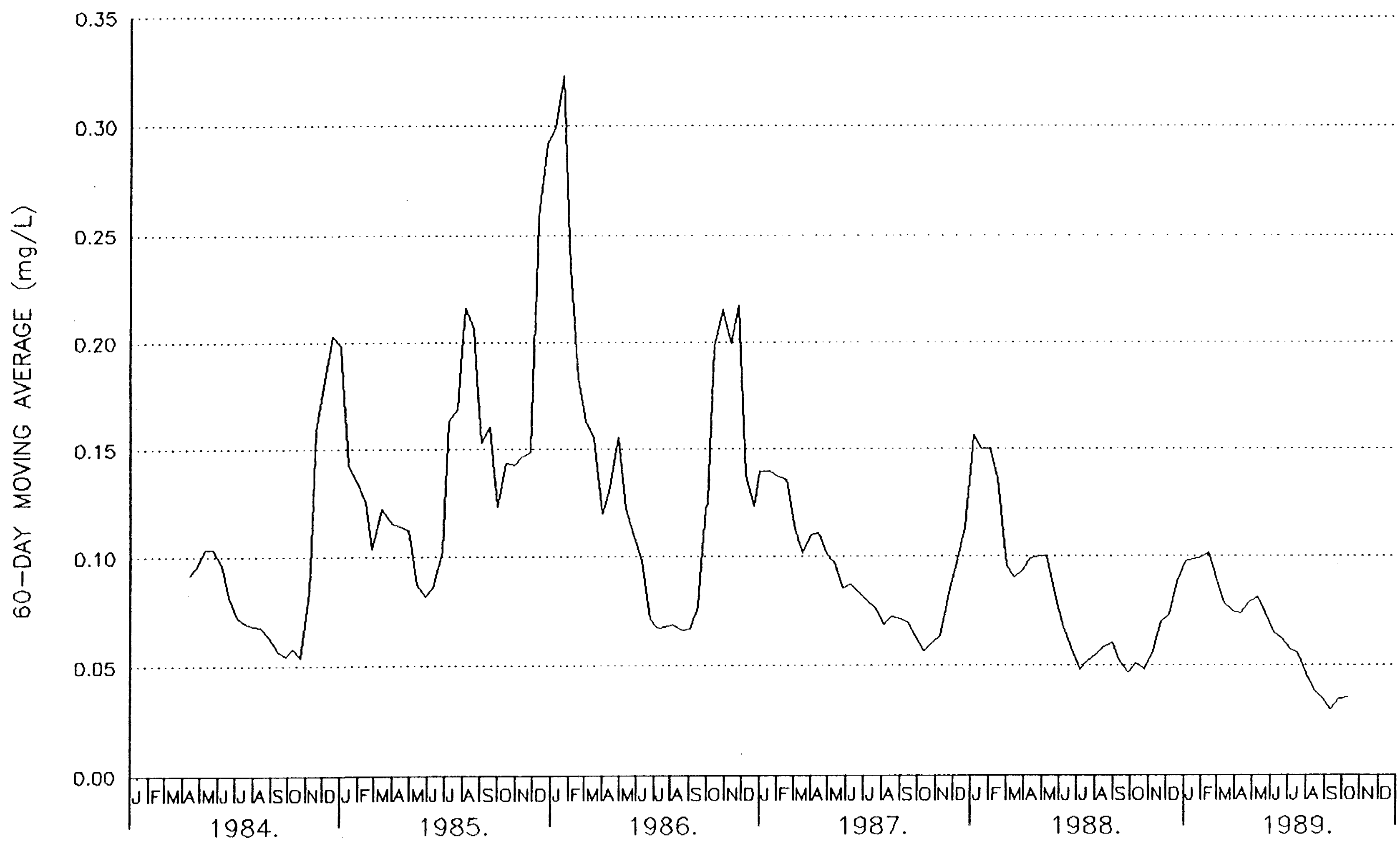

Figure 42

TOTAL DISSOLVED NITROGEN
SIMILKAMEEN RIVER (1984 – 1989)

Environmental Management Associates

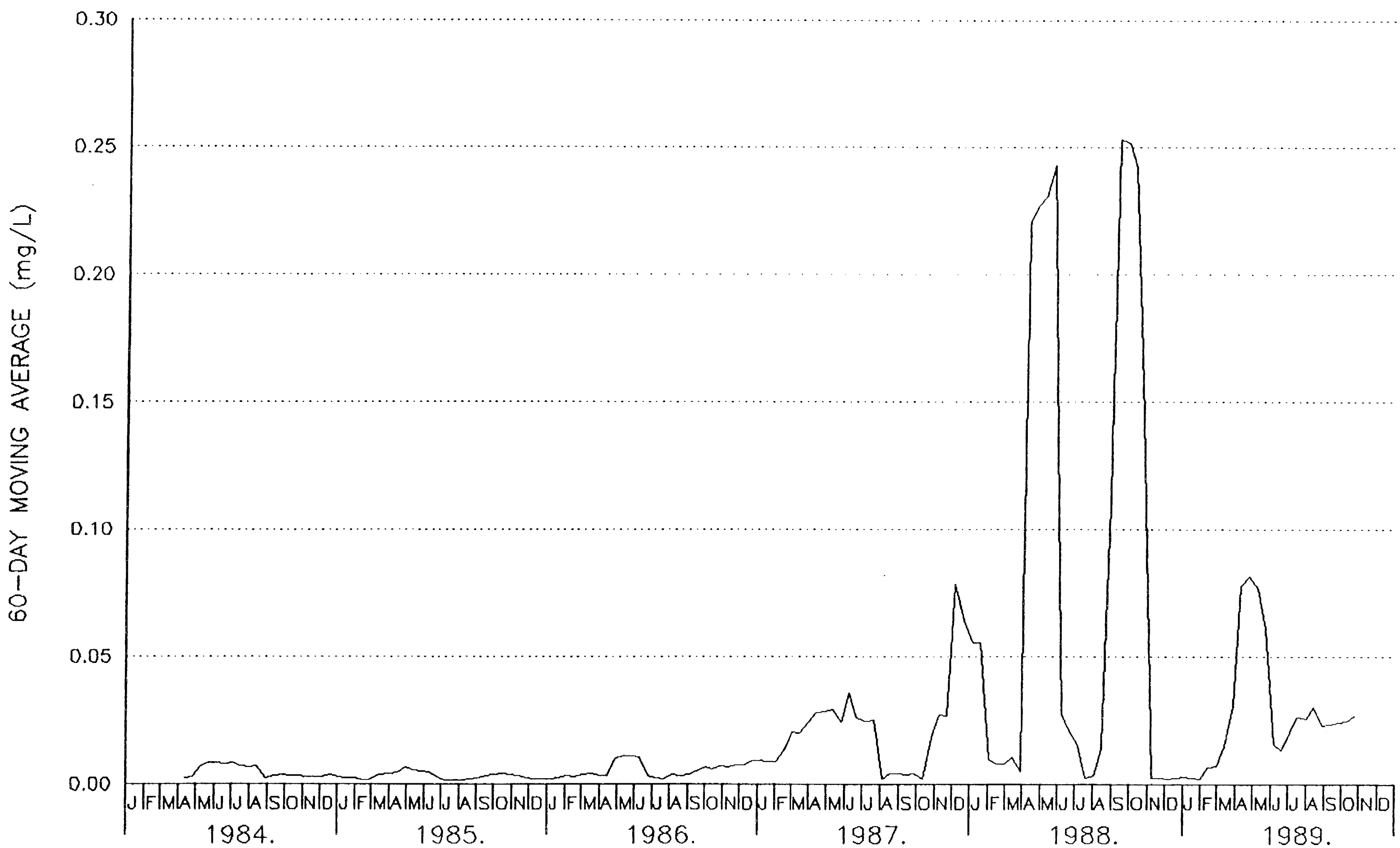

Figure 43

TOTAL COPPER
SIMILKAMEEN RIVER (1984 – 1989)

Environmental
Management Associates

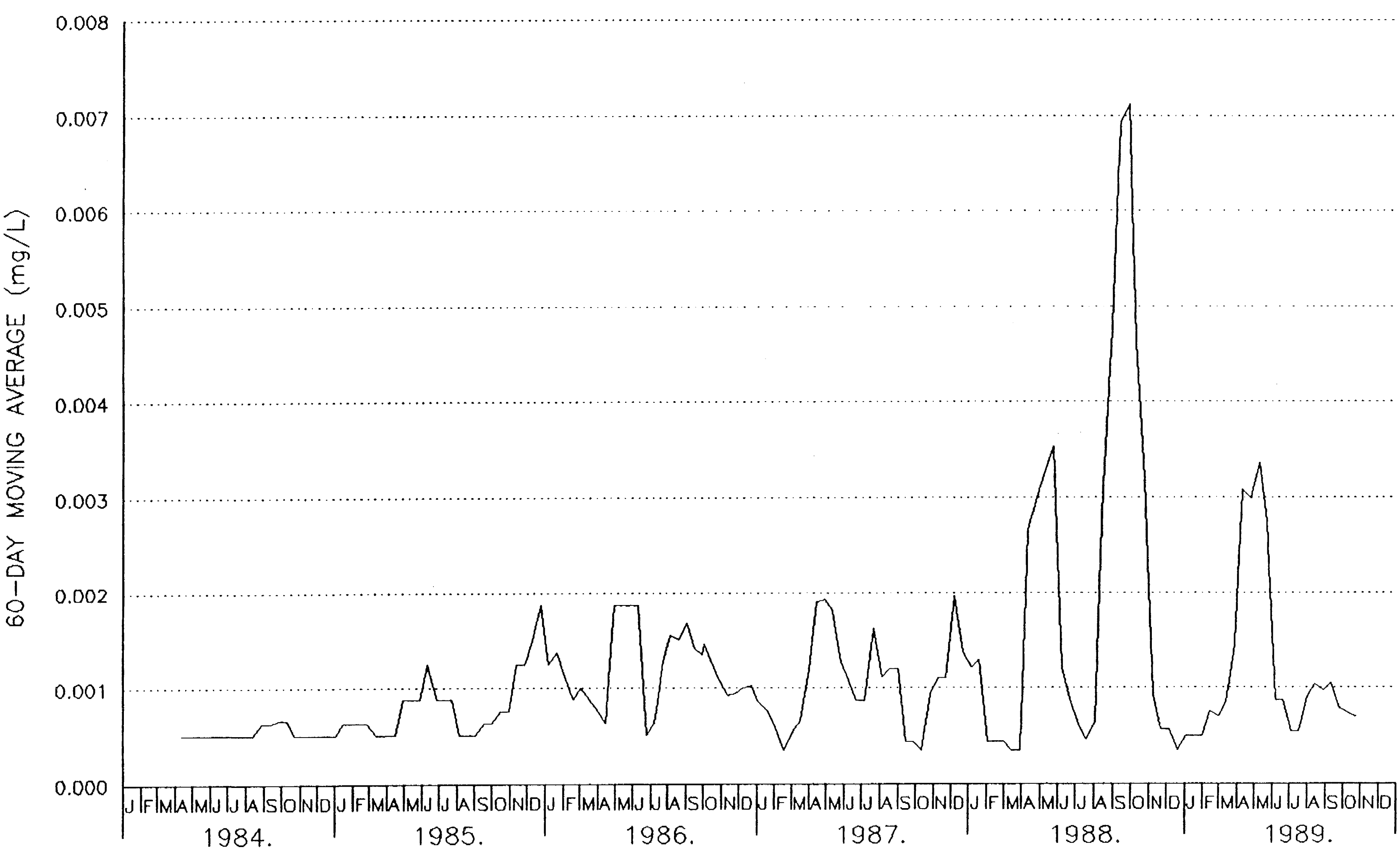

Figure 44

TOTAL LEAD
SIMILKAMEEN RIVER (1984 – 1989)

Environmental Management Associates

sampling site (as recorded on the dates that the river was sampled; t_s = 2.24, P = 0.03; Figure 40). But in contrast to the Flathead River, flows in the Similkameen River did not change significantly over the course of the study (t_s = -0.22, P = 0.83), which may explain why trends in water quality were detected less frequently for the Similkameen River compared with the Flathead River.

Interestingly, flow-adjusted concentrations of $(NO_2^- + NO_3^-)$-N did not change significantly (P >0.05) from 1984 to 1989 (Table 11), whereas actual $(NO_2^- + NO_3^-)$-N concentrations decreased significantly from 1984 to 1989 (Table 13). This implies that changes in Similkameen River flows might have contributed to the trend detected for $(NO_2^- + NO_3^-)$-N concentrations, which is unexpected based on the lack of trend detected in river flows. Inspection of the time-series plot of residuals shows an increase in flow-adjusted concentration from 1984 to 1985 followed by a gradual decrease (Figure 45), as was also observed for actual concentrations of $(NO_2^- + NO_3^-)$-N and dissolved nitrogen (Figures 41 and 42). This is exactly the same pattern observed in the Flathead River (where there are presently no significant N-producing human activities), suggesting strongly that the trend is spurious, probably produced by laboratory contamination of water samples. Laboratory blanks often contained 0.01-0.03 mg/L nitrate, a level that would normally be insignificant, but which, because of the extremely low levels of nitrate-nitrite in these rivers, (means near 0.1 mg/L) is easily capable of overwhelming any subtle trends in river nitrate+nitrite-nitrogen concentrations.

It should be noted, however, that laboratory blanks are available for one period only, and the same level of contamination may not be present in later samples. If the trend in nitrate+nitrite-nitrogen concentrations were natural, resulting from changes in the rate of mineralization of organic nitrogen, then an increase, rather than a decrease, would be expected, given the simultaneous trend of increasing water temperatures. The observed pattern of nitrate-nitrite concentrations would only arise if nitrogen assimilation by primary producers were increasing at a faster rate than was decomposition. If the trend is real, it is too small to be of immediate ecological significance.

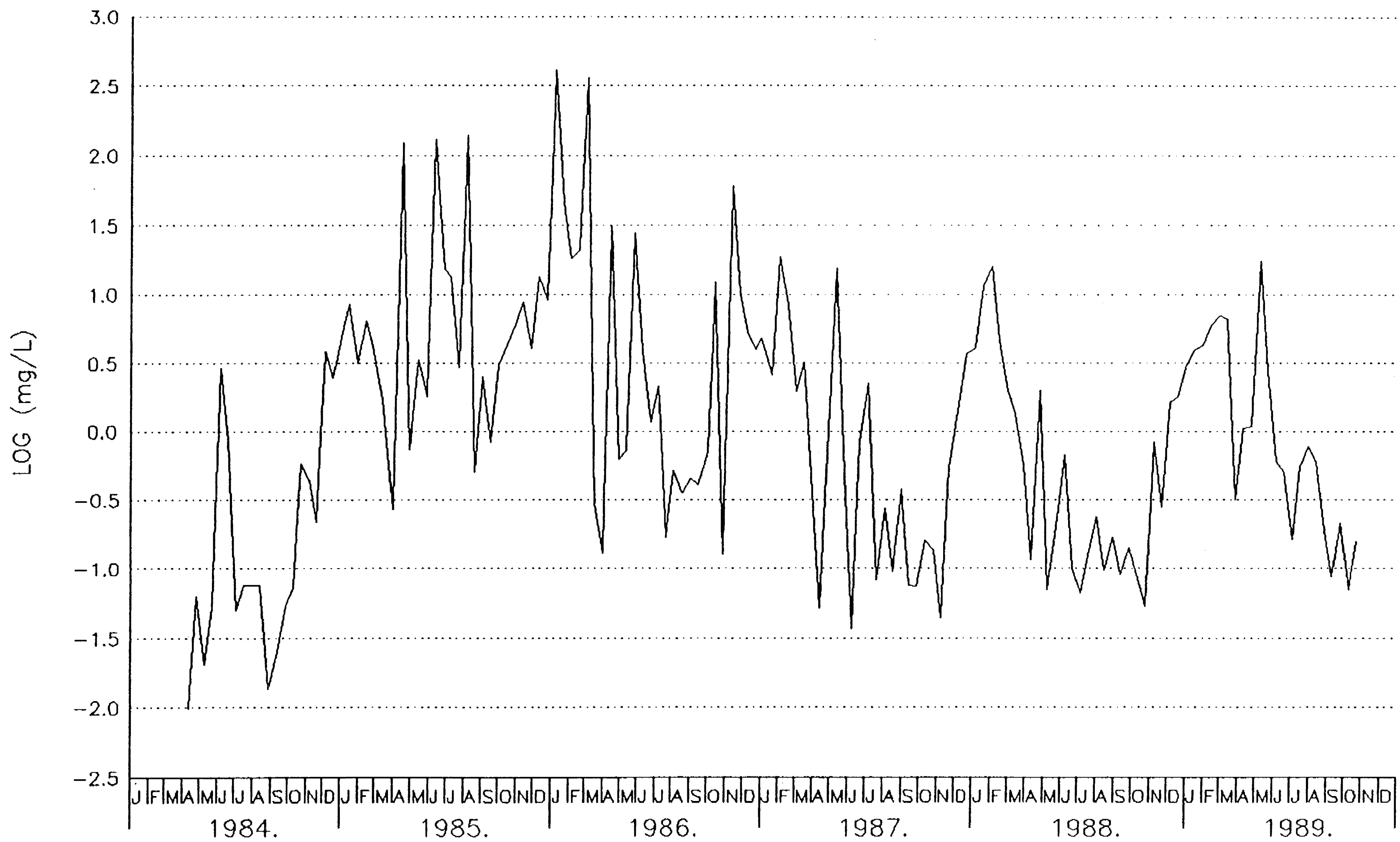

Figure 45	FLOW−ADJUSTED NITRATE+NITRITE−NITROGEN SIMILKAMEEN RIVER (1984 − 1989)	Environmental Management Associates

The source of the increases in lead, copper and cyanide concentrations in 1988-1989 cannot be ascertained with certainty. Both metals and cyanide are associated with metal mining and milling, in particular for gold. Hence, a number of sites upstream could be the ultimate source, including presently active mines and old tailings piles left along the river. The abrupt increase in copper and lead concentrations corresponds with the construction of the Candorado tailings reprocessing project near Hedley and the Corona Nickel Plate Mine (L. Swain, personal communication, 1991). Relatively high levels of lead, copper and cyanide could be associated with disturbance during excavations in the early days of operation of these mines or from leaching from tailings piles or ponds. However, samples taken nearer the mine sites over the same interval do not show significantly elevated levels of cyanide or either metal compared with samples taken immediately upstream (L. Pommen, personal communication, 1993). Pommen and Ryan (1992) concluded that the non-attainment of cyanide objectives was probably caused by artificial contamination in federal preservative vials rather than the metal mines in the basin. Moreover, because cyanide concentrations do not increase significantly immediately below the mine sites, the possibility of other, basin-wide sources, including natural loading, cannot be ruled out.

7. EVALUATION OF THE MONITORING PROGRAM

7.1 Sampling Frequency

The original sampling programs for the Flathead and Similkameen Rivers were designed primarily to monitor long-term trends in river water quality. In particular, it was anticipated that the sampling frequency would be adequate to detect a linear trend of 10%. Data collected on these rivers from 1984 to 1989 were used to assess the adequacy of the present sampling design and to determine whether sampling at less frequent intervals would provide comparable information with respect to the detection of long-term trends.

The magnitude of trends that were detected in the two rivers was computed from the change in concentration over time, as estimated with the seasonal Kendall slope estimate divided by the median concentration recorded during the entire sampling period. Trends of a magnitude of less than 2% per year were detected with weekly sampling on the Flathead River, and trends of a magnitude of 5% per year were detected with fortnightly sampling on the Similkameen River (Table 14). Regardless of the actual cause of the trends (e.g., artifact of methods, natural changes due to river flow or anthropogenic sources), it is apparent that the sampling design is adequate to detect trends of a magnitude of 10%.

The evaluation of sampling frequency was based on analysis of actual data collected from the Flathead and Similkameen rivers, rather than a more theoretical approach utilizing Monte Carlo simulations (e.g., Loftis et al., 1989b). In addition to the magnitude of the trend, a number of factors affect the detection of long-term trends:

1. the statistical method employed,
2. the sampling regime, e.g., length of sampling period, sampling frequency, and
3. characteristics of the data, e.g., seasonality, serial correlation, probability distribution, and variance.

Table 14. Magnitude of Trends Detected (at $P < 0.05$) in the Flathead and Similkameen Rivers.

Variable	Magnitude (%/yr)
FLATHEAD	
Water Temperature	3.0
Conductivity	1.8
Turbidity	20
Total Dissolved Nitrogen	18
Total Phosphorus	5.8
Iron (Total)	22
Manganese (Total)	6.3
Zinc (Total)	43
SIMILKAMEEN	
Water Temperature	5.4
$(NO_2^- + NO_3^-)$-N	5.0
Total Dissolved Nitrogen	9.5
Copper (Total)	60
Lead (Total)	12

Factors 1 and 2 can be controlled by the investigator, but factor 3 is inherent in the data. Data from the Flathead and Similkameen Rivers are widely variable both in terms of data characteristics and the magnitude of trend detected. The statistical method employed in this study (i.e., Kendall test) is widely used to test for trends in water quality (Smith et al., 1987; Berryman et al., 1988), so alternative methods were not evaluated. The length of the sampling period is fixed by the period for which the rivers have been sampled (i.e., 1984 or 1985 to 1989). This period (approximately five years) is likely the shortest period for which a reasonable power of trend detection for river water quality is attainable (Smith and McBride, 1990).

The lower bounds for sampling frequency that could be evaluated were fixed by the sampling regime followed on the Flathead (weekly) and Similkameen (fortnightly) Rivers. In any case, water quality data become increasingly redundant at intervals of less than ten days (Whitfield, 1983), so little gain in the power of trend tests would likely result from more intense sampling.

The upper bounds for sampling frequency depend largely on characteristics of the data (e.g., seasonality, noise) and the length of the data record. For example, quarterly sampling may be adequate to detect trends, even for strongly seasonal and highly variable data, if an adequate data record (e.g., 30 years) is available. Such sampling would not however, be expected to detect trends over a short period (e.g., five years).

For the assessment of sampling frequencies, we assumed that the shortest time interval that would be considered was weekly on the Flathead River and fortnightly on the Similkameen River and the longest time interval was quarterly sampling. Therefore, we evaluated weekly (Flathead River only), fortnightly, monthly, and quarterly frequencies.

As would be expected, there was a reduction in the number of variables for which trends were detected when longer sampling intervals were utilized; i.e., the probability increased of accepting a false null hypothesis (Type II error). On the Flathead River, the number of trends detected (at $P < 0.1$) declined from eight based on weekly sampling to seven, four and one for fortnightly, monthly, and quarterly sampling, respectively (Table 15). On the Similkameen River, the number of detected trends declined from five based on fortnightly sampling to three for monthly or quarterly sampling (Table 16).

The detection (or lack of detection) of trends at less frequent sampling regimes was not related entirely to the magnitude of the trend. For instance, trends in dissolved nitrogen, but not total copper, in the Similkameen River were detected with monthly and quarterly sampling frequencies, even though the magnitude of the trend for dissolved nitrogen (9.5% yr^{-1}) was considerably lower than that for total copper (60% yr^{-1}). This may be a reflection of the relatively high variation associated with concentrations of total copper (CV 47%; Table 5) compared with dissolved nitrogen (CV 9%), as the power of trend tests are strongly affected by random temporal variability (i.e., standard deviation) of the data (Loftis et al., 1989b).

Surprisingly, trends for specific conductance in the Similkameen River were detected with monthly and quarterly sampling but not with fortnightly sampling (Table 16). This rejection of the (apparent) true null hypothesis (Type I error) was an artifact of the selection of the monthly and quarterly data. By chance, "samples" with relatively low conductivity values were selected in 1984-1986 and "samples" with relatively high conductivity values were selected in 1988-1989 (Figure 46).

7.2 Variables and Media Sampled

Based on results of analysis of the five or six years of data collected so far, it is now possible to suggest refinements to the original monitoring program. This is done by applying three consecutive tests: (1) Are all the measured variables useful? Are all the key variables being measured? (2) Is the correct form of each variable being measured? Is it necessary to measure more than one? (3) Is each variable being measured in the correct medium? Water quality monitoring will be most useful when the correct forms of the right variables are measured in the best media.

Table 15. Comparison of Kendall Tests on Samples Collected Weekly, Fortnightly, Monthly, and Quarterly at the Flathead River, 1985-89.

Variable	Weekly		Fortnightly		Monthly		Quarterly	
	P	Slope	*P*[1]	Slope	*P*	Slope	*P*	Slope
Water Temperature	0.04	0.16°C/yr	0.83		0.60		0.48	
Conductivity	<0.001	4.2 μS/cm/yr	0.02	3.3 μS/cm/yr	0.06	2.0 μS/cm/yr	0.36	
Turbidity	0.002	-0.15 NTU/yr	0.065	-0.075 NTU/yr	0.14		0.88	
$(NO_2^- + NO_3^-)$-N	0.22		0.76		0.30		0.88	
Dissolved N	<0.001	-0.014 mg/L/yr	0.008	-0.010 mg/L/yr	0.05	-0.0050 mg/L/yr	0.38	
Total Phosphorus	0.03	-0.0007 mg/L/yr	0.34		0.52		0.54	
Arsenic	0.16		0.50		0.46		0.70	
Copper	0.18		0.70		0.44		0.34	
Iron	<0.001	-0.013 mg/L/yr	0.03	-0.009 mg/L/yr	0.35		0.34	
Lead	0.56		0.87		0.90		0.64	
Manganese	<0.001	-0.0010 mg/L/yr	0.004	-0.00075 mg/L/yr	0.03	-0.0010 mg/L/yr	0.34	
Selenium	0.54		0.89		0.30		0.20	
Zinc	0.006	-0.0017 mg/L/yr	0.008	-0.0013 mg/L/yr	0.007	-0.0010 mg/L/yr	0.02	-0.0011 mg/L/yr

[1] Seasonal Kendall slope estimate computed only for those variables with a significant ($P<0.10$) long-term trend.

Table 16. Comparison of Kendall Tests on Samples Collected Fortnightly, Monthly, and Quarterly at the Similkameen River, 1984-89.

Variable	Fortnightly		Monthly		Quarterly	
	P	Slope[1]	*P*	Slope	*P*	Slope
Water Temperature	<0.001	0.5°C/yr	<0.001	0.75°C/yr	0.01	0.7°C/yr
Conductivity	0.89		0.06	3.3 μS/cm/yr	0.02	5.3 μS/cm/yr
Fecal Coliforms	0.94		0.27		0.76	
Turbidity	0.62		0.69		0.49	
$(NO_2^- + NO_3^-)$-N	0.05	-0.001 mg/L/yr	0.22		0.41	
Dissolved N	<0.001	-0.0086 mg/L/yr	<0.001	-0.008 mg/L/yr	0.02	-0.014 mg/L/yr
pH	0.13		0.47		0.67	
Total Phosphorus	0.57		0.57		0.58	
TDP	0.71		0.55		0.73	
Arsenic	0.60		0.40		0.69	
Copper	<0.001	0.0024 mg/L/yr	0.15		0.15	
Cyanide	0.10		0.54		0.60	
Iron	0.98		0.48		0.40	
Lead	0.06	0.00006 mg/L/yr	0.65		0.42	
Manganese	0.59		0.55		0.62	
Selenium	0.69		0.70		0.76	
Zinc	0.44		0.33		0.81	

[1] Seasonal Kendall slope estimate computed only for those variables with a significant ($P < 0.10$) long-term trend.

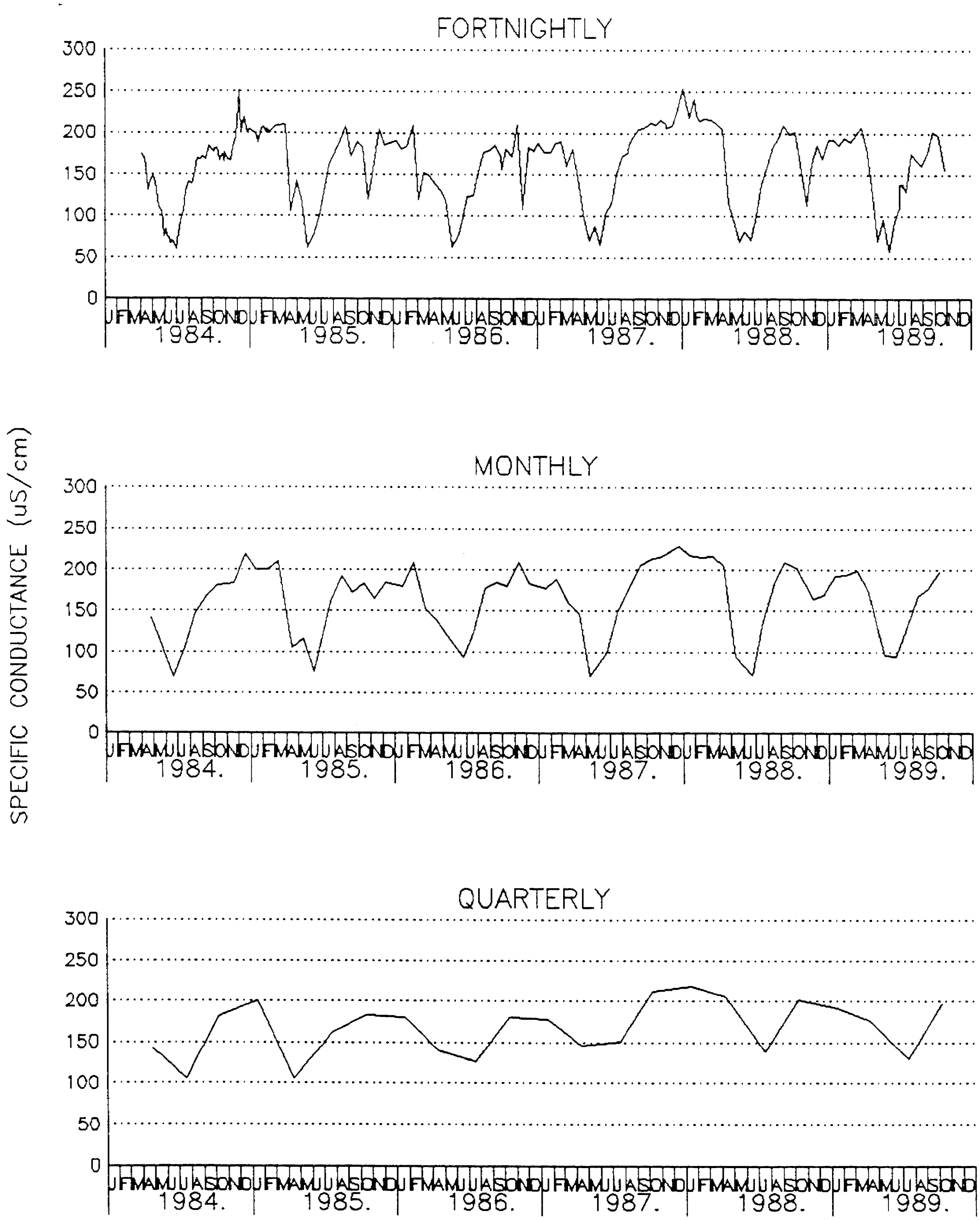

Figure 46	SPECIFIC CONDUCTANCE SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

This analysis selects variables and media based on chemical or ecological factors; laboratory costs or expediency have not been extensively considered. Sampling of biota is here restricted to direct measurement of chemicals accumulated within organisms; the use of the organisms themselves as indictors of water quality is discussed in Section 7.3. The analysis begins with the variable list presently being measured in the water, and then briefly suggests additional or replacement variables better measured in sediments or organisms.

7.2.1 Water Quality Variables

Temperature: Since water temperature affects the rate of virtually every chemical or physiological process, as well as the nature of aquatic life the rivers can support, temperature measurement of water and air clearly should continue.

Colour: Colour quickly summarizes both the rapidity of light attenuation in water, and the water's aesthetic appeal and suitability for domestic use, so measurement of colour should continue. Unfortunately, colour has been consistently measured as apparent colour (unfiltered samples) while the water quality criterion (Pommen, 1989) is established for true colour (filtered samples). Consequently, the two cannot be directly compared. Since apparent colour also overlaps with turbidity and non-filterable residue, true colour should be measured on all future samples.

Turbidity and NFR: Turbidity and non-filterable residue (NFR) are essentially different measures of the same thing - suspended solids - so the necessity of measuring both may be questioned. Turbidity is an indirect measure, in that it measures light scattering by suspended solids whereas NFR measures the mass of particles directly. Theoretically, dissolved matter may also contribute to turbidity, but both the Flathead and Similkameen Rivers are low in dissolved material, and even if that changed, colour measurements would detect it. There was a significant trend of decreasing turbidity on the Flathead River, but that apparently was merely a response to decreasing flows. B.C. water quality criteria for both NFR and turbidity are expressed in terms of percentage change from upstream or a pre-disturbance state (Pommen, 1989) so neither are applicable to routine monitoring at the transboundary sites. Numeric objectives have been proposed for both turbidity and NFR on the Flathead River (Valiela et al., 1987), but it is difficult to imagine one being violated and not the other. Suspended solids (NFR) is the more quantitative measure, has a more easily interpretable scale, and bears a direct, simple relationship with many other variables, including all those constituents transported in the solid phase. Unfortunately, turbidity has been measured far more frequently than NFR in the past (>200 times compared with 33 times on the Flathead River). Abandonment of turbidity now would limit the usefulness of the data already collected. Therefore, while NFR is still the preferred variable, measurement of turbidity should continue at least for the next few years.

Filterable residue and conductance: Filterable residue, the total mass of dissolved (and colloidal) material in the river water, is a good approximation of the salinity, or total dissolved solids content of the water. (The different measurements diverge only in highly coloured water rich in dissolved organic matter). Solute content is a fundamental aspect of water quality and monitoring of filterable residue should continue.

A parallel argument to that raised against turbidity may perhaps be made for conductance. Conductance acts as a surrogate for dissolved solids content, and in most waters the two are tightly correlated. Again, however, far more data have been collected to date for conductance than for filterable residue in these rivers, and to discontinue conductance now would make detection of future trends difficult. Unlike turbidity, conductance is widely used as a quick measure of salts content, is measured on a single, non-arbitrary scale and is directly comparable from one site or time to another. Hence, continued measurement of conductance, with occasional confirmation with filterable residue, appears to be the best choice for future monitoring.

pH: The pH of water is a fundamental determinant of its suitability for aquatic life, and influences fates and behaviours of virtually all dissolved constituents, including toxic substances. Hence, measurement of pH should continue unchanged. The pH is presently being measured by both Federal and Provincial laboratories because of earlier problems of Federal pH determinations. This also should continue, to provide continuing confirmation of pH data.

Alkalinity and Hardness: Although closely related, both these variables measure fundamental aspects of river water chemistry, and should be continued. Hardness data are necessary to determine critical levels of potentially toxic constituents such as copper, lead and nickel. Measurement of phenolphthalein alkalinity, which is based on titration to pH 8.3, is superfluous and should be discontinued.

Major Ions: There is no utility to regular monitoring of the individual major ions, Ca, Mg, K, Na, Cl or Sulphate. Major ion composition of a river's water is determined largely by the geology of the region through which it flows, and except in rare and extreme situations, their influence on water quality is expressed through the total ion concentration, or salinity (NRC, 1977). It is inconceivable that any intervention in either the Flathead or Similkameen River could significantly alter the ionic balance without also affecting salinity, which is already being measured. The B.C. criterion for calcium (>8 mg/L), that was violated in one sample of nearly 200 is based on susceptibility to acidification, an attribute which is better predicted by alkalinity. Concentrations of Na, Ca and Mg are necessary to calculate the sodium absorption ratio (SAR) of irrigation water, but again, given that SAR is a nearly invariant property of water in a given river reach, and SAR guidelines are based on safe limits for up to 100 years of irrigation (CCREM, 1987), there is no need to measure these ions continually. Concentrations of individual ions, in particular chloride, are sometimes used as a conservative tracer, against which changes in more dynamic constituents may be compared. Ion loads transported by rivers are also useful for estimating the rate of chemical weathering within the basin. But both these purposes are served as well or better by total dissolved solids, at least in the context of a routine monitoring program (e.g., Taylor et al., 1986). Major ions are, however, quickly and routinely measured in the course of normal sample analysis, so the individual ion concentrations are virtually a free byproduct. Still, no priority should be given to their retention.

Silica: Silica is important in fresh waters principally as a component of diatom frustules; in rivers, silica concentrations tend to be very stable, and depend almost entirely on the geological formations through which the river flows (Wetzel, 1975). Riverine diatom populations, which are a major component of the benthic algae in the Flathead River (Martin et al., 1987) and probably in the Similkameen River as well, do not assimilate enough silica to influence river concentrations. Monitoring of silica has continued because of a known problem of cyanide contamination in sand applied to winter roads (J. Zeman, personal communication 1991). There are no other foreseeable human disturbances in the basin that would be expected to alter silica inputs. Silica loads may be used to estimate rates of chemical weathering of landforms within the basin, but again that function is served adequately by TDS. Hence, monitoring silica in these rivers is valueless and should be discontinued.

Fluoride: The fluoride criteria for protection of aquatic life are tentative, pending further research (Pommen, 1989), and were never exceeded on either river, despite the large number of samples (200). Therefore, there is probably no need to continue measuring fluoride. The present data set contains enough information on background concentrations and seasonal patterns.

Phosphorus: Phosphorus is the key limiting nutrient in most aquatic ecosystems. There are many different chemical forms of phosphorus, and although only dissolved forms are directly available for plant uptake, in reality most successful models of production (in lakes) have been based on total phosphorus (e.g., Dillon and Rigler, 1975; Prairie et al., 1989). Both the Flathead and Similkameen Rivers carry low concentrations of total phosphorus, except during spates, when concentrations may reach 0.1-0.3 mg/L (Figures 6 and 14). A concentration of 0.1 mg/L total phosphorus or more is considered a heavy load for a river, and entails a risk of enrichment for lakes downstream (USEPA, 1986). Clearly, monitoring of total phosphorus should continue on both rivers.

Dissolved phosphorus was measured only on the Similkameen River, and results are presented graphically in Appendix B. As would be expected, dissolved phosphorus concentrations were very low, mostly <8 μg/L and often below the detection limit, and there was no temporal trend. Ordinarily there is little information to be gained from continued monitoring of dissolved phosphorus, because of rapid plant assimilation and adsorption onto suspended particles. But in these rivers, dissolved phosphorus is probably a better indicator of biologically available phosphorus because it excludes the much larger quantity of particulate phosphorus, most of which is associated with inorganic particles, and thus of no ecological significance. In the present data set, dissolved phosphorus increases sharply during spring freshet, as does total phosphorus, but also during other months when total phosphorus did not respond (Figures B21, B22). Hence, monitoring of dissolved phosphorus, at least on the Similkameen River, can be justified and should continue.

Cyanide: The measurement of cyanide is of obvious utility on the Similkameen River because of its toxicity to animal life at low concentrations, and its use in extraction of gold and silver from low-grade ore (CCREM, 1987). Given that gold mining and milling are already major activities in the Similkameen basin, and that several operations to reprocess old tailings piles along the river by the cyanide heap-leaching method are operating or proposed, (Swain, 1985, 1990) measurement of cyanide should definitely continue on the Similkameen River. Cyanide has not been routinely measured on the Flathead River, nor are such measurements necessary, even as a source of background levels in an undisturbed basin, because cyanide is not derived from geological sources, and hence natural levels are always very low (CCREM, 1987).

There are inconsistencies in the measurement of cyanide on the Similkameen River that need to be resolved. Cyanide exists in fresh water in a wide range of forms of which CN^- (cyanide) and HCN (hydrogen cyanide) collectively termed free cyanide, are the toxic forms. Other important forms are thiocyanate (SCN^-) and metal complexes, the latter grading in stability from simple metal salts (e.g., $ZN(CN)_2$) through moderately decomposable complexes with nickel or copper, to recalcitrant iron complexes such as $(Fe(CN_6))^{-3}$ and $(Fe(CN_6))^{-4}$ (Zeman, 1990).

There is no routine method available for free cyanide, even though water quality guidelines are often specific for that form (CCREM, 1987). B.C. Environment (Pommen, 1989; Swain, 1985, 1990) measures, and has set water quality criteria, for cyanide in terms of weak-acid dissociable cyanide (free cyanide plus labile metal complexes) for protection of aquatic life, and strong-acid-dissociable cyanide plus thiocyanates for protection of raw drinking water. Environment Canada measures cyanide as simple cyanide and total cyanide (Zeman, 1990). Simple cyanide and weak-acid-dissociable cyanide are equivalent, although measured by different methods, but total cyanide and strong-acid-dissociable cyanide are not, as the former includes cyanide from some extremely stable complexes (e.g., cobalt-cyanide) as well as thiocyanate. The Similkameen River data base includes data for total cyanide from Environment Canada, and a few recent strong-acid-dissociable cyanide data from B.C. Environment.

The Provincial objectives for weak-acid-dissociable cyanide, or Federal guidelines for free cyanide, cannot rigorously be compared against either total or strong-acid-dissociable cyanide. Here, it has been assumed for convenience that all cyanide is, or can produce, free cyanide, but this is probably very inaccurate and overestimates the level of free cyanide contamination. Future sampling should settle on one approach, but should include a measure of simple (or weak-acid-dissociable) cyanide to estimate free cyanide, and total cyanide (or strong-acid-dissociable cyanide plus thiocyanates) to measure the total pool of cyanide-bearing compounds. The Federal scheme of simple and total cyanide is attractive because of its low detection limit (0.5 μg/L), but total cyanide includes thiocyanate and stable gold or cobalt cyanide complexes whose direct toxicity is low (Singleton, 1986). Utilization of the Provincial method would allow comparison with B.C. criteria, but the detection limit for this method (5 μg/L) is equal to the chronic criterion (Singleton, 1986). Whichever method is selected, future samples should be analyzed consistently, and if possible by the same laboratory. A comparison of results from split samples analyzed by both laboratories would help reconcile the extant data.

Nitrogen: The present strategy for nitrogen sampling is unusual. Nitrate-nitrite nitrogen and total dissolved nitrogen have been measured on both rivers, supplemented with ammonia-N on the Similkameen River. While a trend of declining $(NO_2^-+NO_3^-)$-N concentrations was evident, in both rivers, this was confounded by laboratory contamination, and levels of all three forms of nitrogen were consistently low relative to environmentally significant levels (see Appendices A and B). Hence, there is no compelling reason to continue this monitoring scheme. In particular, the measurement of dissolved nitrogen should be discontinued, since it overlaps with both nitrate-nitrite and ammonia, and measures only a relatively small and insignificant nitrogen pool (the unique part is dissolved organic nitrogen). Measurement of total nitrogen should be undertaken in its place, as this is a better estimator of nitrogen availability and nutrient loading to the rivers, and is more likely to reveal a trend if nitrogen income should increase.

The argument that particulate nitrogen should be excluded because of low biological availability, although sound for phosphorus, does not apply to nitrogen. A large part of the nitrogen income of lotic water bodies arrives in coarse or fine particulate organic matter (ultimately plant detritus) that releases available nitrogen through decomposition (Cummins et al., 1989). This particulate nitrogen may contribute substantially to primary (bacterial) or secondary production in the river without ever entering the pool of dissolved nitrogen in the water column. Failure to measure this nitrogen seriously underestimates the total quantity of available nitrogen. Monitoring ammonia is sensible on the Similkameen River, because of the potential sources of cattle (especially) and municipal sewage effluent in the basin, but nitrate-nitrite levels are consistently so low compared with water quality guidelines that a violation is scarcely imaginable. Nitrate-based explosives used in surface mining may contribute nitrate to surface waters (Pommen, 1983) but any significant increase would be reflected in total nitrogen levels. Summarily then, future monitoring should be restricted to total nitrogen in both rivers and ammonia nitrogen in the Similkameen River.

Fecal Coliforms: Fecal coliform bacteria, an indicator of possible enteric pathogens, have been measured on the Similkameen River only, and counts >10 CFU/100 ml have been commonplace over the period of record (Figure 17). Sewage contamination should not be an issue, because none of the communities in the basin discharge sewage directly to the river, but as long as cattle have unrestricted access to the river or its tributaries, fecal coliform contamination will remain a potential problem. Hence, fecal coliform monitoring should continue unchanged on the Similkameen River. No such monitoring is required on the Flathead River because of the absence of bacterial sources.

Metals: The following metals, all as totals, have been or are presently being measured: arsenic, selenium, mercury, cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc. Of these, iron, cadmium, manganese, copper, lead and zinc exceeded water quality objectives or criteria on one or both rivers. Metals mining, both for gold and silver and for base metals is active throughout the Similkameen River basin (Swain, 1985, 1990), so metals may be expected to reach surface waters from accidents, tailings ponds seepage and disturbance of tailing piles. Thorough monitoring of metals is thus appropriate on this river. Natural processes, specifically river erosion, may also contribute high levels of metals, particularly iron, so the Flathead River provides a useful site to derive background levels for comparison with the Similkameen or other rivers. If large-scale development for extraction of coal or natural gas ever proceeds in this basin, then elevated metals levels are possible from erosion of disturbed rock. Summarily, monitoring of metals should continue on both rivers.

The next question is which metals to measure. Iron, and to a lesser extent, manganese are commonly found in high concentrations in rivers draining the Rocky Mountains, and both of these exceeded water quality guidelines in at least one of the rivers. Although those elevated levels were apparently natural (linked to flow, and hence sediment transport), any further increase from natural or anthropogenic sources would be significant; consequently Fe and Mn monitoring should continue. Mining for copper, lead and zinc is active in the Similkameen basin (Zeman and Slaymaker, 1988) so monitoring of those metals is warranted.

Mercury and cadmium are present at low levels in both rivers, and should be monitored because of their extreme toxicity. Selenium and nickel are often found in the same ore bodies as lead and copper (CCREM, 1987), so monitoring of these metals could be justified. Arsenic and chromium are both contained in ferric minerals, so high levels are possible in these rivers that carry such high iron concentrations during peak flows. Chromium concentrations frequently violated the site-specific criteria for the lower Similkameen River, but arsenic concentrations were generally one to two orders of magnitude less than the lowest water quality criterion. Thus, while chromium monitoring should continue, arsenic should be assigned a lower priority. While a number of other metals could be added to the list (aluminum, molybdenum, uranium, vanadium, silver) only molybdenum is likely to occur at environmentally significant concentrations at the U.S. Border (Swain, 1990). Hence, molybdenum should be added to the monitoring list. (Environment Canada now measures 16 metals, including all of the above, except uranium, plus Ba, Be, Li, and Sr; A. Ryan, personal communication, 1991).

Recognizing there are serious limitations on total metals data, this is still the best form to measure for the time being. This conclusion is principally one of practicality. In these rivers, in which much of the total metals load probably occurs as inert particles, especially during spring freshet, measurement of dissolved metals would provide a better estimate of concentrations of metals that are directly affecting aquatic life. Efforts to establish a protocol for filtering samples in the field without contamination, however, have so far proved unsuccessful, in part because of the low levels at which some metals are now being measured. The best course, therefore appears to be to continue with measurement of total metals, but also to continue development of a reliable method of field filtration. In the meantime, estimating environmental hazard based on total metal concentrations will overestimate risk and therefore lead to conservative management decisions. Continued measurement of total metals also preserves the usefulness of the present data set, and allows comparison with many water quality criteria and objectives.

All of the above assumes continued measurement of metals in the water. Complementary sampling of other media is discussed in the next section.

Additional Variables: The above discussion embraces the complete list of variables recommended for future sampling in the water column. Most other routinely measured variables such as phenols, oil and grease, BOD, or surfactants are superfluous in these rivers because of the lack of industrial sources, while others, such as pesticides, are best measured in other media.

7.2.2 Sampling Sediments and Biota

Monitoring of some metals in sediments should be considered as a supplement to water-column sampling. The list of metals to be measured would be the same as in the water, with the deletion of iron and manganese, whose levels would be predictably high. Cyanide should be measured as well, because simple metal cyanides tend to be very insoluble (Zeman, 1990) but nevertheless may contribute free cyanide to overlying or interstitial water. For cyanide and all metals the total concentration would be measured.

The choice of sediments, rather than biota, for monitoring metals is based on availability and expected metals levels. Biota, particularly benthic invertebrates, do accumulate some metals, and are a good indicator of what metals are actually entering the food chain. But bioaccumulation factors for metals are not large (<10) and vary from one metal or organism to the next (Krantzberg, 1989; Burrows and Whitton, 1983). In general, the sequence of metals concentrations is: water < fish < sediment ≤ invertebrates (Duzzin et al., 1988). Clearly, fish would be a poor choice. Fish accumulate significant quantities of Hg and Cd, but concentrations of other metals (Pb, Cu, Zn) are relatively insensitive to ecosystem loading (Johnson, 1987). Sediments are preferred over invertebrates because the former are present at all times of the year (except spring spate) and are easily collected in quantities sufficient for analysis. Cyanide is not bioaccumulated; it is either cleared from the system quickly, or the organism dies (Zeman, 1990). Hence, for cyanide as well, sediments is the appropriate medium.

Sediment sampling differs fundamentally from sampling of the water column. First, the absolute quantity of any given metal is of less interest than the long-term trend (although the USEPA has proposed criteria for metals in sediments; Giesy and Hoke, 1989). Sediments measure the accumulation of material through time, and in these rivers the system is neatly reset each spring by scouring flood flows. Sediment sampling need not be monthly; twice a year is adequate (early spring and fall), but enough replicates should be taken at each occasion (5-10) to allow calculation of a mean and variance. The absolute value of the mean has little value but is necessary for trend detection. Further, because the largest mass of metals is found associated with fine particles (< 50 μm diameter; Duzzin et al., 1988; Huang and Liaw, 1978) samples should be screened to exclude larger particles; the final data set should include the proportion of fine sediments in the sample, as well as the proportion of organic matter, another important covariate, so that results can be standardized as necessary. Recently, acid-volatile sulphide has been suggested as a better correlate of metals in sediments, (Zarba, 1990) but this method has not seen widespread use, and organic matter provides a correction for pesticides as well (see below). The porosity (hence water content) of the sediments should also be measured, by oven-drying and computation of wet and dry weights; this provides an estimate of the total mass of material in the sediments.

Pesticide residues are the only contaminants likely to pose problems that are not already being monitored. Pesticide residues are a potential problem because of agricultural use, particularly in fruit production on the eastern side of the basin. Monitoring for pesticides should concentrate on a few specific compounds, selected according to use patterns in the basin, toxicity, solubility and persistence in the environment. Malathion and parathion (organophosphates) are widely used on fruit trees and atrazine, lindane and 2,4-D are likely contaminants based on experience in other areas, but the target pesticides to monitor should be decided from purchase records specific to the basin, possibly augmented by a screening survey to see which chemicals are presently occurring in greatest concentrations. Pesticide concentrations in water are invariably fleetingly small, so sampling should be directed at sediments or biota where insoluble compounds will accumulate. Pesticides tend to be strongly bioaccumulative in fat tissue so invertebrates or (especially) fish are the best monitors. The most useful fish species are probably sculpins (Cottidae) or longnose dace (*Rhinichthys cataractae*) because they feed exclusively on benthic insects (Scott and Crossman, 1973) and therefore maximize biomagnification, are non-migratory, and are present in abundance in the Similkameen

River (Swain, 1985). (Sampling in the Flathead River should not be necessary.) Suckers, which ingest sediments and invertebrates, and salmonids are other options, but the latter feed on a variety of food types, and both groups are highly migratory, which limits their use as site-specific monitors. Fish would be sampled once a year, in mid-summer, and again sampling must include sufficient replicates that confidence limits can be assigned to the estimates.

In the particular case of the Similkameen River, the addition of fish monitoring just for pesticides may not be justifiable if sediment samples are also being collected. If concentrations of pesticides in sediments are sufficiently high for monitoring, then it is probably more efficient to delete fish sampling. Again, a preliminary survey would quickly resolve this issue. An alternative to directly measuring pesticides and metals, biomonitoring, is described in the next section.

7.3 Biomonitoring

Biomonitors (also known as bio-effects monitors or ecological indicators) are here restricted to mean use of abundance or community structure of aquatic organisms to register the quality of their environment, as opposed to direct measurement of contaminants in living tissue. The literature on this topic is vast, and no attempt will be made to review it here. Rather, suggested methods most applicable to the Flathead and Similkameen Rivers will be described, and the rationale for the choice briefly given.

Three main classes of ecological indicator may be distinguished, according as they assess: (1) presence of sensitive species and structure of biotic communities; (2) ecological processes; (3) toxicity or stress effects. The first class includes indicator species, diversity and biotic indices, community structure comparisons (by taxonomic group or guilds) and simple measures of the numbers of species or individuals. Ecological processes commonly measured are (algal) productivity, photosynthesis, respiration, decomposition and nutrient dynamics. Toxicity tests are based on mortality, growth inhibition or other physiological dysfunctions of test organisms exposed to water or sediments from the environment in question, but include measures of deformities in resident organisms (e.g., Warwick, 1989).

Kelly and Harwell (1990) have summarized the criteria for selecting indicators of ecosystem change. A screening-level indicator for long-term monitoring must respond quickly to stresses, (to ensure early detection), be specific to the stress or stresses anticipated, must be economical to monitor, without requiring advanced expertise or difficult laboratory procedures, and must be directly relevant to a change in the ecosystem. A high percentage of false positive responses is tolerable in a screening indicator, because detections will be verified by other means, but the indicator should reliably respond if a stress to the system occurs; i.e., the incidence of false negatives must be low (Kelly and Harwell, 1990).

Ecological processes, despite their obvious relevance to health of the ecosystem, have been found to be quite insensitive as early signals of change in aquatic systems (Schindler, 1987). The usual response of ecosystems to stress is to maintain ecosystem processes by altering species composition and abundance. Therefore, measurement of ecosystem processes has been deleted from the recommended monitoring program.

Of the three gross trophic levels in streams, benthic invertebrates, and to a lesser extent benthic algae have been often used or proposed as indicators, but use of fish is rare. Fish are migratory, hard to catch, lack the intimate association with sediments characteristic of algae and invertebrates and are represented by too few species to allow detection of subtle community changes. As top predators fish are the last to respond to an ecosystem stress that may be debilitating to one of their food sources (e.g. Munkittrick and Dixon, 1988). Fish are relatively large and have characteristically long life cycles; earliest indicators of ecosystem change are small, rapidly reproducing organisms (Schindler, 1987). For all these reasons fish have been excluded from the recommended monitoring program in favour of benthic animals and algae.

The proposed monitoring program has two parts: (1) field sampling of benthic invertebrates and periphyton, and (2) laboratory toxicity tests of benthic sediments. Most of the general principles concerning biomonitoring with invertebrates apply to algae as well. Both have been shown to respond in predictable ways to natural or anthropogenic stresses, including sediments, nutrients and metals, the three most probable stresses on the Flathead and Similkameen Rivers (e.g., Sladacek, 1986; Clements et al., 1988; Warwick, 1989; Metcalfe, 1989; Newman and McIntosh, 1989). However, to gain the maximum sensitivity necessary to detect subtle trends, sampling and analysis must be rigorous and carefully planned (Barton, 1989). Algae are a biologically different group from invertebrates, but show a broadly parallel response pattern. They therefore act as a useful double-check on results from invertebrate collections.

The benthos and algae sampling should follow these fundamental principles:

1. Sampling need be no more frequent than twice a year. Late March-early April and late September-early October are the optimal times. Sampling must proceed at the same time each year, and spring samples must precede spring peak flows. Although the above plan will render samples six months apart, spring and fall analyses should be considered separate data sets, as they will contain some different species.

2. Sampling must be quantitative with respect to the relative numbers of individuals and species from one sample to the next, but should not attempt to quantitatively or exhaustively sample the entire community. This point cannot be over-emphasized. Status of the ecosystem will be assessed by comparing relative abundances of common species or groups from one sampling time to the next. As long as these species are sampled reliably, there is little return from the enormous extra effort required to quantify densities of the much larger number of rare species, whose distributions are characteristically patchy in space and time.

3. Sampling should be geared toward larger numbers of smaller samples. The most abundant 10-20 species carry all the information necessary to typify the environment and detect trends, and larger samples merely include more rare species while over-sampling common ones. Similarly, loss or under-representation of small species or instars is not a concern as long as the bias is constant, because results will be analyzed comparatively. Most standard sampling devices, such as the Surber sampler, or Eckman or Ponar grab, take samples that are far too large. Smaller samples can be sorted quickly, and the saved effort expended on collection of more replicates (ideally 5-10 per site visit). Subsamples drawn from a pooled sample do not represent true replication (Hurlbert, 1984).

4. Every effort should be made to reduce environmental sources of sampling error. Hence, sampling schedules should be closely adhered to, and changes in methods of sampling, sorting or collecting, even relatively small differences such as net mesh size, should be avoided. Use of artificial substrates (multiple plates or rock trays for invertebrates, plexiglass slides for algae) is advisable; if these are used the colonization period should be fixed, preferably at three or four weeks.

5. Species identifications need not be carried beyond the lowest taxonomic level easily achieved. Most diatoms can be identified to species (Martin et al., 1987) but for other algae and invertebrates, separations to genus or even family may be all that is practical. This will not impede analysis if the same level of taxonomy is maintained from year to year.

Analysis of periphyton samples would use relative abundances of sensitive species or higher taxa (e.g., Evanson et al., 1981), proportions of diatoms versus non-diatom algae, and the autotrophic index (nitrogen and phosphorus content per unit of chlorophyll) (Martin et al., 1987). Preferred statistics for analysis of invertebrate samples are: (1) proportion of stoneflies plus mayflies (except Baetidae); (2) percent similarity coefficient; (3) functional group analysis, especially the proportion of collectors-gatherers plus scrapers and proportion of filterers. These indices should be sensitive enough to catch perturbations, simple enough to be rapidly calculated and relatively free from background variation. Most importantly they do not depend on absolute measures of abundance or production, and do not require that the entire community of periphyton or benthos be sampled.

Sediment toxicity tests are suggested as an alternative to direct measurement of metals or other contaminants. Toxicity tests account for bioavailability of the various constituents present, and interactions between them, and circumvent problems of relevance and uncertain extraction efficiencies that dog direct contaminant measures. Their chief limitations are the lack of standard protocols and the inability of any single test to accurately measure all toxicants. Consequently the use of a battery of simple screening tests is recommended (Dutka and Gorrie, 1989).

So-called sediment toxicity tests actually measure the effect of sediment pore water. Most of the contaminants sorbed to sediment particles are not available and are in equilibrium with the concentrations in pore water, through which benthic organisms derive most of their exposure to the contaminant. This is convenient, because simple methods exist for extraction of pore water (usually with small volumes of clean water), which allows sediments to be "diluted" (i.e., by diluting the extracted pore water) to perform the toxicity tests and compare with standards (Giesy and Hoke, 1989).

Extracted pore water is then tested for acute and chronic toxicity using standard tests. Tests commonly used include the Microtox (bacterial luminescence assay), acute toxicity to *Daphnia magna* (Dutka and Gorrie, 1989), the life-cycle test (survival, growth and fecundity), with *Ceriodaphnia* (Giesy and Hoke, 1989), and the 10-day growth and survival test with the midge *Chironomus tentans* (Rosin et al., 1989). All of these tests are well-tested and require small volumes of sediment extract. On the Flathead and Similkameen Rivers, it would be best to perform a preliminary survey to determine the most useful tests. Sediment toxicity would be measured twice yearly, on the same occasions as the algal and invertebrate surveys.

Morphological deformities in benthic invertebrates increase in the presence of a wide variety of stresses, and offer potential for a sensitive early indicator of ecosystem contamination (Schindler, 1987). Warwick (1985, 1989; Warwick and Tisdale, 1988) has championed the use of deformities in chironomid larvae as a powerful system of stress detection. This approach holds promise, but its application to the Flathead and Similkameen Rivers must await further standardization of methods. Taxonomists should be instructed, however to note the incidence of conspicuous deformities in the animals they identify.

7.4 Recommended Monitoring Program

The monitoring program summarizes the recommendations made above concerning timing, variables and media for long-term monitoring of the Flathead and Similkameen Rivers. For the most part, the program is identical for both rivers, with the exceptions noted. Table 17 details the proposed monitoring plan.

The variables measured in the water column have been reduced to the key variables necessary to characterize the rivers or detect probable changes, and the frequency of sampling has been reduced to once per month. In the present short data set, approximately 60% of the trends observed with weekly or fortnightly sampling would still have been detected if monthly sampling had been employed. As more data are collected, the power of trend tests conducted on monthly data will increase, and considering the lack of anthropogenic impacts on the two rivers, monthly sampling is probably adequate. Generally, accuracy of statistical tests for step changes also are little improved by sampling >12 times per year (Hirsch, 1988). More frequent sampling during the spring spate is an option if information on seasonal violations of water quality criteria is wanted, but this must not be permitted to interfere with regular monthly sampling as time series analysis is considerably more difficult with irregularly spaced data.

If the monthly sampling schedule is followed, the statistical methods used here should be adequate for trend detection. The Kendall tests are readily carried out by most statistical

Table 17. Summary of Proposed Monitoring Program

A. MONTHLY WATER SAMPLES[1,2]

Temperature (°C) (water and air)[7]
Colour (TCU)
Nonfilterable Residue
Turbidity
Conductance
pH (laboratory)
Alkalinity (Total)
Hardness
Total Phosphorus
Dissolved Phosphorus
Ammonia[4]
Total Nitrogen
Simple Cyanide[3,4]
Total Cyanide[3,4]
Fecal Coliform Bacteria[4]
Metals (all Totals)
- Cadmium
- Chromium
- Copper
- Iron
- Lead
- Manganese
- Mercury
- Molybdenum
- Nickel
- Selenium
- Zinc

B. TWICE YEARLY SEDIMENT SAMPLES

Chemical Monitoring or	Sediment Toxicity Tests[5]
(all as Totals)	
Cadmium	48-h *Daphnia* mortality
Chromium	*Ceriodaphnia* life cycle
Copper	Microtox Test
Cyanide	
Lead	10-d *Chironomus tentans* growth test
Nickel	
Organic Carbon	
Pesticides[4,6]	
Selenium	
Zinc	

plus
% fines (<50 μm) porosity (water content)

C. TWICE YEARLY BIOTA SAMPLES

Benthic Invertebrates and Periphyton:
- place 5-10 substrates early March, late August
- retrieve substrates early April, late September

1 Weekly or fortnightly additional sampling optional during spring spate (May-June).
2 Following present sampling methods.
3 Measured before (simple cyanide) or after (total cyanide) exposure to UV light.
4 Measured on Similkameen River only.
5 Exact tests to be decided by preliminary survey.
6 Specific compounds to be determined by preliminary survey.
7 Automatic sampling at shorter intervals averaged to monthly mean.

packages, and have been used in a number of water quality studies (e.g., Smith et al., 1982; Berryman et al., 1988; Hipel et al., 1988). Evaluation of abrupt changes in river water quality that may arise from a new source of effluent to the river would require different statistical methods (e.g., t-tests, median tests). A quality assurance/quality control (QC/QA) program should be integrated into the routine field sampling program. The QC/QA program should include field blanks and split samples; presumably the laboratories follow their own QC/QA procedures. Sampling for quality control should be conducted twice a year at each sampling site. This would amount to 50% of all samples being utilized for quality assurance, i.e., two blanks and two split samples for every 12 samples collected.

Two forms of cyanide, either simple and total, or weak- and strong-acid-dissociable, would be measured. Cyanide, fecal coliforms, and ammonia would be measured only in the Similkameen River. There are a number of choices for sampling of sediments and biota. Chemical monitoring of metals (excluding iron and manganese), cyanide and possibly pesticides could be done directly by sampling sediments each March or April (before spring spate) and each autumn. Five to ten replicates should be taken, depending on cost, and constituents measured on the fine fraction to maximize detections. The specific pesticides to be measured would depend on results of a preliminary screening, but should contain one herbicide, such as 2,4-D and one insecticide, such as malathion. Ordinary parametric or non-parametric tests could be used to compare time periods, and hence determine trends in sediment quality.

Measuring sediment toxicity is probably a more ecologically meaningful way of testing sediment quality. Table 17 lists four commonly used tests for toxicity of sediment pore water, but not all of these would be necessary or applicable in these rivers. Again, a preliminary survey is needed to facilitate that decision. Sediment toxicity tests are intended to replace, not supplement, chemical analysis of sediments, so the latter should be forgone unless toxicity tests begin to show problems.

Annual monitoring of fish for pesticides is not shown in Table 17 because it is probably more efficient to rely on toxicity tests or sediment analysis for that information. If fish monitoring is used, sculpins and longnose dace are the preferred species, and sampling should be carried out in late summer. Ten replicates of each species would be needed because of the expected high frequency of concentrations below detection limits.

Sampling of benthos and periphyton should proceed twice yearly, in spring and fall, at the same time that sediment samples are taken. Algae may be sampled by scraping rocks, but the preferred method is to place anchored plexiglass slides (ten) in the river for three weeks to one month and examine the periphyton that has colonized (Newman and McIntosh, 1989). Benthos sampling may use small-area samplers, or preferably, artificial substrates such as rock-filled trays or multiple plates placed in the river for one month. It is important that spring samples precede the spring spate. Preferred statistics for analysis of invertebrate and periphyton samples are given in Section 7.3. Of course, if all data on benthos samples, and if possible the samples themselves, are retained, then retrospective analyses with new methods are possible in the future.

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APPENDIX A

Time-Series Plots

Flathead River

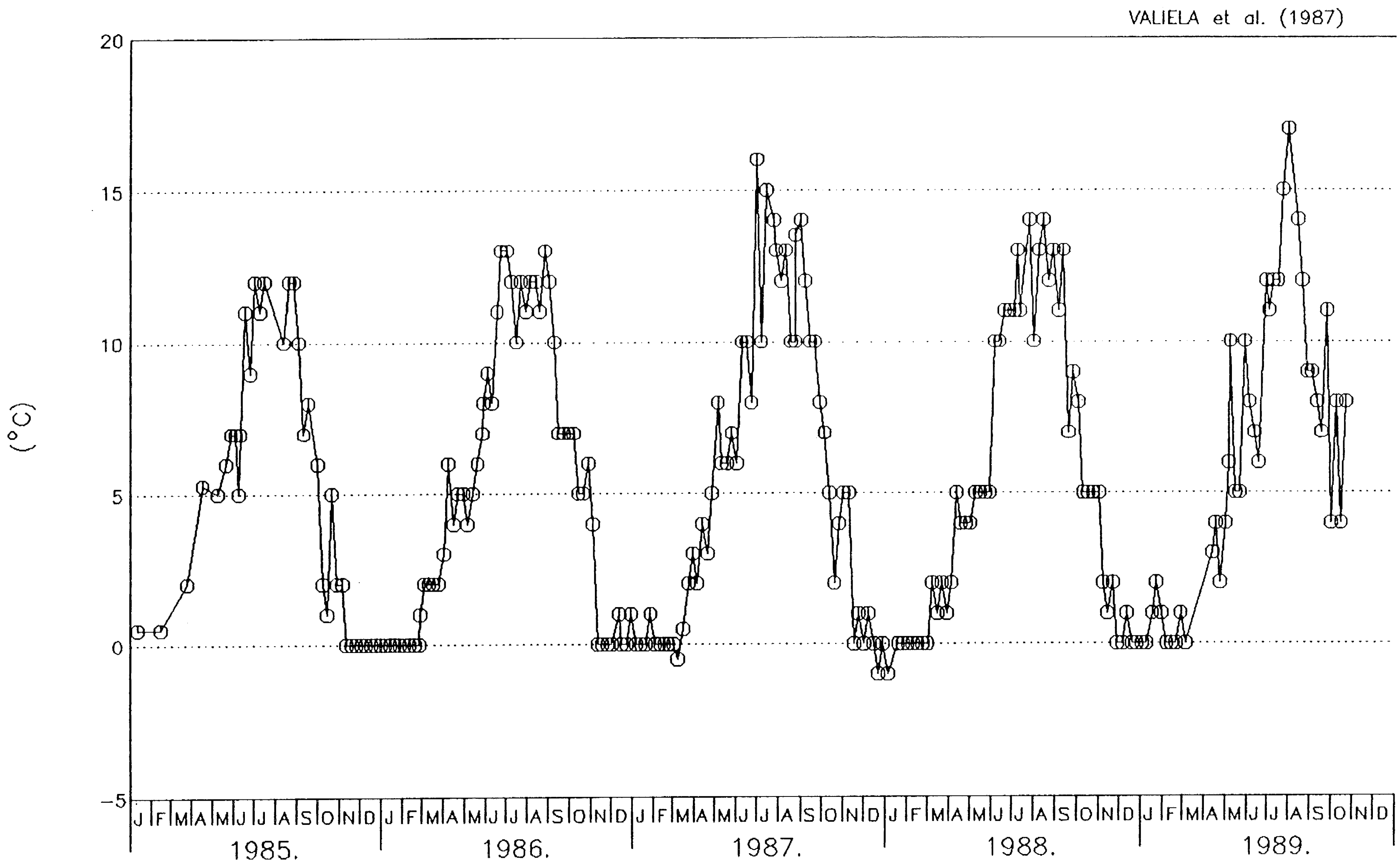

Figure A1

WATER TEMPERATURE
FLATHEAD RIVER (1985 – 1989)

Environmental
Management Associates

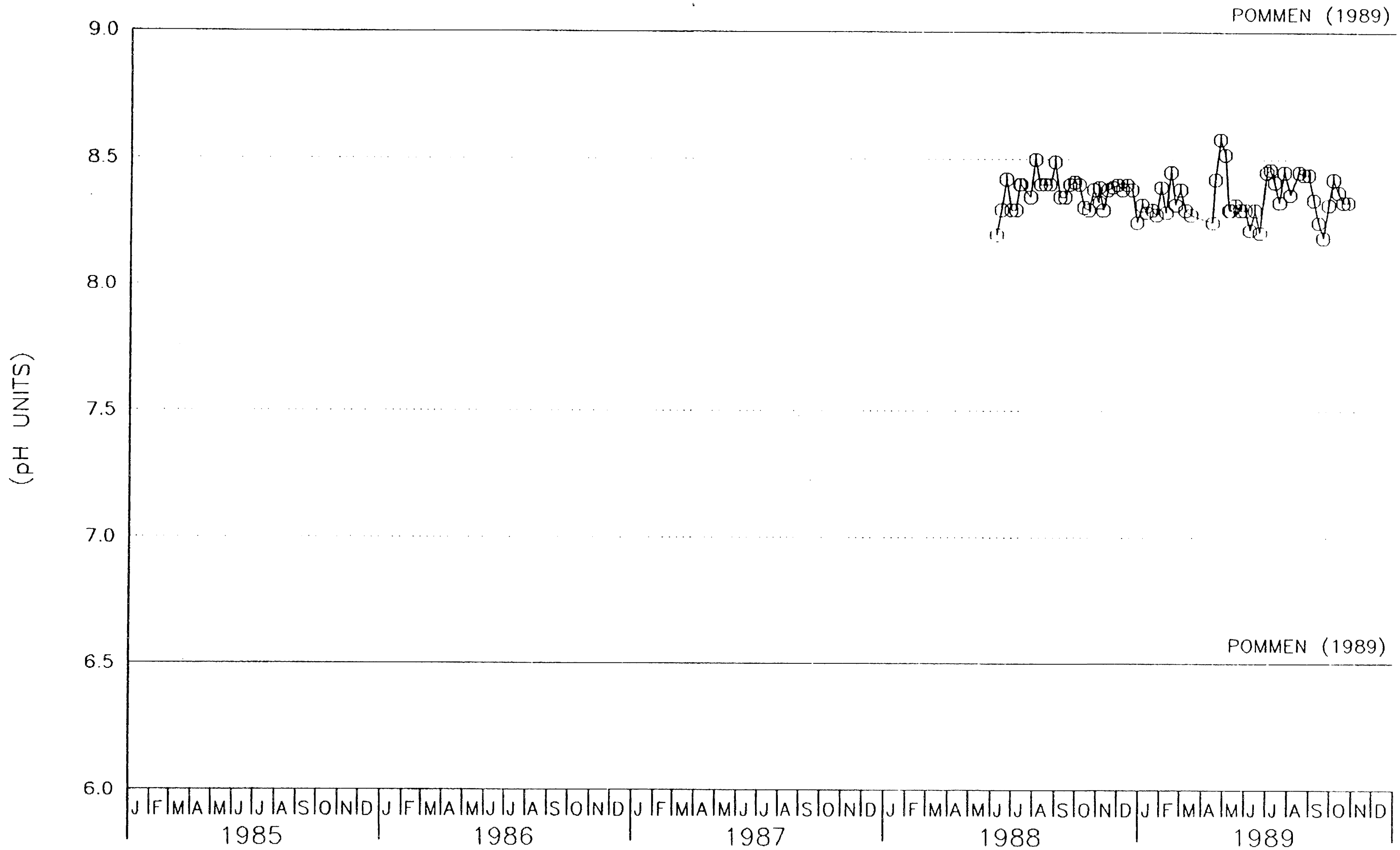

Figure A2

pH
FLATHEAD RIVER (1985 – 1989)

Environmental Management Associates

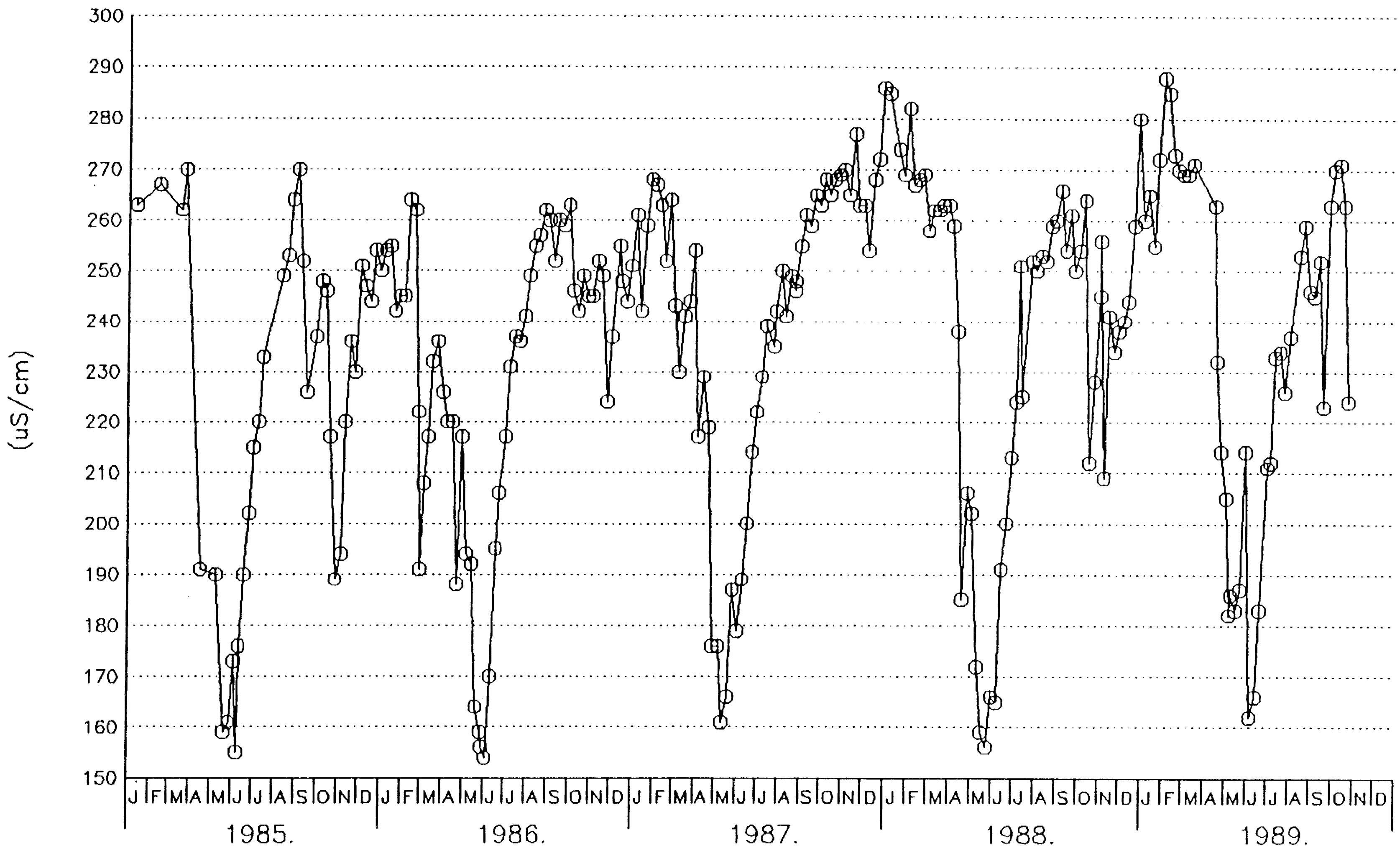

Figure A3

SPECIFIC CONDUCTANCE
FLATHEAD RIVER (1985 – 1989)

Environmental
Management Associates

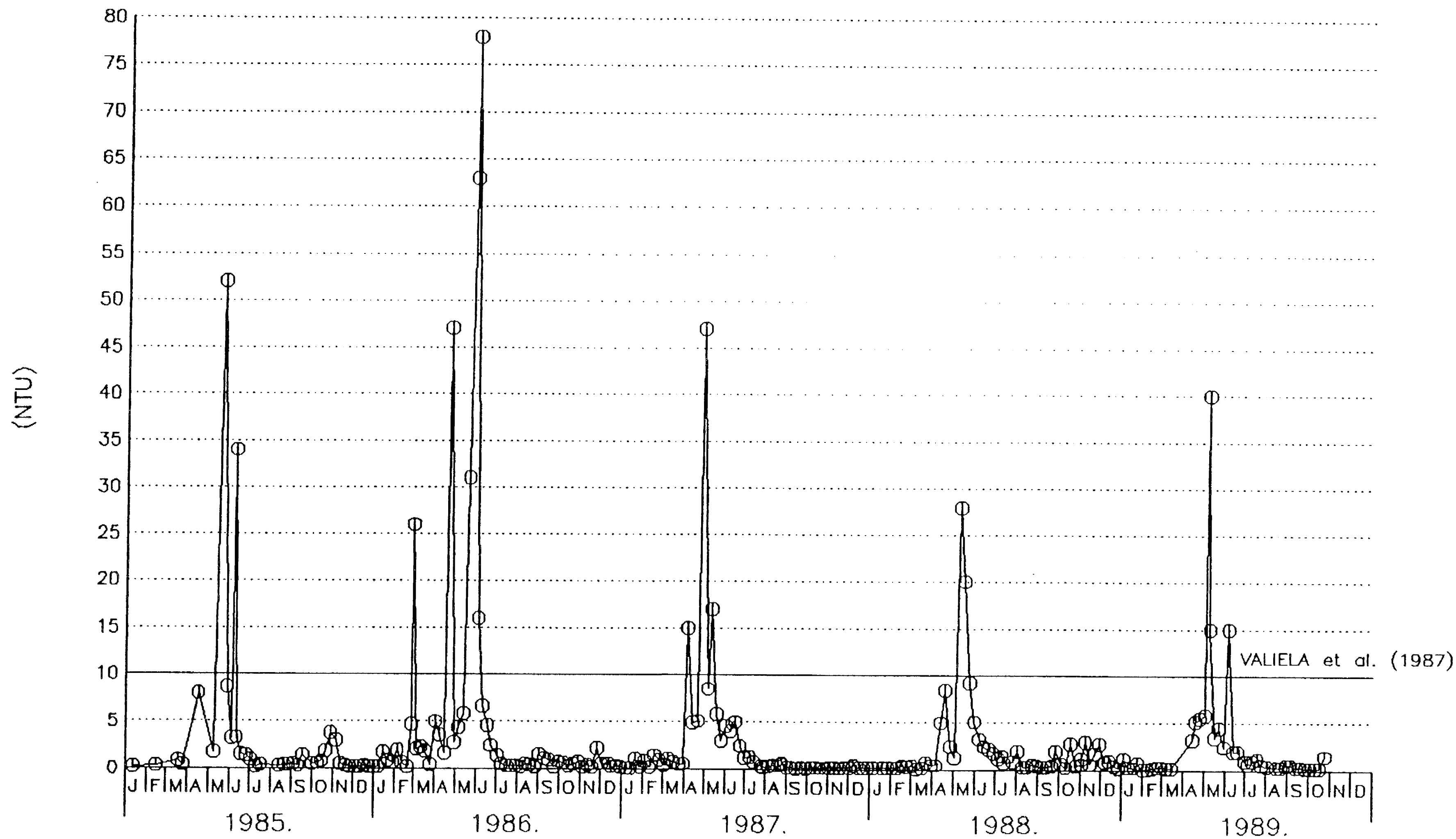

Figure A4	TURBIDITY FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

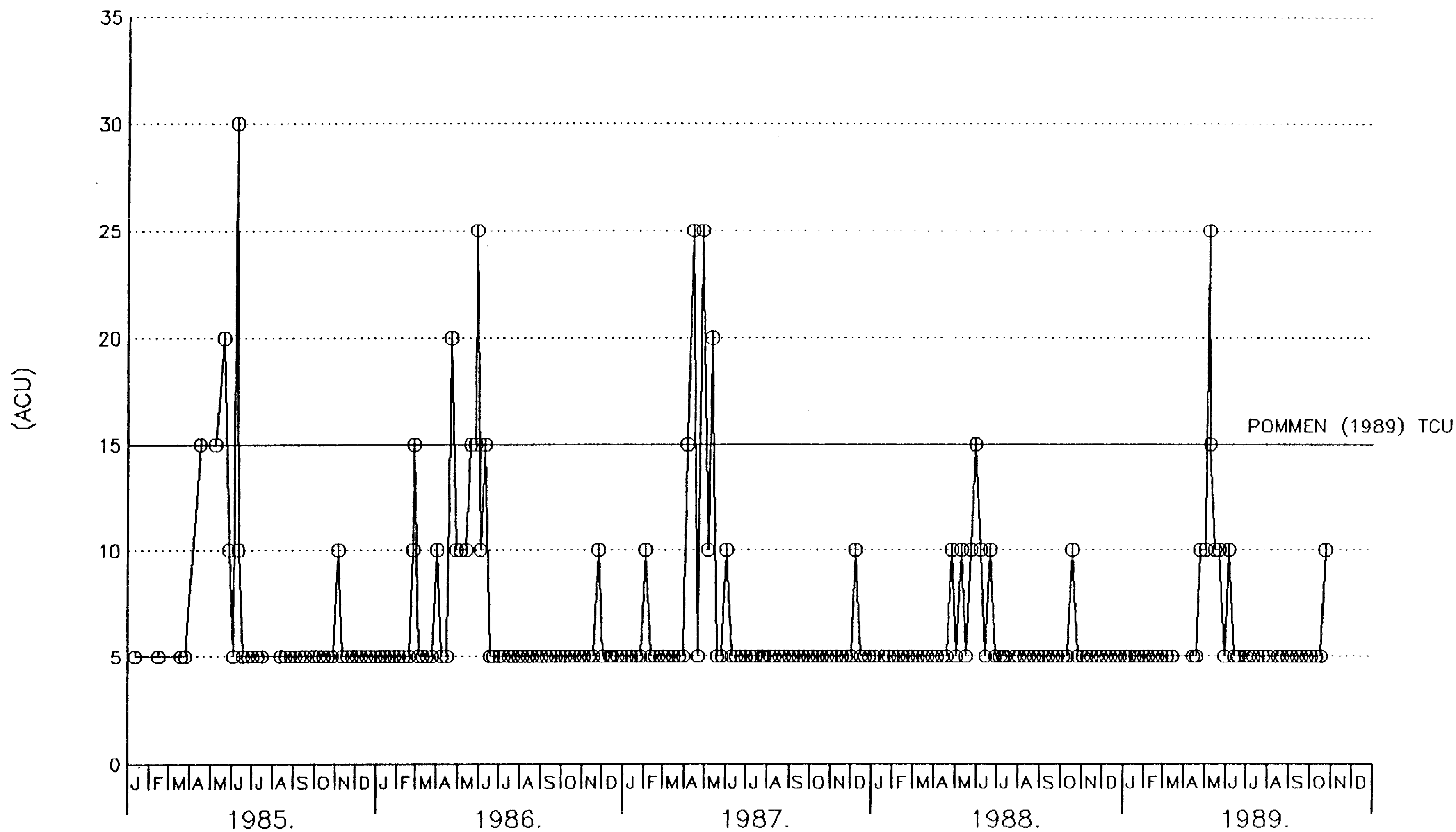

Figure A5

APPARENT COLOUR
FLATHEAD RIVER (1985 – 1989)

Environmental
Management Associates

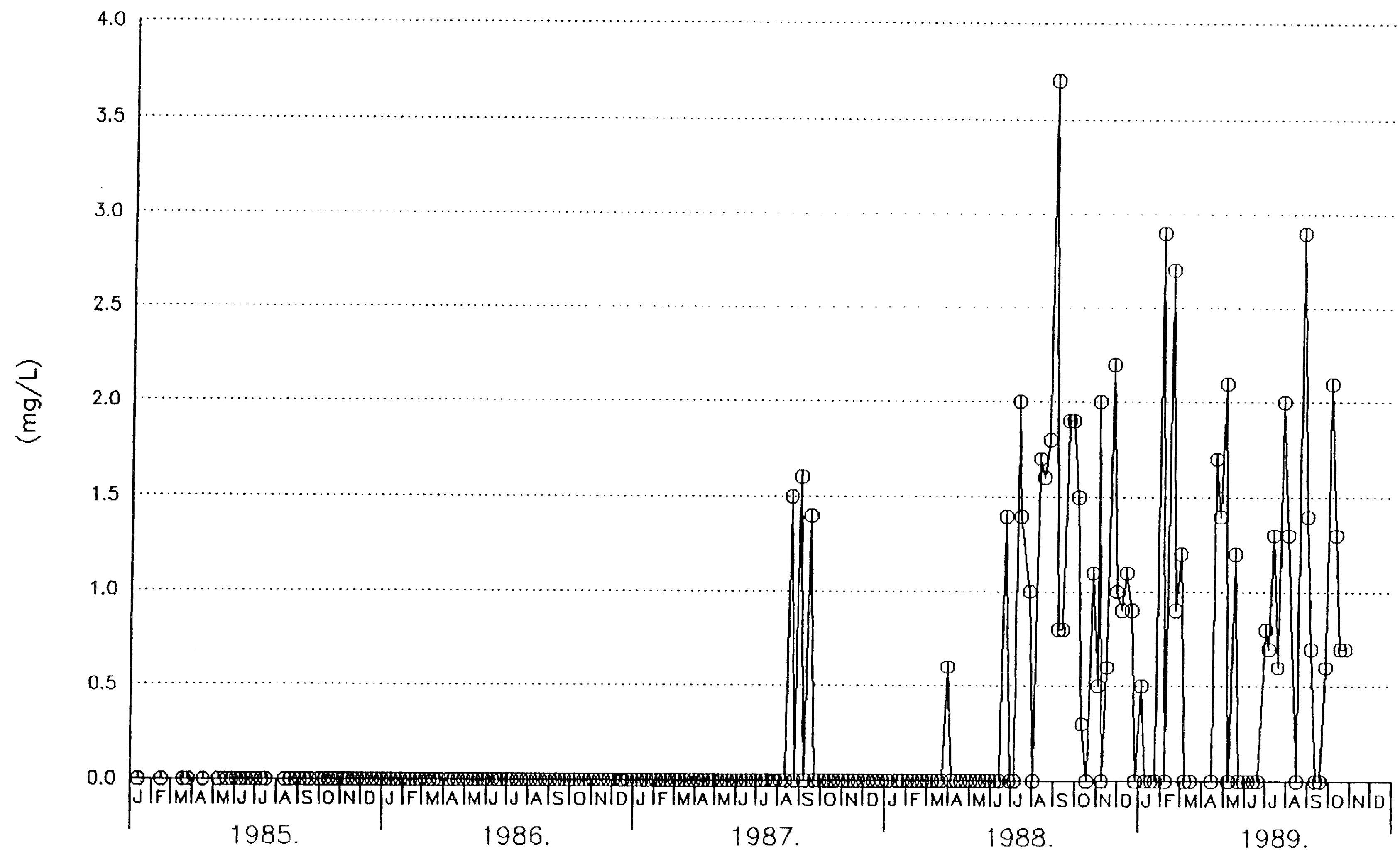

Figure A6	PHENOLPHTHALEIN ALKALINITY FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

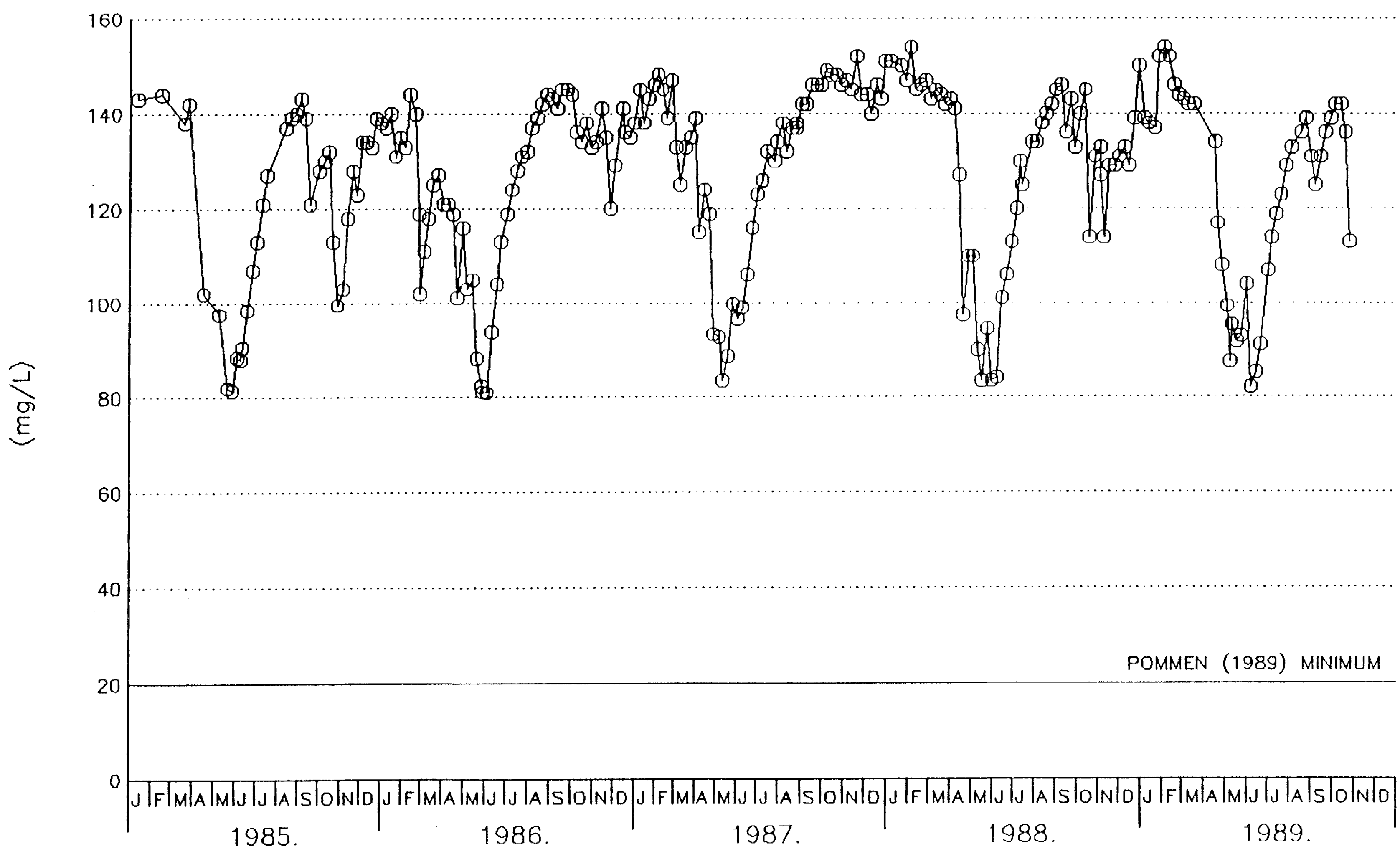

Figure A7

TOTAL ALKALINITY
FLATHEAD RIVER (1985 – 1989)

Environmental Management Associates

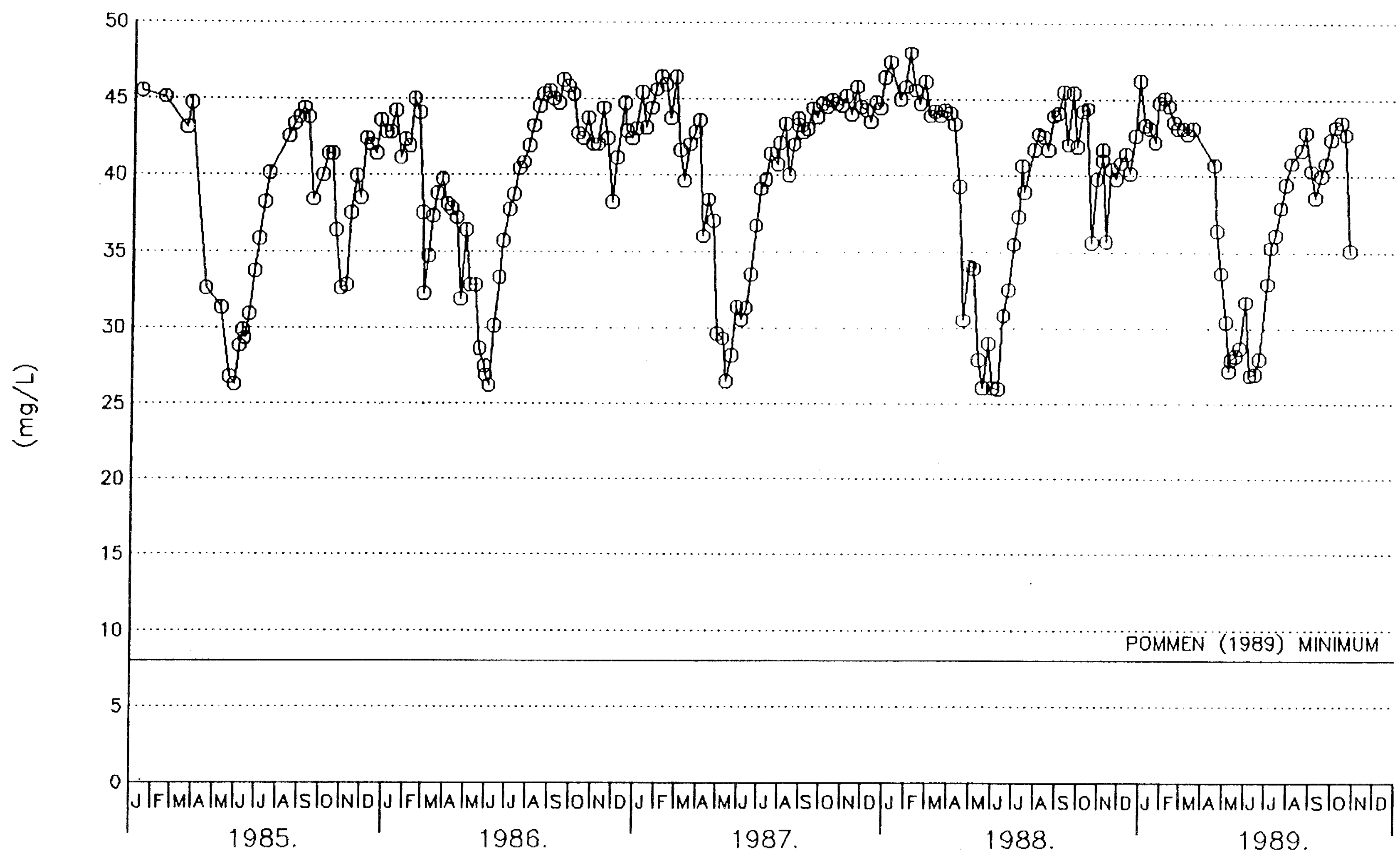

Figure A8	CALCIUM FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

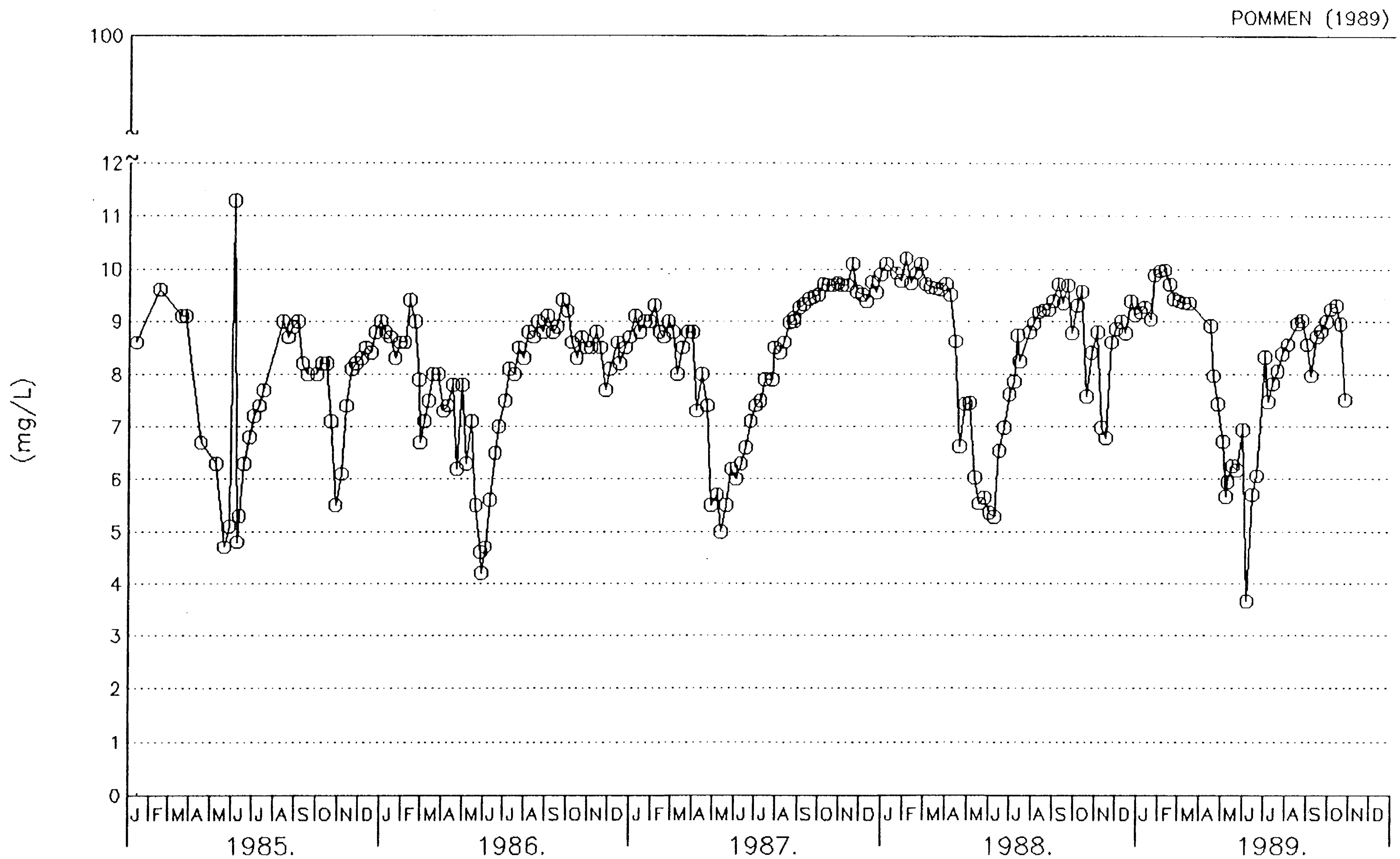

Figure A9

MAGNESIUM
FLATHEAD RIVER (1985 – 1989)

Environmental Management Associates

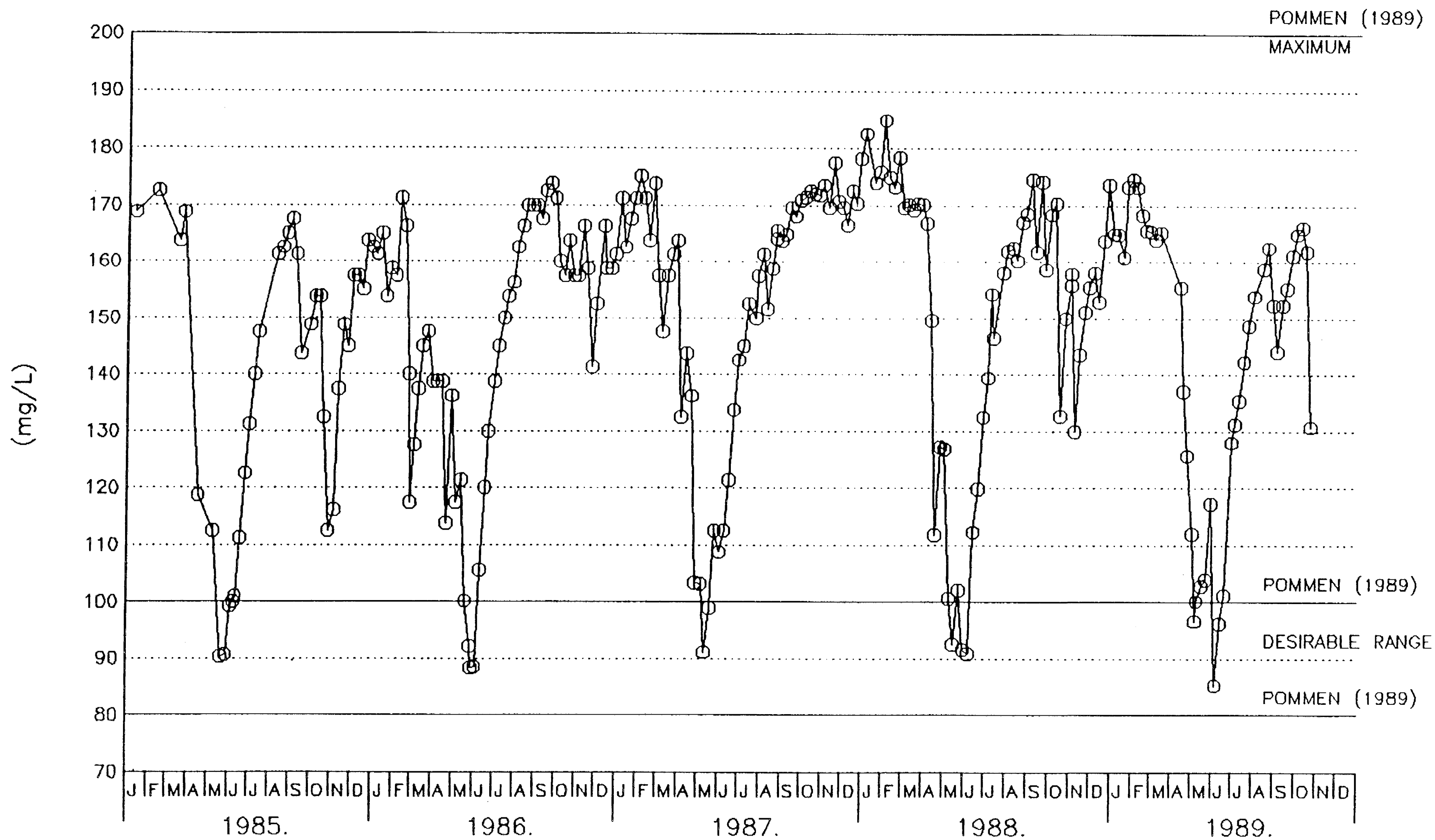

Figure A10	TOTAL HARDNESS FLATHEAD RIVER (1985 - 1989)	Environmental Management Associates

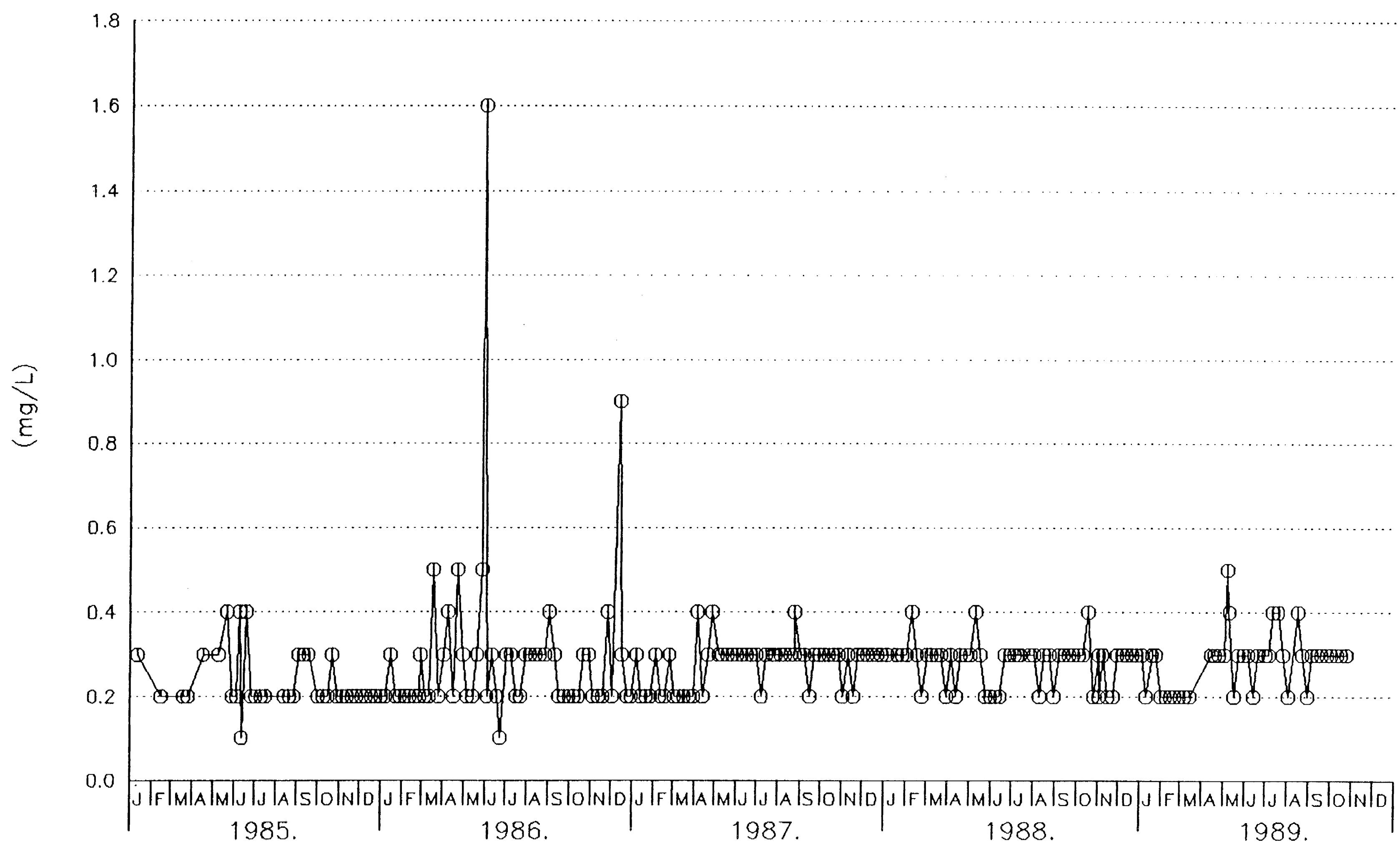

Figure A11	POTASSIUM FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

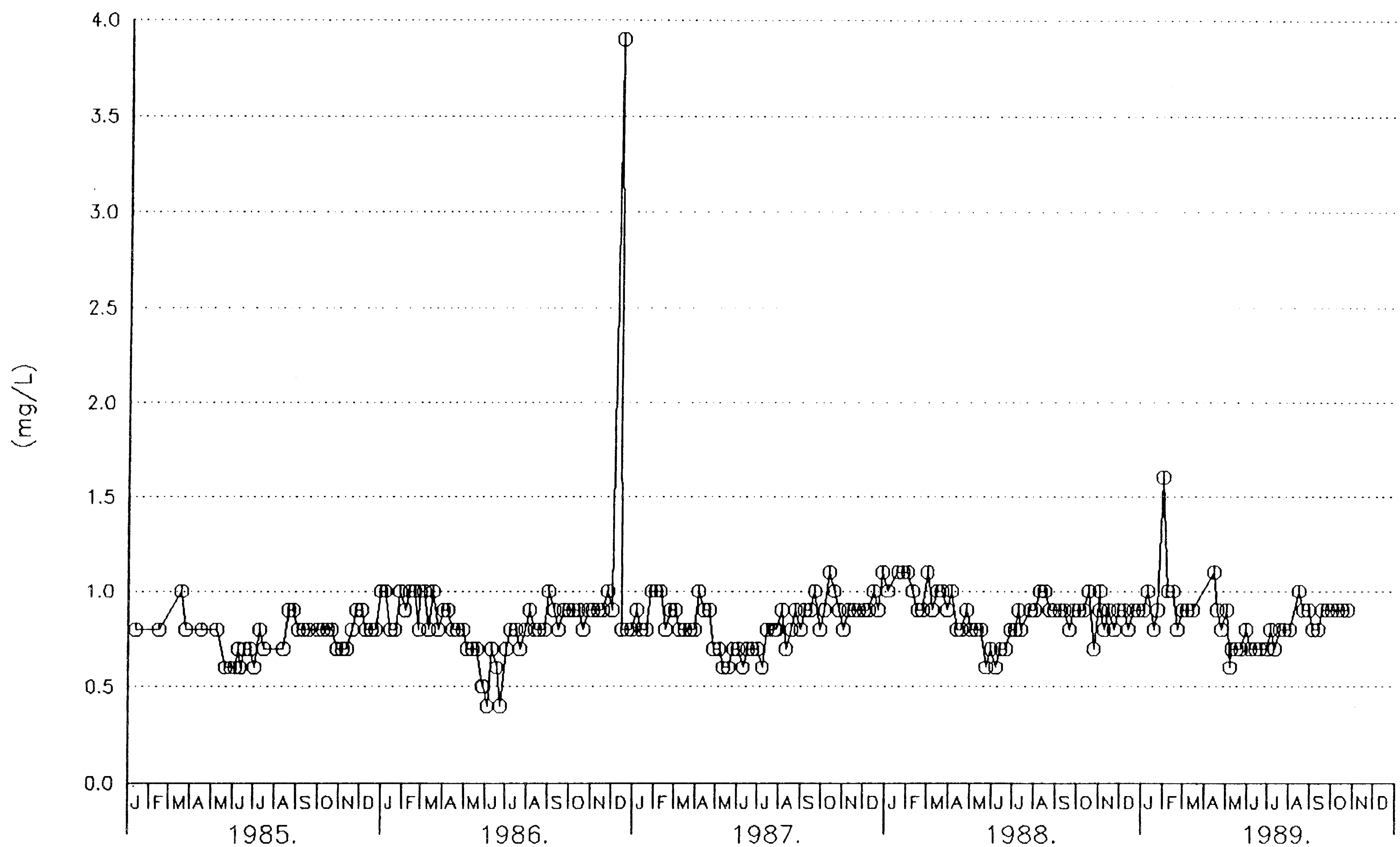

Figure A12	SODIUM FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

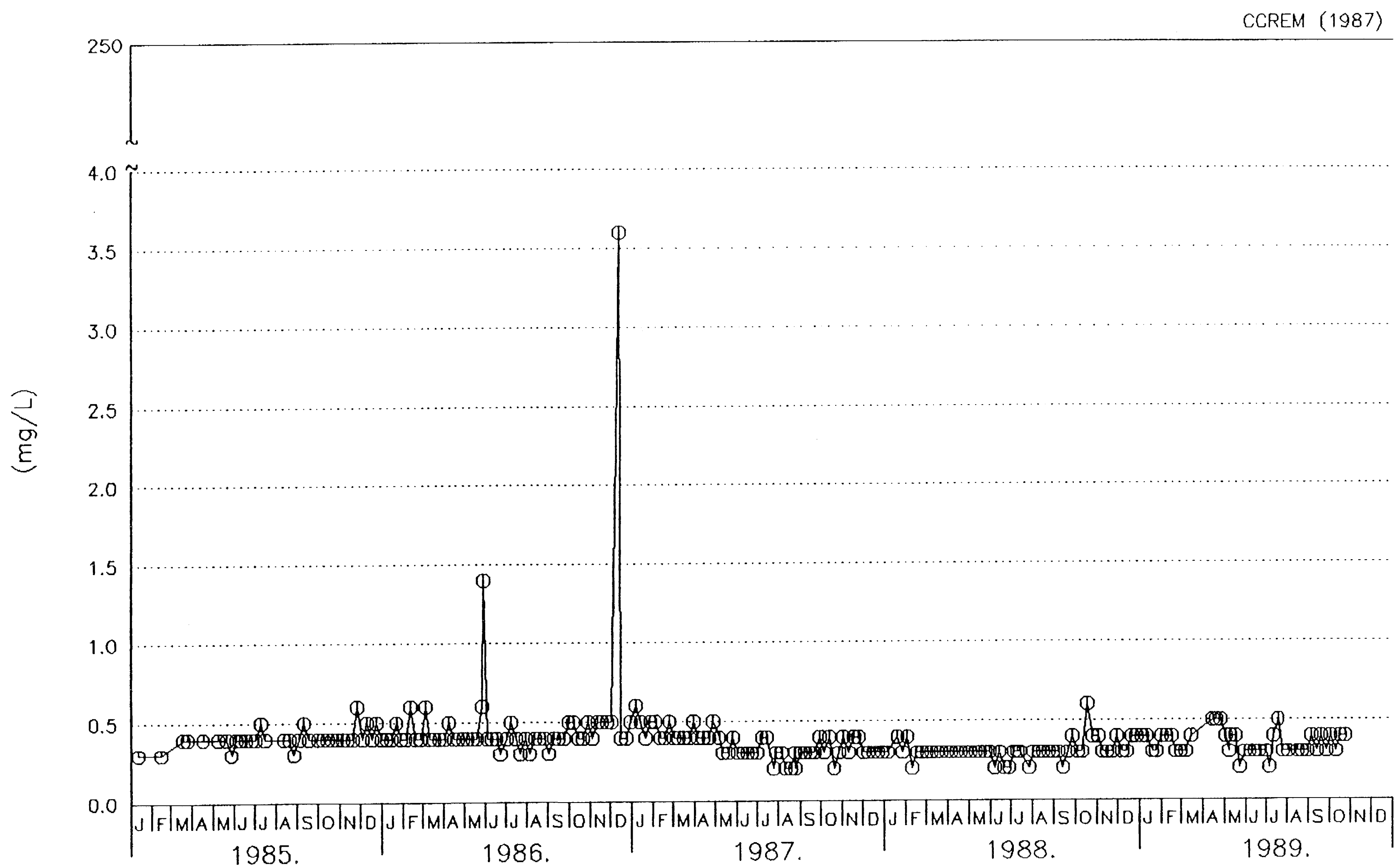

Figure A13	CHLORIDE FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

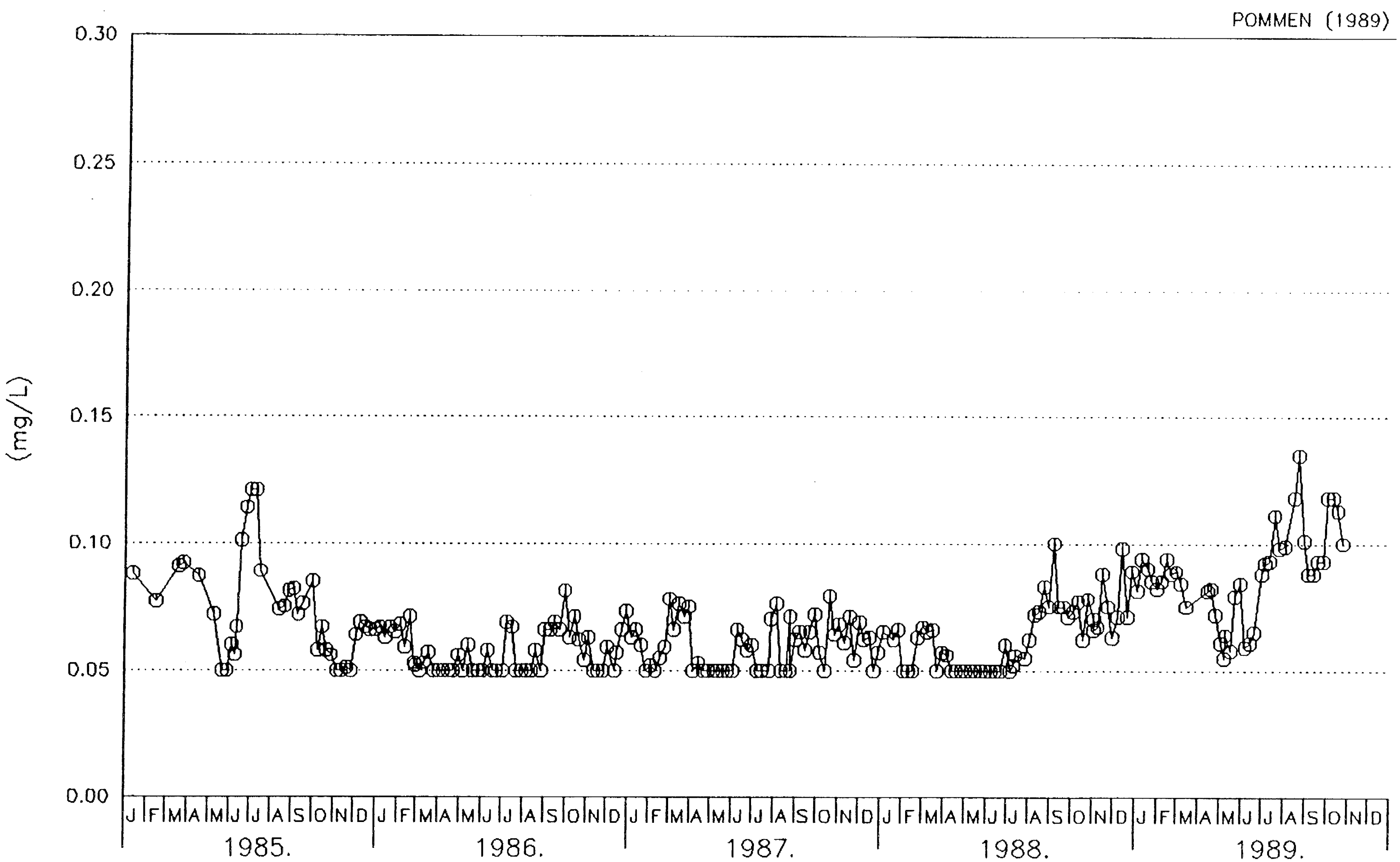

Figure A14	FLUORIDE FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

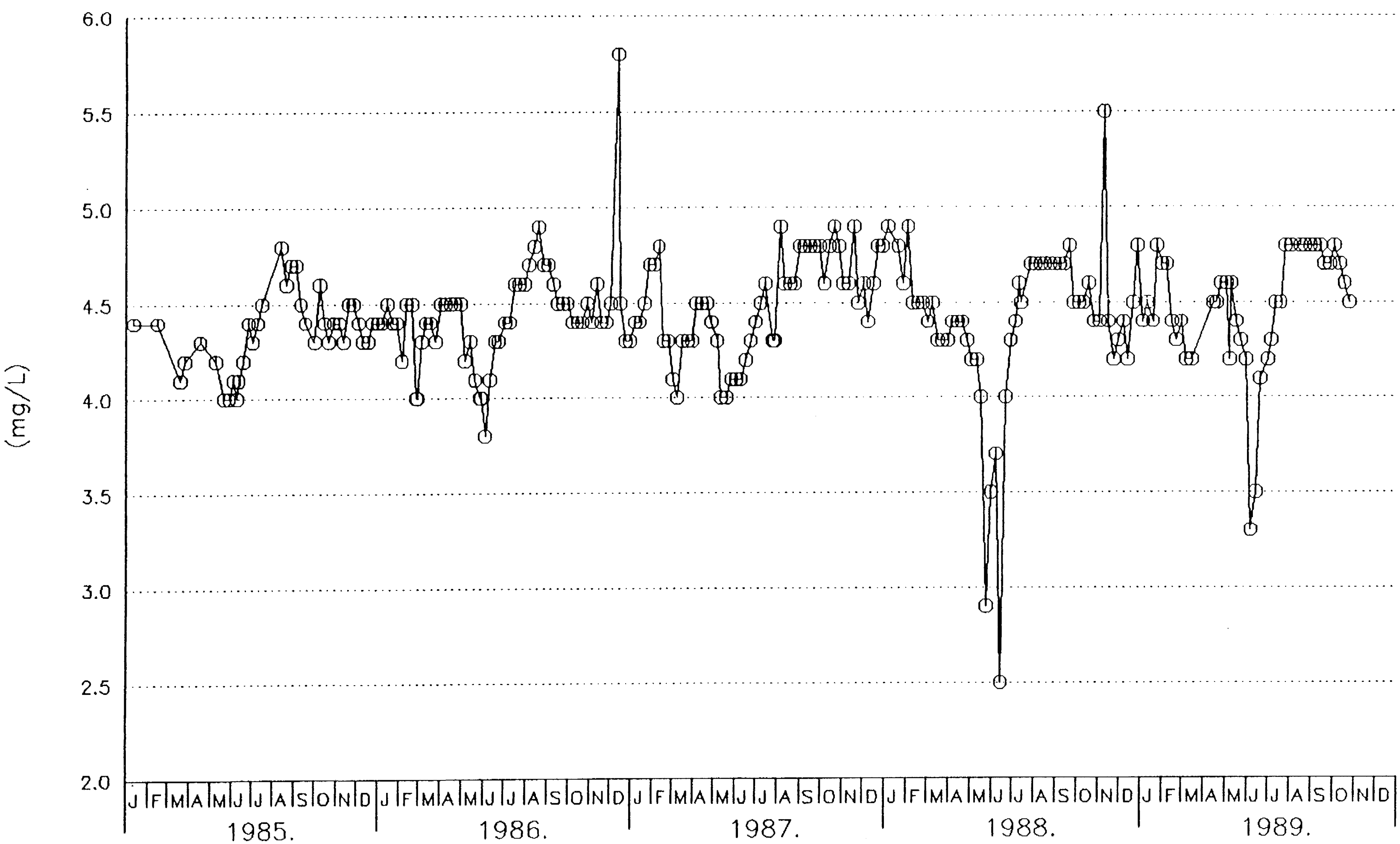

Figure A15

REACTIVE SILICA
FLATHEAD RIVER (1985 – 1989)

Environmental
Management Associates

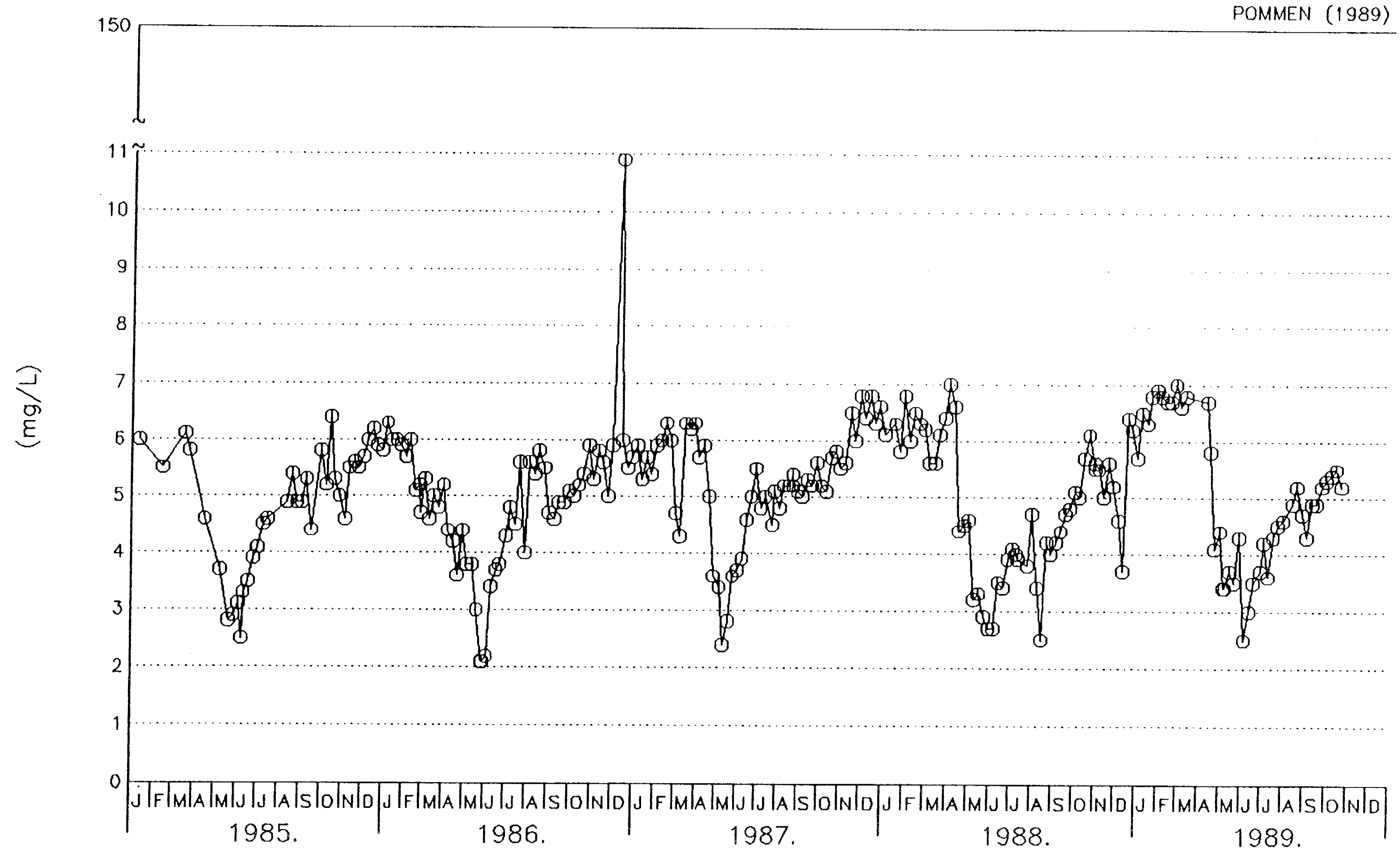

Figure A16	SULPHATE FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

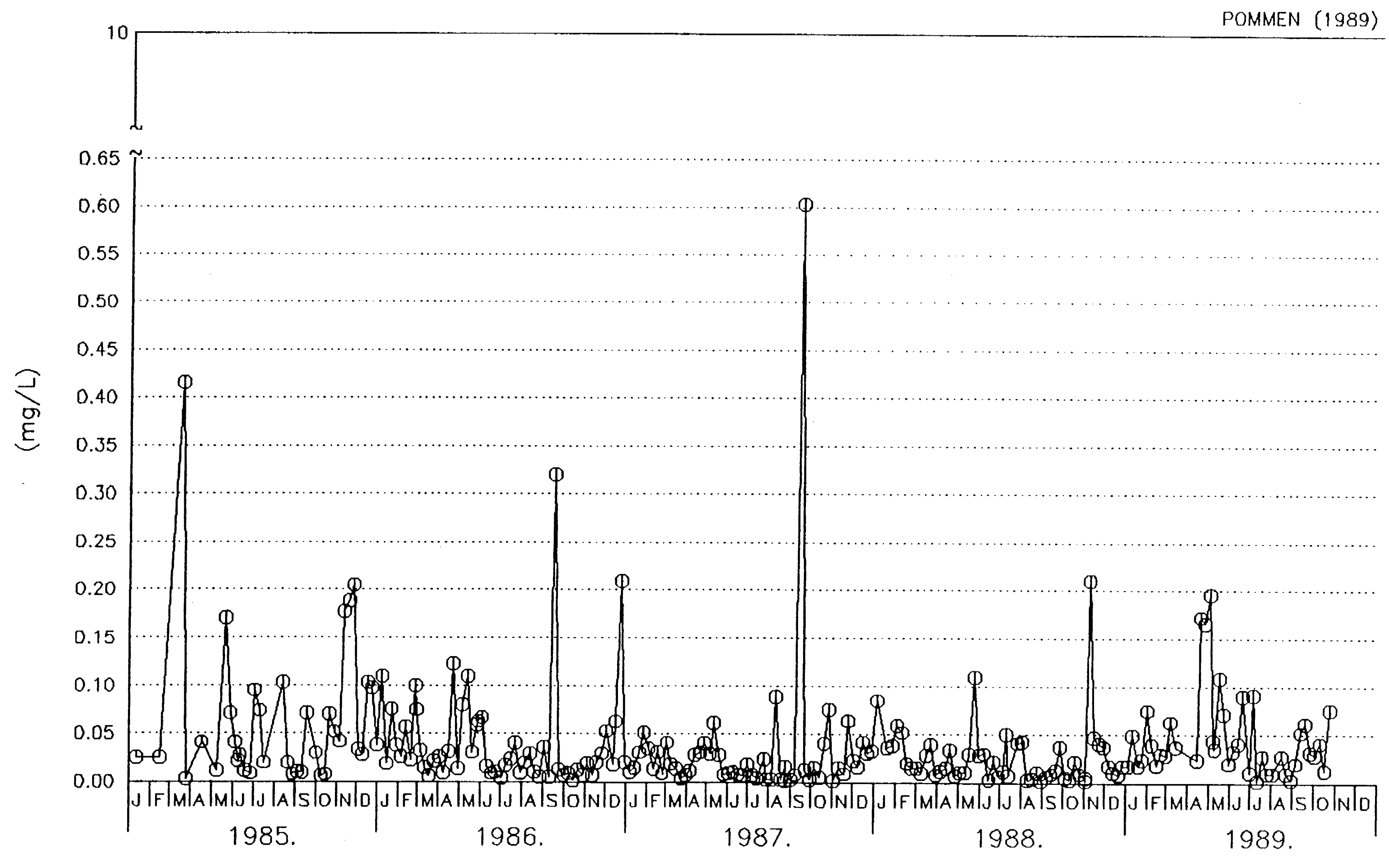

Figure A17	NITRATE+NITRITE−NITROGEN FLATHEAD RIVER (1985 − 1989)	Environmental Management Associates

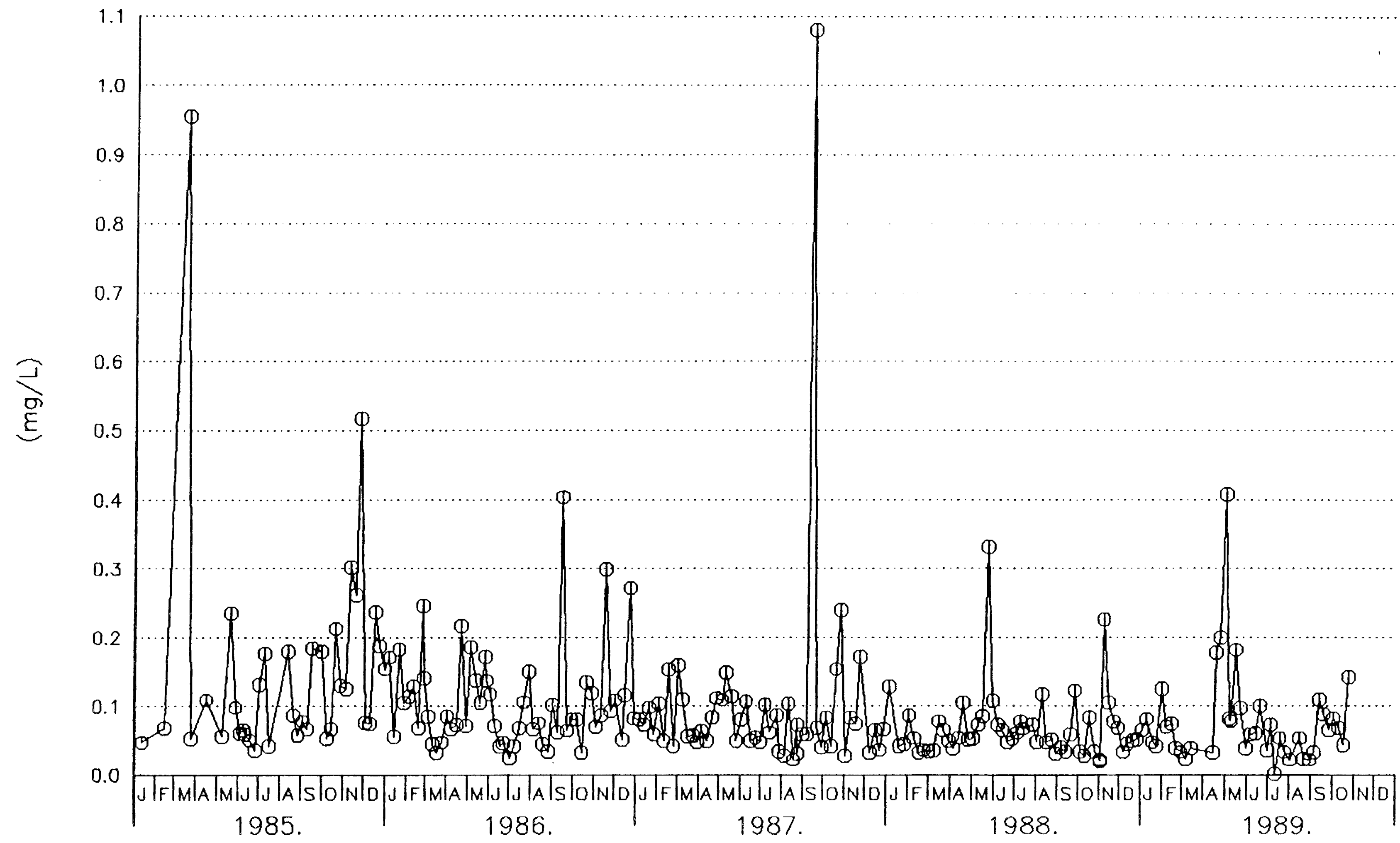

Figure A18	DISSOLVED NITROGEN FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

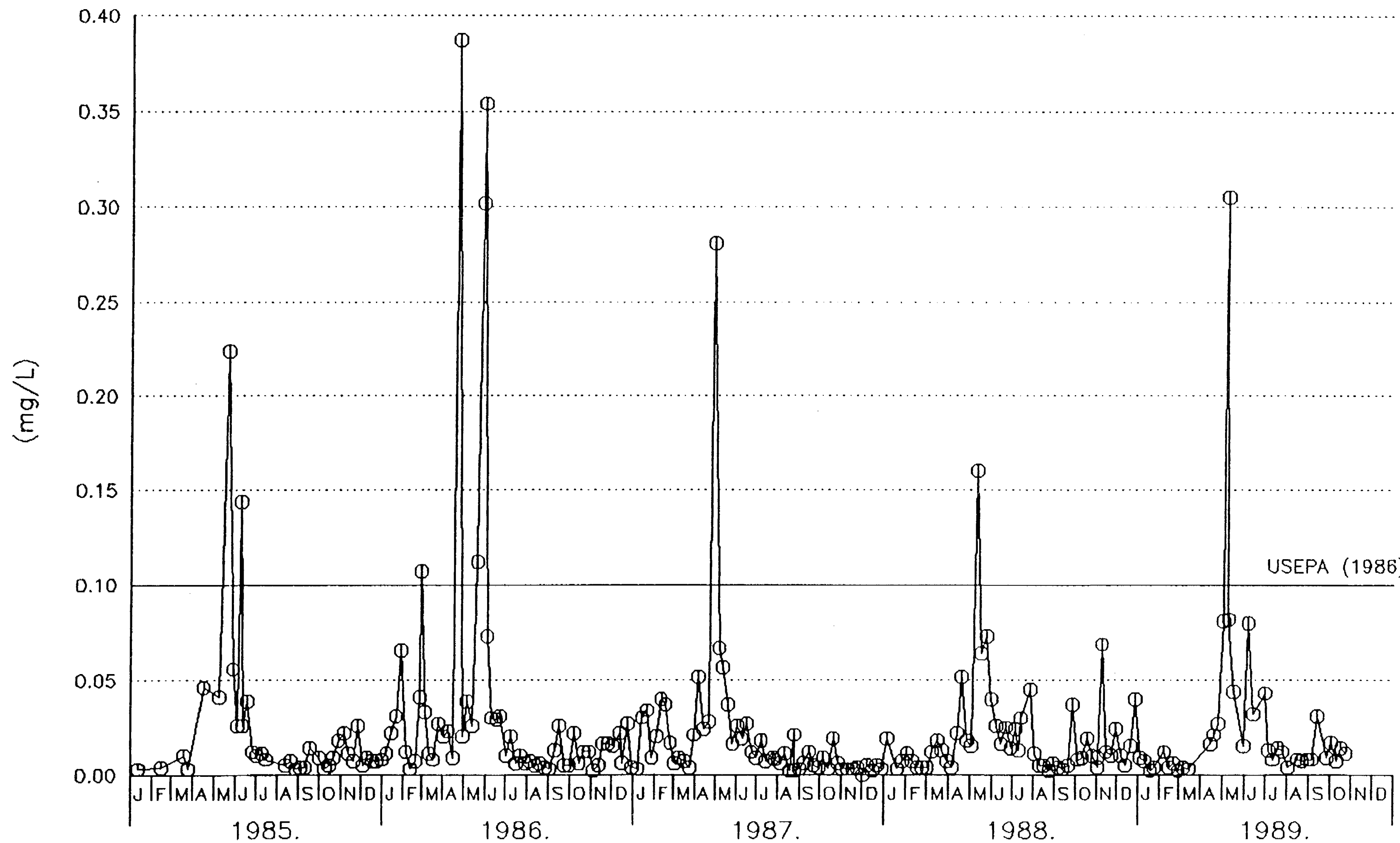

Figure A19

TOTAL PHOSPHORUS
FLATHEAD RIVER (1985 - 1989)

Environmental Management Associates

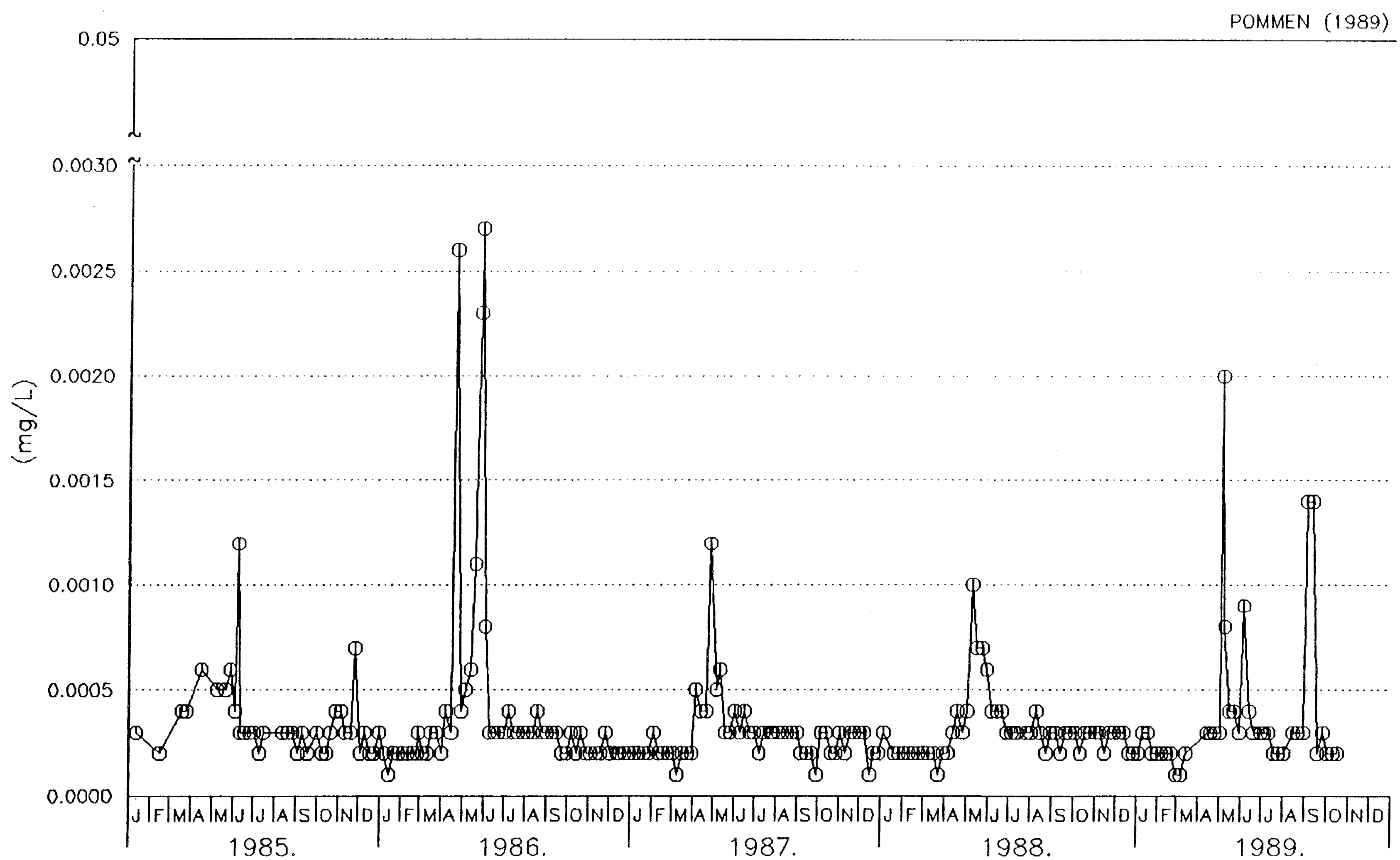

Figure A20	TOTAL ARSENIC FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

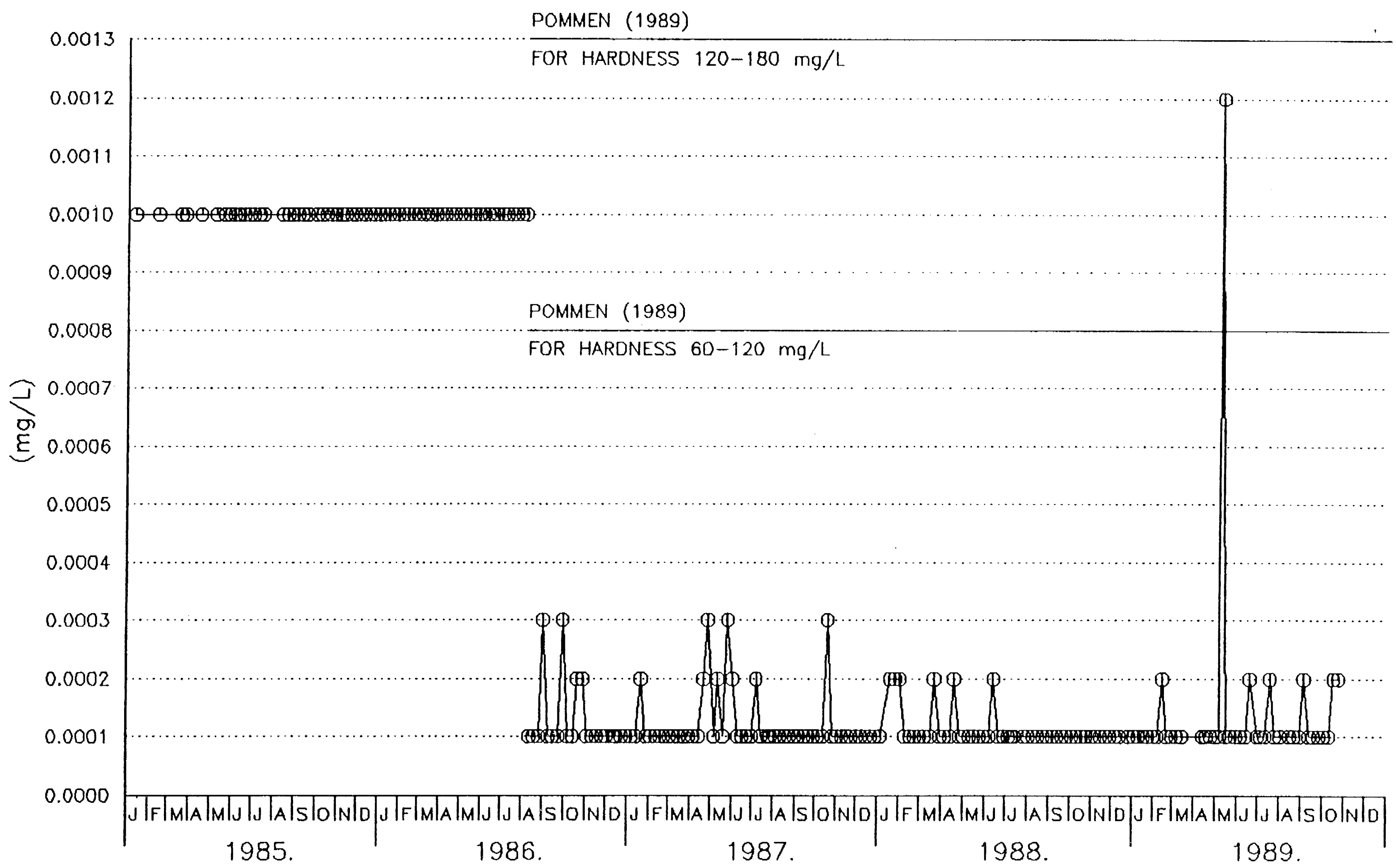

Figure A21	TOTAL CADMIUM FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

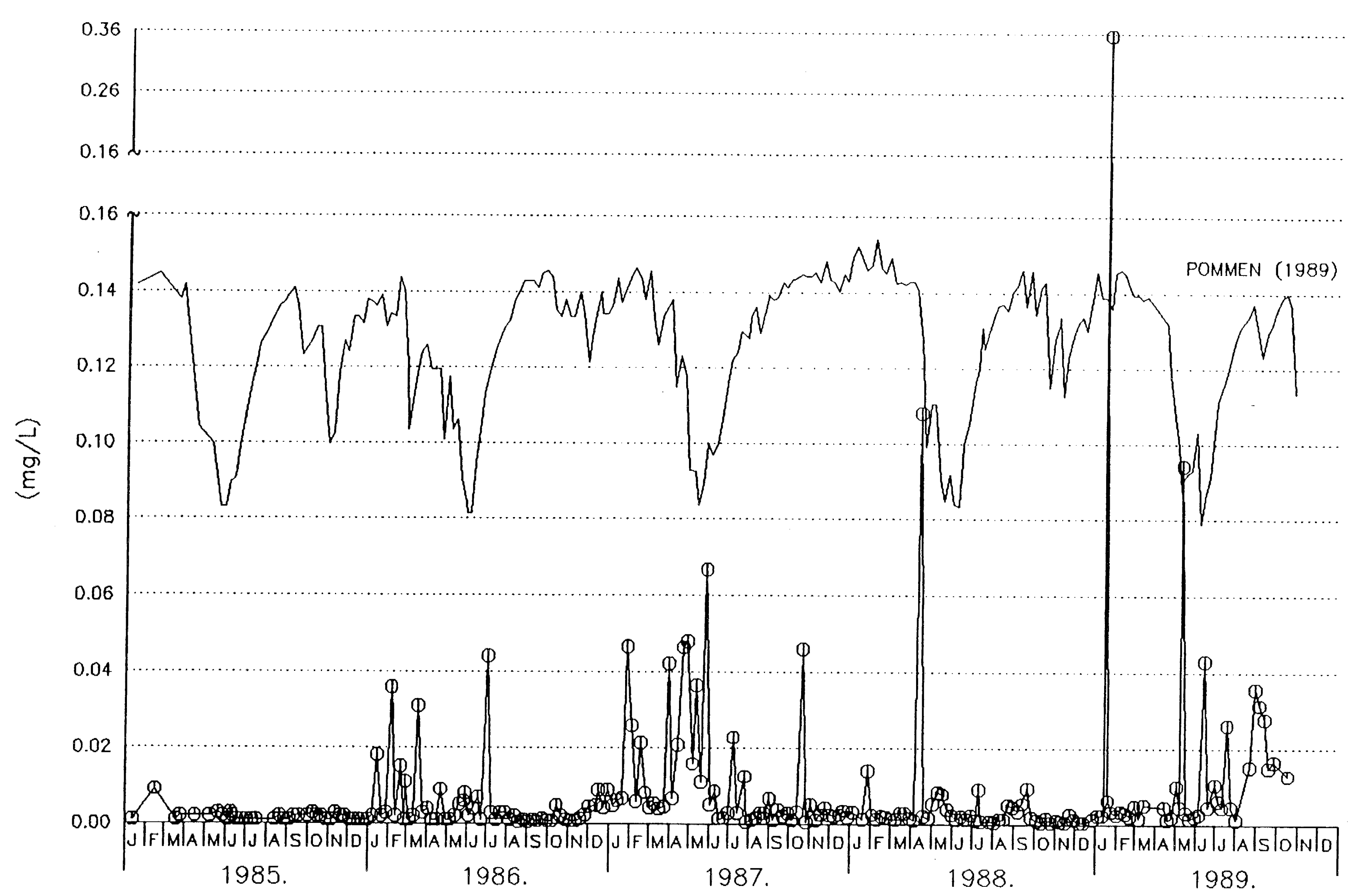

Figure A22	TOTAL COPPER FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

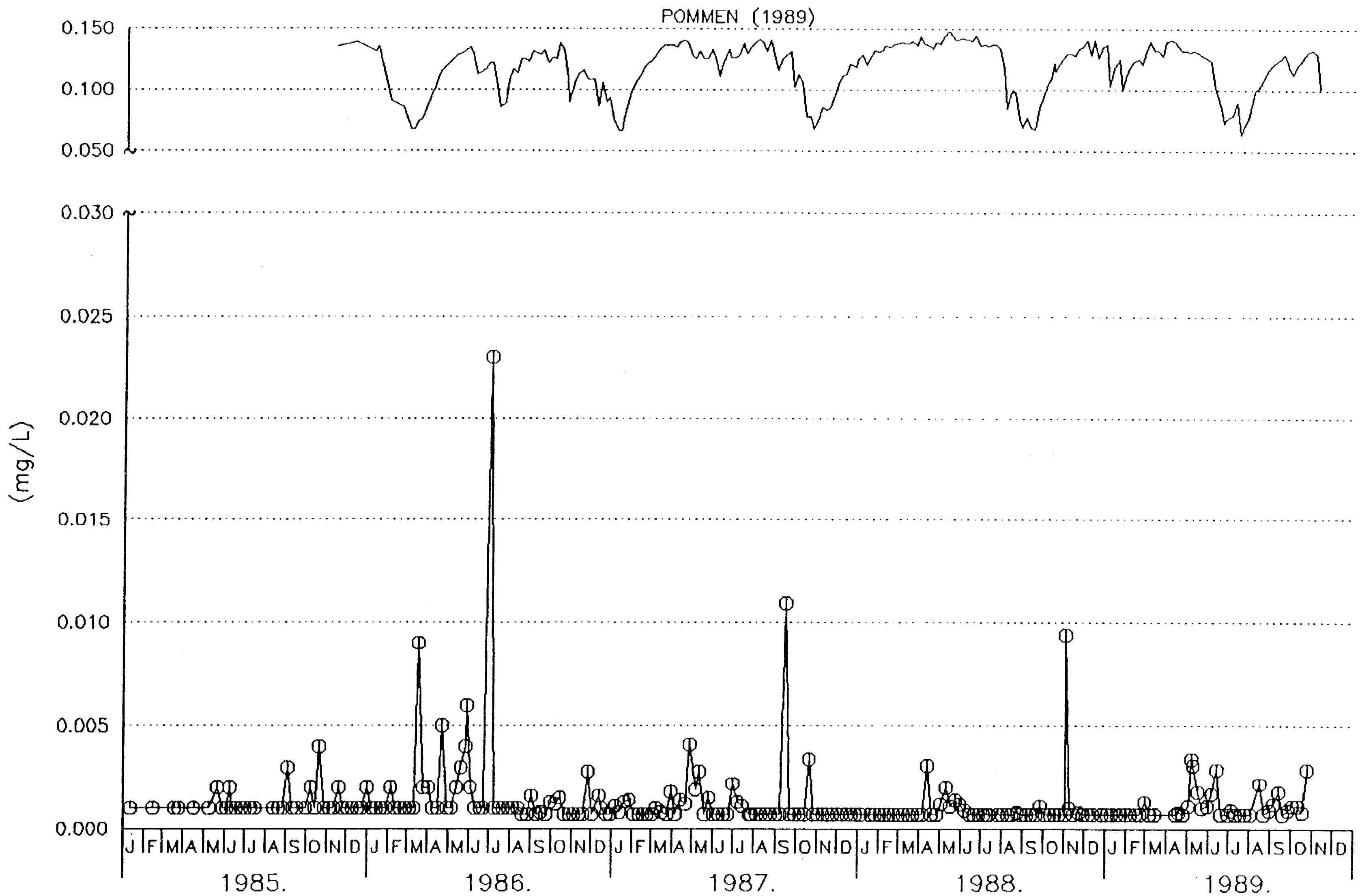

Figure A23	TOTAL LEAD FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

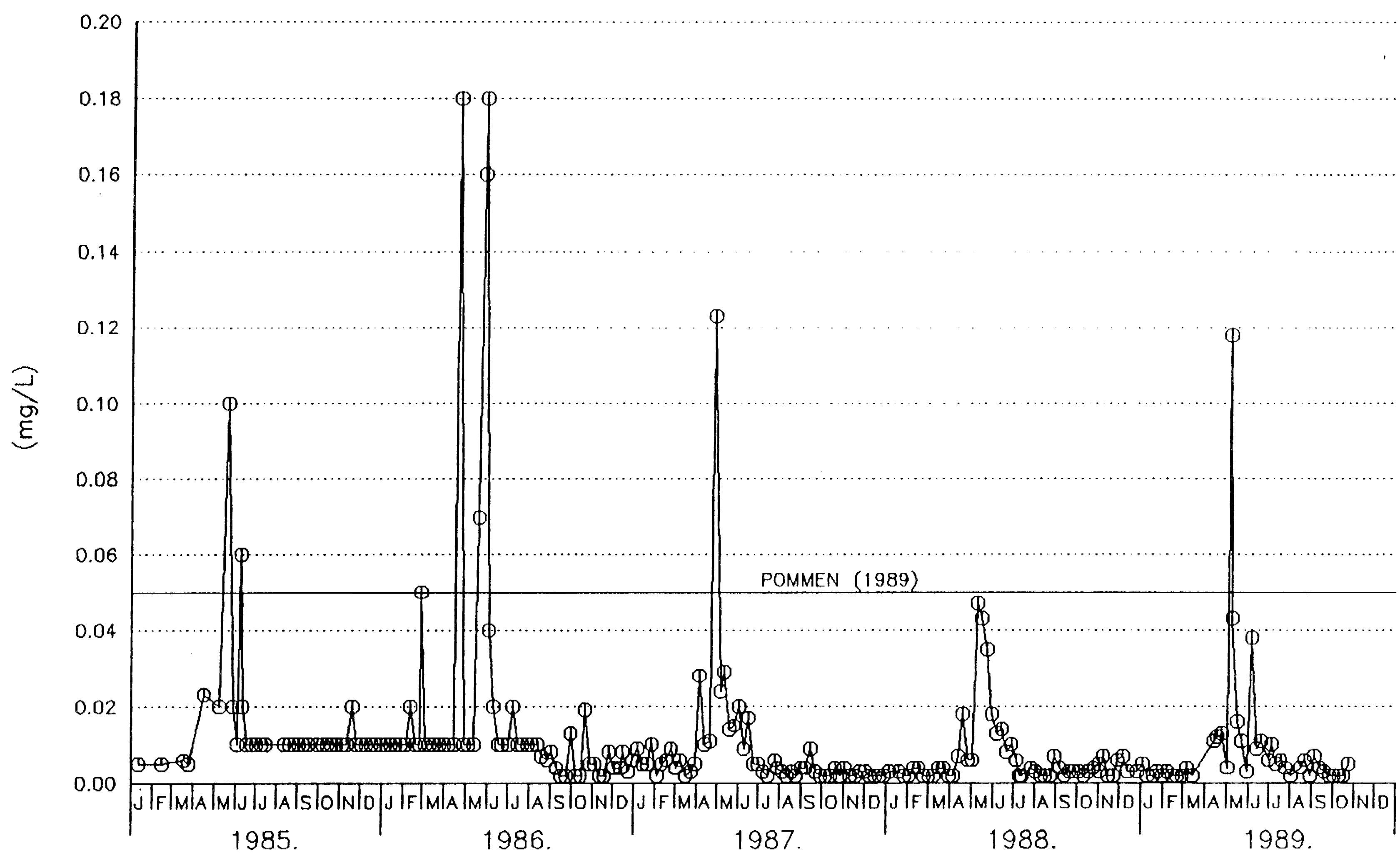

Figure A24	TOTAL MANGANESE FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

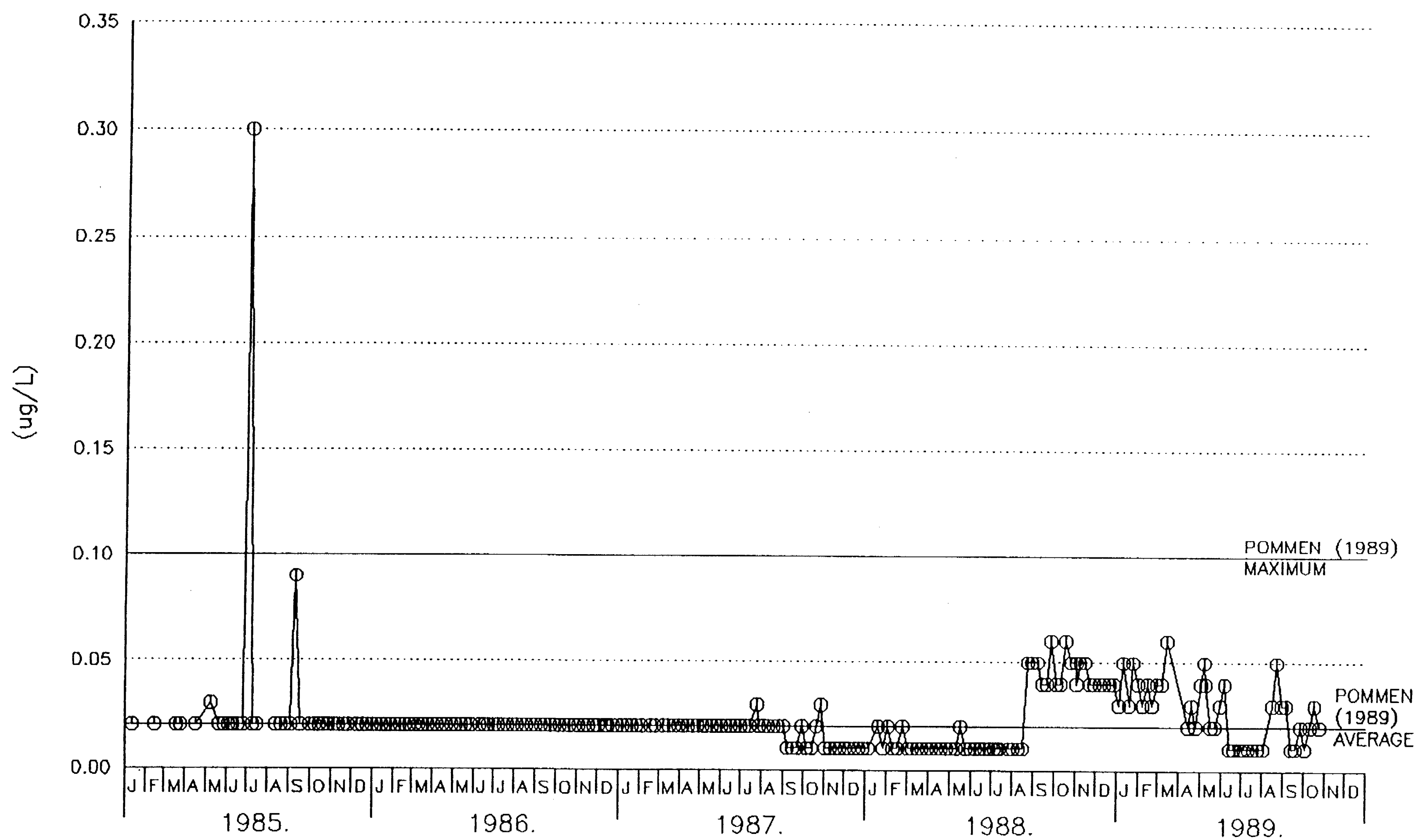

Figure A25	TOTAL MERCURY FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

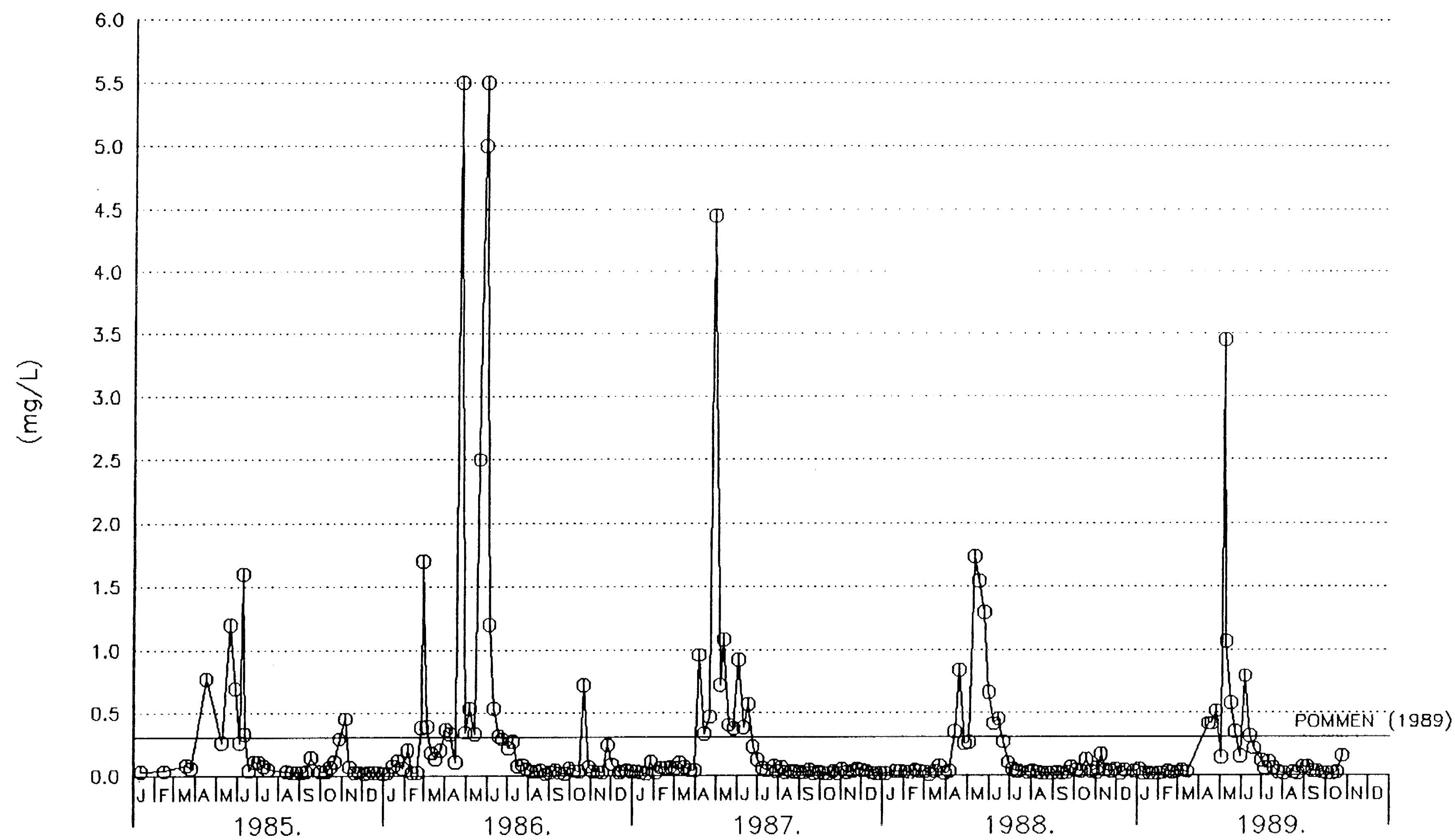

Figure A26	TOTAL IRON FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

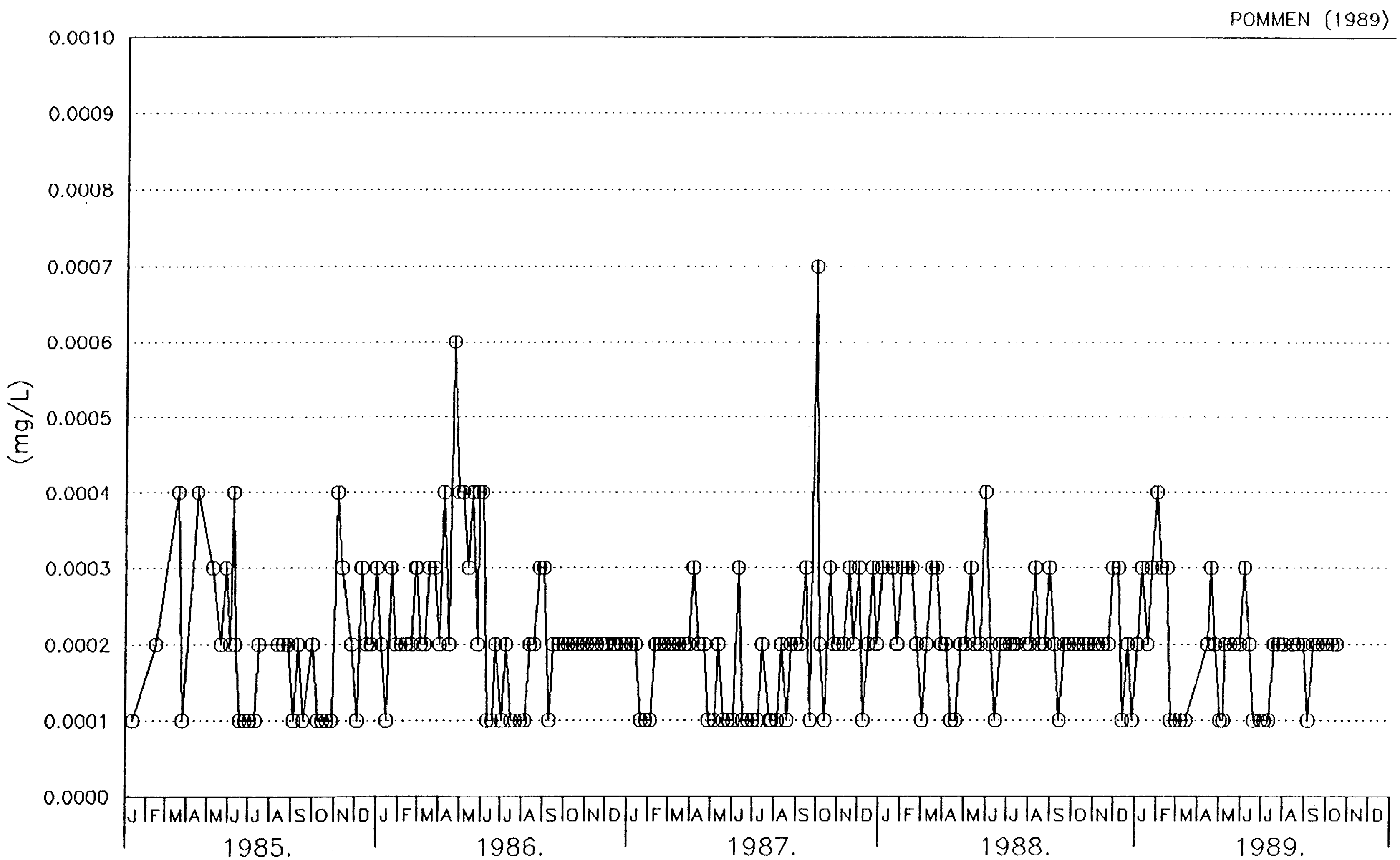

Figure A27	TOTAL SELENIUM FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

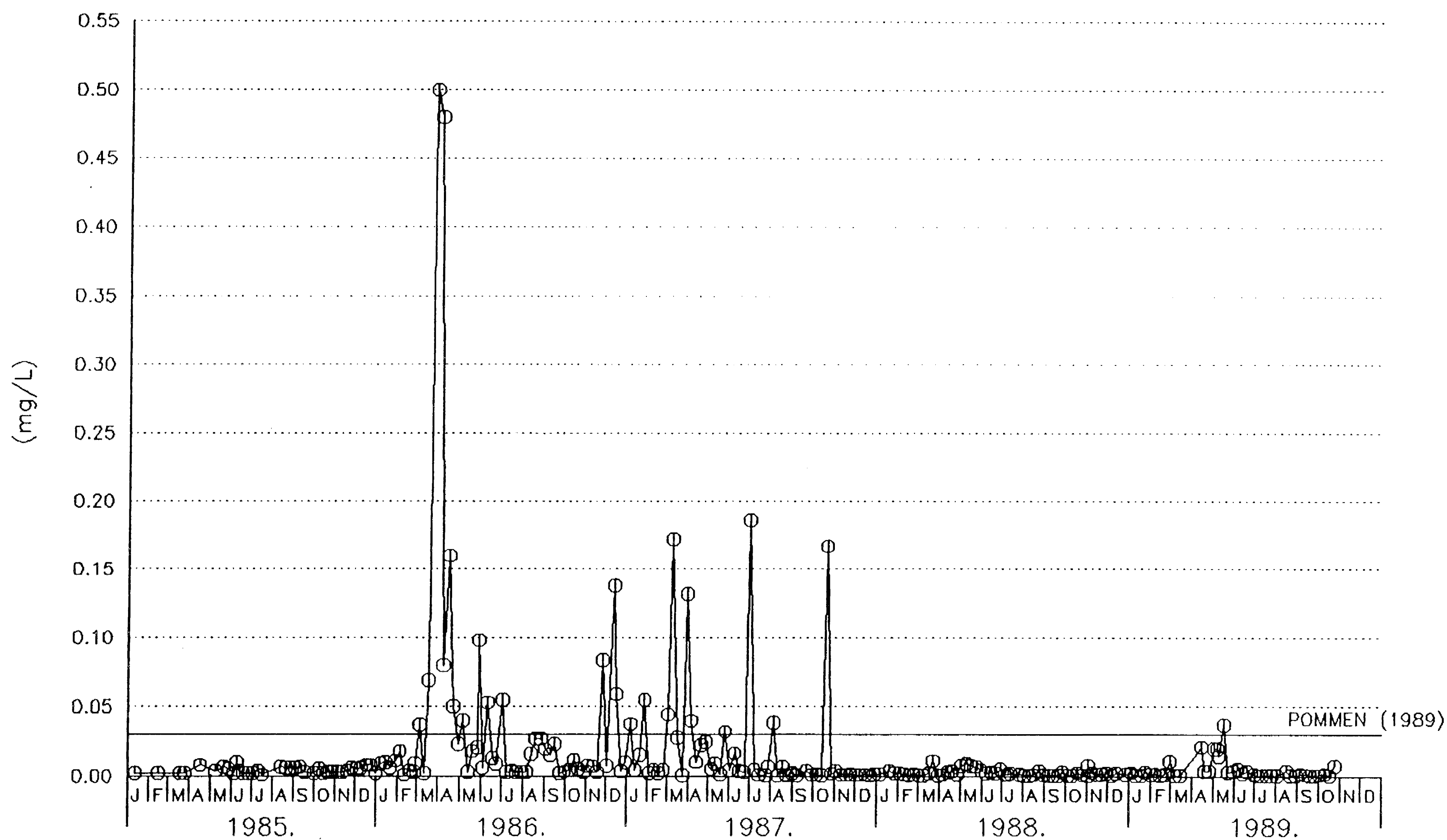

Figure A28	TOTAL ZINC FLATHEAD RIVER (1985 – 1989)	Environmental Management Associates

APPENDIX B

Time-Series Plots

Similkameen River

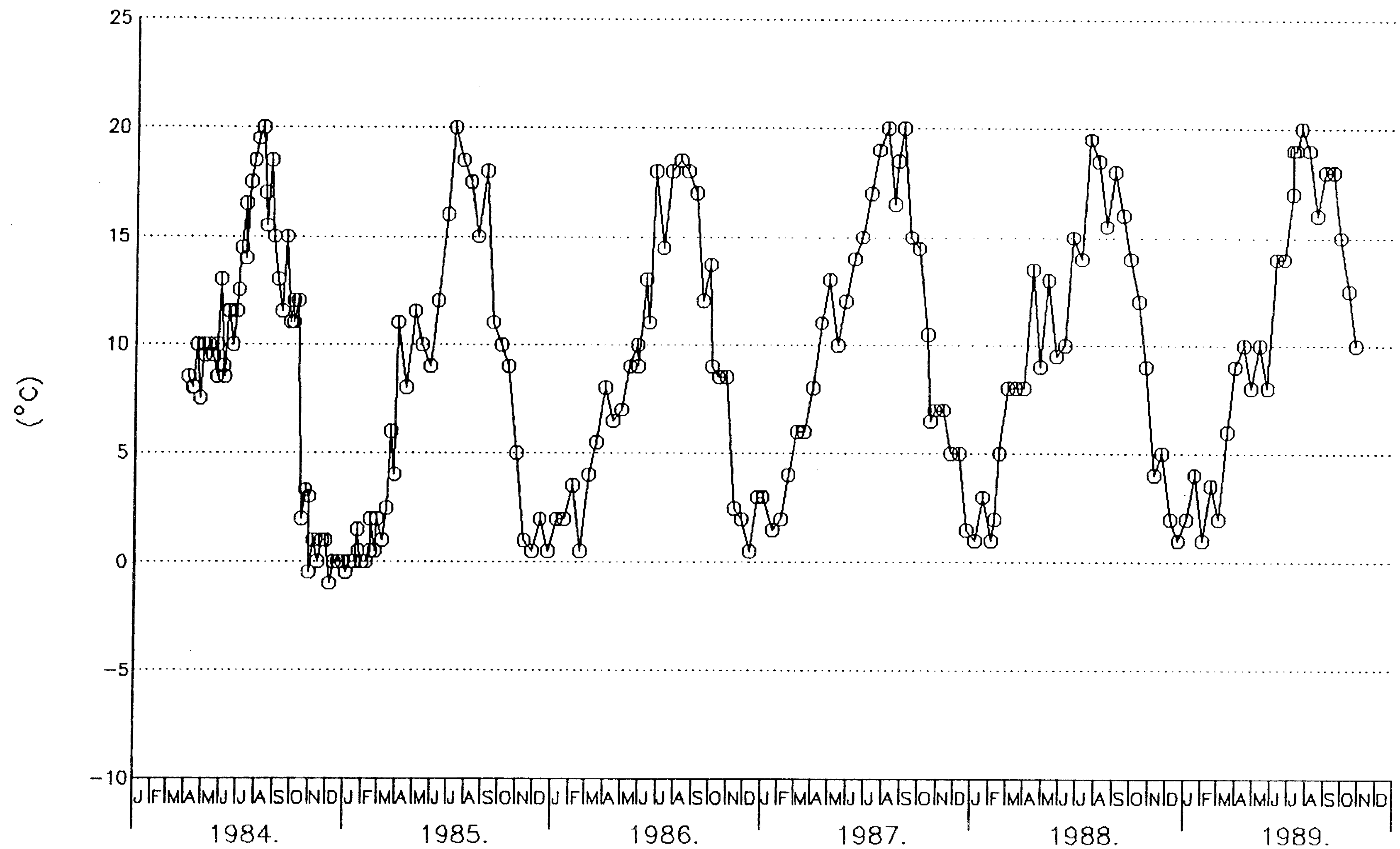

Figure B1	WATER TEMPERATURE SIMILKAMEEN RIVER (1984 - 1989)	Environmental Management Associates

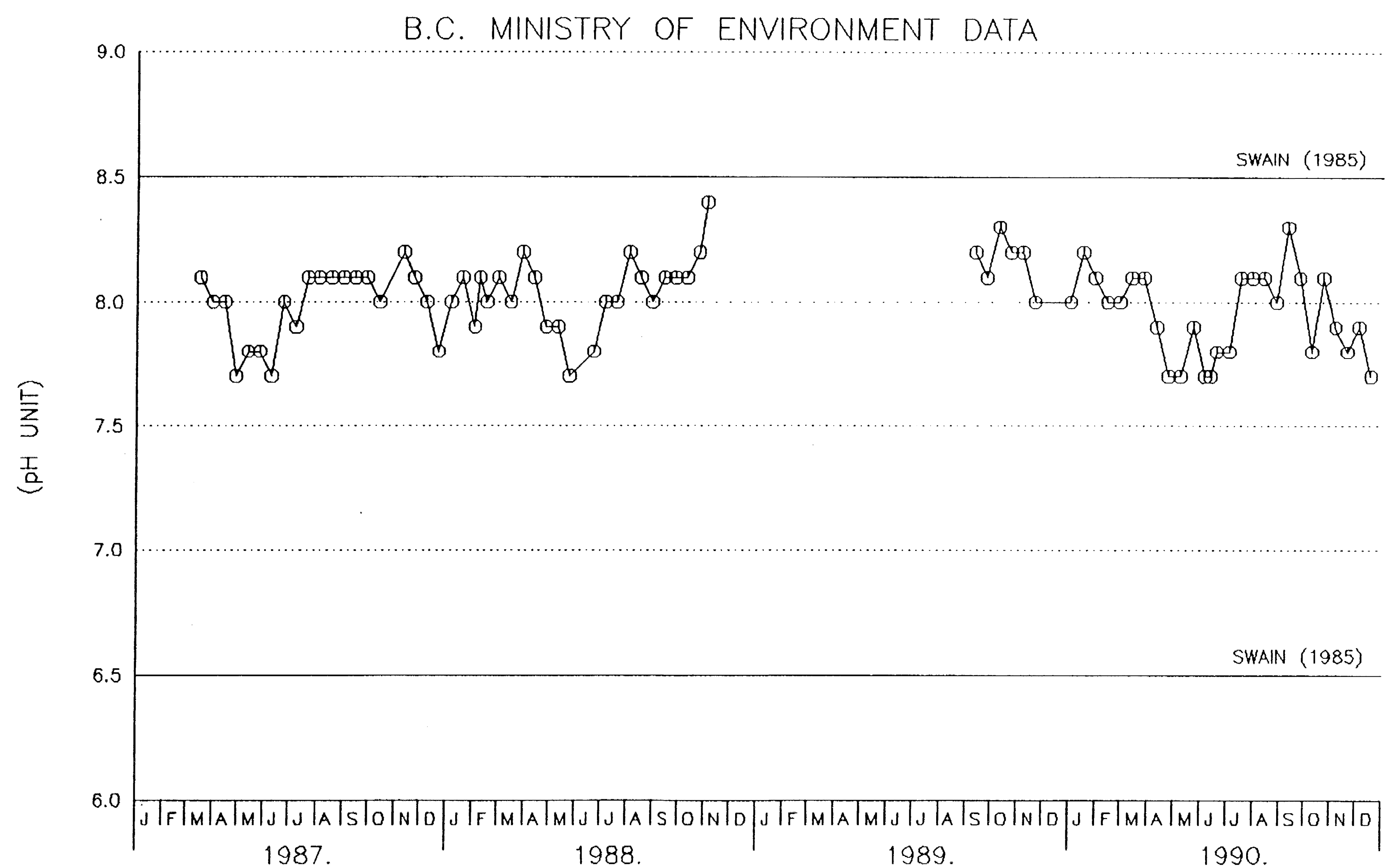

Figure B2	pH SIMILKAMEEN RIVER (1987 – 1990)	Environmental Management Associates

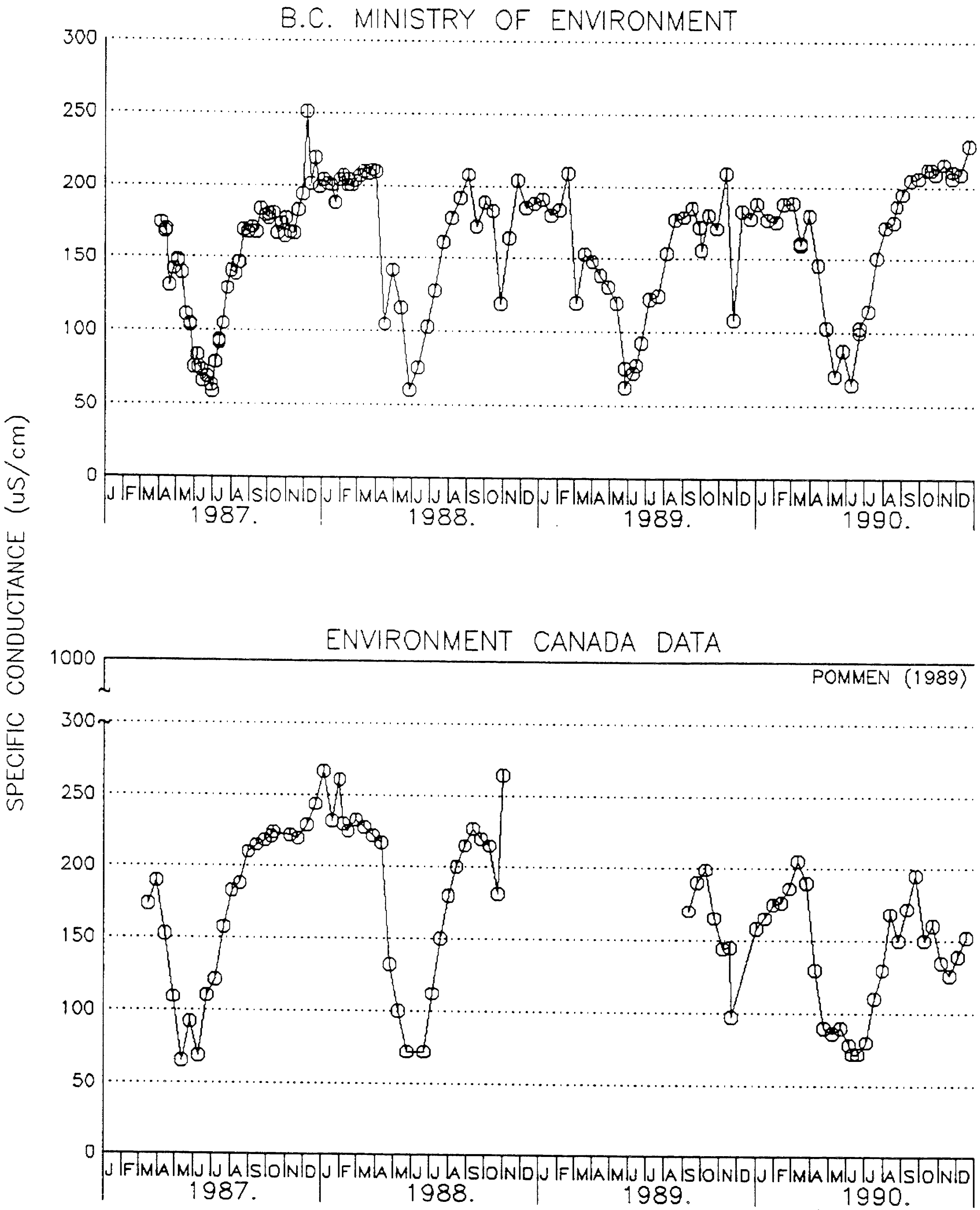

Figure B3	SPECIFIC CONDUCTANCE SIMILKAMEEN RIVER	Environmental Management Associates

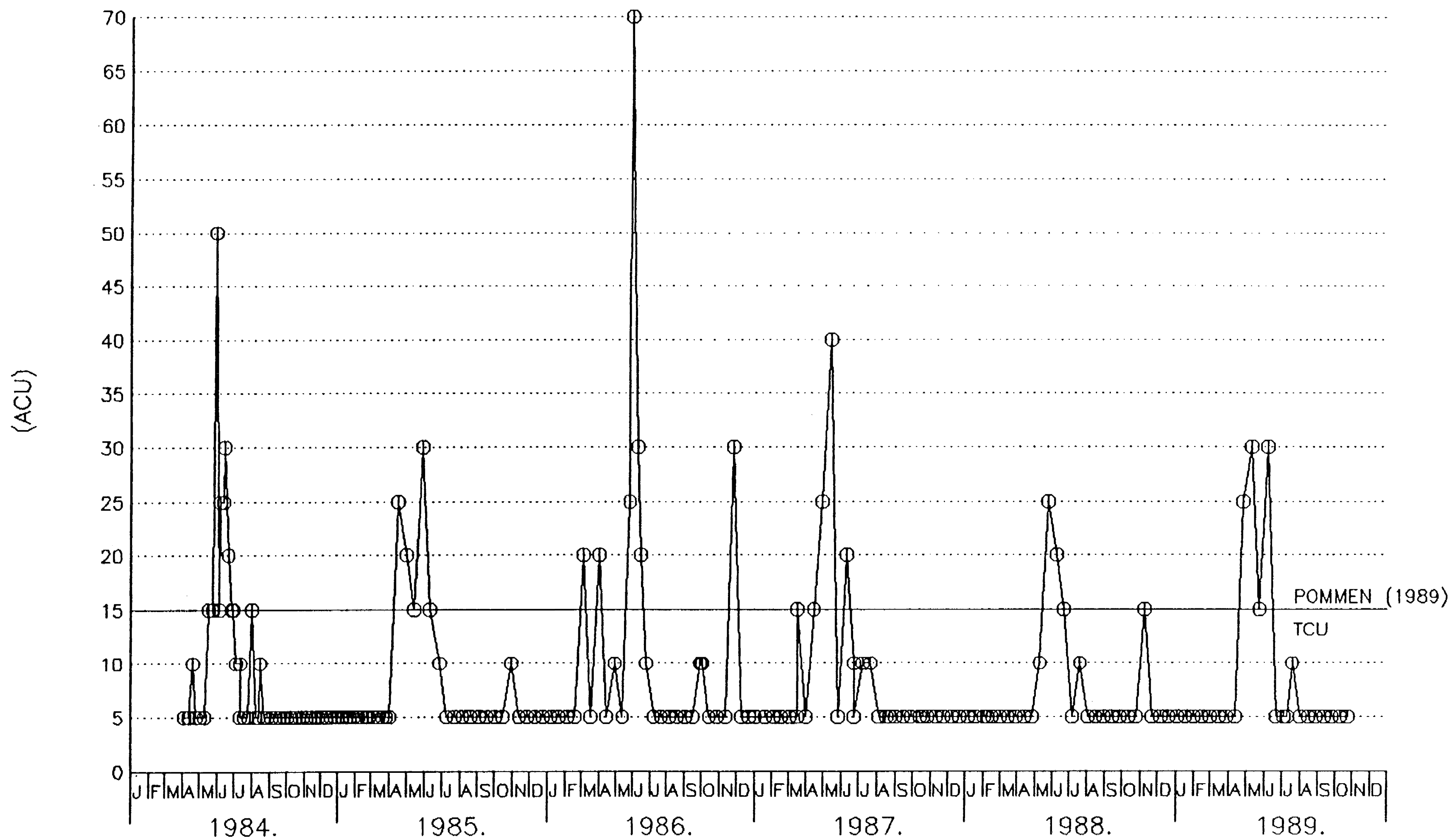

Figure B4

APPARENT COLOUR
SIMILKAMEEN RIVER (1984 – 1989)

Environmental Management Associates

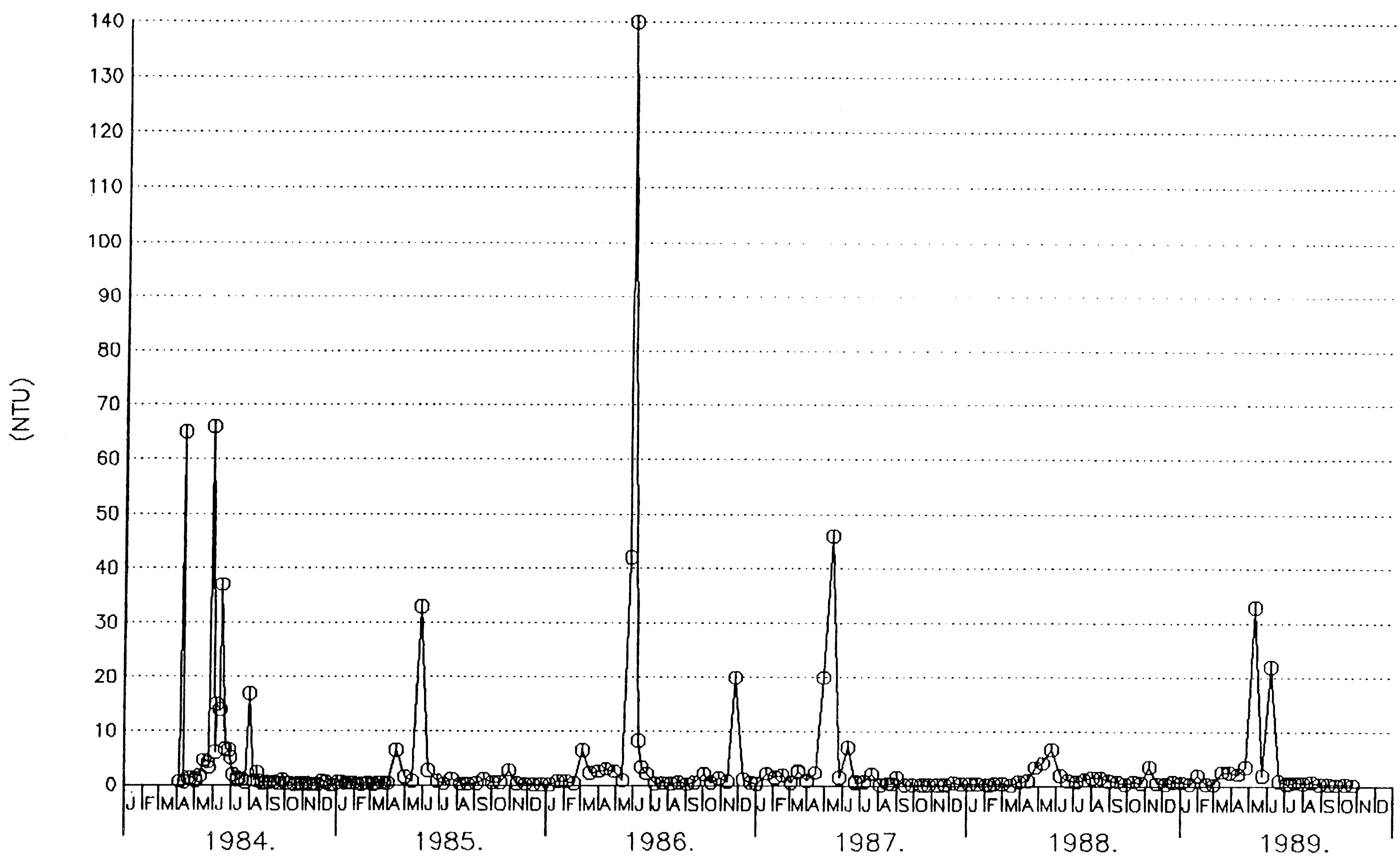

Figure B5	TURBIDITY SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

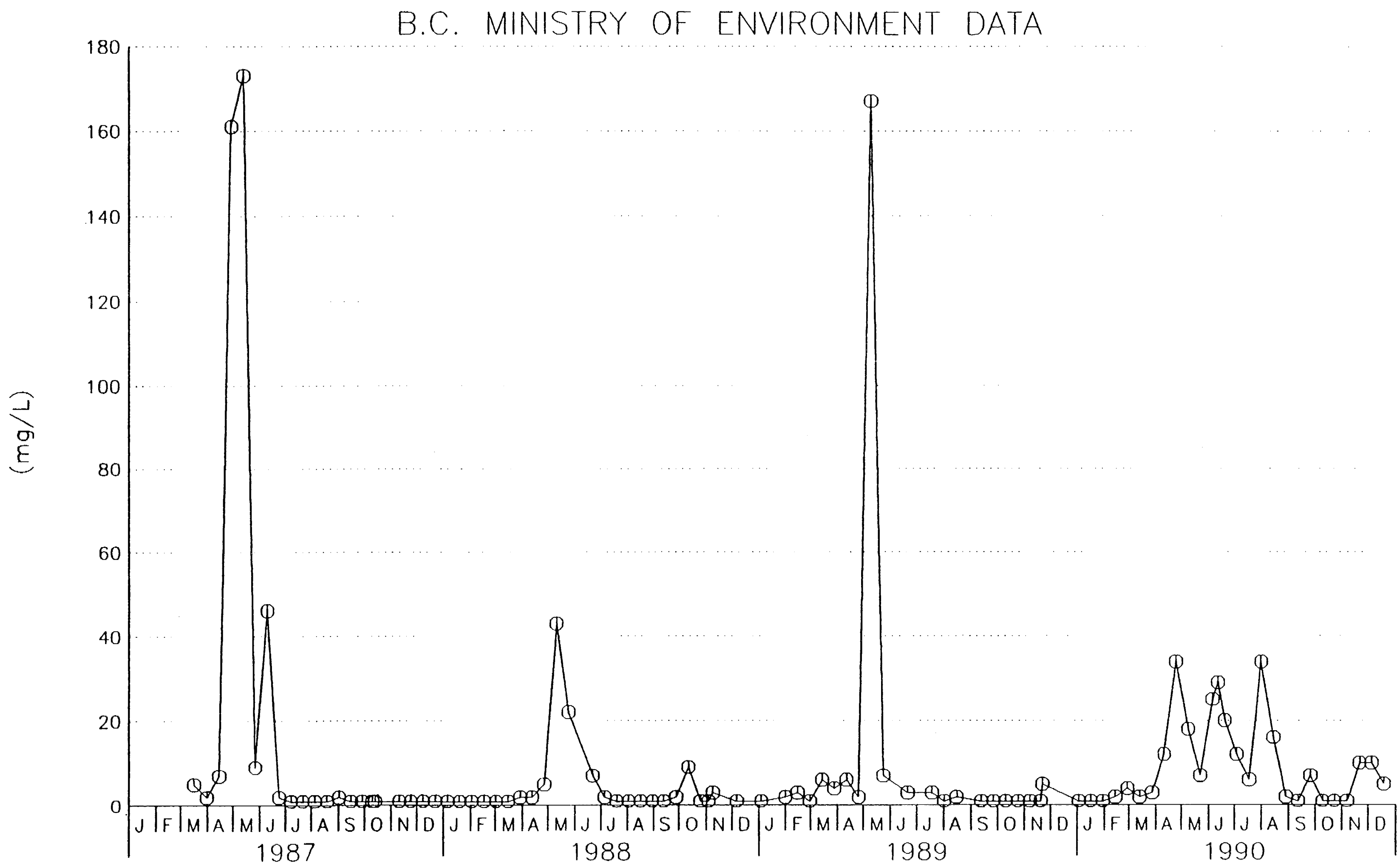

Figure B6 | NON-FILTERABLE RESIDUE SIMILKAMEEN RIVER (1987 – 1990) | Environmental Management Associates

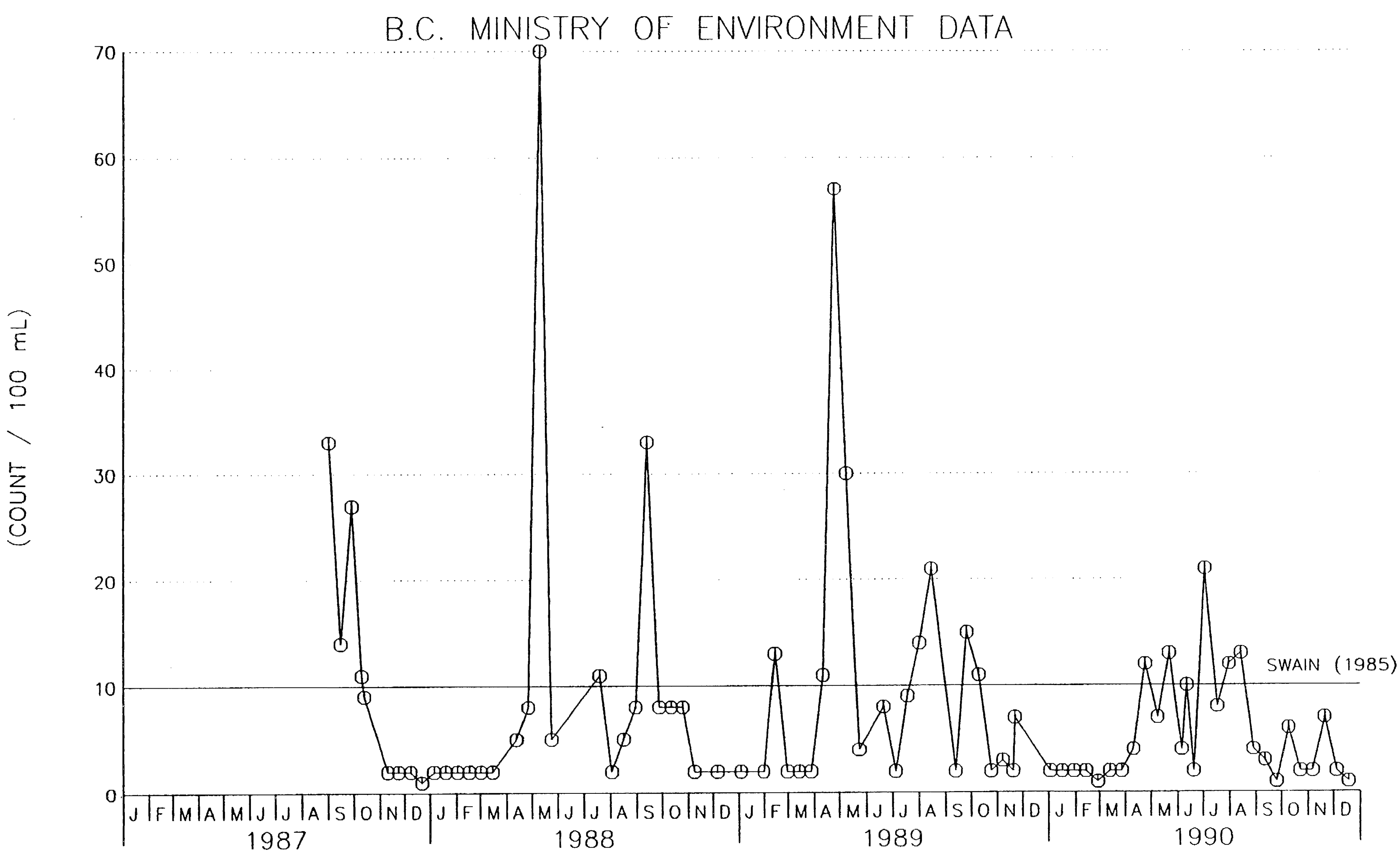

Figure B7	FECAL COLIFORMS SIMILKAMEEN RIVER (1987 – 1990)	Environmental Management Associates

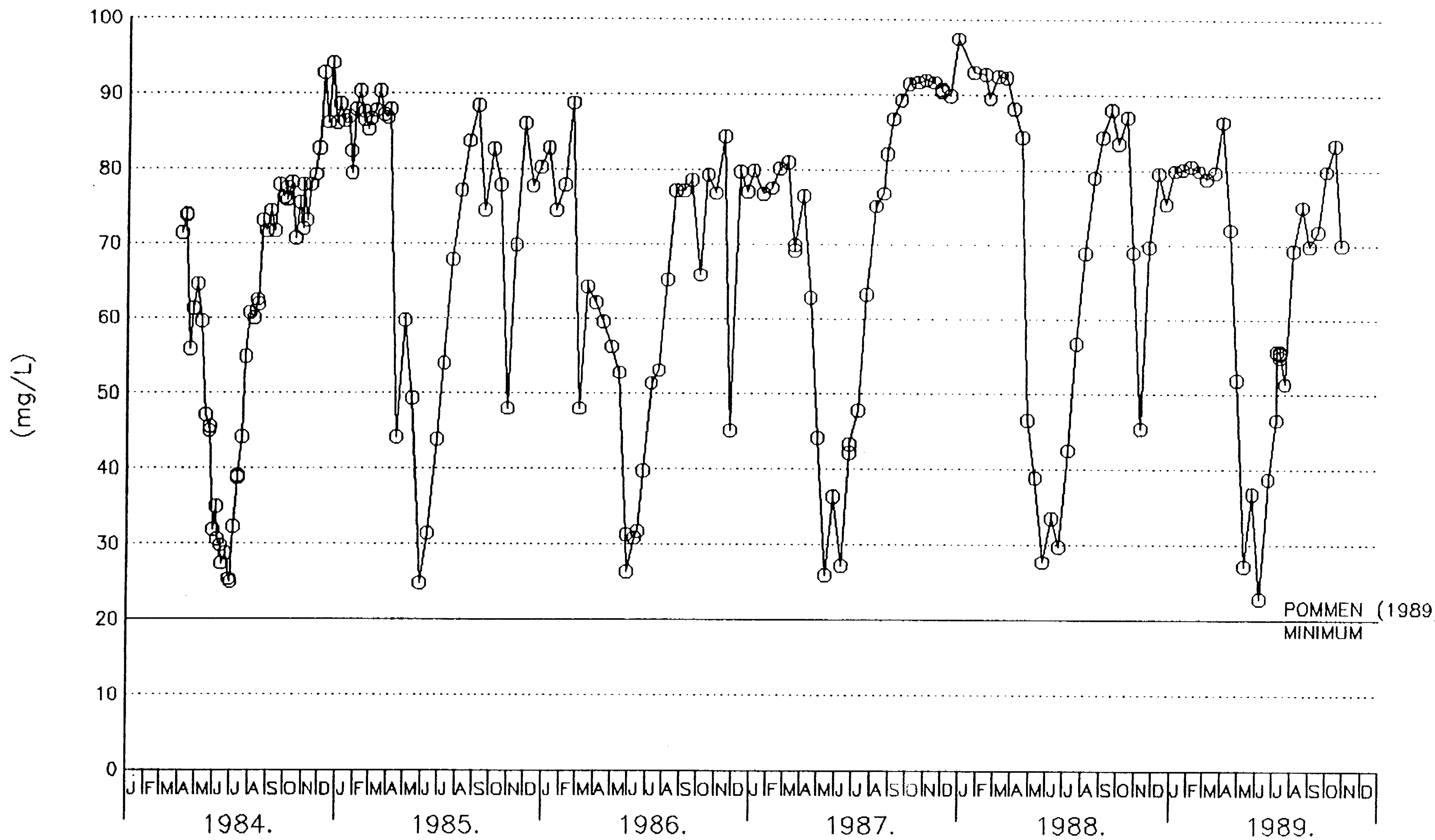

Figure B8

TOTAL ALKALINITY
SIMILKAMEEN RIVER (1984 – 1989)

Environmental
Management Associates

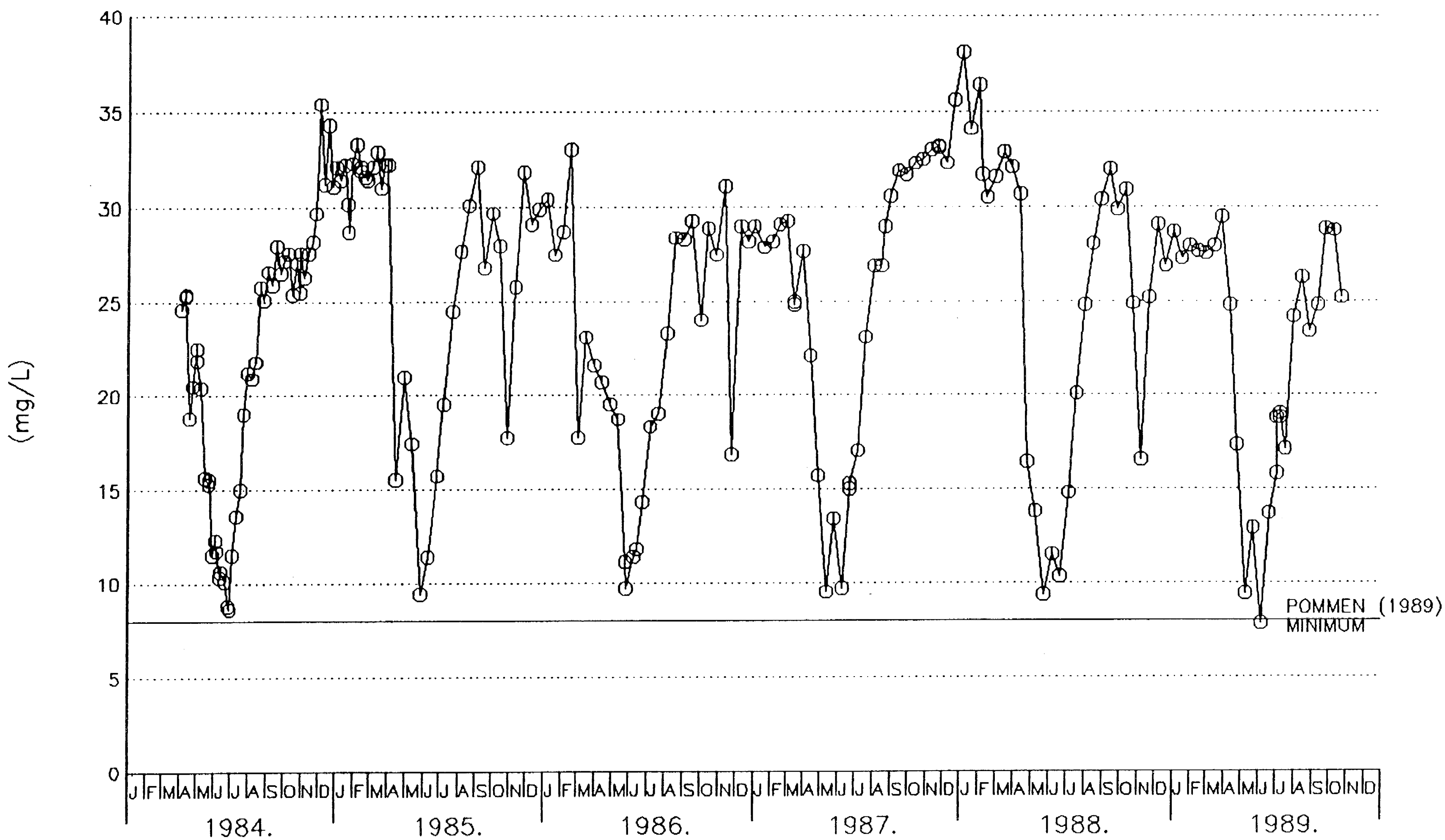

Figure B9	CALCIUM SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

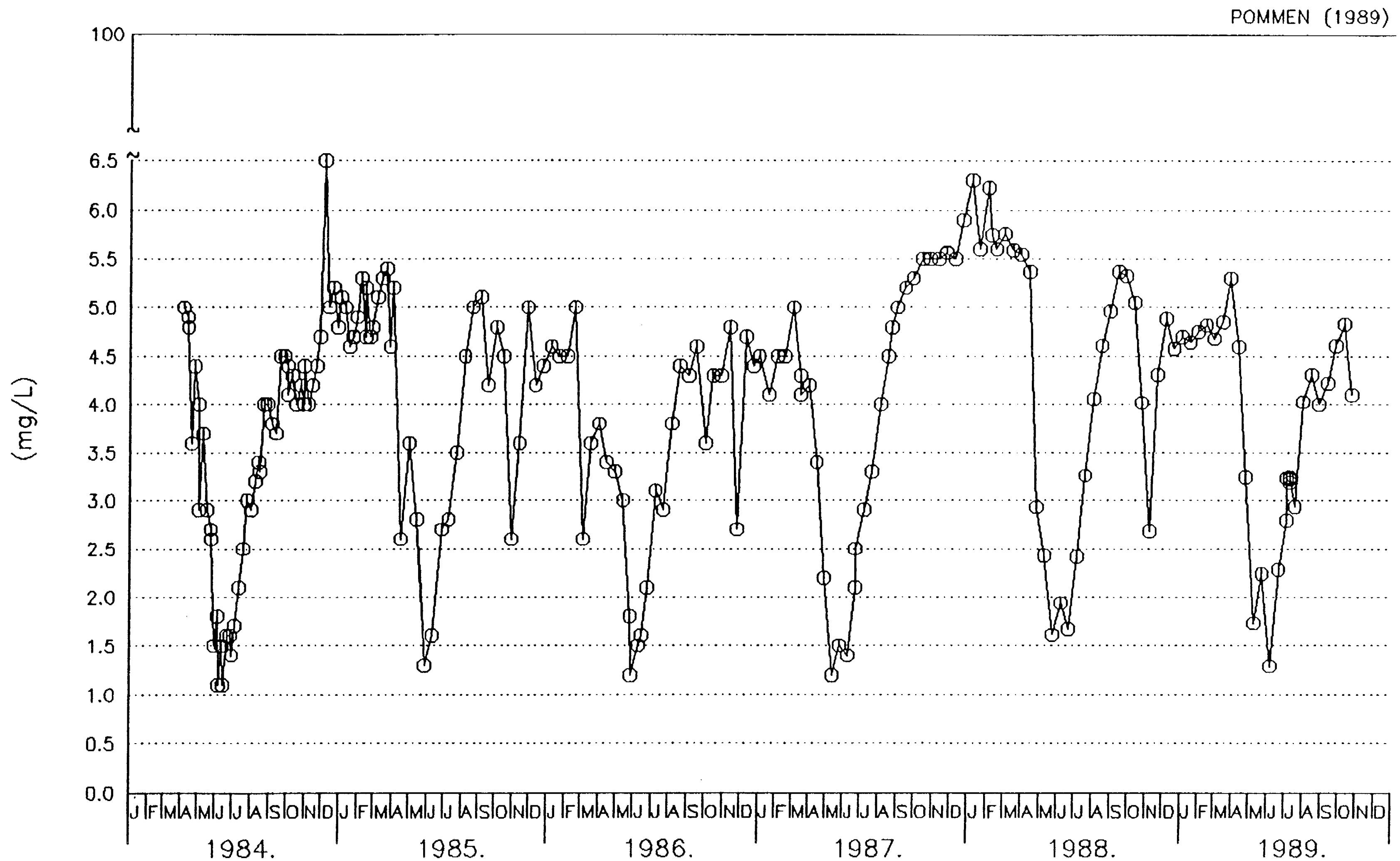

Figure B10	MAGNESIUM SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

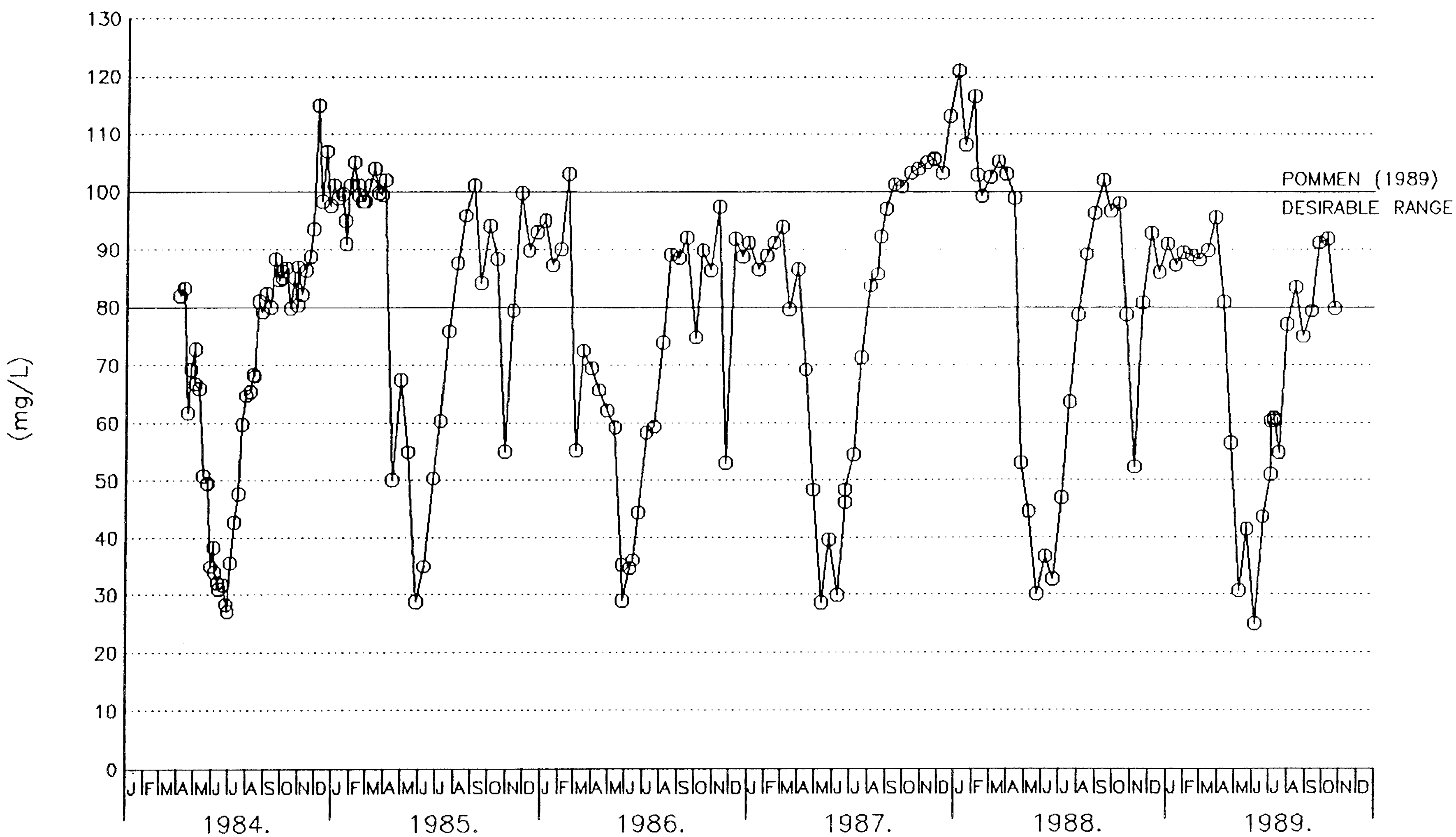

Figure B11	HARDNESS SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

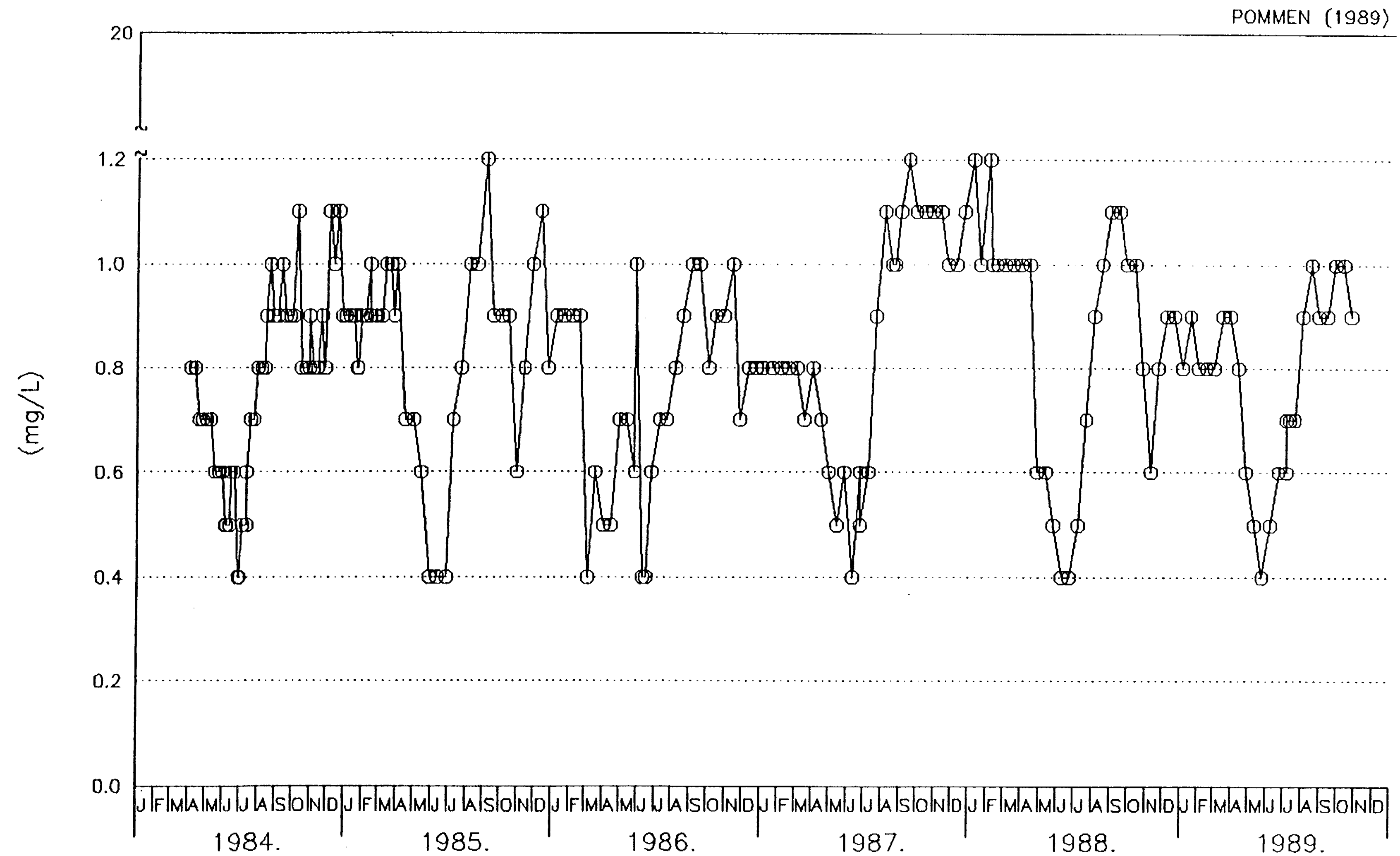

Figure B12

POTASSIUM
SIMILKAMEEN RIVER (1984 – 1989)

Environmental Management Associates

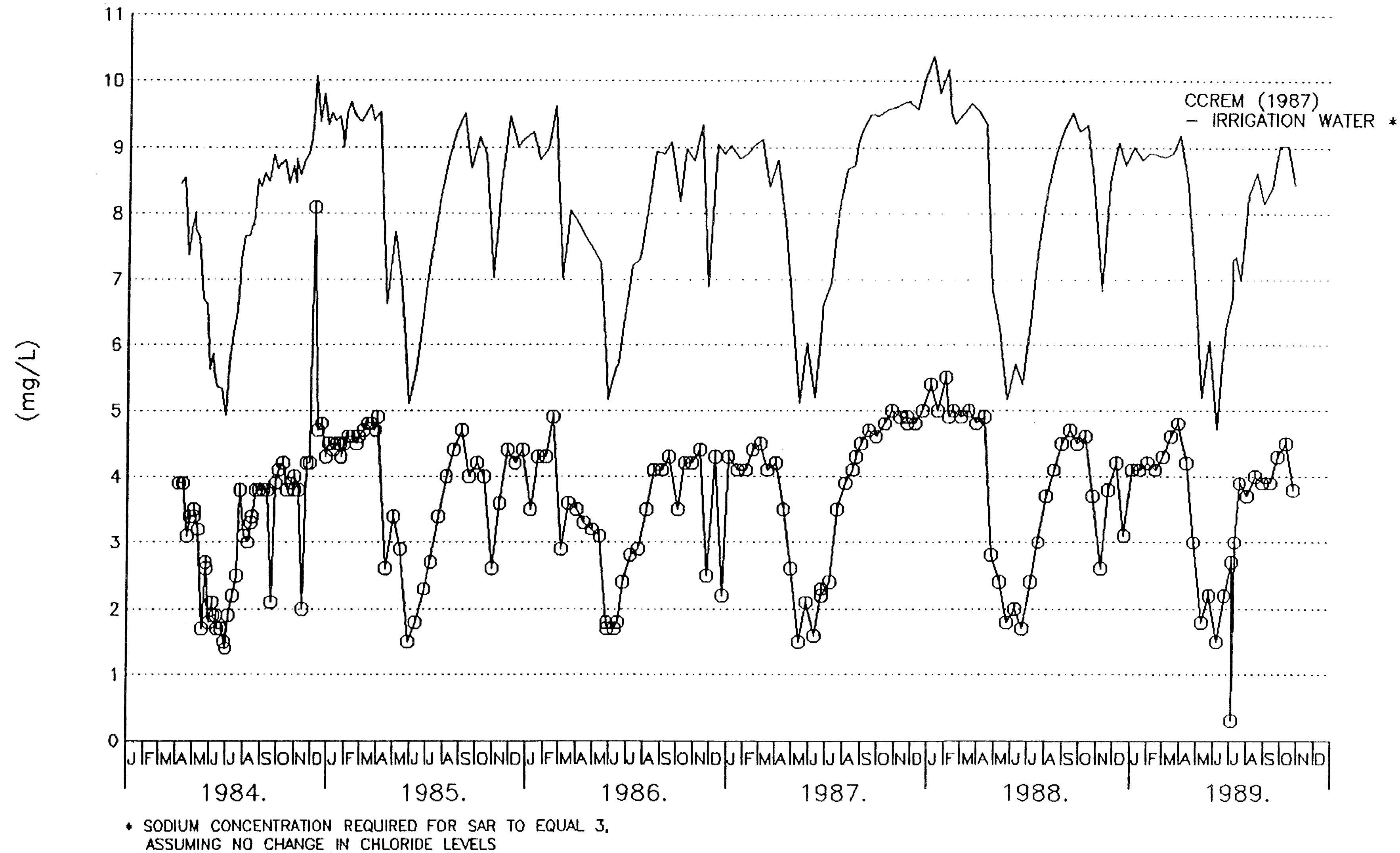

Figure B13	SODIUM SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

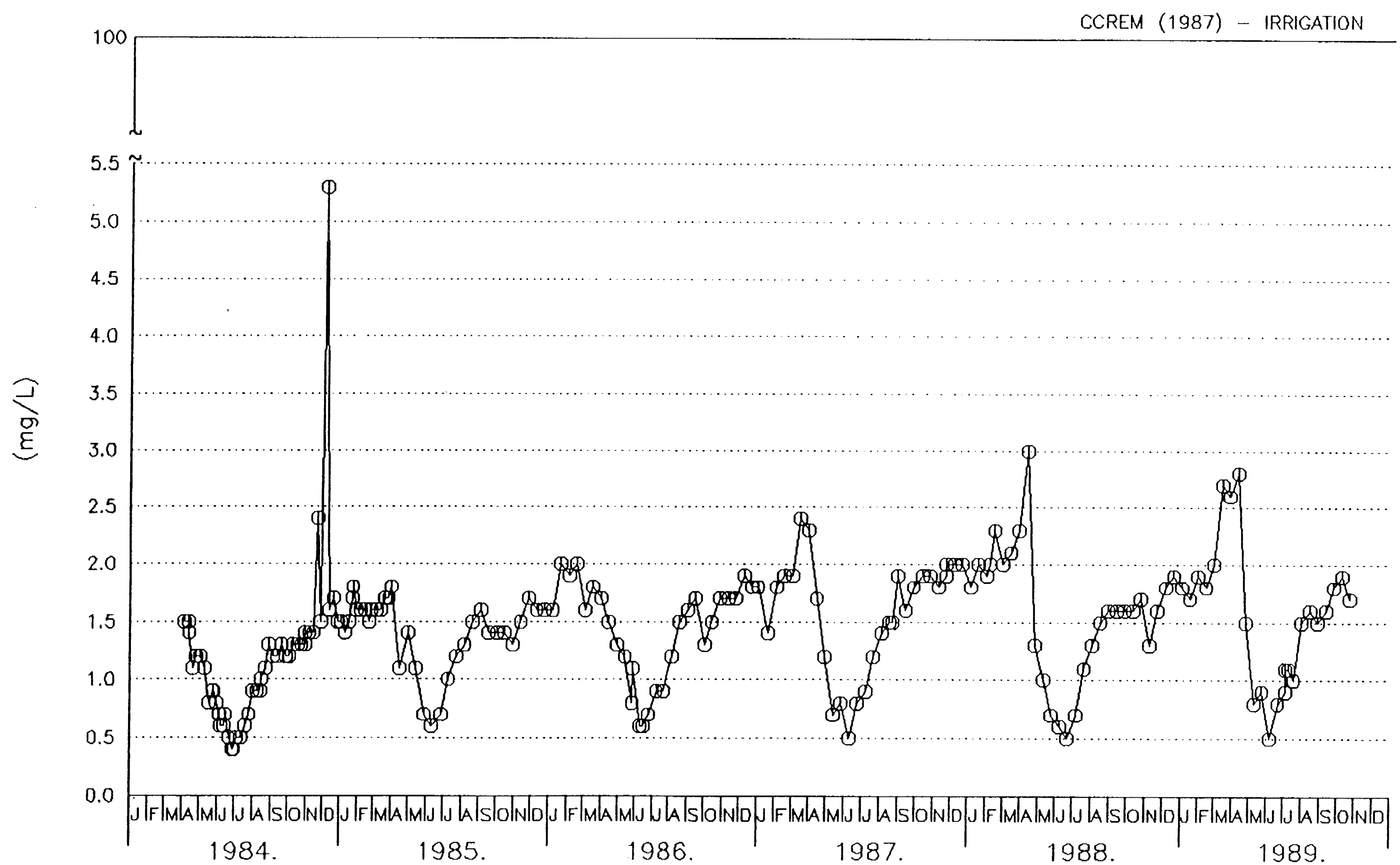

Figure B14	CHLORIDE SIMILKAMEEN RIVER (1984 - 1989)	Environmental Management Associates

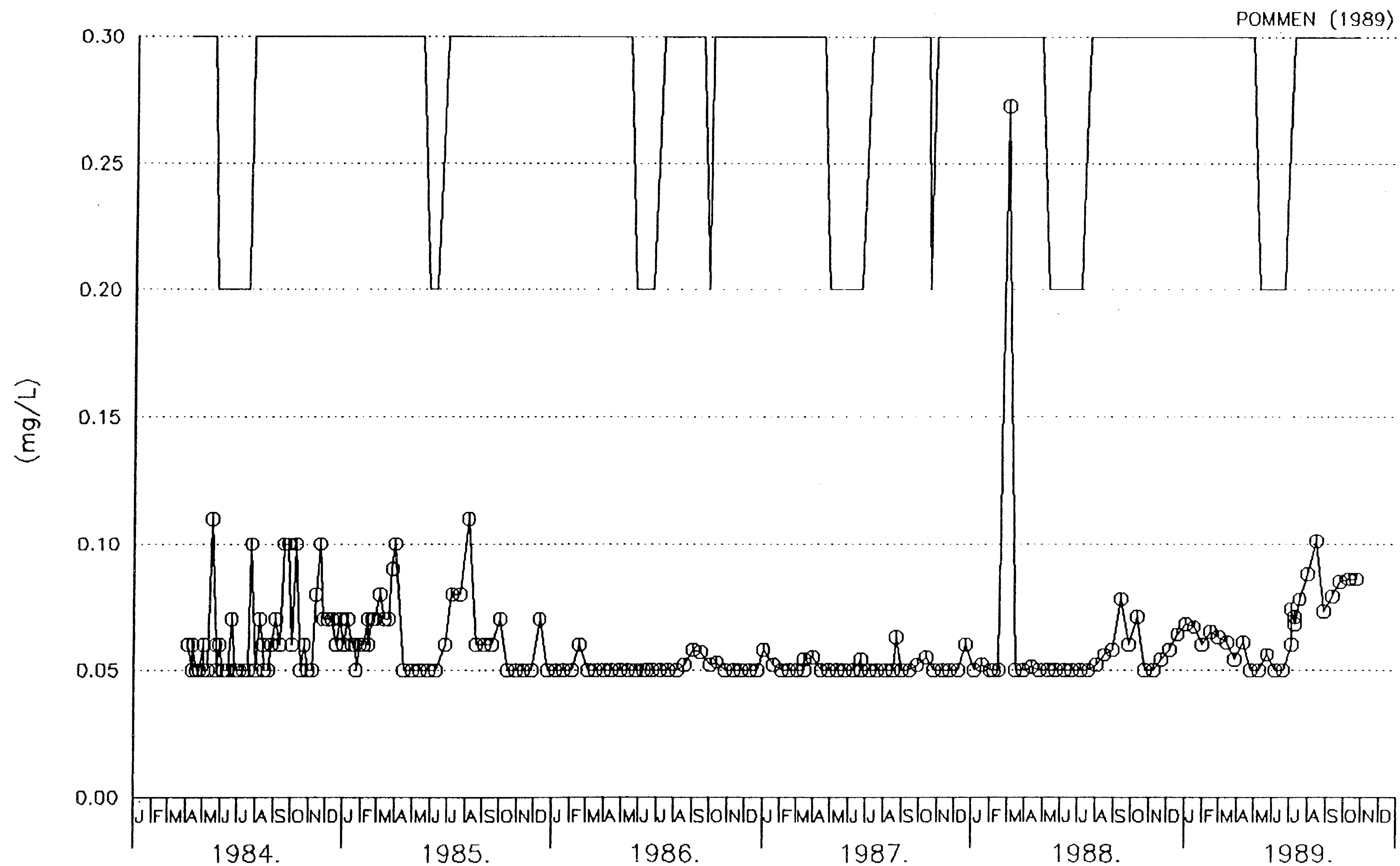

Figure B15	FLUORIDE SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

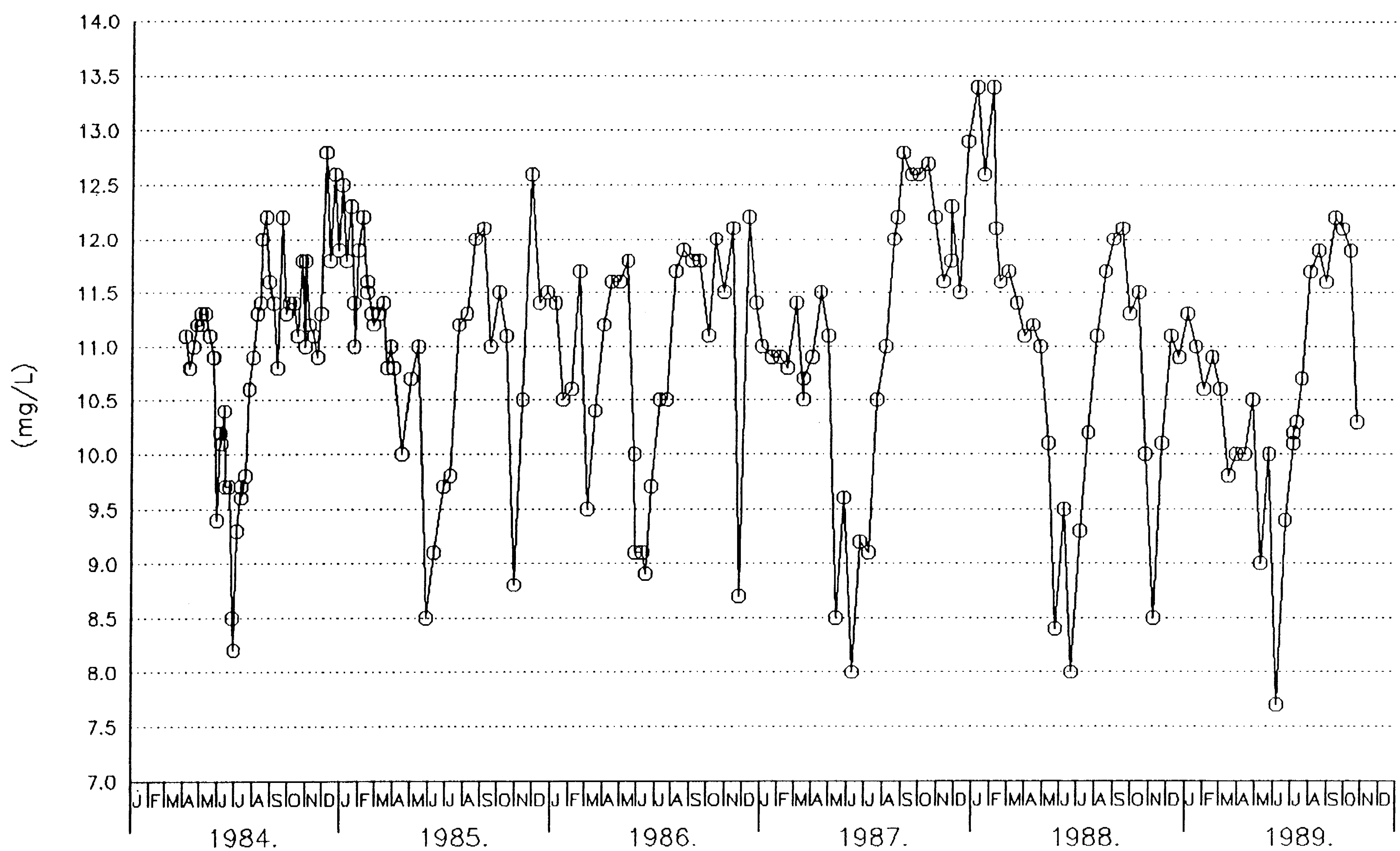

Figure B16	REACTIVE SILICA SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

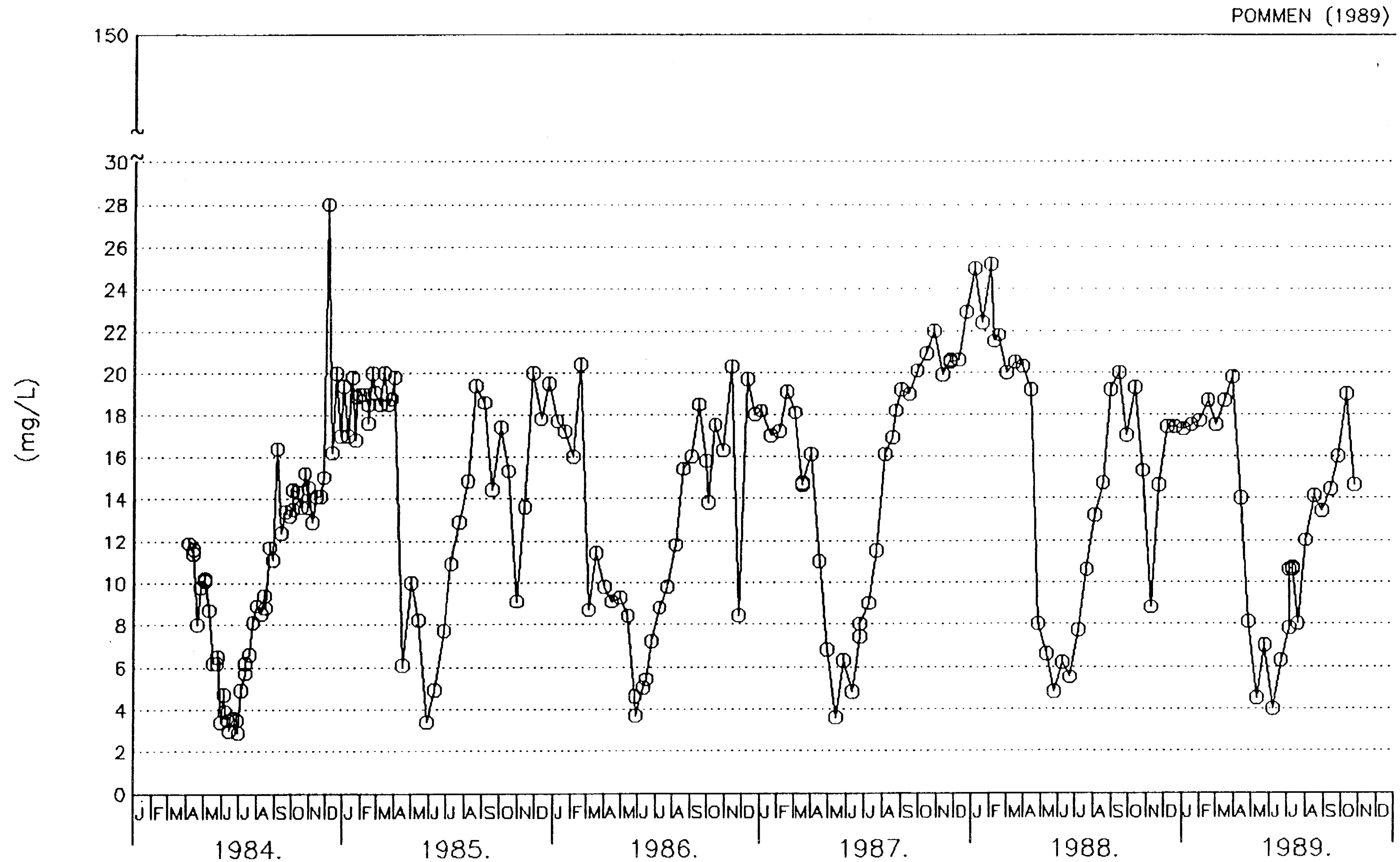

Figure B17	SULPHATE SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

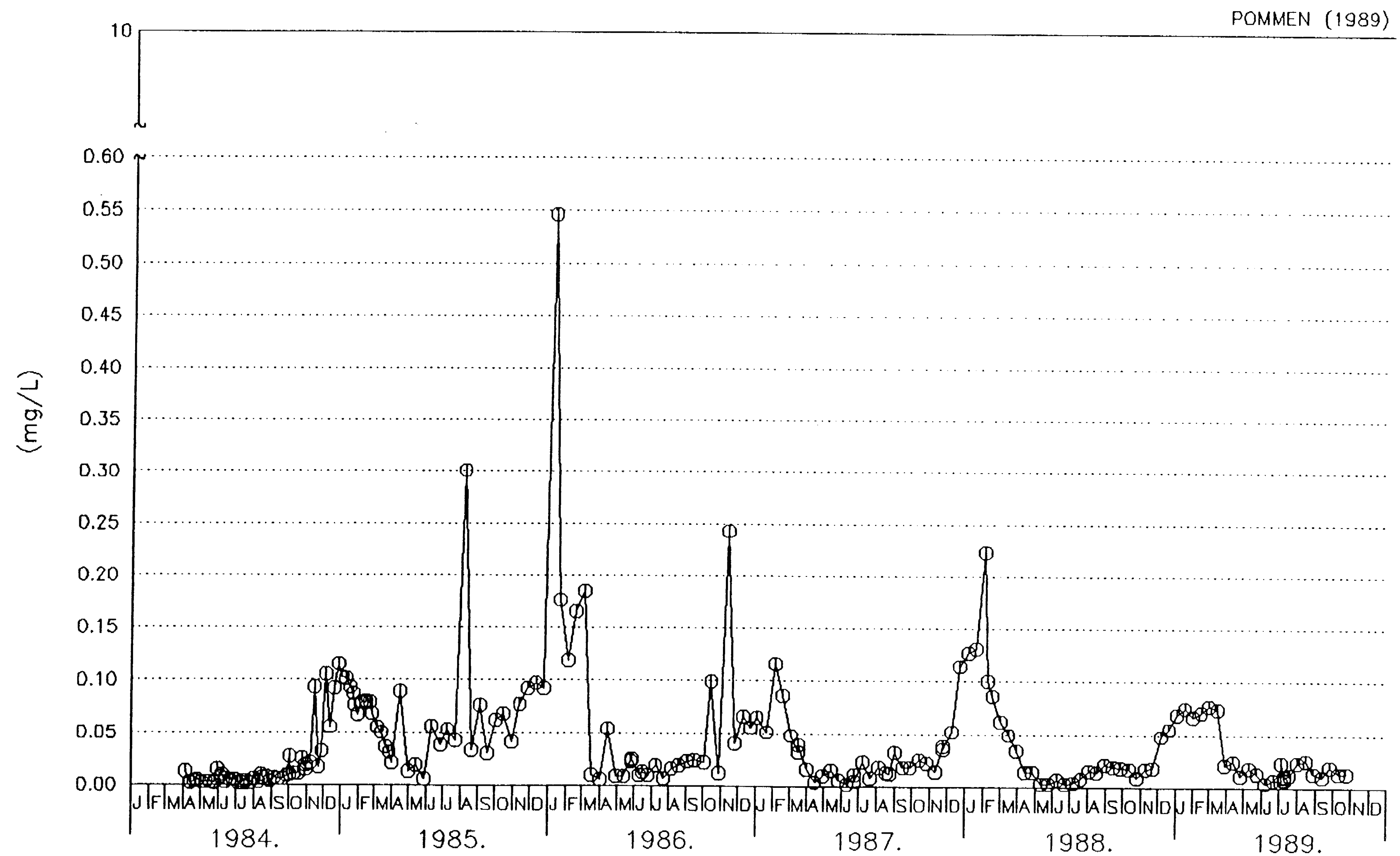

Figure B18	NITRATE+NITRITE–NITROGEN SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

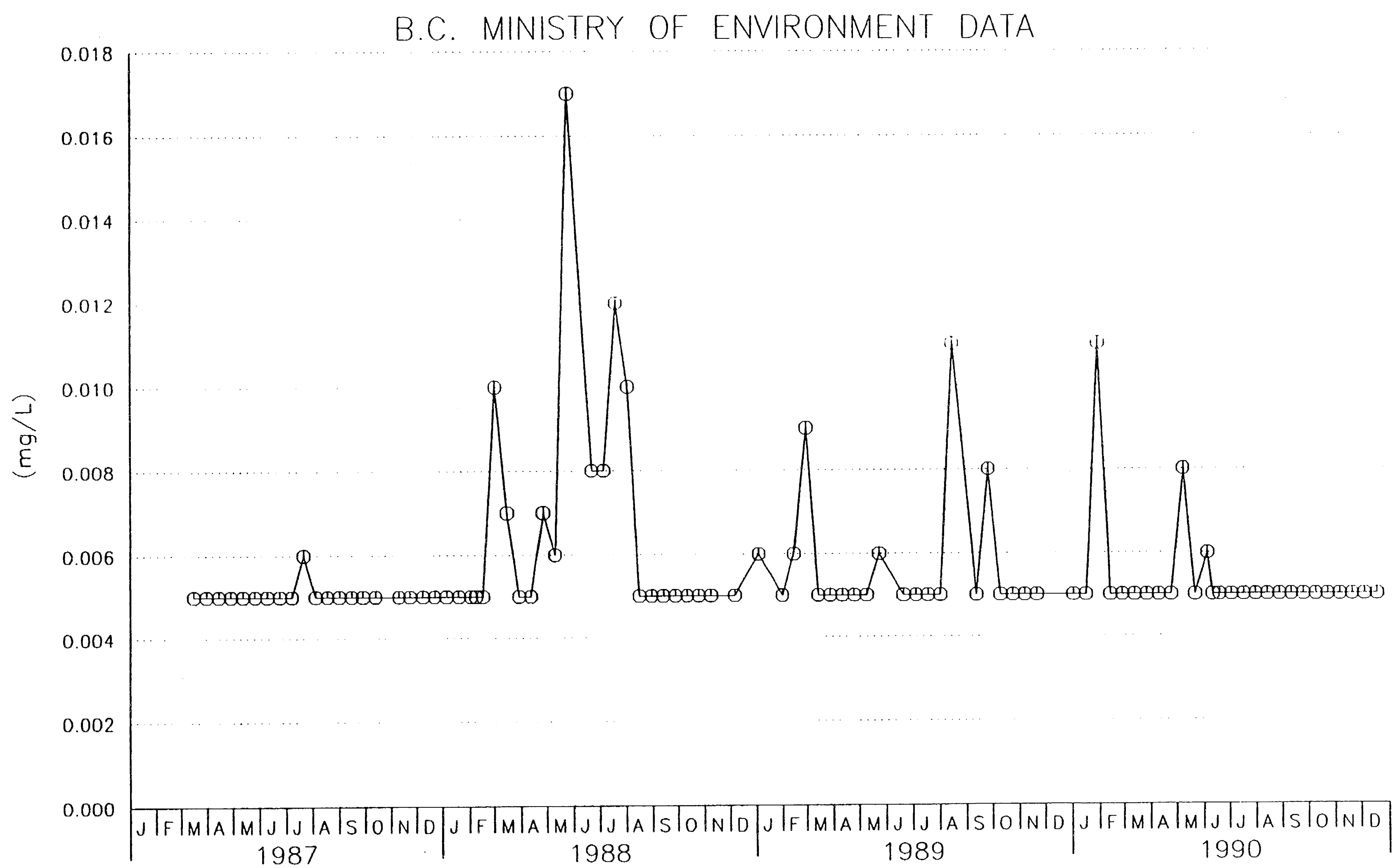

Figure B19	AMMONIA–NITROGEN SIMILKAMEEN RIVER (1987 – 1990)	Environmental Management Associates

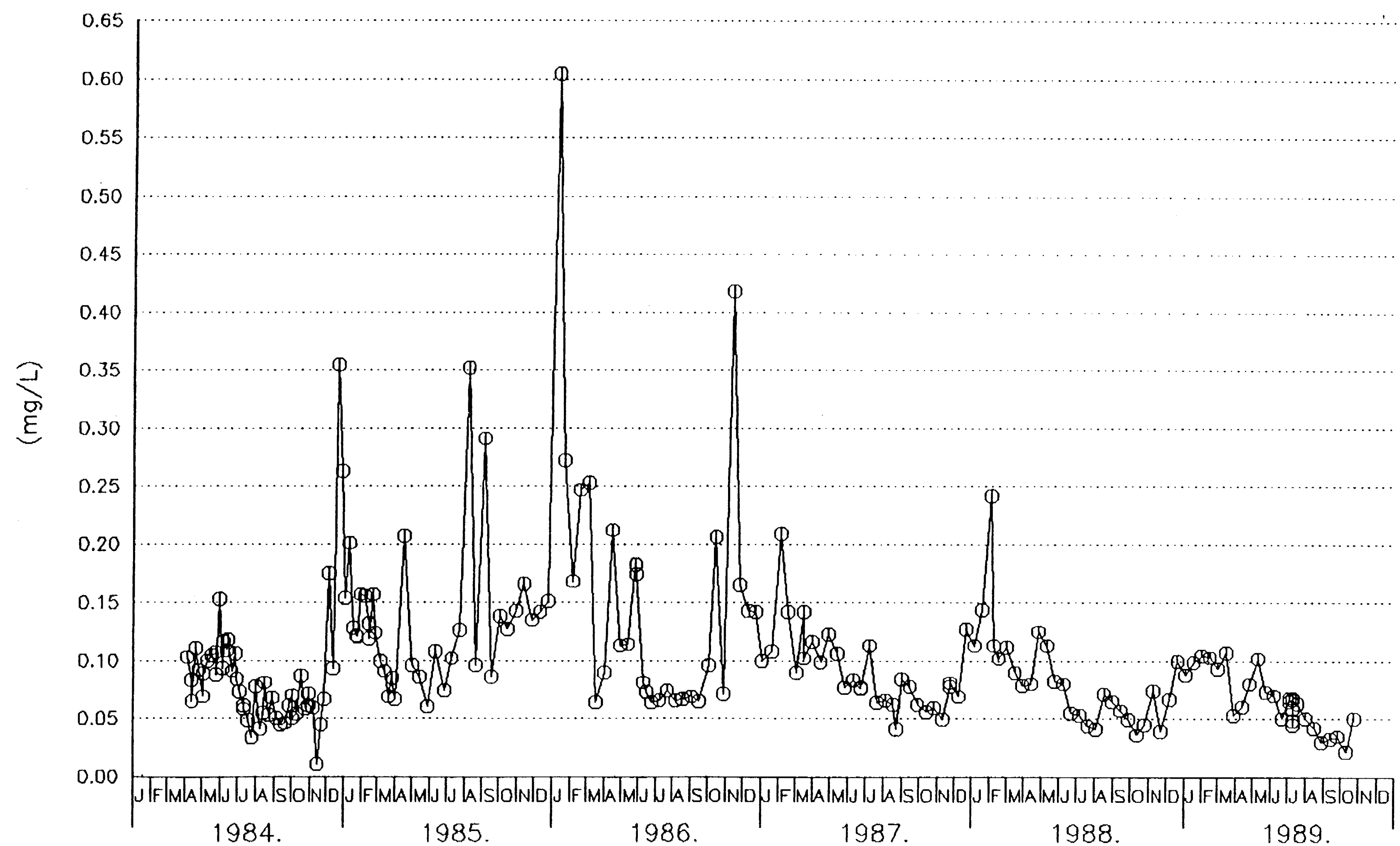

Figure B20	DISSOLVED NITROGEN SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

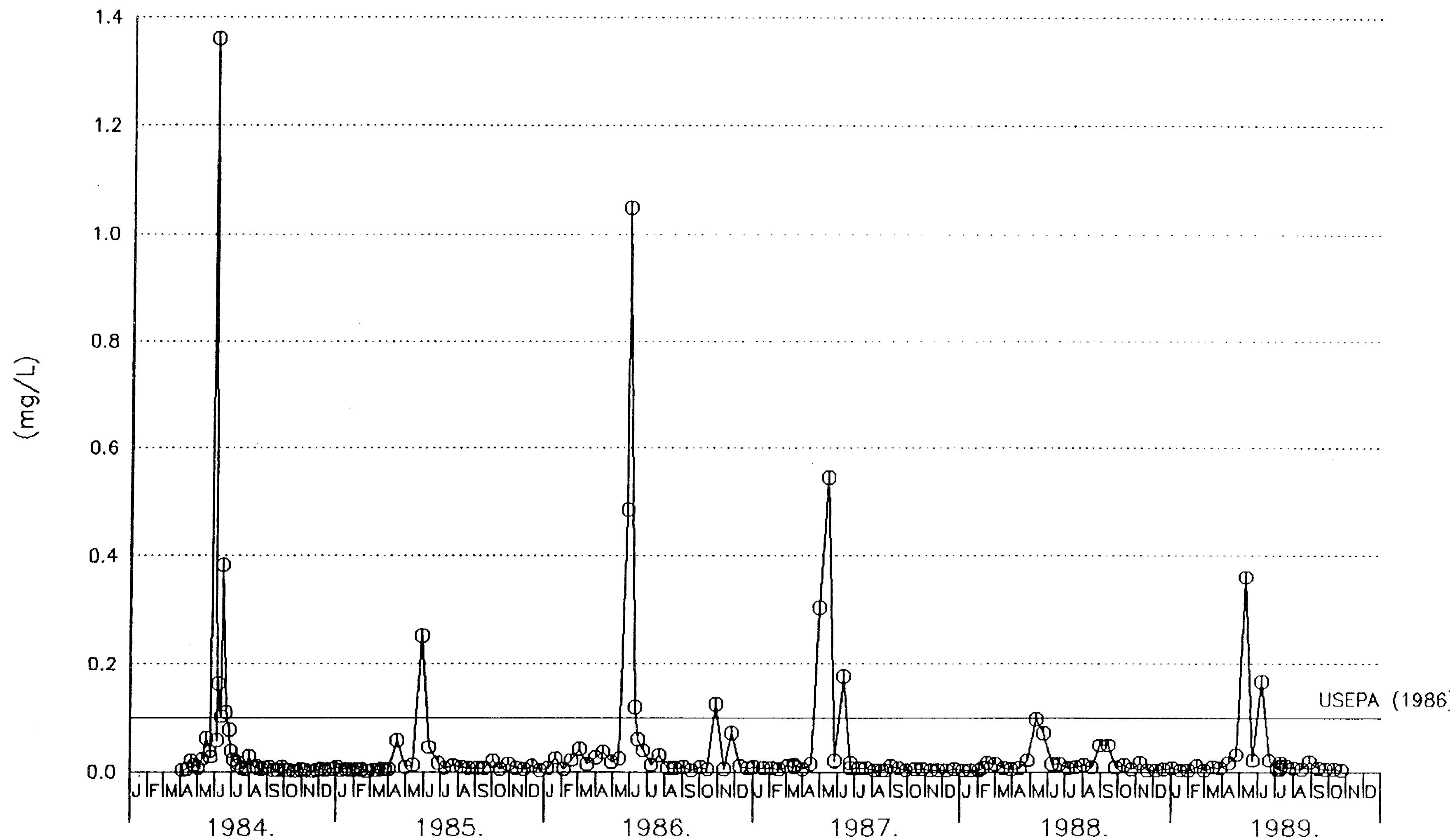

Figure B21 | TOTAL PHOSPHORUS SIMILKAMEEN RIVER (1984 – 1989) | Environmental Management Associates

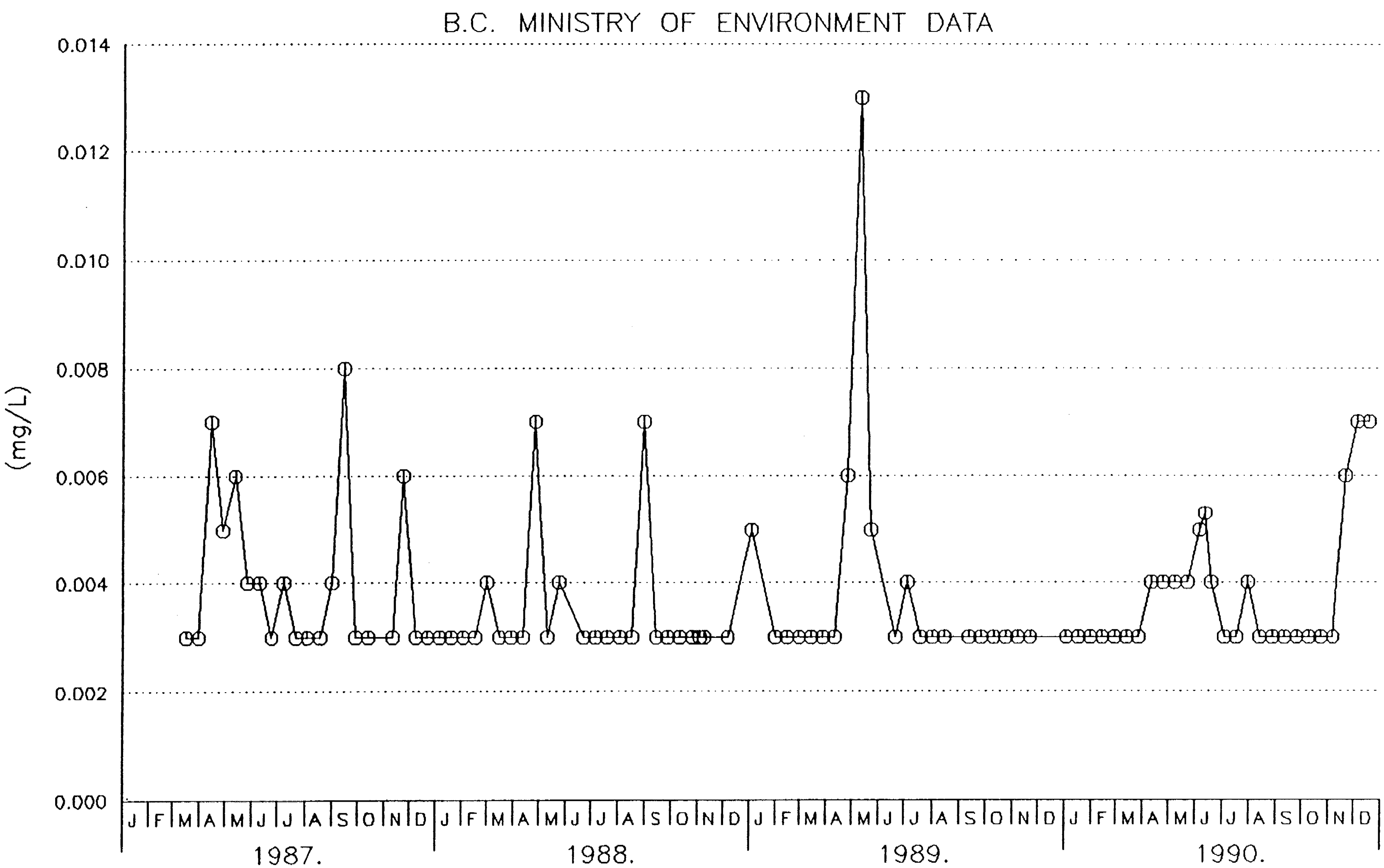

Figure B22	DISSOLVED PHOSPHORUS SIMILKAMEEN RIVER (1987 – 1990)	Environmental Management Associates

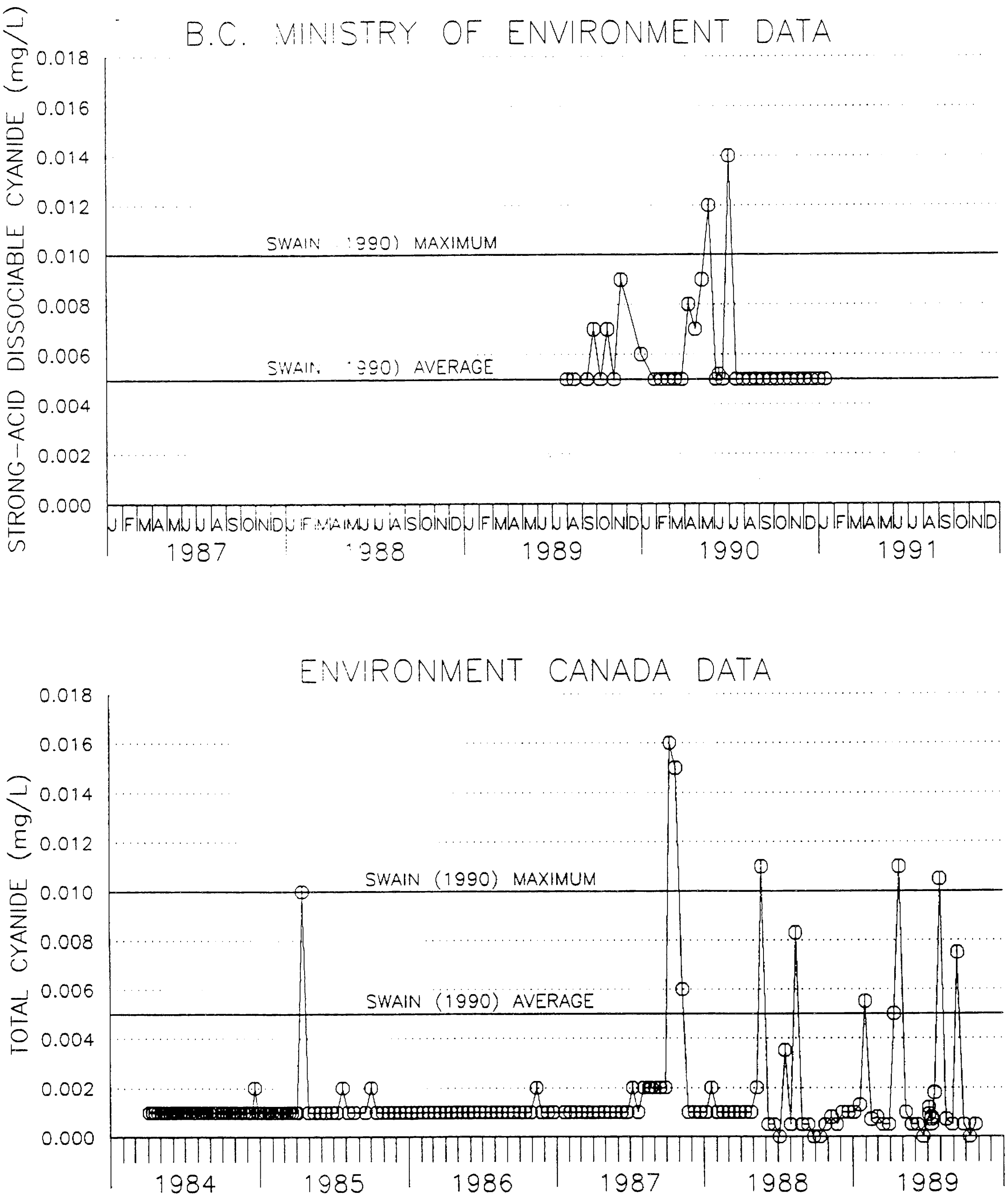

Figure B23	CYANIDE SIMILKAMEEN RIVER	Environmental Management Associates

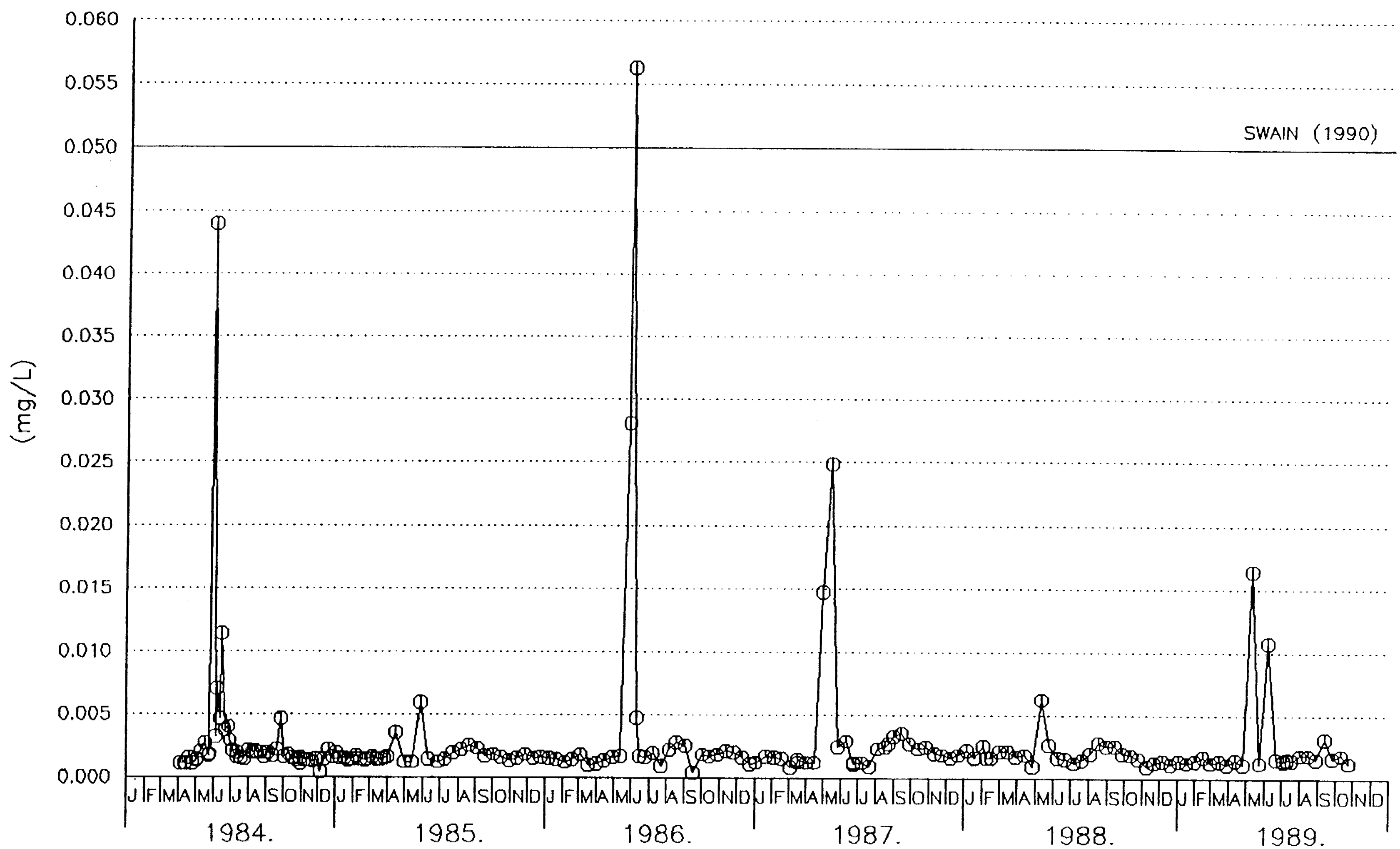

Figure B24

TOTAL ARSENIC
SIMILKAMEEN RIVER (1984 – 1989)

Environmental Management Associates

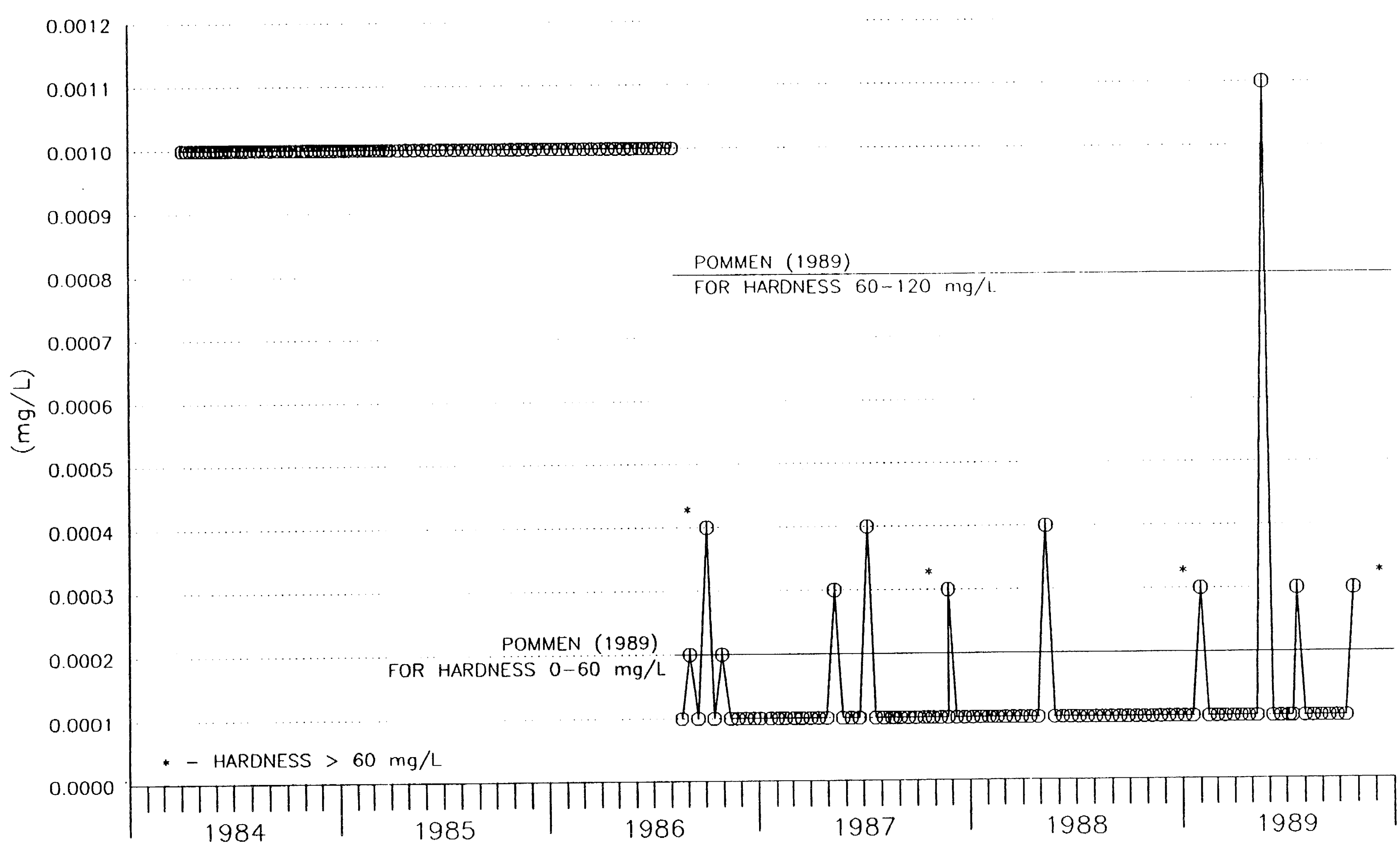

Figure B25	TOTAL CADMIUM SIMILKAMEEN RIVER (1984 - 1989)	Environmental Management Associates

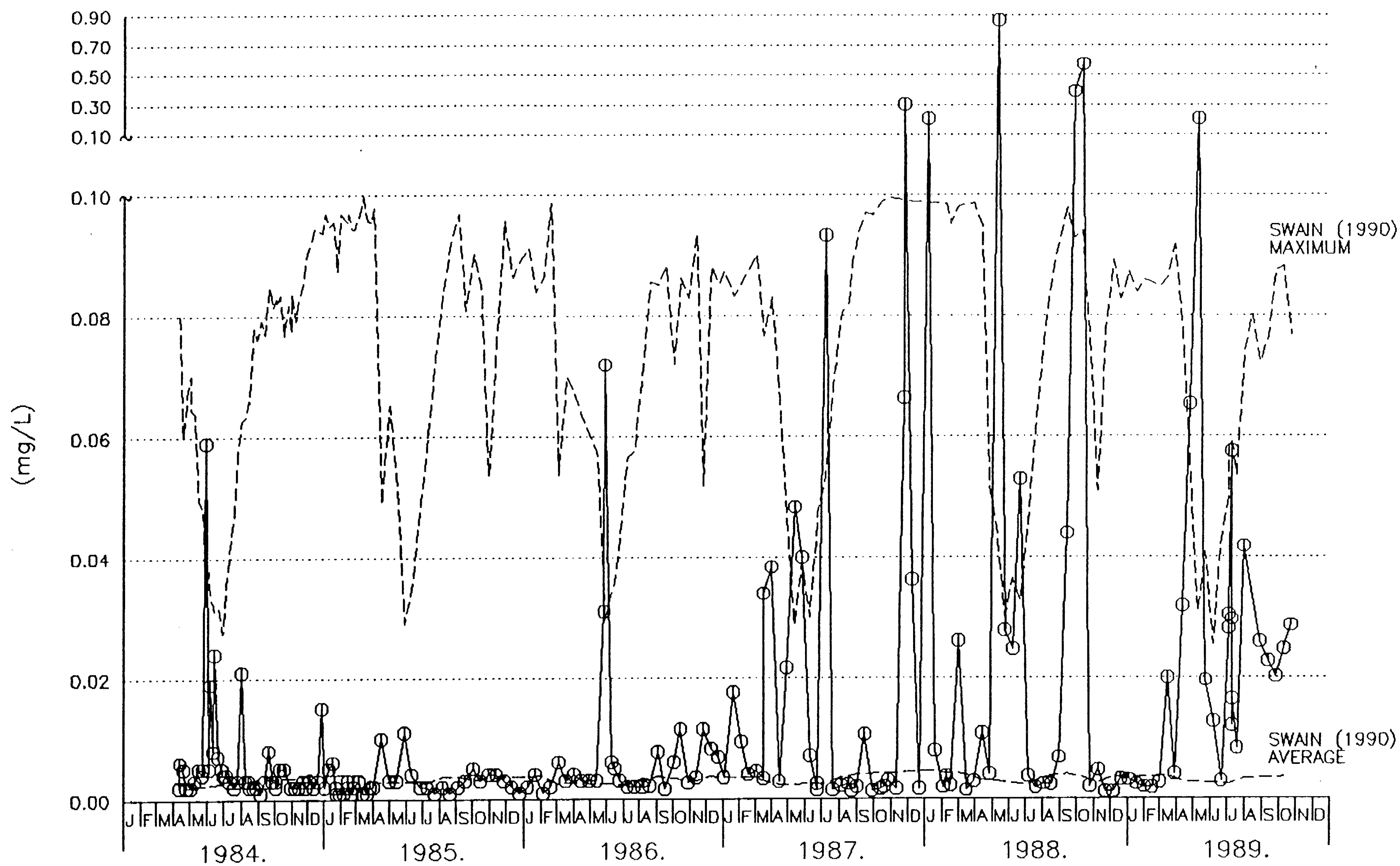

Figure B26	TOTAL COPPER SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

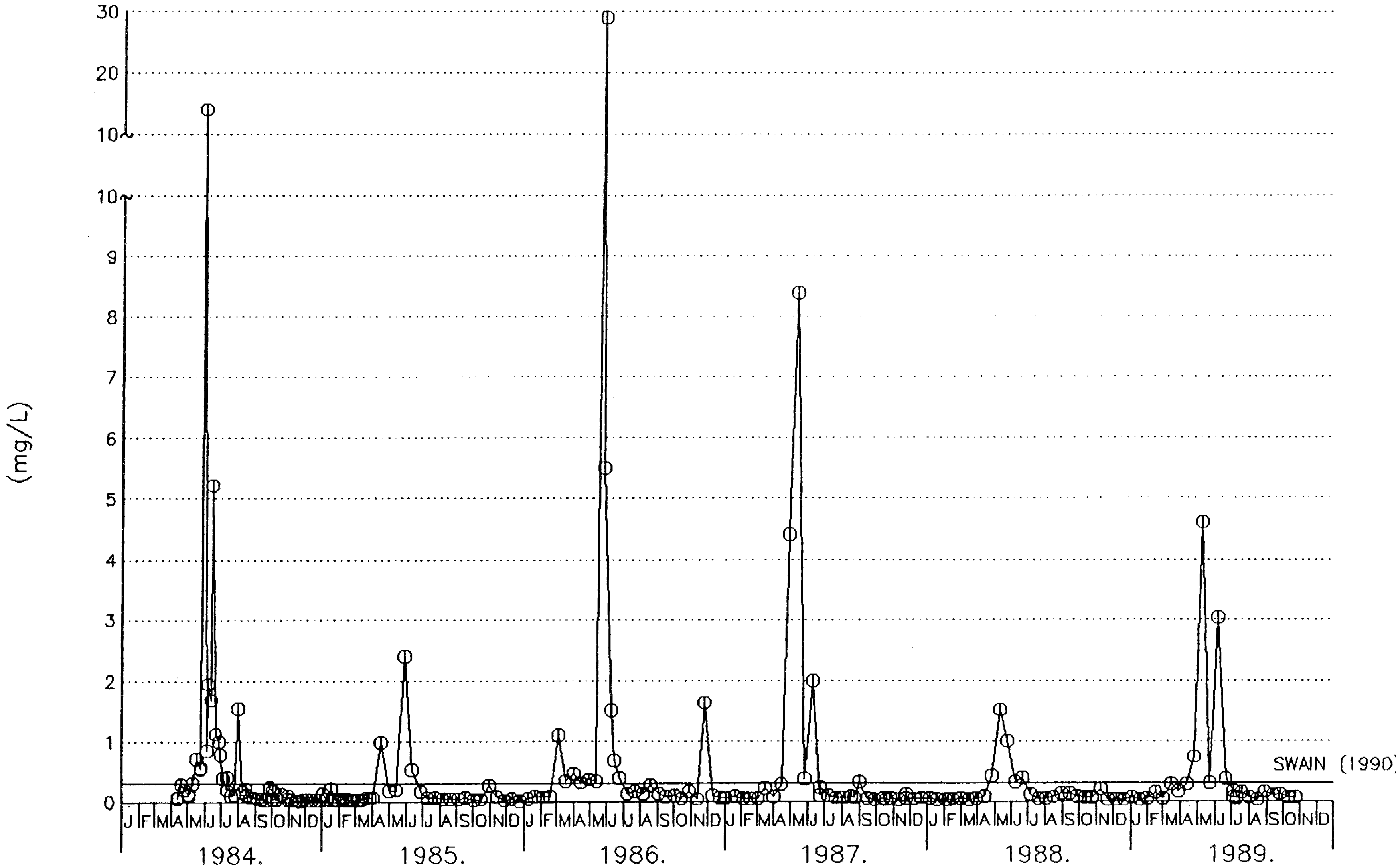

Figure B27

TOTAL IRON
SIMILKAMEEN RIVER (1984 – 1989)

Environmental
Management Associates

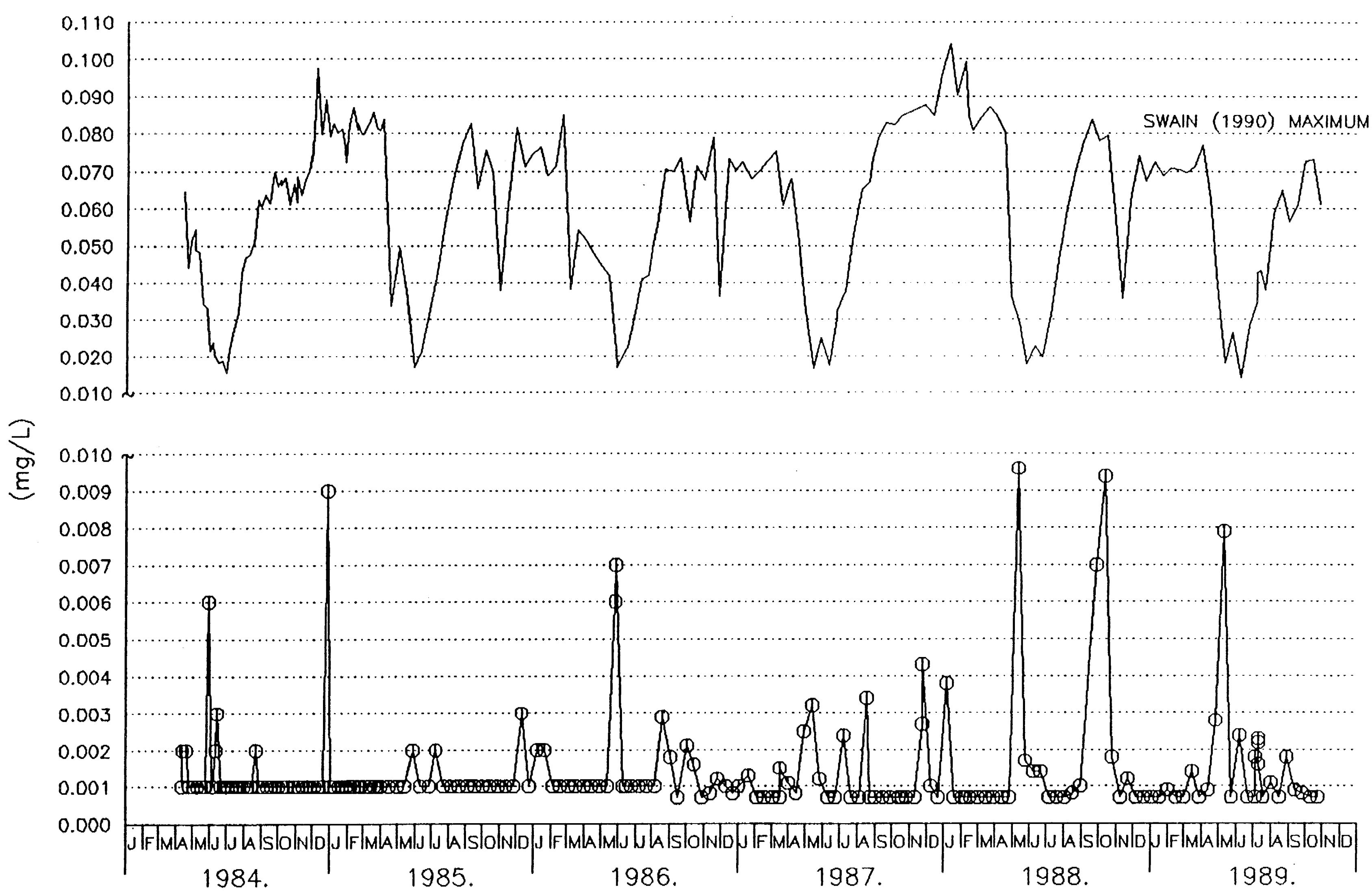

Figure B28	TOTAL LEAD SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

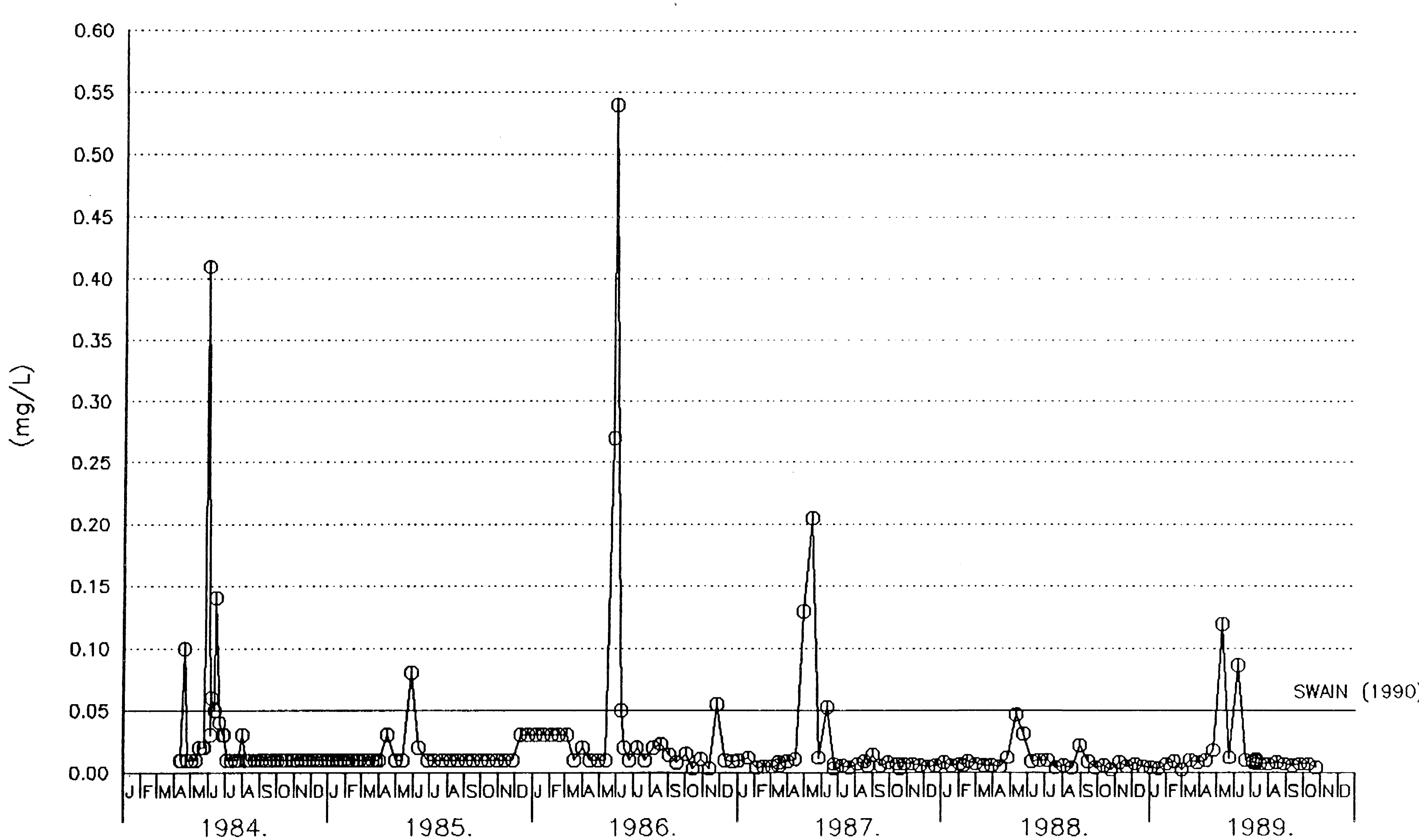

Figure B29	TOTAL MANGANESE SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

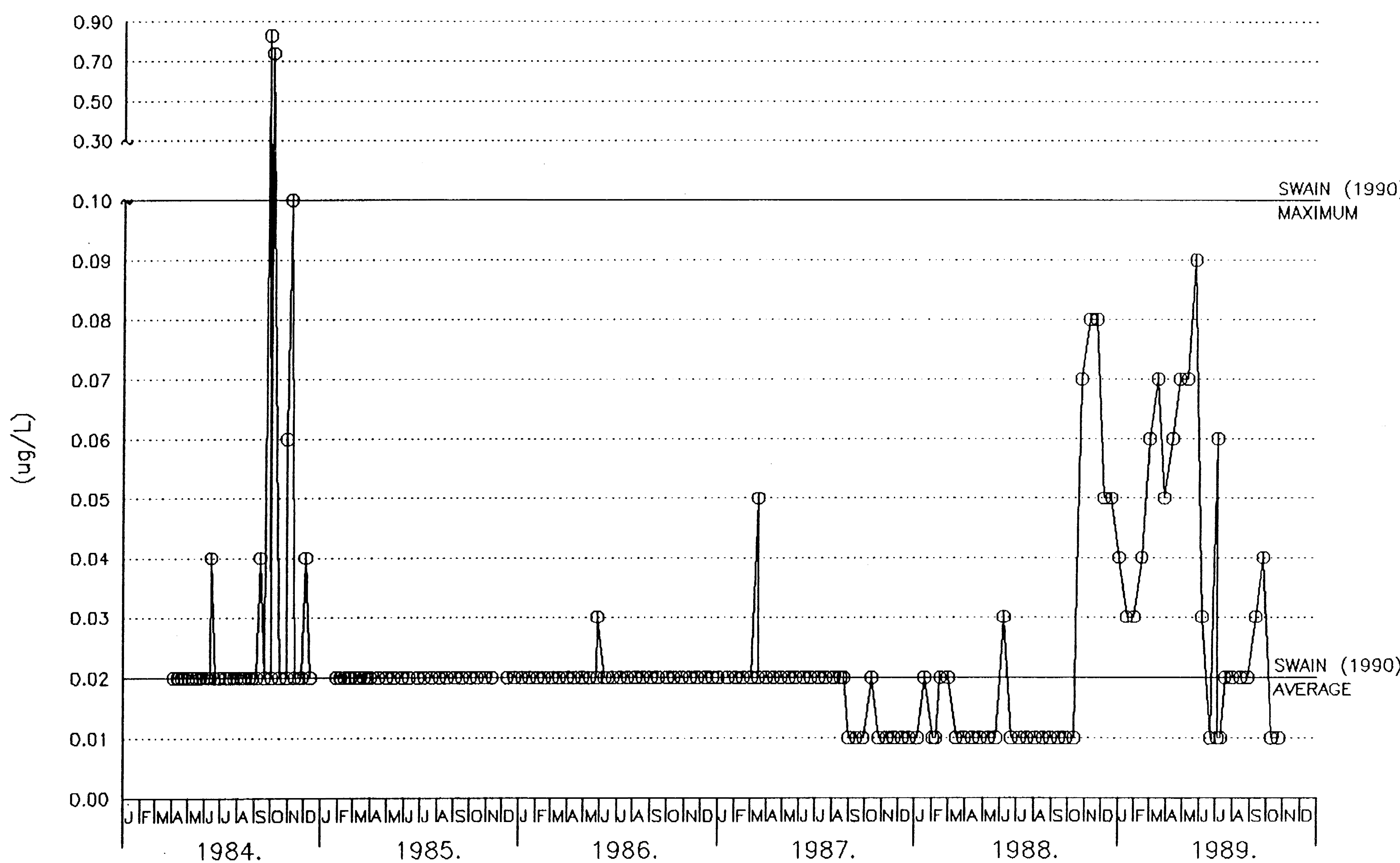

Figure B30	TOTAL MERCURY SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

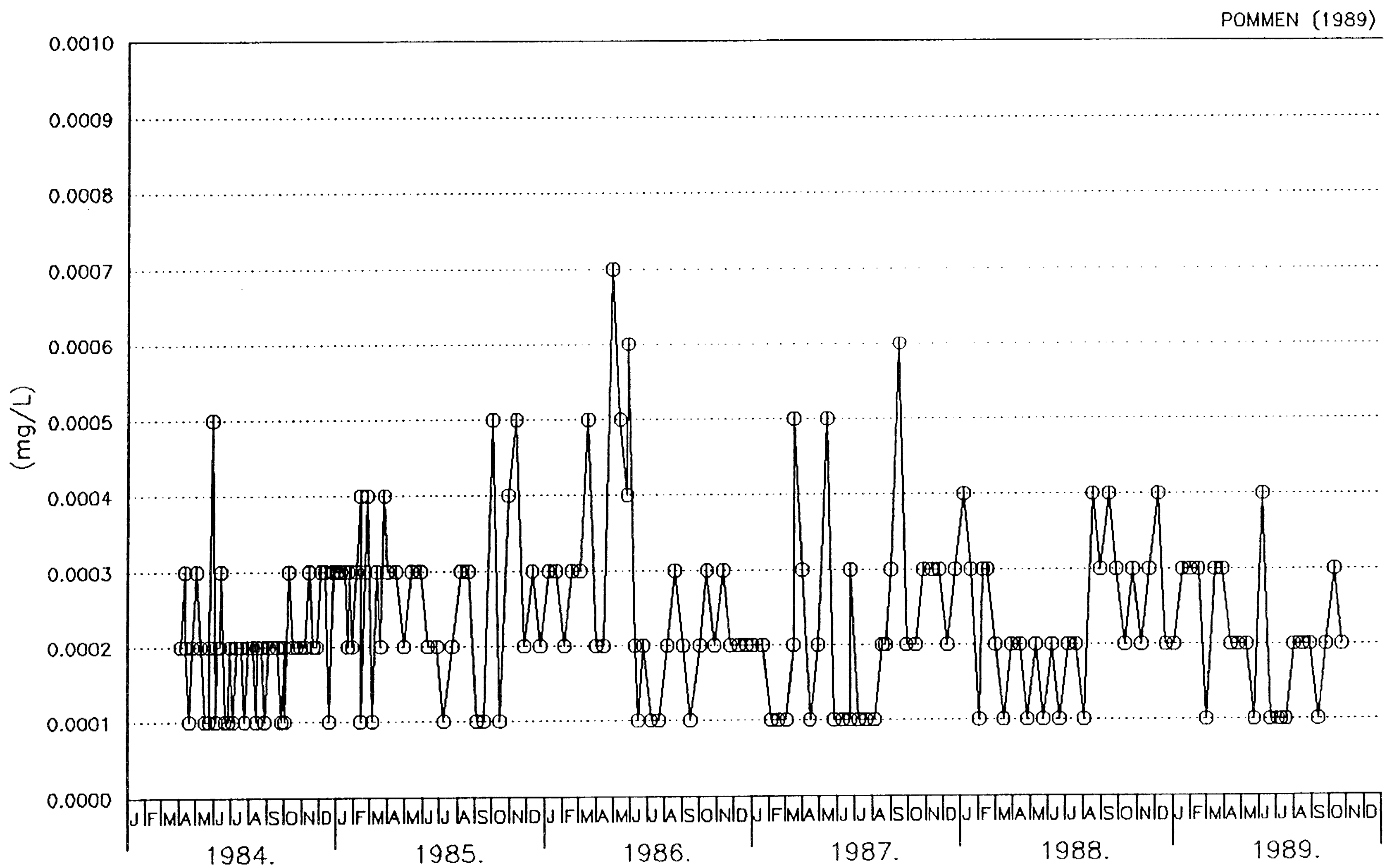

Figure B31	TOTAL SELENIUM SIMILKAMEEN RIVER (1984 – 1989)	Environmental Management Associates

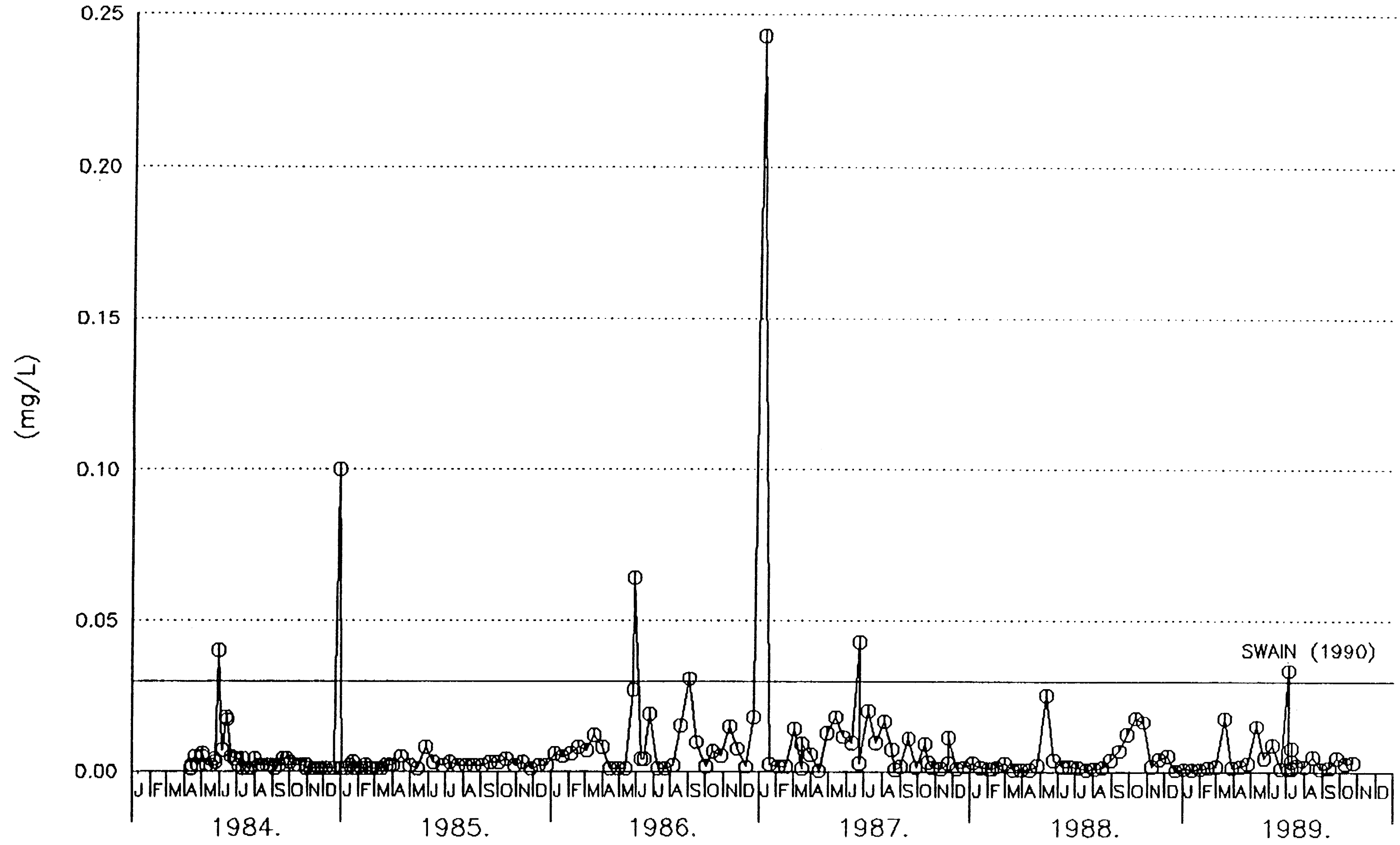

Figure B32

TOTAL ZINC
SIMILKAMEEN RIVER (1984 – 1989)

Environmental Management Associates