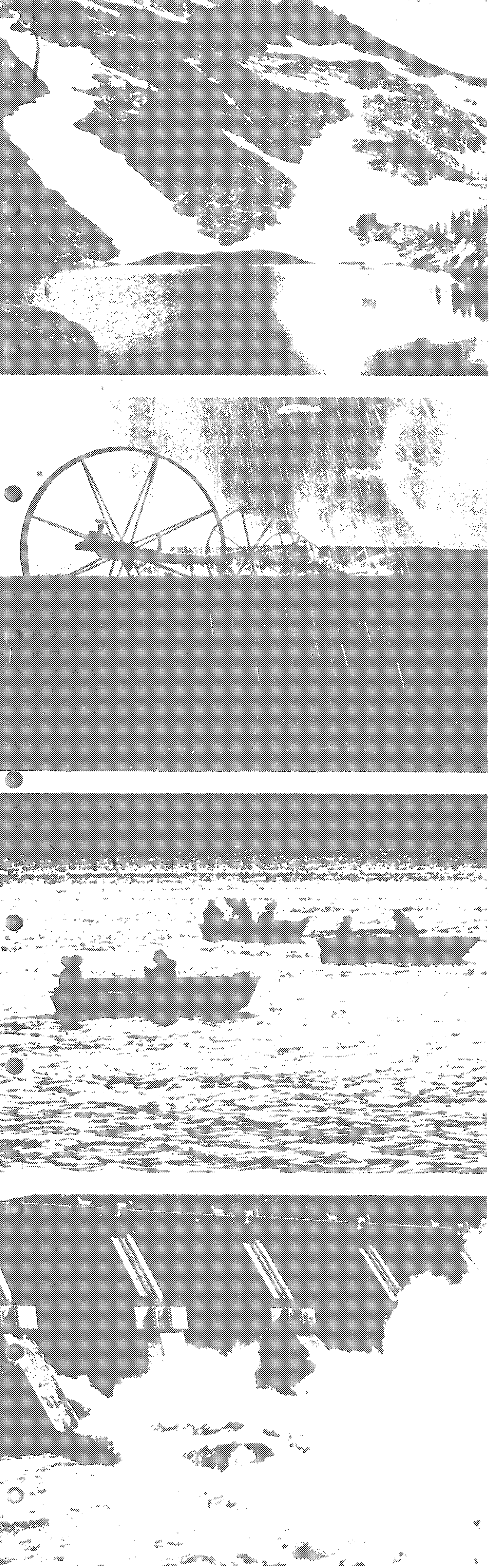

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BASELINE STUDY TO DETERMINE THE WATER QUALITY AND THE PRIMARY AND SECONDARY PRODUCERS OF THE SPOKANE RIVER, PHASE I

by
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STATE OF WASHINGTON
WATER RESEARCH CENTER

WASHINGTON STATE UNIVERSITY AND
THE UNIVERSITY OF WASHINGTON

Pullman, Washington January, 1984

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Project Completion Report

to

State of Washington Department of Ecology
7272 Cleanwater Lane
Olympia, Washington

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ABSTRACT

This report contains substantial baseline data that will be of considerable value in assessing the impact of treated sewage effluent on the water quality of the upper Spokane River. In addition, the baseline data will aid in the analysis of the potential degradation of the river with increasing human activity in the Spokane Valley.

The investigation into the water quality of the upper Spokane River from RM 72.7 (RK 117) upstream to RM 95.1 (RK 153), the Washington-Idaho stateline, attempted to define the present condition of the river. In general, there was a decrease in quality of the physicochemical and biological water quality indicators as the water moved downstream. Addition of aquifer water to the river during low flow, an increase in the amount of urban runoff with a concomitant decrease in quality of the runoff, and an increase in human densities and activities along the river are the most likely causes of the degradation of the water of the upper Spokane River. The annual weighted mean concentration of zinc was approximately 100 $\mu g \cdot \ell^{-1}$, and it ranged in concentration from 5 to 225 $\mu g \cdot \ell^{-1}$. The source of zinc in the river is ultimately the result ofpast and present mining activities in the upper drainage region.

The periphyton and benthic invertebrates populations were dense and indicative of meso-eutrophic conditions. The lower study area was more eutrophic than the upper.

Artificial and rock substrates were compared in periphyton and macroinvertebrate studies. Certain aspects of the sampling are compared and discussed. Recommendations are made concerning future sampling programs and methodologies.

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INTRODUCTION

Project Description

Completion of the Liberty Lake Sewage Treatment Plant in 1982 will cause a discharge of 250,000 gallons per day (gpd) (1135.5 m^3/day) of secondary-treated sewage effluent to the upper Spokane River. The upper Spokane River now supports a good game fishery that in turn is based upon a fair to very good distribution of fish food organisms such as benthic insects, zooplankton and, for the most part, clean water algae (Funk et al., 1973, 1975). In addition, the river waters are considered to be of good quality with the exception of some metallic constituents, primarily zinc (0.1-0.2 mg/ℓ), that are transported into the system from mining activity in the watershed area. The U. S. Environmental Protection Agency (EPA) also has cited occasions of nitrogen super-saturation during high flow and oxygen levels less than saturation during low flow and high temperature (EPA, 1973). Water quality of the river from the outlet of Coeur d'Alene Lake to the state line generally met Washington State Class A standards and Class B standards from the state line to the city of Spokane.

The level of effluent discharge into the river is not expected to affect the fishery or the diversity of fish food organisms immediately, but environmental concerns have been expressed by the Washington State Department of Game and several citizen groups at hearings held at Spokane and Liberty Lake. These concerns are directed toward subtle effects of biotic diversity change, esthetics, and the real possibility of population growth in the area until effluent discharge surpasses 3×10^6 gpd (1.14×10^4 m^3/day). Interest in the new effluent discharge to the river has grown from about fifty individuals in initial public hearings on September 25, 1978 to "standing room only" by the last public hearing on the treatment plant on January 19, 1979. However, interest in pollutants added to the river has occurred over a lengthy period of time, beginning in 1936 when several papers were presented to the Northwest Scientific Association concerning raw sewage pollution of the Spokane River and its relationship to health (Brice, 1936; Butler, 1936; Harris, 1936). Several communities, including the city of Coeur d'Alene, Idaho, were sewered shortly after that time. However, the major contributor of raw wastes to the river was the city of Spokane, which did not treat its effluent until 1948, when a primary plant was completed. Considerable impetus for improving water quality occurred in 1970, largely through the efforts of businessmen, environmentalists, and several political figures, and a 1974 World's Fair was proposed on the theme of "Progress Without Pollution." The resulting publicity campaign, along with legal and financial support of the Clean Water Act of 1972, stimulated the upgrading of the Spokane treatment facilities. In 1977, the city of Spokane completed an advanced waste treatment plant with phosphorus removal.

There now exists within the Spokane community and the surrounding area a strong common desire not to add additional pollutants in any form to any watercourse without some knowledge of the causes and consequences of the addition (Public Hearings, Liberty Lake, 1979). Fortunately, in the region of the proposed Liberty Lake sewage treatment plant (STP) outfall, there exists some limited background information. During a 1975 Office of Water Research and Technology (OWRT) investigation of the river, a water quality and macroinvertebrate station was established (Funk et al., 1975). In addition, there are some data from the U. S. Geological Survey (USGS) taken at Liberty Lake Bridge (Harvard Road) and the results of several surveys from the EPA and its precursor, the Federal Water Quality Administration

(FWQA) as well as state agency data (Cunningham and Pine, 1969). Most of these data, while not pertaining directly to this study, will aid in evaluating long-term water quality trends.

Concern also has been expressed recently over the growth of human populations in the study area and the possibility of polluting the ground water. The old Liberty Lake sewage treatment plant was overloaded and discharging almost directly into the Spokane aquifer (M. Kennedy Engineers, 1978). The construction of the new sewage treatment plant and sewer is 90% complete and is expected to be completed in late 1982. Ironically, the reduction in nutrient input to Liberty Lake and the Spokane aquifer as the result of the sewer system will increase the nutrient loading somewhat to another aquatic environment, the Spokane River.

The impacts of raw and poorly-treated wastes upon a stream environment have been well-documented (Gaufin and Tarzwell, 1952, 1956; Hynes, 1960, 1970; USHEW, 1961; Jones, 1964; MacKenthun and Ingram, 1967; Cunningham and Pine, 1969; MacKenthun, 1969; Cairns et al., 1970; Funk et al., 1973, 1975; Gaufin, 1973; Miller et al., 1974; Soltero et al., 1974; Cairns and Dickson, 1976). Most studies have dealt first with the effluent already in the receiving stream and then with restoration to some postulated previous community structure after a period of time. This study was directed toward obtaining background information in order to observe the subtle changes to the river taking place when high quality secondary effluent is added. Construction delays have prevented post-effluent observations for the time period of this report, but it is hoped that a second study can be made when the Liberty Lake Sewage Treatment Plant becomes operational.

The effluent source will be the Liberty Lake sewage treatment plant. It is thought that within a short period of time (<5.0 yrs) the plant will discharge approximately 1.0 x 10^6 gpd (≅3785 m^3/day). If higher discharges are allowed, lime coagulation is proposed for removal of phosphorus. Plans include effluent disinfection with chlorine at all operation levels followed by dechlorination before release (M. Kennedy Engineers, 1978). The forty-year mean flow of the Spokane River near the proposed discharge point is 6,258 cfs (171.1 m^3/s). However, in 1976 the maximum flow was 29,000 cfs (847 m^3/s), and the minimum flow was 1020 cfs (28.9 m^3/s).

Project Goals

The goals of this research project were to provide additional water quality and biological baseline data in the vicinity and downstream of the proposed Liberty Lake Sewage Treatment Plant (STP) and to assess short-term changes in water quality and biological diversity after initial operation of the plant. The baseline data should aid in the development of control programs that will provide water quality protection for the river.

Specific Objectives

The specific objectives of the study were:

1. To conduct analyses and assessment of key or indicator parameters that will show changes in the water quality of the river above and below the proposed STP outfall;
2. To inventory macroinvertebrate species at selected stations above and below STP outfall locations and to develop diversity indices that will suggest individual or community change;
3. To inventory periphyton primary production occurring in the downstream area below the STP outfall with control stations above the outfall;

4. To identify and count phytoplankton occurring in the pool areas above and below the STP outfall area;
5. To recommend long-term survey activities needed to ensure that Spokane River waters are adequately monitored as the discharge rate increases, including both the interim period between intensive surveys and requirements of the second intensive survey.

METHODS AND MATERIALS

Study Area

Ten sampling stations were established along the upper Spokane River from the Washington-Idaho Stateline RM 95.2 (RK 153.2) to the entry of Hangman Creek RM 72.6 (RK 116.9). Sampling at Stateline, RM 95.2 (RK 153.2), was discontinued in March, 1980, in order to add station Harvard II, RM 92.2 (RK 148.4), approximately 75 m downstream from the proposed Liberty Lake sewage outfall. The upper Spokane River and the locations of the sampling stations are shown in Figure 1. The site descriptions for sampling stations are given in Table 1 and the river flow is represented in Figure 2.

Physicochemical Methods

Conductivity, pH, dissolved oxygen, CO_2, HCO_3^- $CO_3^=$, and temperature were measured on site in accordance with the American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater, 14th ed. (APHA, 1975). Heavy metal (Cu, Pb, Zn, Hg, Ni, Cd) determinations were made by atomic absorption methods also described in Standard Methods (APHA, 1975). Total Kjeldahl-nitrogen, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, total phosphorus, total soluble phosphorus, soluble reactive phosphorus, chlorides, and chemical oxygen demand were determined using a Technicon II Autoanalyzer following Technicon II Methods (1971-1977) and EPA Methods for Chemical Analysis of Water and Wastes (USEPA, 1979). Suspended solids and BOD were performed following APHA (1975). The above mentioned analyses were performed on water samples from every station listed in Table 1.

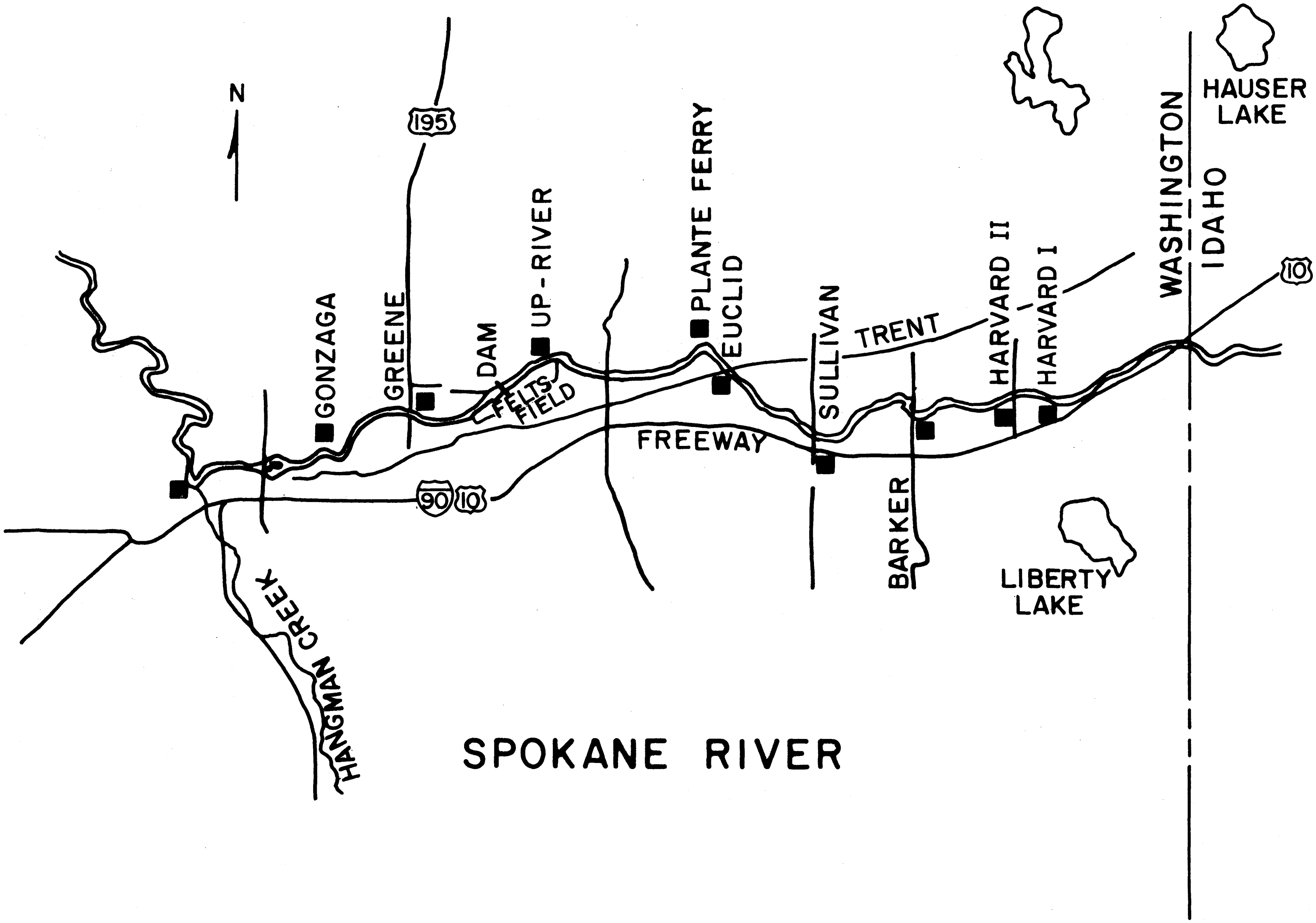

Figure 1. Upper Spokane River, from Washington-Idaho Stateline to Hangman Creek

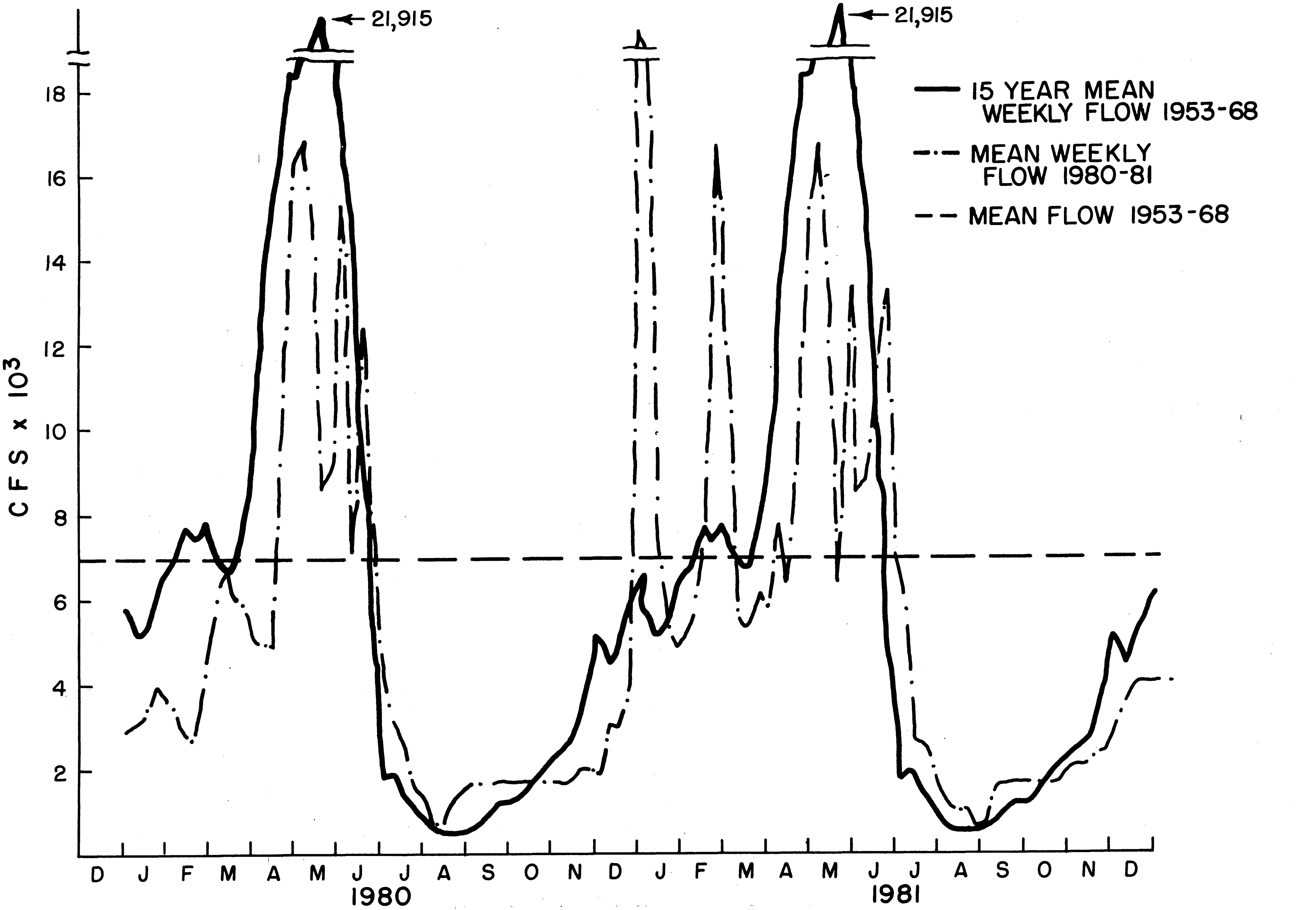

Figure 2. Spokane River Flow below Post Falls

Table 1. Description of Sampling Sites

Station	River Mile/kilometer	Width (minimum) (m)	Depth (m)	Relative Velocity (Low Flow)	Substrate (cm/m in diameter)
Stateline	95.2/153.2	40	1	Moderate	Gravel (5-15 cm)
Harvard I	93.1/149.8	25	1.5	Fast	Rocks and boulders (15-20 cm; 0.5-1 m)
Harvard II	92.2/148.4	40	1.5	Moderate	Rocks and boulders (15-20 cm; 0.5-1 m)
Barker	90.4/145.5	50	1	Fast	Gravel to rocks (10-20 cm)
Sullivan	87.9/141.5	25	2	Very Fast	Boulders (1-3.5 m)
Euclid	85.8/138.1	25	3	Fast	Rocks and boulders (30-50 cm; 0.5 m)
Plantes Ferry	84.2/135.5	50	3.5	Moderate	Gravel to rocks (10-30 cm)
Upriver Reservoir	82.4/132.6			Very Slow	Detritus, sand, and gravel
Greene Street	78.2/125.8	50	10	Slow	Gravel and rocks (5-500 cm)
Gonzaga	75.5/121.5	55	10	Slow	Gravel and rocks (5-500 cm)
Hangman	72.6/116.9	75	1.5	Fast	Rocks and boulders (30-50 cm; 0.5-7 m)

Biological Methods

Phytoplankton

Phytoplankton samples were collected biweekly during the bio-reactive period (June through September) and monthly for the remainder of the year. Chlorophyll *a* concentrations were determined by techniques modified from Standard Methods (APHA, 1975). Sonification procedures were added to insure complete disruption of the cells for chlorophyll *a* extraction. The authors of this report have found that sonification can improve the efficiency of chlorophyll *a* extraction by as much as 10 to 20% over other methods without sonification (unpublished data). This is especially true when chlorophyll *a* concentrations are more than 8 $\mu g \cdot \ell^{-1}$. Enumeration and identification were determined following methods described by Jackson and Williams (1962).

Periphyton

To assess the effects of the future sewage effluent upon the periphyton and to better estimate the quantity and community structure of the periphyton, both artificial and natural substrates were employed.

The artificial substrate used was developed in recent river investigations (Funk et al., 1975). Three equal sections of glass tubing (each section 8.0 cm in length, surface area = 25.3 cm^2) were held in place by a center cord. The cord and tubing were enclosed within a barbeque basket placed in the river at a depth of 1 m for three to six weeks (depending upon the season) to allow for colonization. Upon recovery, one section of the tubing was scraped for chlorophyll *a* extraction. Another tube was scrapped for ash-free dry weight. The third tube was scraped and the periphyton used in identification and enumeration. Figure 3 shows the glass tube substrate.

The predominant natural substrate in the Spokane River is rocks. Therefore, rocks from the Spokane River bed at the sampling locations were used for the natural substrate after being collected and cleaned. The rocks were placed in barbecue baskets similar to those containing the glass tubing. After the three- to six-week colonization period, the periphyton was scraped from a known area of rock surface delineated by a plexiglass ring (either 2.5 or 3.8 cm id.) by a nylon brush. A watertight seal was provided by a thin layer of foam rubber attached to the rim of the ring and pressed against the surface of the rock, allowing the periphyton to be aspirated. Figure 4 shows the aspirating device. The procedure was repeated three times, and the resulting samples were randomly selected for chlorophyll a analysis, ash-free dry weight determination, identification and enumeration.

Ash-free dry weight measurements were made by methods outlined in Standard Methods (APHA, 1975). Chlorophyll a procedures modified by sonification followed Standard Method procedures (APHA, 1975). Enumeration methods followed those of Jackson and Williams (1962).

Bacteria

Fecal coliform determinations were made at each sampling station following methods (MPN and membrane filter technique) outlined in Standard Methods (APHA, 1975) and Bordner and Winter (1978).

Macroinvertebrates

Three methodologies were employed to investigate the macroinvertebrate community within the river: multiple-plate composition board samples,

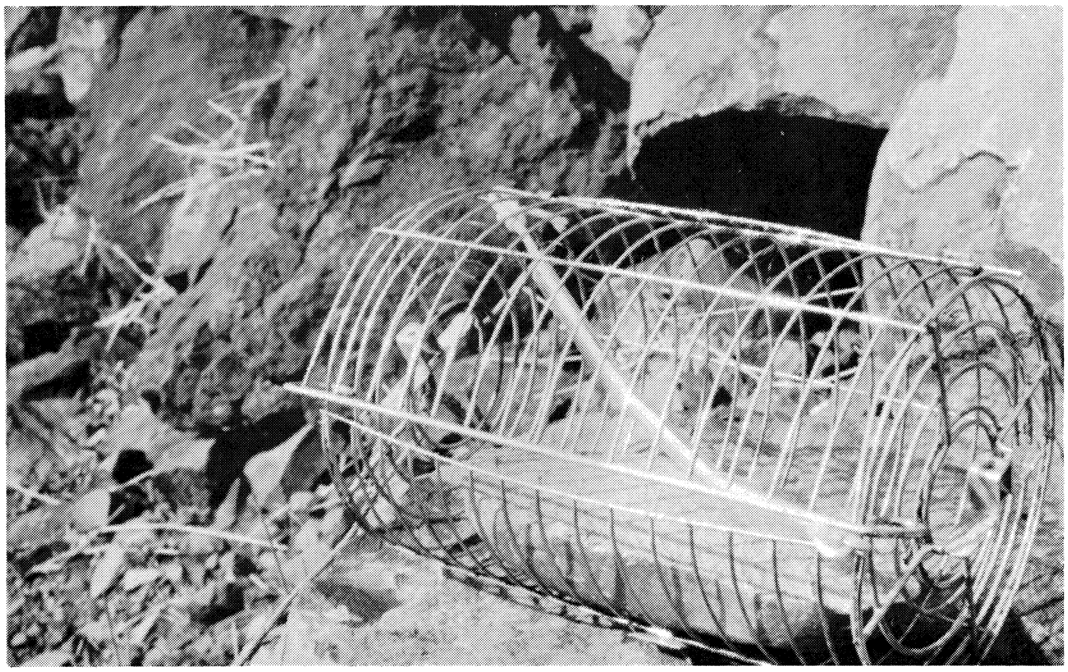

Figure 3. Glass tube substrate enclosed in barbecue basket

Figure 4. Aspirating device to remove periphyton from rock surface

rocks placed inside barbeque baskets, and a suction sampler. Mean diversity of the macroinvertebrate community was calculated using the Shannon-Weaver formulation (Margalef, 1957; Pielou, 1977).

The multiple-plate sampler was similar to that used by Hester and Dendy (1962). The sampler was made of 0.3 cm thick tempered hardboard cut into 7.6 x 7.6 cm plates with holes in the center. Tubing (0.9 cm diameter) was used as spacers (0.6 cm). The sampler was composed of a total of eight plates and seven spacers placed on a 0.6 cm rod. The total area of the sampler was 0.093 m^2. Figure 5 shows the multiple-plate sampler.

The second method used was a rock basket sampler similar to those rock-filled baskets used by Mason et al. (1967). The baskets were 25.4 cm long and 17.8 cm in diameter, filled with rocks varying from 5.1 to 10.2 cm in diameter. The rocks were obtained directly from the sampling site. The average surface area of the rocks in the basket sampler was 0.135 m^2. Figure 6 shows the rock basket sampler.

The third type of sample was taken by a modified suction sampler somewhat resembling that in the dome sampler used by Gale and Thompson (1975). It consisted of a metal band enclosure 17.8 cm high and 36.8 cm in diameter, with a plexiglass plate cover. A 7.6 by 10.2 cm strip of closed cell foam was attached to the bottom of the band with a 7.6 cm overhang to seal the sampler onto rocky substrates. Mounted on top of the plexiglass plate were a series of four differently sized sieves (500 μ, 750 μ, 3190 μ, 6380 μ) and a pump to provide the suction. The pump was powered by a 12-volt motorcycle battery mounted to the side of the metal band. Figure 7 shows the suction sampler.

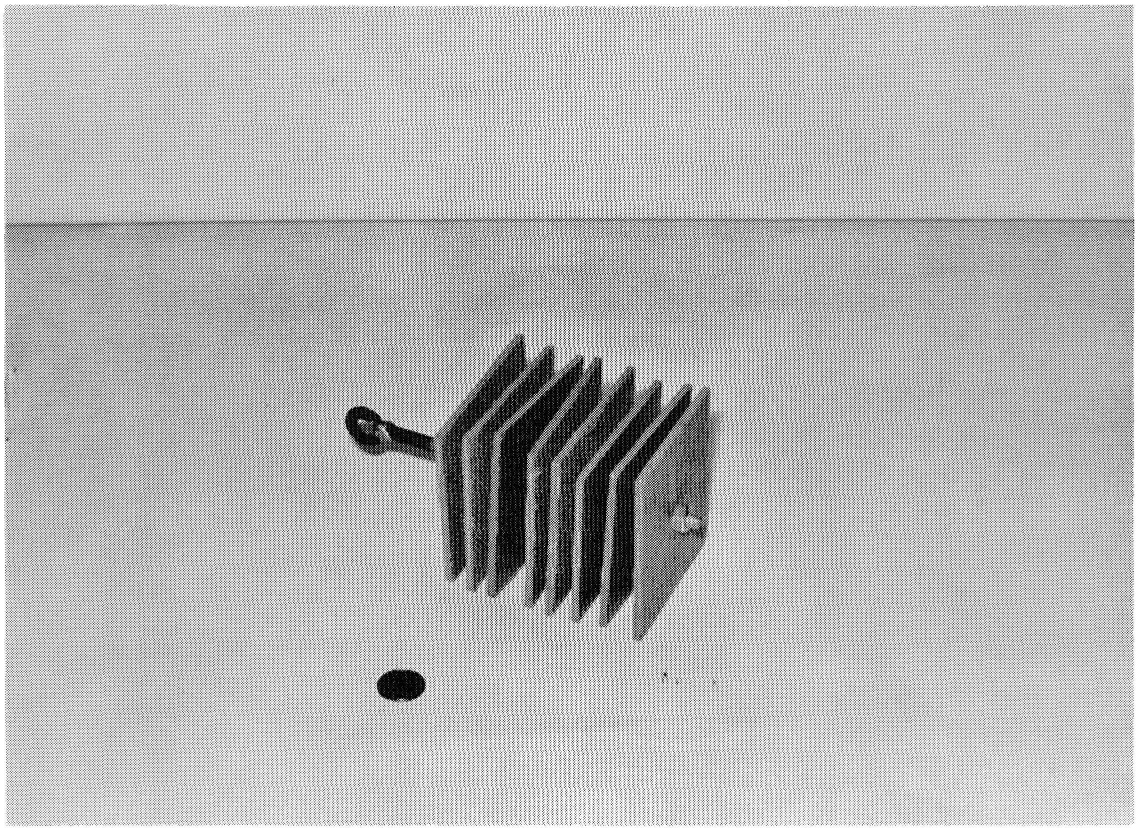

Figure 5. Multiple-plate sampler

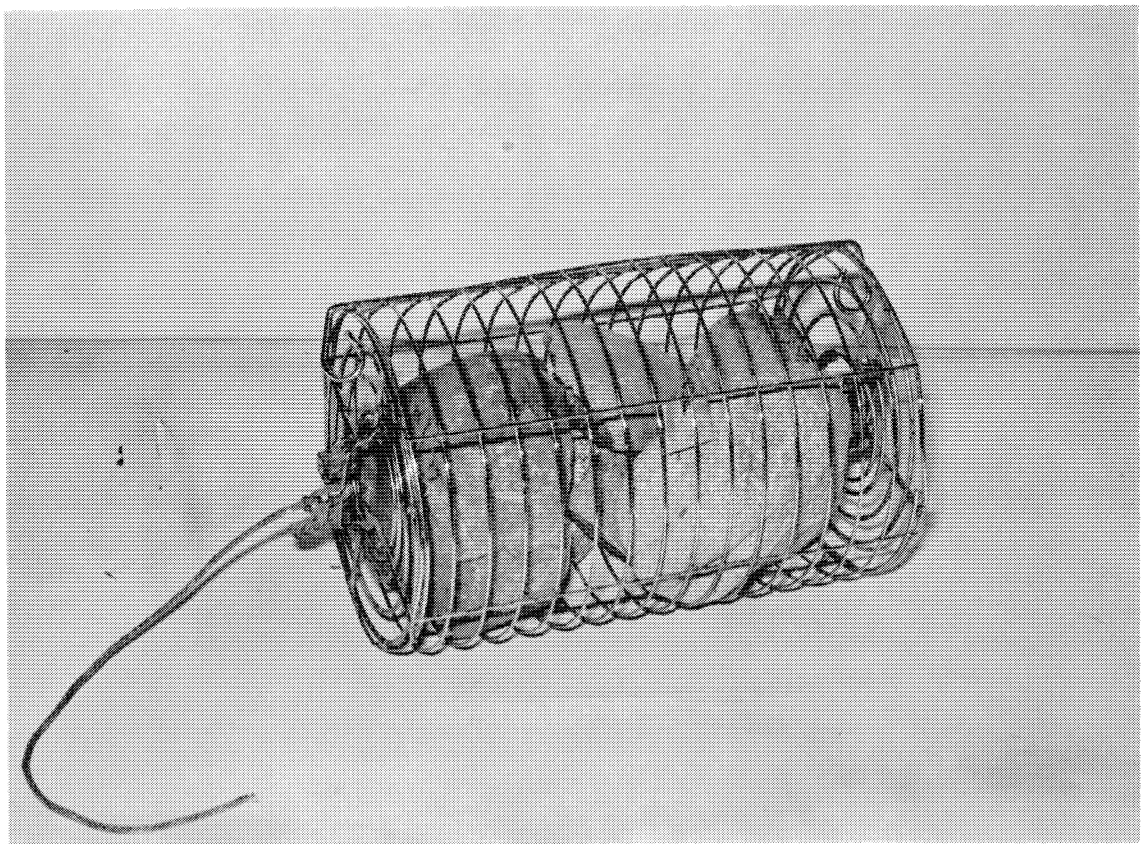

Figure 6. Rock basket sampler

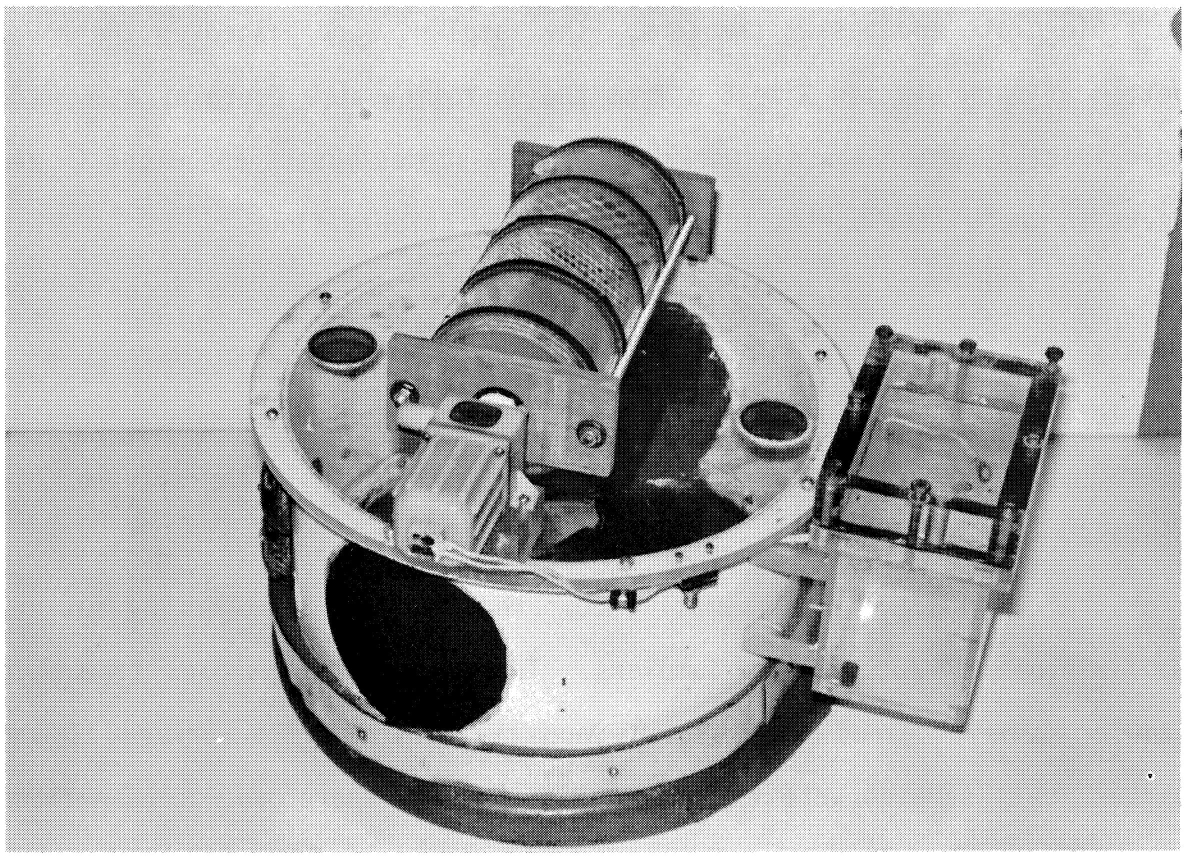

Figure 7. Suction sampler

The first series of macroinvertebrate sampling involved paired multiple-plate and basket samplers. The samplers were placed on the river bottom at each station 3 to 6 m from the shoreline at a depth of 1 m. The colonization period was six weeks during the summer months and eight to ten weeks in the winter months to ensure complete colonization.

To avoid loss of organisms upon retrieval, the samplers were removed slowly with catch nets placed under the samplers. After removal, each sampler was immediately placed in a bucket of water and scraped clean of organisms. The organisms were preserved in 70% ethanol after sieving. In the laboratory, the organisms were sorted, counted, and identified.

The second series of sampling compared the samples taken by basket, multiple-plate, and suction samplers. Three replicate samples from each sampler were obtained at Stateline and half-way between Harvard II and Barker. All samples were taken from mid-channel; therefore, scuba methods were necessary. After a six-week colonization period, the basket and multiple-plate samplers were retrieved. At this time, three replicate samples were obtained using the suction sampler. All samples were handled as described above.

RESULTS

Physicochemical Conditions

Thirty-one physicochemical parameters were monitored at the ten stations previously described. Sampling was carried out biweekly throughout the more biologically active (growth) period from June to September and monthly during the late fall, winter, and early spring, the mostly biologically quiescent periods.

Several considerations were made in regard to the sampling regimes. Of prime consideration was the establishment of water quality conditions at two stations above the proposed outfall, one at the outfall, and four below. For the baseline study, four stations represented presently stabilized conditions: Stateline; Harvard I, above the proposed outfall; Harvard II, at the outfall; and Barker, below the outfall. The next three stations--Sullivan, Euclid, and Plantes Ferry--were in the recharge area of the Spokane aquifer. The Upriver station was downstream of the domestic sewage of the community of Millwood and some industrial effluent. The Greene Street, Gonzaga, and Hangman stations received some light industrial input and localized runoff from the city of Spokane. The following narrative describes certain perturbations with brief causal explanation included. Data from stations representative of the areas described are presented in a series of graphs (Figures 8 through 19). The detailed data presented in Appendices A through I provide baseline information from which present and future comparisons can be made as development along the river proceeds.

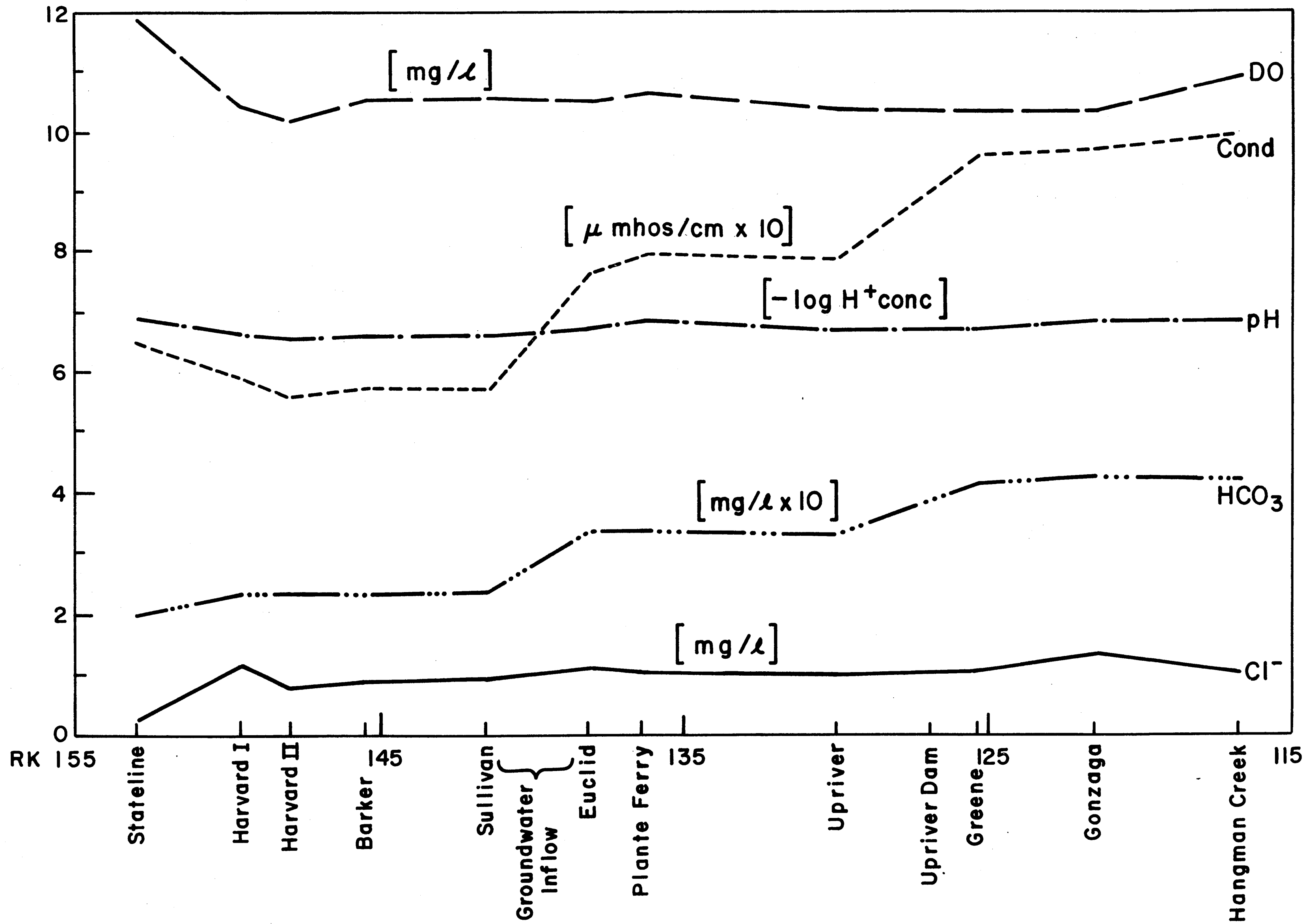

Figure 8. PHYSICOCHEMICAL MEASUREMENT MEANS BY RIVER KILOMETER. NOVEMBER 1979 TO OCTOBER 1981. (Sample number at each station ≈ 38)

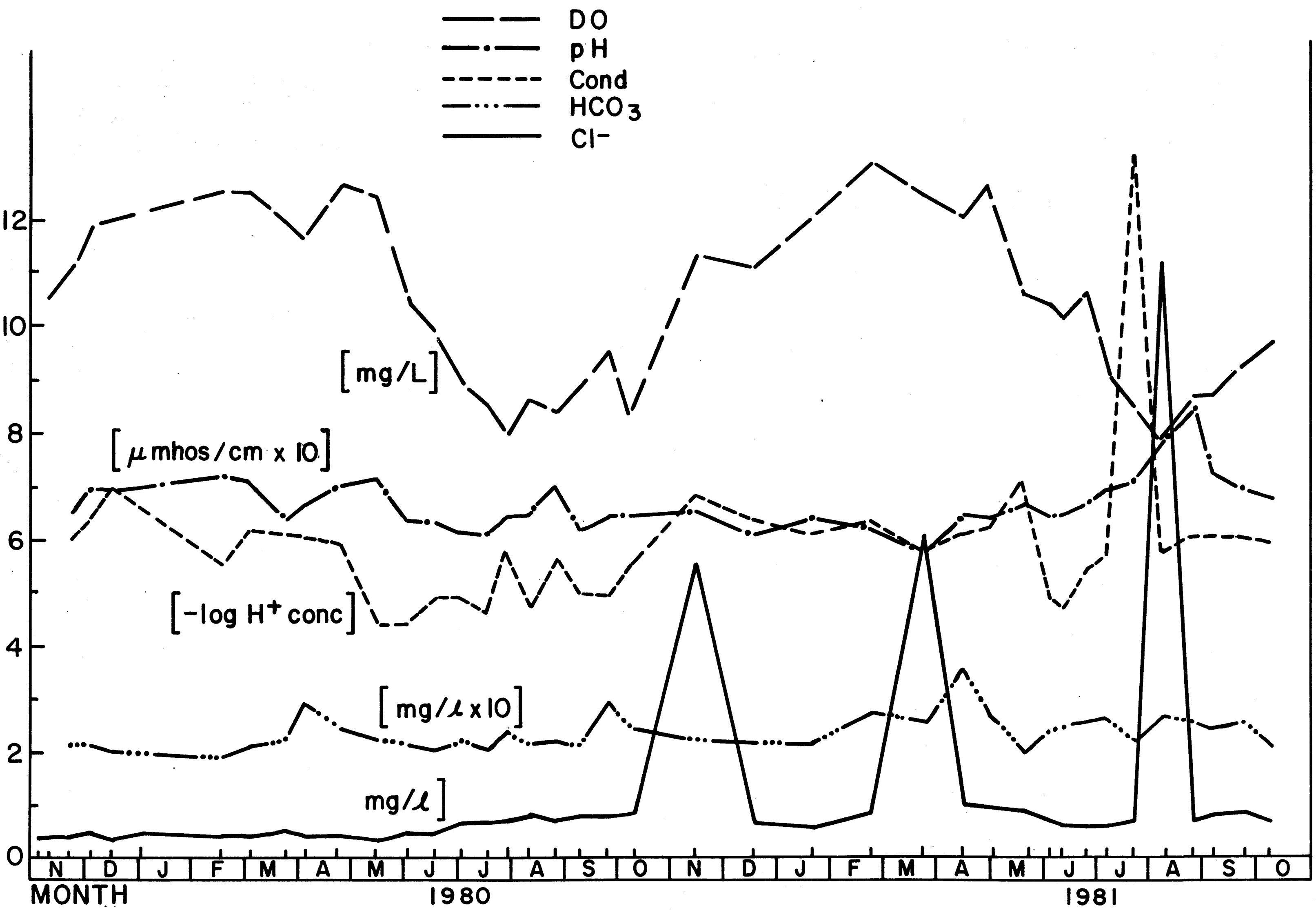

Figure 9. PHYSICOCHEMICAL MEASUREMENTS BY DATE AT HARVARD I

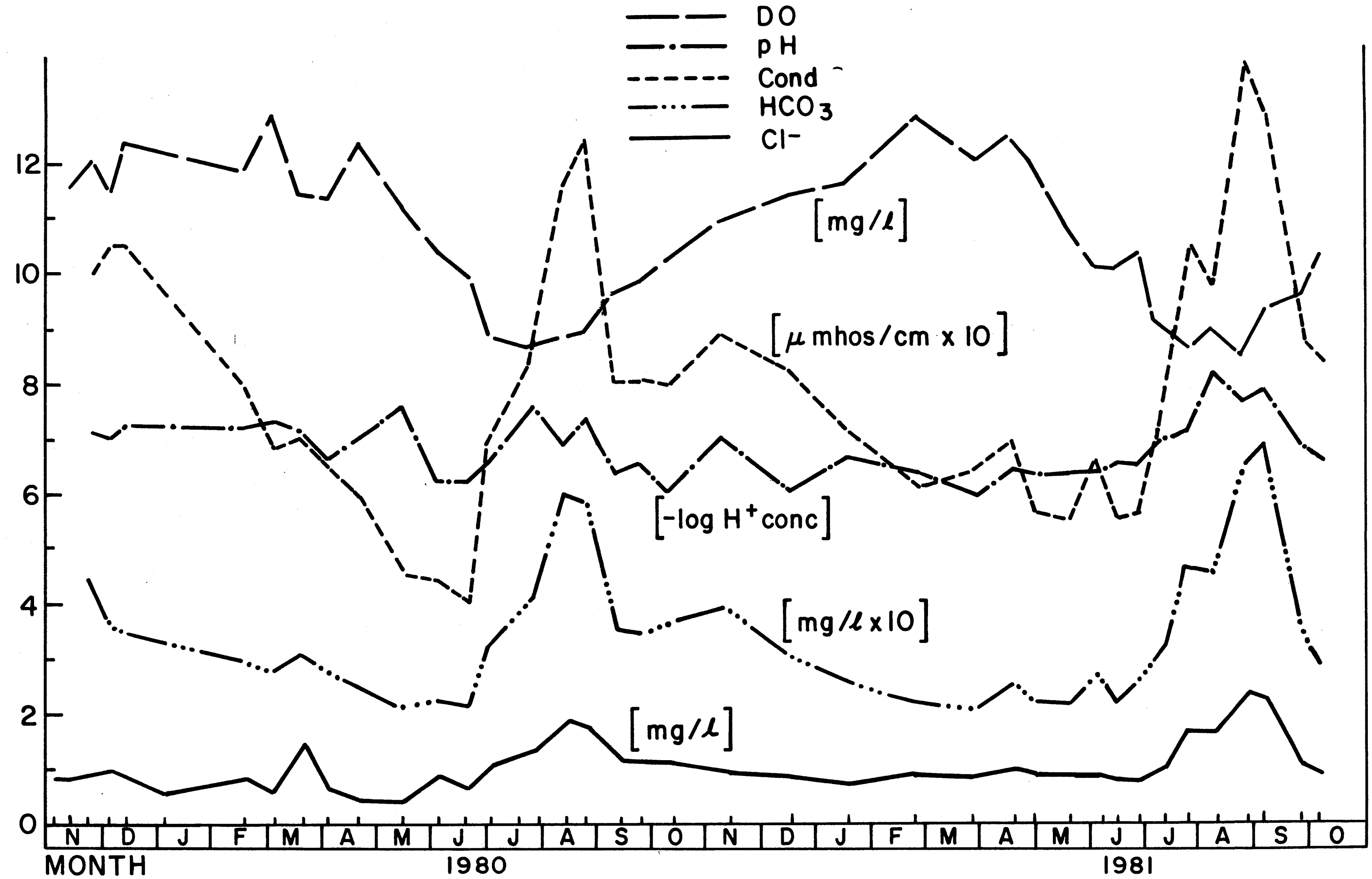

Figure 10. PHYSICOCHEMICAL MEASUREMENTS BY DATE AT PLANTES FERRY

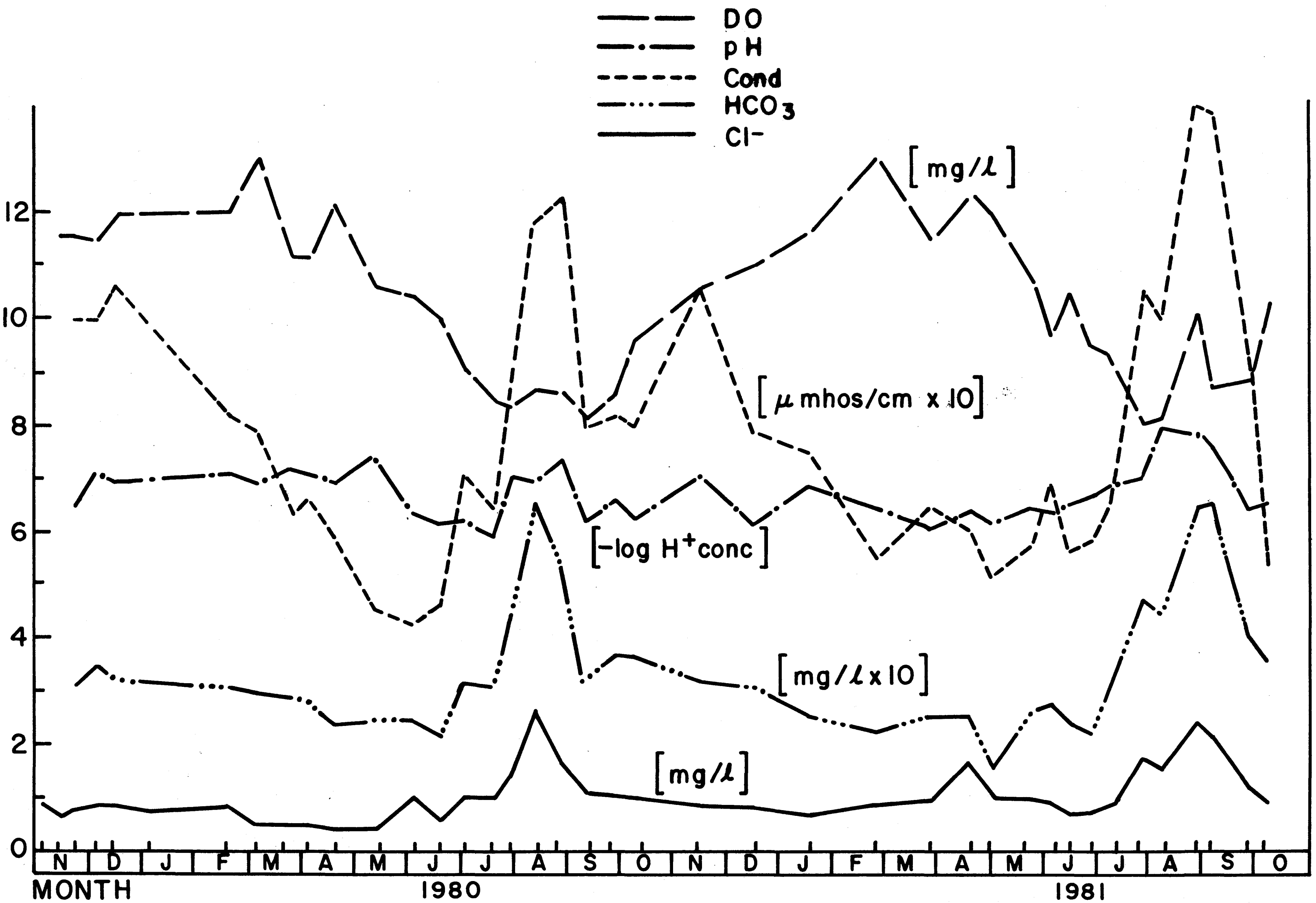

Figure 11. PHYSICOCHEMICAL MEASUREMENTS BY DATE AT UPRIVER

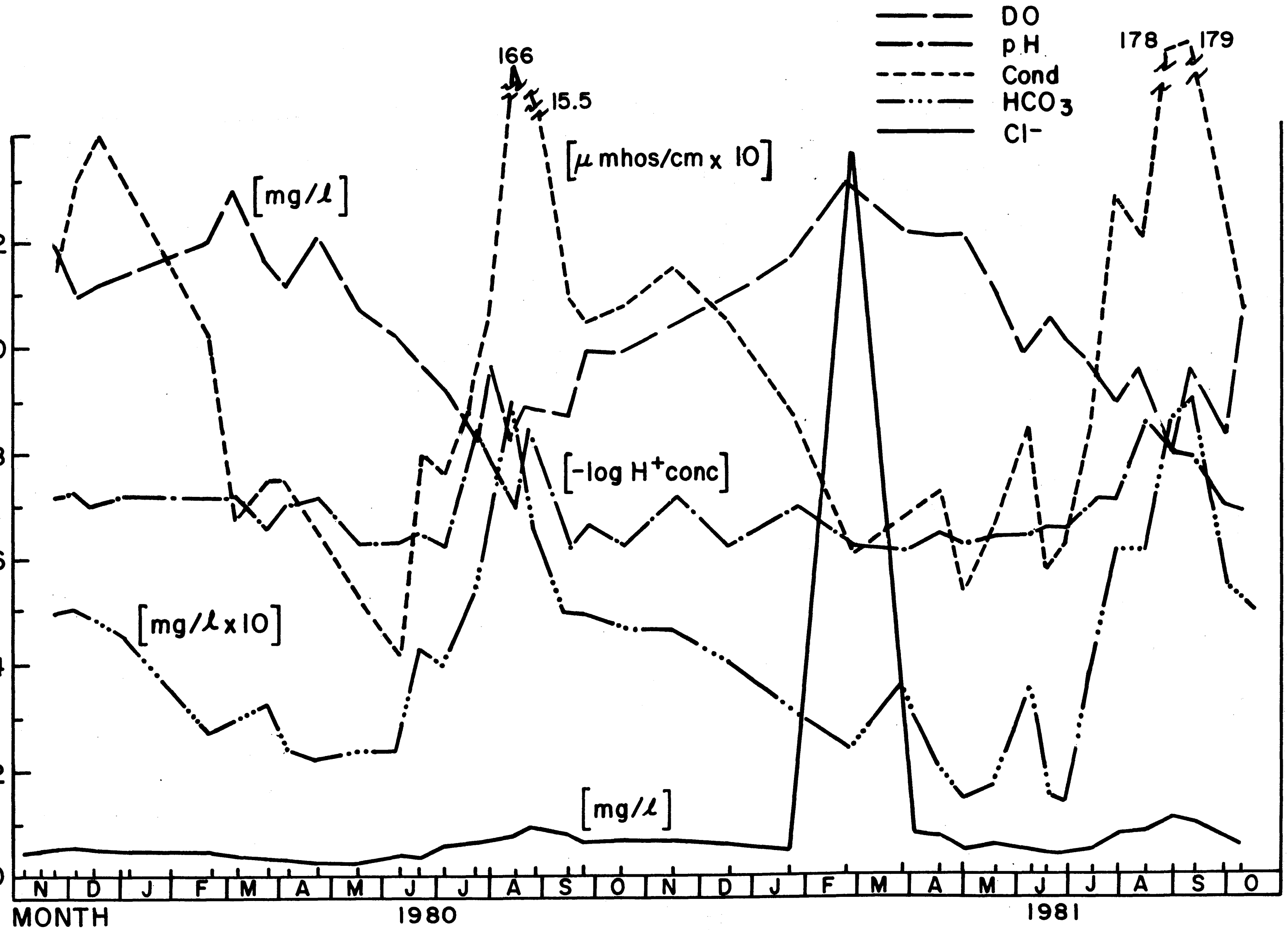

Figure 12. PHYSICOCHEMICAL MEASUREMENTS BY DATE AT GONZAGA

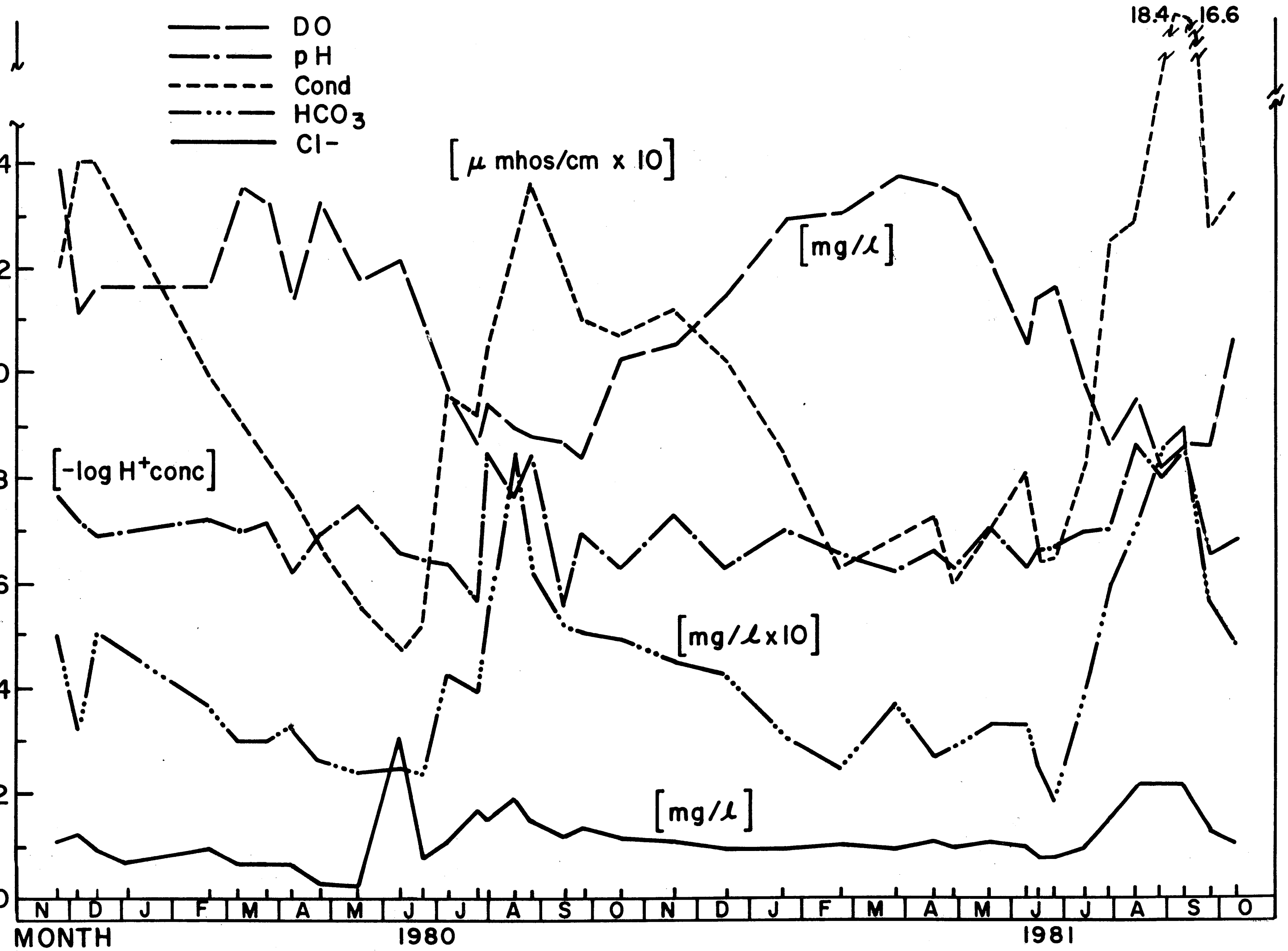

Figure 13. PHYSICOCHEMICAL MEASUREMENTS BY DATE AT HANGMAN CREEK

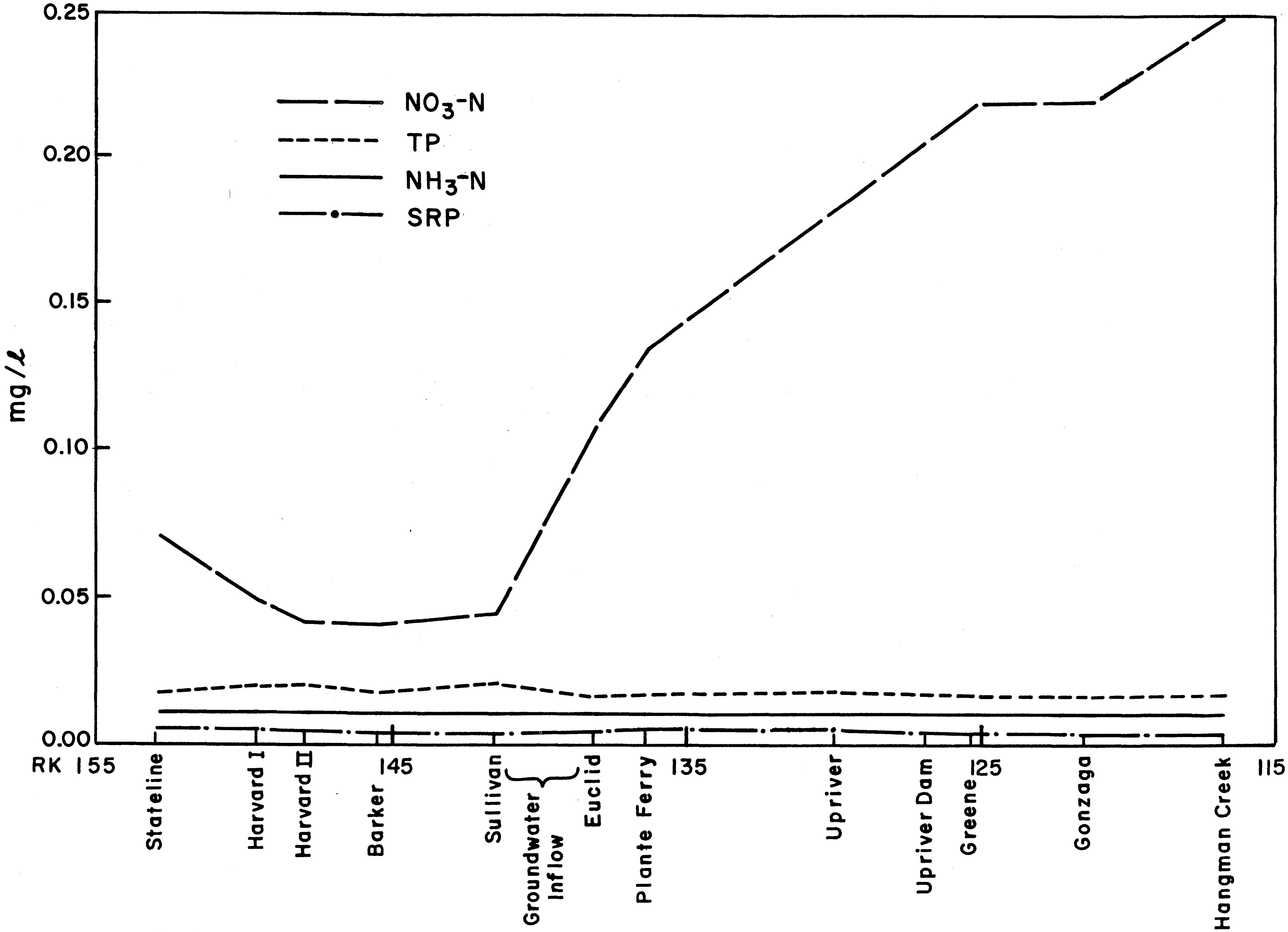

Figure 14. MEAN CONCENTRATION OF NUTRIENTS BY RIVER KILOMETER

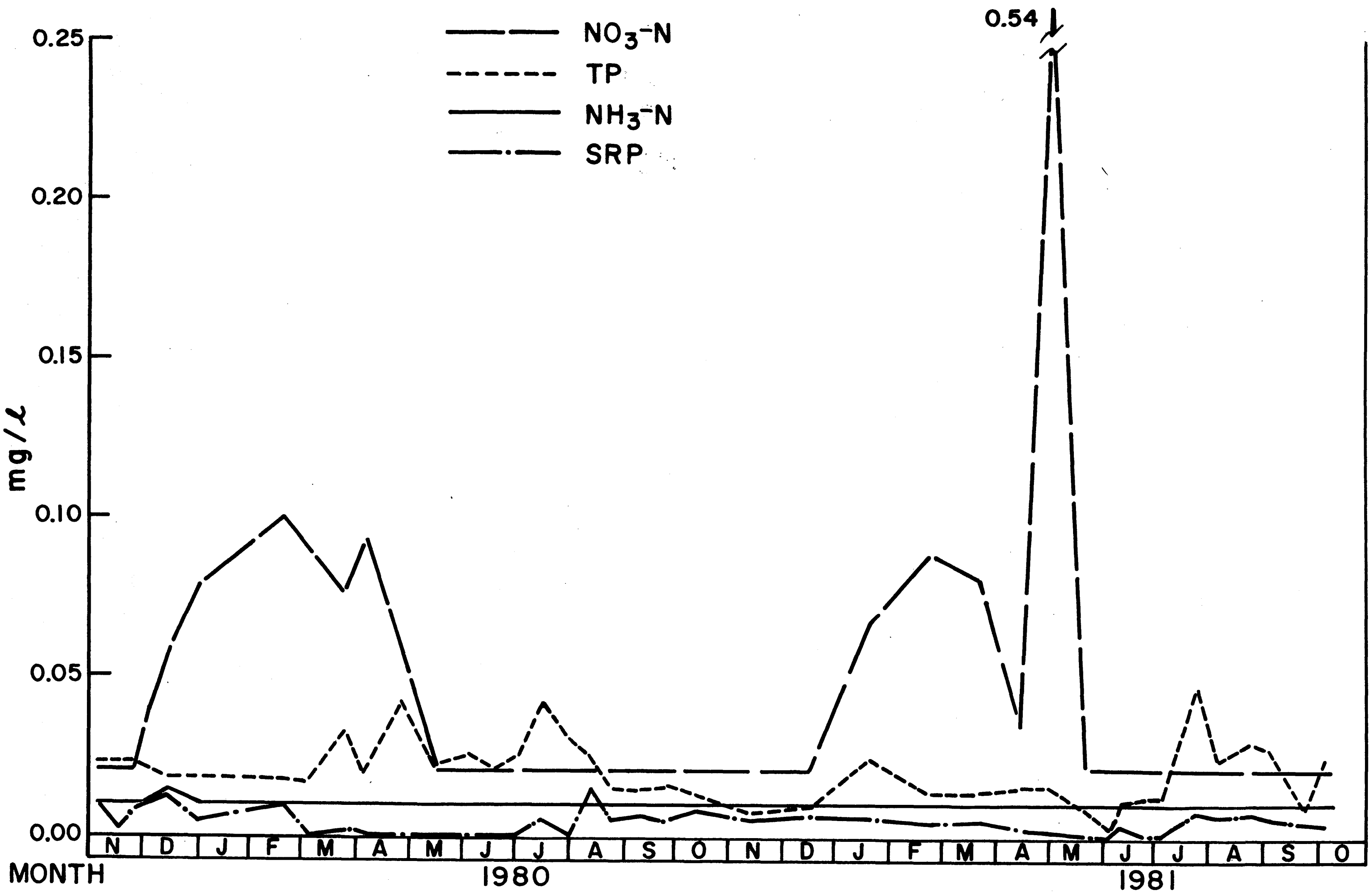

Figure 15 NUTRIENT CONCENTRATION BY DATE AT HARVARD I

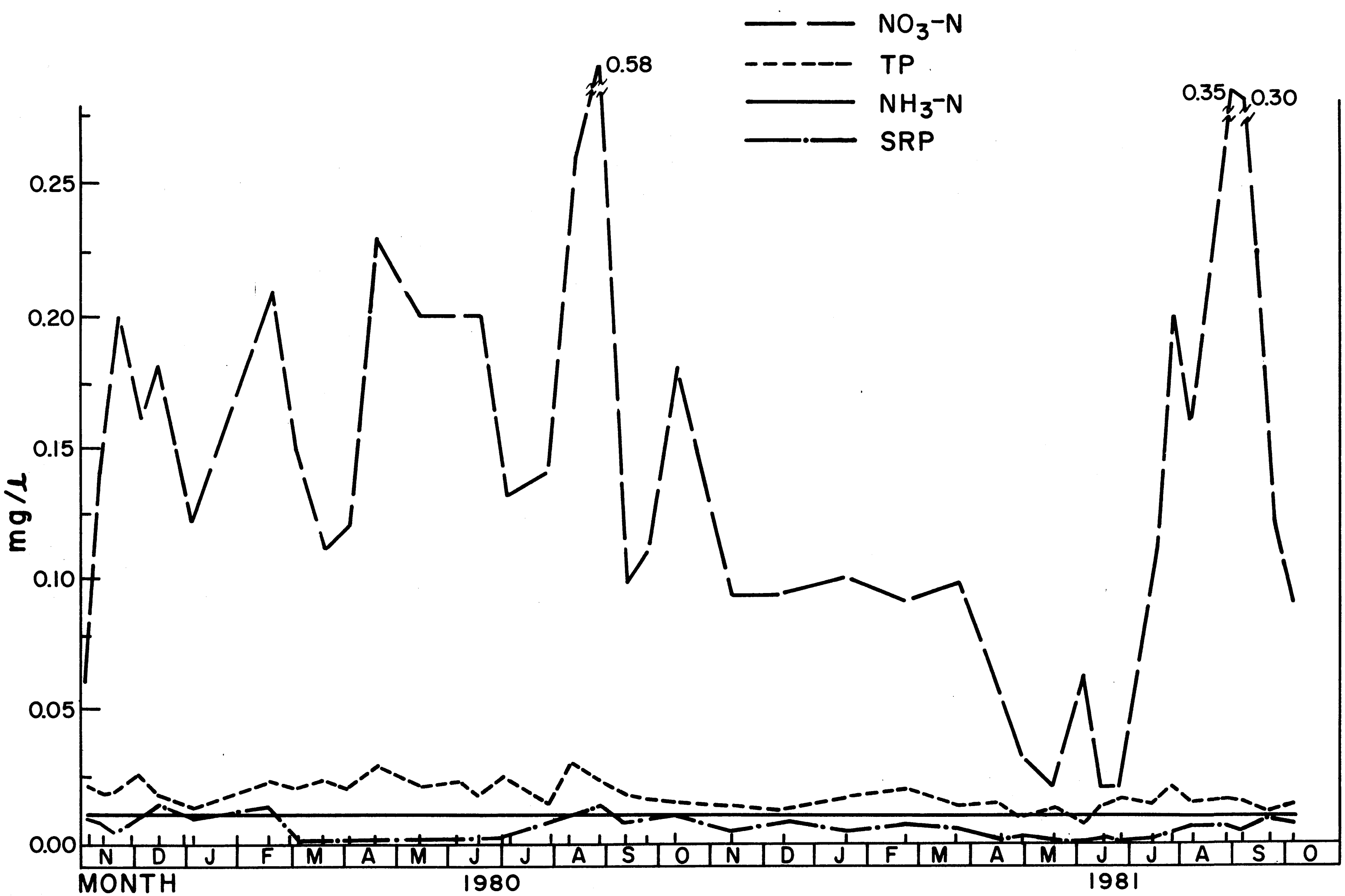

Figure 16. NUTRIENT CONCENTRATION BY DATE AT PLANTES FERRY

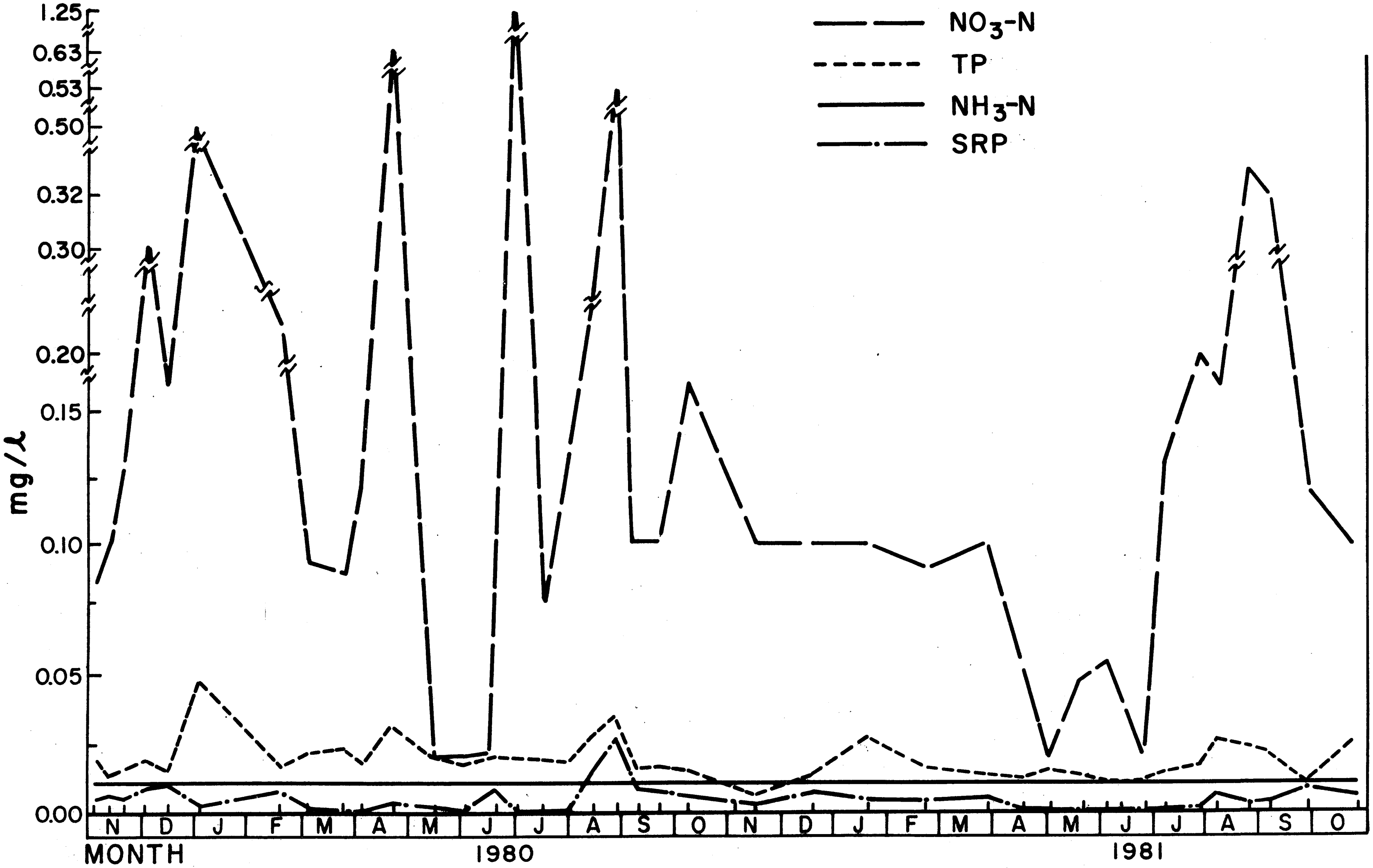

Figure 17. NUTRIENT CONCENTRATION BY DATE AT UPRIVER

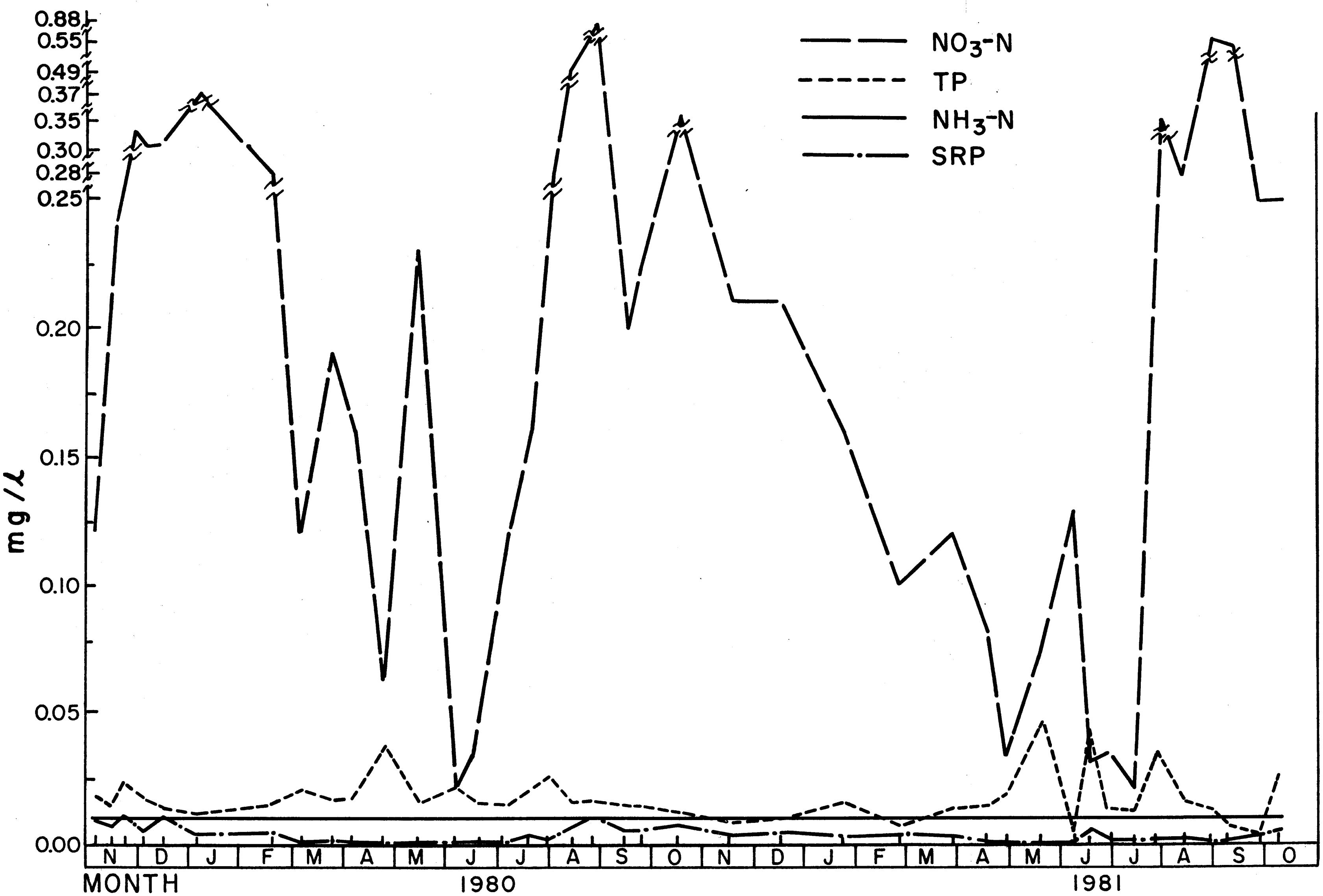

Figure 18. NUTRIENT CONCENTRATION BY DATE AT GONZAGA

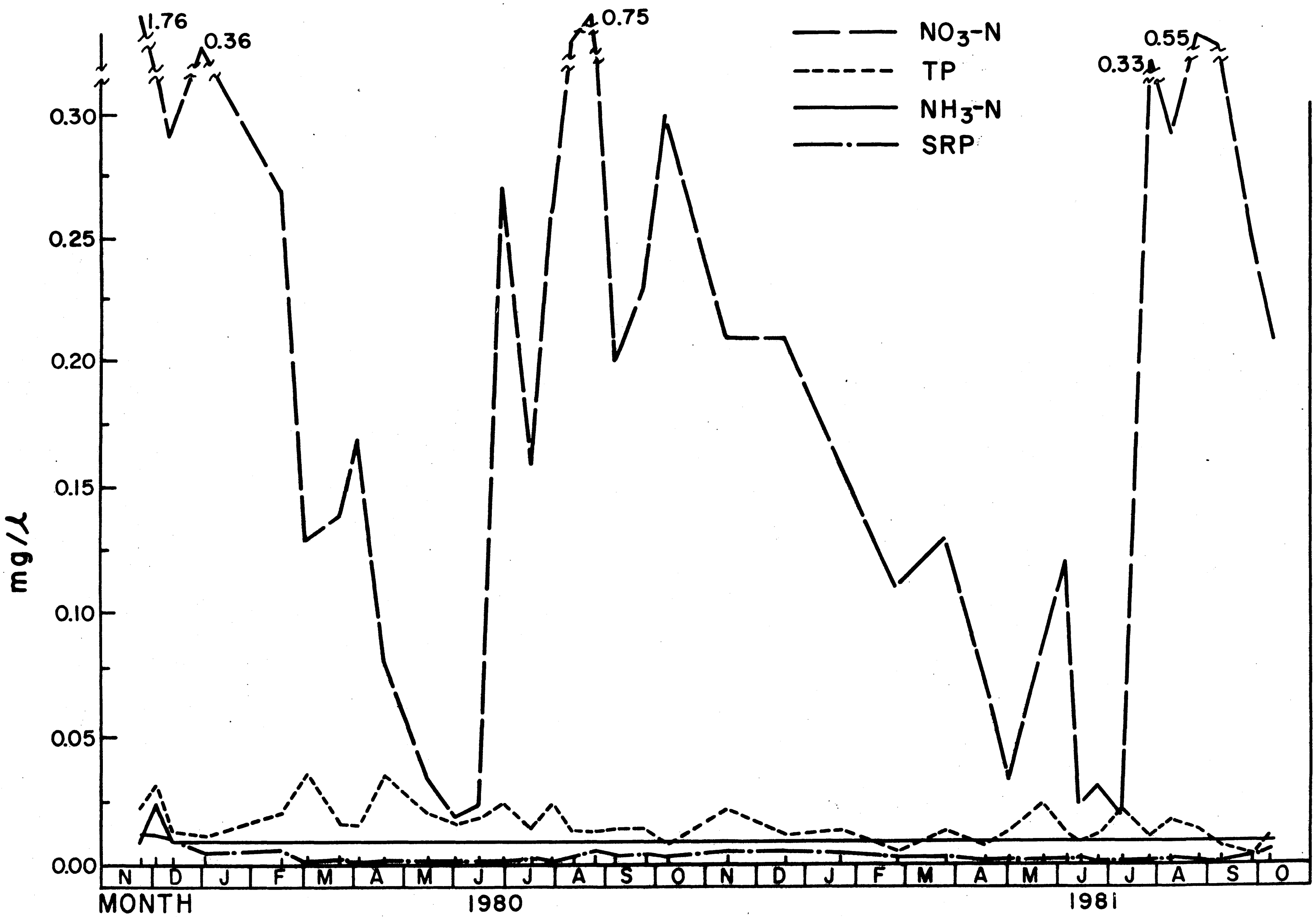

Figure 19. NUTRIENT CONCENTRATION BY DATE AT HANGMAN CREEK

Temperature

The temperature of the waters in the Spokane River ranged from 2.0 to 23.5°C during the study (Table A-1, Appendix A). The Spokane aquifer has a considerable impact on the temperature of the river. Where the aquifer water recharges the river, there is a dramatic decrease in temperature during the summer months. The change can be seen by comparing the mean temperatures for May through September at Sullivan with the mean temperatures from Euclid: mean temperatures at Sullivan were 16.6°C in 1981, and 16.8°C in 1980, while the mean temperature at Euclid was 15.3°C for both years. During the summer, there was as much as a 5°C difference between maximum temperatures above and below the aquifer recharge. The upper portions of the river reached a high temperature of 23.5°C, since its waters are directly derived from warmer surface waters of Coeur d'Alene Lake. The highest temperature recorded at Euclid was 19.5°C.

pH

The pH in the upper Spokane River ranged from a low of 5.4 to a high of 8.5 (Table A-1, Appendix A). The highest pH values occurred during the summer and corresponded to the peak photosynthetic activity within the river. The pH along the ten river stations occasionally varied as much as 1.4 units on the same day. The pH of the Spokane River is relatively low, usually between 6.0 and 7.5, largely because of the acidic nature of its headwaters, the low alkalinity buffering capacity, and the addition of industrial wastes (Funk et al., 1975).

Dissolved Oxygen

Dissolved oxygen (DO) ranged from 7.5 to 13.9 mg/ℓ in the upper Spokane River (Table A-1, Appendix A). Low DO occurred in the summer months. Although 7.5 mg/ℓ of DO is high enough to support aquatic organisms, the DO should be prevented from dropping below that level. High DO occurred during spring runoff and corresponded to high flows.

Carbonates, Bicarbonates and Carbon Dioxides

The concentration of inorganic carbon in the river is relatively low (16 to 90 mg/ℓ shown as $CaCO_3$) and, as previously mentioned, is characteristic of the water in the drainage area (Table A-1, Appendix A). The carbon dioxide concentration ranged from 0 to 3 mg/ℓ. Four times during the study, carbonates were present at two stations in late July and August of both 1980 and 1981. The appearance of carbonates was probably related to algal photosynthetic activity at Gonzaga and Hangman Creek. Alkalinity in the form of bicarbonates ranged from 15 to 89 mg/ℓ as $CaCO_3$. Under low flow conditions, the alkalinity of the river at Euclid and below is influenced by the Spokane aquifer water and is appreciably higher than upstream. The upstream stations above Euclid had bicarbonate concentrations in the 20's to low 30's mg/ℓ as $CaCO_3$ for most the year.

Conductivity

Conductivity increases rapidly after the intrusion of Spokane aquifer water below Sullivan and continues to increase as domestic and industrial effluent are added. Conductivity rises from a mean value of ≅65 μmhos at Stateline to 95 μmhos at Gonzaga. The conductivity of the river when not impacted by the entry of aquifer water was in the 40's to 70's $\mu mhos/cm^2$.

Biochemical and Chemical Oxygen Demand

The five-day biochemical oxygen demand (BOD_5) ranged from less than 1 to 4.8 mg/ℓ O_2 with the majority of the measurements ranging from <1 to

1.0 mg/ℓ O_2 (Table A-1, Appendix A). The river has relatively good water quality in terms of BOD_5, in agreement with the DO measurements.

The chemical oxygen (COD) demand was somewhat higher than the BOD_5 (Table A-1, Appendix A). Because of relatively low oxygen-consuming constituents in the upper river and high flows which increase aeration and dilution in the river, the impact on the DO of the upper Spokane River is minimal. However, this may not be true of the impact of COD on DO in the lower Spokane River where the effect is cumulative because of dams and quiescent waters.

Suspended Solids

The solids carried by the upper Spokane River are not deposited on the river bed because of the high velocities during the spring. Some deposition may occur during low flow periods, but deposits are carried downstream during high flow periods. Earlier studies (Funk et al., 1975) confirmed that the river bottom, almost without exception, is well-scoured to heavy shingle, boulders, or basalt bedrock. However, the solids may play an important role in the bioavailability of certain metals such as zinc as the water moves downstream. This was demonstrated earlier by bioconcentrations of metals in algae and, to some extent, in macroinvertebrates and fishes (Funk et al., 1973, 1975). The data for total and volatile suspended solids are given in Table A-2, Appendix A.

Chlorides

The chloride concentration in the upper Spokane River was low except for a few isolated observations (Table A-2, Appendix A). During low flow, Spokane aquifer water increased the chloride concentration in the river at and below Euclid. Although the concentration of chloride was doubled, it usually was below 2.0 mg/ℓ. Most of the time, the concentration of chloride was less than 1.0 mg/ℓ.

Several physicochemical indicators (DO, pH, conductivity, HCO_3^-, Cl) are summarized by station in Figure 8. Representative stations are summarized by date in Figures 8 through 13.

Nitrogen and Phosphorus

Nutrient content of the river during the study is shown by station in Figure 14. Representative stations are summarized by date in Figures 15 through 19.

Phosphorus is considered to be the most limiting of the two prime nutrients (nitrogen and phosphorus) in the upper Spokane River. That statement can be made with confidence because the N:P ratio is rarely less than 10:1 (Table A-2, Appendix A). In fact, most of the time the N:P ratio is much greater than 10:1. This is due to the relatively high concentration of nitrate-nitrogen present in the river. The Spokane aquifer is probably a major contributor of nitrate-nitrogen to the river, especially at and below Euclid during summer and fall.

The majority of phosphorus occurs in the organic form or is absorbed to particles, while a high percentage of nitrogen is in a readily available form (NO_3-N) and can move rapidly through soils and ground water. It is very important that the amount of phosphorus loading to the river be closely regulated. The impact of increased phosphorus additions in the upper Spokane River could have considerable effect on the primary production in the river. That impact would be particularly important in the reservoir area below the city of Spokane. The term "increased phosphorus" is considered to be relative since 0.01 mg/ℓ soluble phosphorus is recognized by many authorities to be enough to produce algal bloom conditions under quiescent conditions (Sawyer, 1947; MacKenthun, 1969). MacKenthun (1969) also has stated that 1 lb (0.45 kg) of phosphorus theoretically can produce 1000 lb (454 kg) of algae. The level of phosphorus in the river approaches that amount necessary for bloom conditions. Large populations of diatoms, especially *Asterionella formosa*, are supported throughout the year, and on occasion the nuisance algae (blue-greens) achieve bloom proportions in the summer period, especially at the lower river stations Plantes Ferry to Hangman Creek (Table C-1, Appendix C).

Metals

During this study, the concentrations of copper, nickel, cadmium, lead and mercury in the upper Spokane River were relatively low at the ten stations sampled (Table A-3, Appendix A). Copper concentrations ranged from less than 1 to 8.0 μg/ℓ. Nickel concentrations were slightly higher, varying from less than 5 to 22 μg/ℓ. Cadmium concentrations ranged from less than 1 to 7 μg/ℓ, and lead concentrations ranged from less than 1 to 8 μg/ℓ. Mercury concentrations were most often less than 0.5 μg/ℓ, although the mercury concentration on one occasion did reach 70 μg/ℓ at one station. During the study, copper, cadmium, and lead concentrations were usually less than 1 μg/ℓ, whereas nickel concentration was usually less than 5 μg/ℓ.

In the upper Spokane River, the level of zinc, unlike the other metals measured, was high (Table A-3, Appendix A). The zinc concentrations ranged from 5 to 225 μg/ℓ during the study. It is significant that most of the total zinc concentrations were in a filterable fraction (zinc that passes through a 0.45 μm pore filter membrane). The zinc concentrations in the river were highest from January through June, which corresponds to the period of higher flows (Figure 2). As the flows decreased (July through November), the zinc was two to three times less than during the early winter months of 1980 and 1981. As the flow in the river increased in December of 1979 and 1980, the zinc concentrations also increased. Therefore, it appears that there is a correlation between flow and zinc concentrations in the river.

Biological Indicators of Water Quality

Fecal Coliforms

Initially fecal coliforms were enumerated on m-FC agar (Difco) according to Standard Methods (APHA, 1975). Because of the presence of stressed organisms, presumably from high zinc concentrations in the river, the MPN method was employed to increase recovery. The MPN method allowed attenuated organisms to survive, thereby having a consistently higher percentage recovery than the MF method. The MPN method yielded values closer to the true indicator organism concentration.

The range of fecal coliforms in the upper Spokane River during the study varied from less than 1 to approximately 840 bacteria per 100 mℓ. The summary of the fecal coliform data is presented in Table B-1, Appendix B. The main trend observed was that the downstream stations had significantly higher counts than the stations in the upper river. Often in the summer of 1980 and 1981, the fecal coliform density exceeded class standard for the river, especially at Greene Street, Gonzaga, and Hangman Creek stations. The sources of fecal coliforms were not identified in this study. However, as the river traverses more densely-inhabited areas, the fecal coliform load carried by the river increased. According to Washington State standards, fecal coliform criteria of the river are as follows: from Stateline to Gonzaga, the Spokane River meets the Class A (excellent) classification; from Stateline to Barker, the water meets Class AA (extraordinary) except during the months of August and September when the dissolved oxygen level drops below 9.5 mg/ℓ (fecal coliform concentrations meet Class AA standards); at Hangman Creek, the Spokane River fails to meet Class A standards because of the high fecal coliform levels but meets the criteria of a Class B (good) stream.

Periphyton

In order to assess the present state of primary productivity in the upper Spokane River, artificial (glass) and natural (rock) substrates were placed in the river for colonization as previously described. A portion of the study also was directed at determining which substrate was the most reliable in assessing productivity. These biological indicators, along with the phytoplankton and macroinvertebrate studies, represent the most sensitive indicators of improvement or deterioration of river environments. They continually sense the constituents of the aquatic environments, whereas individual water samples represent only the immediate quality of the water passing the sample point. The periphyton cells of each substrate were enumerated and identified (Table C-1, Appendix C) as were biomass by ash-free weight and chlorophyll a determinations (Table C-2, Appendix C).

The results of the enumeration and identification studies show that diatoms were the most common attached algal group. They consistently occurred in every sample on both glass and rock substrates. The dominant diatom was Synedra; it was found in concentrations as high as 21,000 cells/mm^2. Synedra was found during the entire year, but the highest number of cells were encountered in the winter months. Another very common diatom, Fragilaria, was found in densities of up to 16,000 cells/mm^2. The higher concentrations occurred in summer and winter, although Fragilaria was common throughout the year.

Examples of the dominance of Synedra and Fragilaria among the diatom counts are frequent. At Harvard II on August 12, 1980, Synedra and Fragilaria accounted for 766 and 1094 (cells/mm^2), respectively, of the 1932 diatoms found on the rock substrate. At Barker on January 4, 1980, they accounted for 8371 and 6619 (cells/mm^2), respectively, in addition to 3309 other diatoms. At Upriver on June 18, 1980, there were 10,703 (cells/mm^2) Fragilaria and 7541 (cells/mm^2) Synedra out of 24,567 diatoms per mm^2. At Greene Street on February 18, 1980, there were 21,318 (cells/mm^2) Synedra, 16,353 (cells/mm^2) Fragilaria, and 11,388 other diatoms per mm^2 on the rock substrate.

Other common diatoms encountered in the Spokane River were Achnanthes, Amphora, Asterionella, Cymbella, Diatoma, Gomphonema, Melosira, Navicula, and Tabellaria. Of the above diatoms, all but Asterionella are known to be stalked or affix to the substrate by various attachment mechanisms (Smith, 1950; Prescott, 1962; Patrick and Reimer, 1966). The presence of Asterionella, a diatom associated with a planktonic existence, among the attached algae can be attributed to the cells settling out since Asterionella was a dominant phytoplankton.

Diatoms often are grouped by genera into associations. Common associations include Gomphonema-Diatoma (Hynes, 1970) and Achnanthes-

Gomphonema-Synedra (Round, 1965). Although further study would be required for a definitive statement, the data presented in this report suggest that no associations exist between these genera on the Spokane River.

Blue-green algae were the second most numerous group of algae encountered among the periphyton. The highest densities of blue-green algae at all stations occurred during the summer months. The most common genus of blue-green algae was Lyngbya sp. Small filaments of Lyngbya cells were commonly found entangled among the clumps of stalks and gelatinous material often associated with periphyton. Lyngbya occurred in the highest densities of any of the genera of algae. On July 16, 1980, there were 66,995 Lyngbya cells/mm^2 at Upriver on the rock substrate. Lyngbya accounted for the only blue-green algae encountered on many occasions. Such was the case at Harvard I on February 18 and July 2, 1980; at Barker on January 4, March 22, July 2, and December 17, 1980; at Euclid on December 16, 1979, February 18, and March 4, 1980; and at Gonzaga on April 30, 1981. When other blue-greens were present, the majority of cells counted were Lyngbya; for example, at Harvard II, 15,700 out of 19,381 cells/mm^2 and at Barker, 12,033 out of 12,331 cells/mm^2, both on July 2, 1980; at Sullivan, 3,846 Lyngbya and 118 Anabaena cells/mm^2 on July 8, 1981; at Upriver, 11,320 out of 13,207 cells/mm^2 on March 22, 1980, and 30,401 out of 32,681 cells/mm^2 on July 16, 1980; and at Hangman, 16,269 out of 16,413 cells/mm^2 on the rock and 40,866 out of 70,153 cells on the glass on July 8, 1980.

Other common blue-green algae observed in the Spokane River were Anabaena and Oscillatoria. Some blue-greens that occurred infrequently included Gloeotrichia, Nostochopsis and Spirulina. Chroococcus was found at Plantes Ferry on December 16, 1979, in densities of 11,823 cells/mm². Oscillatoria was especially common at Upriver where the flow decreases considerably, approaching a lentic situation. Oscillatoria occurred on June 18, 1980, at 36,974 cells/mm² and on July 16, 1980, at 19,704 cells/mm² at Upriver station.

The green algae were the third most frequently encountered group of attached algae found on the Spokane River. Microspora was the most common genus among the green algae. Other green algae observed included Cladophora, Rhizoclonium, and Ulothrix. Microspora was dominant on December 16, 1979, at Harvard I; on October 10, 1980, there were 736 Microspora cells/mm² out of 760 green algae at Harvard II; at Barker on January 4, 1980, 7,982 out of 10,318 cells/mm² green algae were Microspora; at Euclid on November 14, 1980, 439 out of 659 cells/mm² on the glass rods were Microspora; at Upriver on March 22, 1980, 1,698 cells/mm² were Microspora, 943 cells/mm² were Gonatozygon, and 516 cells/mm² were Cladophora. At Hangman on September 24, 1980, 1,199 out of 1,294 green algae cells/mm² were Microspora.

The green algae were present in the highest numbers during the colder months, especially at Hangman, Barker, and Sullivan. At Hangman, green algae cell counts were about 4,000 cells/mm² in December, 1979, but only in the hundreds in the summer of 1980. At Sullivan, the green algae numbered about 3,800 cells/mm² in December, 1979, 1,900 in February, 1980, and under 400 in July and August of 1980. Barker station had green algae counts of over 10,000 cells/mm² in January, 1980, about 340 and 120 cells/mm² in December, 1980, while in the March, July, and September samples, the green algae numbered less than 100 cells/mm².

According to Hynes (1970), the green algae, along with the blue-greens, are the expected dominant attached algae in the summer in a lotic environment. This was infrequently observed on the upper Spokane River. Possibly the high zinc concentrations encountered throughout the study period had an effect on the expected seasonal growth pattern of the Chlorophyta.

A qualitative comparison of the growth on rock and glass substrate of the different algae groups showed no apparent trends, as demonstrated by the data presented in Figures C-1 to C-11, Appendix C.

Chlorophyll a concentrations were variable, and no correlation between rock substrate and glass substrate was readily apparent (Figure D-1 through Figure D-11, Appendix D).

In 43 cases, greater ash-free dry weight was on the rock substrate of periphyton rather than on the glass substrate (Figures E-1 to E-11, Appendix E). On fourteen occasions, the glass substrate had more periphyton biomass than the rock substrate, and of these, seven occurred at the Upriver station on June 18, July 16, August 26, 1980, February 26, June 11, and July 24, 1981. The other stations where the glass had higher values of ash-free dry weight were Harvard I, Greene Street, Gonzaga, and Hangman.

Paired t-tests (Huntsberger and Billingsley, 1977) were run on the ash-free dry weight, chlorophyll a values and the numbers of cells/mm^2 in the diatom, green algae, and blue-green algae groups to determine if a preference was demonstrated for rock or glass substrate (Table 2). The null hypothesis was that no selectivity for rock or glass substrate was observed at the 80% confidence level except that which would be expected by chance. All data were normalized by base 10 logarithms (Bliss, 1967).

Table 2. Summary of Paired T-Test for Substrate Preference

Parameter Tested	Mean Difference	Variance	n	Calculated t	Table t	Reject Null Hypothesis
Ash-free Dry Weight	3.76 mg/cm²	2.36	59	4.10	1.67	Yes
Chlorophyll a	0.18 μg/cm²	0.31	57	2.51	1.67	Yes
Diatoms	-0.10 cells	0.44	55	-1.15	1.67	No
Green Algae	-0.19 cells	1.99	49	-0.93	1.68	No
Blue-Green Algae	0.28 cells	2.36	49	1.26	1.68	No

The null hypothesis was rejected for ash-free dry weight and chlorophyll a. Hence, it would seem that the algae did colonize the rock and the glass substrate with a preference. Once the periphyton were established, they were better able to carry on primary production on the rock substrate as demonstrated by the higher ash-free and chlorophyll a values. The significantly higher amounts of these biomass indicators on the rock substrate would seem to indicate that the rougher rock substrate provides a more productive habitat for the algae. The reason for this might be that the periphyton can more easily attach themselves to the rougher rock than to the smooth glass. Interstices in the rock would provide better havens out of the tugging current than the glass could.

The statement on the effect of flow on algae production can be reinforced by looking at the Upriver station. There, the rock had more ash-free dry weight on 8 out of 13 samples. The chlorophyll a values were greater on the rock on only 5 out of 12 samples. Therefore, at a station where flow was not a major factor, the difference in periphyton production on rock versus glass substrates was reduced.

Macroinvertebrates

Population Summary: Macroinvertebrate populations in the Spokane River are dominated by the insects of orders Ephemeroptera (mayfly), Trichoptera (caddisfly), and Diptera (Table F-1, Appendix F). Within the entire study area, Baetis sp. was the only genus of mayfly observed. Several species of caddisfly were collected including the net spinners Hydropsyche spp. and Cheumatopsyche sp. Other prevalent families of caddisflies were the limnophilids Onocosmoecus sp. and Dicosmoecus sp. and the leptocerid Ceraclea sp. The third dominant group of macroinvertebrates was composed of a number of species of the dipterian family chironomidae. Table F-1, Appendix F, shows a complete list of those chironomids found. The sporadic occurrence of Simulium sp. in large numbers was most likely caused by a highly contagious distribution of that group. Other organisms commonly observed in the Spokane River were Antocha sp., Parargyractis sp., and Physa sp.

Variation in community structure resulted from seasonal and habitat variation between stations. During summer low flows, the stations can be differentiated into four habitat types. Harvard I, Sullivan, Euclid, and Hangman Creek stations are located at fast-flowing stretches with a relatively deep mid-channel. At Stateline, Harvard II, and Barker, a shallow river channel with high velocity results in riffle zones across portions of the river. The river deepens with reduced velocity at Plantes Ferry, Gonzaga, and Greene Street stations. The last station was just upstream from the Upriver Dam in a lentic environment.

After high spring flows, samplers retrieved in the summer of 1980 at Harvard I, Sullivan, Euclid, and Hangman Creek contained a large percentage of hydropsychids. Mayflies and chironomids were also abundant. Fall 1980 samples showed some variation in dominance with a possible increase in the percentage of chironomids (Figures F-1 to F-12, Appendix F).

Those stations with riffle areas, Stateline, Harvard II, and Barker, showed no noticeable differences in the macroinvertebrate community sampled. Similarity in samples from these stations may in part be caused by the nearshore placement of the samplers. Although habitats across transects at these stations differ, samplers were placed nearshore at a constant depth of one meter, where velocities were considerably less than midstream. This placement created more uniform sampling between stations but most likely failed to accurately represent the benthic population in mid-channel sections.

The deeper, slower moving water at Plantes Ferry, Gonzaga, and Greene Street did produce a change in the macroinvertebrates sampled. The decrease in velocity with the absence of riffle zones resulted in a considerable reduction in the hydropsychid population. In addition to the decrease in hydropsychids, the mayfly, Baetis sp., was less abundant at the Upriver station. Samples from the reservoir contained considerable numbers of the caddisfly Polycentropus sp. and damselflies and dragonflies Ischnura sp., Enallagma sp., and Aeshna sp. The chironomids were consistently observed in high numbers along with other organisms, such as Physa sp., oligochaetes, and turbellarians.

A characteristic aspect of all the stations was a low diversity and evenness of organisms. Table F-1, Appendix F, shows that a large number of organisms had been collected, but their appearance in individual samples were far and few between. Another aspect of the macroinvertebrate population was the low numbers and limited number of species of Plecoptera (stoneflies) collected, a group expected to be found in large numbers in a river of this type and apparent water quality. Similarly, a more diverse group of Ephemeroptera (mayflies) would be expected, but as stated earlier, only one species was found.

The relative distribution of organisms collected expressed in a community structure analysis and the total number of organisms are found at the bottom of Table F-1, Appendix F. The first analysis involves calculation of diversity ($\bar{d}$) as determined by the equation:

$$\bar{d} = -\Sigma(N_i/N)/\log_2(N_i/N)$$

where N is the total number of organisms and N_i is the number of individuals per taxon (Wilhm and Dorris, 1968).

The calculated results are slightly lower than in actuality because the chironomids were used in the calculations at the tribe taxonomic level, whereas they actually are composed of a number of species. The difference, however, is considered minimal since 70% of the chironomid population was composed of Orthocladiini sp.

The diversity values shown in F-1, Appendix F, range from 0.00 to 2.84 with a mean of 1.54. Wilhm (1970) reviewed studies of diversity values from polluted and unpolluted streams and found diversity values of 0.00 to 1.60 in polluted streams and 2.60 to 4.61 in unpolluted streams. On this basis, the diversity values from the Spokane River would indicate a somewhat polluted or stressed environment. The stress is probably the result of the high zinc concentrations present in the river. The lack of variety of species and the absence of stoneflies which are present in the upper drainage regions may be caused by a lack of variety of food (Hynes,

1970) rather than metal-induced stress on the organisms. Many stoneflies, mayflies, and chironomids are resistant to zinc (Hynes, 1960; Jones, 1964).

Sampler Comparison: Table F-1, Appendix F, shows results of the multiple-plate (M-P) and rock basket (R) samplers. Both samplers were placed side by side for the same colonization period. Because of the high selectivity of many benthic macroinvertebrates for substrate type (Moon, 1940; Linduska, 1942; Egglishaw, 1969; Williams and Hynes, 1973; Minshall and Minshall, 1977), some differences in the populations collected by the two samplers were expected.

To determine whether possible statistical differences between the multiple-plate and basket samplers exist, paired t-tests were run on total numbers of organisms. Also, paired t-tests were performed to test for selective colonization of the samplers by groups of organisms. These groups included Trichoptera, Hydropsychidae, Limnophilidae, Baetidae, and Chironomidae. Before running the t-tests, a chi-square test was run on the data to test for random distribution. The chi-square test was rejected, indicating contagious distribution; hence, a logarithmic transformation was used to normalize the data.

Results of the paired t-test listed in Table 3 showed significant difference ($P < 0.2$) between the multiple-plate and basket sampler among the order Trichoptera and family Limnophilidae. Both groups showed preference for the multiple-plate sampler. Mason et al. (1973) discuss the importance of substrate geometry in relation to multiple-plate samplers, particularly with the hydropsychid caddisflies. Although no selection by hydropsychids was shown in this study, it was noted in the field that limnophilid caddisflies did utilize the smooth surfaces of the pressboard plate of the multiple-plate samplers for attachments of cases during pupation.

Table 3. Summary of Paired T-Tests (Transformed Data, $\log_{10}$ (x+1)) for the Rock Basket Sampler and Multiple-plate Sampler

Taxon	Calculated t	Table t (0.20,39)
Total No.	0.315	1.301
Chironomidae	0.363	
Baetidae	-0.353	
Trichoptera	1.893	
Hydropsychidae	0.793	
Limnophilidae	1.451	

No selection for substrate type by total number of organisms was found in accordance with results of Mason et al. (1973) and Fullmer (1971). The chironomids and the mayfly Baetidae also demonstrated no selectivity.

The basket samplers in this study utilized rocks from the sampling site, thereby approximating natural substrate to some extent, although placing the rocks in a barbeque basket altered the substrate from the stream bottom. The basket substrate differs from that of the natural stream bottom in that there is alteration of the flow regime, accumulation of debris by the basket, and absence of gravel and detritus between the rocks. For these reasons, it is possible that the samplers discussed above may not adequately represent the true benthic macroinvertebrate population.

In order to identify possible differences, a modification of Gale and Thompson's (1975) suction sampler was used as an additional comparison with the basket and multiple plate samplers. The suction sampler vacuums the undisturbed stream bottom within an enclosed area. Arm ports are provided, enabling the scuba diver to dig up the substrate for collection of burrowing benthic organisms. All samples were taken at mid-stream for a more representative sample of that station. Suction samples were taken upon retrieval of the basket and multiple-plate samplers, which were enclosed in nylon bags during removal to avoid loss of organisms during the swim to shore. Results of this comparison are shown in Tables 4 and 5. Both Stateline and Harvard II stations were found to be dominated by Hydropsyche sp., Cheumatopsyche sp., Ceraclea sp., and Chironomidae. In addition, the Stateline station contained numerous Hydra while Harvard II contained Baetis sp. The specific location of the Stateline samplers were in a deeper (3 m), slower moving pool compared to the shallow (1 m), swifter moving section at Harvard II. Preference for faster flowing water by Baetis sp. and slower flowing water by Hydra would explain the differences between stations.

Differences between samplers are summarized in Tables 6 and 7. The Harvard II basket and multiple-plate samplers show strong selection for the mayfly Baetis sp; a similar selection at both Stateline and Harvard II stations was made by Hydra. The absence of mayflies on the stream bottom as noted by the scuba diver support the results obtained by the suction sampler. Possible selections by Simulium sp. for the basket and multiple-plate sampler were also shown at Harvard II which support Gale and Thompson's findings (1975). The suction sampler collected more of the caddisfly Ceraclea sp. at both stations.

As shown, samples from basket, multiple-plate, and suction samplers were found to contain different populations of benthic macroinvertebrates. Differences between the multiple plate and basket sampler are considered to be minimal. Problems encountered with both samplers in this study involved vandalism. The river has high recreational use during summer low flows, resulting in disturbed or stolen samplers. It is believed that the suction

Table 4. Summary Numbers per m^2 from Stateline on September 26, 1980

Taxon	Sampler								
	Suction			Basket			Multiple-Plate		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Ephemeroptera									
Baetidae									
Baetis				15					
Trichoptera									
Hydropsychidae									
Hydropsyche	9	28	28	30	37	133	11		22
Cheumatopsyche	9	38	38	15	30	44	11	11	11
Immature					52	141		64	
Leptoceridae									
Ceraclea	216	301	357	44	52	252	54		
Nectopsyche	38	9							
Polycentropadidae									
Polycentropus									
Hydroptilidae									
Argraylea			38	15				11	
Phyacophilidae									
Rhyacophila									
Plecoptera									
Perlodidae									
Arcynopteryx									
Lepidoptera									
Pyralidae									
Parargyractis				7					
Coleoptera									
Elmidae (Adult)									
Hymenoptera									
Trichogrammatidae									
Homoptera									
Aphidae									
Hemiptera									
Gerridae									
Metrobates (Imm.)									
Diptera									
Tipulidae									
Antocha									
Simulidae									
Simulium									
Chironomidae	6,327	11,677	14,451	5,200	5,185	4,756	4,891	806	1,581
Hydra	94		38	4,075	19,319	12,037	4,839	4,032	2,720
Others	27	66	140	208	15	169	76	96	226
TOTAL No./m^2	6,720	12,119	15,090	35,719	24,690	17,532	9,882	5,009	4,571
DIVERSITY ($\bar{d}$)	0.39	0.26	0.26	1.11	0.81	1.09	1.07	0.76	1.04

Table 5. Summary Numbers per m² from Harvard II on September 27, 1982

Taxon	Sampler								
	Suction			Basket			Multiple-Plate		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Ephemeroptera									
Baetidae									
Baetis	9	9	9	289	178	103	269	247	172
Trichoptera									
Hydropsychidae									
Hydropsyche	160	75	254	1,526	15	1,222	75	140	161
Cheumatopsyche	179	216	1,156	185		244	32	54	11
Immature				3,014	7	1,711	64	247	
Leptoceridae									
Ceraclea	179	226	207		22		97	54	75
Nectopsyche									
Polycentropadidae									
Polycentropus									
Hydroptilidae									
Argraylea				7					
Phyacophilidae									
Rhyacophila				7					
Plecoptera									
Perlodidae									
Arcynopteryx		9	9						
Lepidoptera									
Pyralidae									
Parargyractis			19	7		7		11	
Coleoptera									
Elmidae (Adult)									
Hymenoptera									
Trichogrammatidae									
Homoptera									
Aphidae				7	7				
Hemiptera									
Gerridae									
Metrobates (Imm.)									
Diptera									
Tipulidae									
Antocha				7			11		
Simulidae									
Simulium				59	7	22		11	
Chironomidae	3,319	3,572	3,676	2,857	111	2,318	2,225	4,450	3,656
Hydra				59				204	32
Others	28	19	74					11	11
TOTAL No./m²	3,874	4,126	5,404	8,094	347	5,627	2,773	5,429	4,118
DIVERSITY ($\bar{d}$)	0.81	0.77	1.30	1.59	1.81	1.51	1.08	1.28	0.71

Table 6. Macroinvertebrate Mean Numbers per m^2 and Standard Deviation (s) from Stateline (Midstream) on September 26, 1980. (n = 3)

Taxon	Sampler		
	Suction	Basket	M-P
Ephemeroptera	0.0 (0.0)	5.0 (8.7)	0.0 (0.0)
Trichoptera	369.7 (94.7)	281.7 (251.9)	65.0 (18.2)
Ceraclea sp.	291.3 (71.0)	116.0 (137.6)	18.0 (31.17)
Plecoptera	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Lepidoptera	0.0 (0.0)	2.3 (4.0)	0.0 (0.0)
Chironomidae	10,818.7 (4,129.5)	5,047.0 (252.1)	2,426.0 (2,169.0)
Simulidae	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
SUBTOTAL:	11,188.7 (4,223.7)	5,336.0 (17.2)	2,491.0 (2,176.3)
Hydra	44.0 (47.3)	20,513.7 (9,132.8)	3,863.7 (1,069.5)
Others	77.7 (57.4)	130.7 (102.1)	132.7 (81.4)
TOTAL:	11,309.7 (4,243.3)	25,980.3 (9,161.9)	6,487.3 (2,948.0)

Table 7. Macroinvertebrate Mean Numbers per m^2 and Standard Deviation (s) from Harvard II (Midstream) on September 27, 1980. (n = 3).

Taxon	Sampler		
	Suction	Basket	M-P
Ephemeroptera	9.0 (0.0)	190.0 (83.6)	229.3 (50.9)
Trichoptera	884.0 (634.8)	2,683.3 (2,430.4)	336.7 (137.5)
Ceraclea sp.	204.0 (134.3)	7.3 (135.5)	75.3 (153.4)
Plecoptera	6.0 (5.2)	0.0 (0.0)	0.0 (0.0)
Lepidoptera	6.3 (11.0)	4.7 (4.0)	3.7 (6.3)
Chironomidae	3,522.3 (183.6)	1,755.3 (1,447.5)	3,443.7 (1,127.6)
Simulidae	0.0 (0.0)	29.3 (0.0)	3.7 (45.6)
SUBTOTAL:	4,427.7 (792.3)	4,596.3 (3,967.4)	4,013.3 (1,221.7)
Hydra	0.0 (0.0)	19.7 (34.1)	78.7 (109.7)
Others	40.3 (29.5)	36.3 (32.0)	14.7 (6.3)
TOTAL:	4,468.0 (820.0)	4,689.3 (3,957.7)	4,106.7 (1,328.0)

sampler more accurately collects the benthic community and eliminates the risk of vandalism. The suction sampler requires a more technical sampling procedure utilizing a scuba diver; however, visual observations made by the diver can provide additional data.

The suction sampler collects organisms from an undisturbed natural substrate present at the beginning of the season. The other samplers are foreign objects placed in the river six weeks previous to collection.

Phytoplankton

The phytoplankton community was dominated by four genera of diatoms in the upper Spokane River (Table G-1, Appendix G). Those algae were Asterionella, Melosira, Synedra, and Tabellaria. The density of Asterionella formosa was observed to be as high as 13,431 cells/mℓ on April 30, 1981. On most occasions, A. formosa was numerically more abundant than the other phytoplanktons. However, the blue-green alga, Aphanizomenon flos-aquae, attained densities of 20,700 cells/mℓ at Gonzaga and 20,000 cells/mℓ at Hangman on September 3, 1981.

There is a rich phytoplankton community in the upper Spokane River that is dominated by diatoms. The densities observed during this study suggest that the potential for nuisance populations of algae could develop if the flow and/or the velocity of the river is greatly reduced. Such a reduction in velocity of the river would create a lentic environment that would be much more conducive to phytoplankton production than the present lotic environment (Appendix I).

SUMMARY

In general, the physical and chemical properties of the upper Spokane River are indicative of good water quality conditions. The most notable exception is the elevated concentration of zinc. The impacts of the excessive zinc concentration, although not defined by this study, are apparent in the absence of certain species of invertebrates and fish.

Periphyton were present in large densities and were dominated by diatoms. There was no definable difference between the density of algae colonizing glass versus natural rock substrate. However, once the periphyton were attached to the rock substrate, they were able to attain a greater biomass and chlorophyll a level than the same density of algae on the glass substrate. Hence, the rock substrate provided the periphyton with an advantage over the periphyton on the glass substrate in the process of primary production.

The macroinvertebrate population throughout the upper Spokane River was dominated by *Baetis* sp. and members of Hydropsychidae and Chironomidae. There was a conspicuous lack of stoneflies in both types and numbers. The lack of stoneflies and the low diversity could have been related to the high zinc concentration and its effect on the food chain in the river; however, the downstream effects of Lake Coeur d'Alene may also have an influence.

The total invertebrate population had a low diversity as indicated by the Shannon-Weaver Diversity Index. Again, the low diversity may have been caused by the high zinc concentration in the river.

Analysis of sampling methodology showed little significant difference between the multiple plate and basket samplers. A comparison of these

samplers to a suction sampler showed significant differences, particularly with the abundance of mayflies collected in the basket and multiple-plate samplers. Visual observations by the investigators support the unbiased application of the suction sampler in that few mayflies were observed on the bottom of the river. It is recommended that the suction sampler be used in future studies in lotic environments to determine the actual invertebrate population.

In conclusion, this report contains substantial baseline data that should be of considerable value in assessing the impact of treated sewage effluent on the upper Spokane River, once post-effluent data using similar methodologies are collected.

RECOMMENDATIONS FOR FUTURE STUDIES ON THE UPPER SPOKANE RIVER

The data reported in this study and in other investigations indicate that the water quality of the upper Spokane River is under stress from two major sources. The first is the relatively high zinc content from upstream addition. Zinc, without doubt, exerts an impact upon the structure of the aquatic communities of the river. The second major source of stress--nutrients and oxygen-demanding substances--comes from two directions, non-point source and point source addition. Currently, the aquatic communities in the upper Spokane River are indicative of a meso-eutrophic condition. It is obvious that the nutrient loading into the river is increasing with time and that this region of the river is approaching its maximum absorptive capacity for nutrients.

A minimal water quality monitoring program including biological parameters is essential immediately downstream of the Liberty Lake STP effluent. The minimal monitoring effort should have three stations (one above the STP effluent--Harvard I--and two below the STP effluent--Harvard II and Baker) where water chemistry is determined, and periphyton and macroinvertebrates are measured and assessed, particularly in regard to their productivity. However, under "real world" situations, the suggested "minimal" study may not be monetarily possible on a yearly basis. The monitoring program should be performed by an independent group separate from the Liberty Lake Sewer District and their consultant. That program may indicate a degradation of water quality, such as increased nutrients, and a change in community productivity and structure in comparison with the upstream station and base line data contained in this report. If degradation occurs, if the discharge of the STP exceeds 1 MGD, or if there are reports of an algal bloom in the Upriver Dam Pool, then a comprehensive and intensive water quality investigation should be initiated immediately.

The impact of nutrients from point sources, such as the Liberty Lake Sewage Treatment Plant effluent, and nonpoint sources resulting from the urbanization of the Spokane Valley can be assessed by periodic comprehensive investigations into the water quality of the river, point sources, and urban runoff. The following list are elements that should be monitored and studied in an intensive program.

1) All of the ten sampling stations shown in Figure 1 and chemical and biological parameters monitored in this report should be continued in order to assure comparability with past and future investigations.

2) The methodologies should be the same as those employed in the present study to assure comparability with past and future investigations. Refinements in natural rock baskets methodologies may be used as long as correlations between differing methodologies are produced. In this way, comparability will be valid (see Table 8).

3) All significant point sources should be sampled and flows should be determined.

4) Gauge stations should be established on the river at Harvard I, Sullivan, and Plantes Ferry in addition to the present stations at Post Falls and Greene Street. The present flow stations monitored in this region of the river (Post Falls and Greene Street) do not allow for accurate determination of nutrient loading by groundwater addition.

Table 8. Recommended Water Quality Sampling Program Summaries

Type of Study	Number of Locations	Number of Samples per Location	Sampling Frequency	Method of Collection	Physical Chemical Parameters/ Biological Parameters
Minimal	3	2	Biweekly May-Sept; Monthly Oct-April	½ m Grab	Analyzed temperature, dissolved oxygen, conductivity, pH, stream velocity at site, flow gauge measurements. Alkalinity, suspended solids, total phosphorus, total soluble phosphorus, soluble reactive phosphorus, ammonia-nitrogen, nitrate plus nitrite-nitrogen, Kjeldahl-nitrogen zinc, chlorine, chloride, calcium, hardness.
	3	2	"	½ m & 1 m Grab	Phytoplankton
		2	"	"	Fecal coliforms
		3	"	Rock Basket Samplers	Periphyton, id./dry weight
		3	"	"	Macroinvertebrates
		3	"	Rock Basket Samplers	Chlorophyll a (Periphyton)
		2	"	½ m & 1 m Grab	Chlorophyll a (Plankton)
Comprehensive	10	2	Biweekly May-Sept; Monthly Oct-April	½ m & 1 m Grab	Analyzed temperature, dissolved oxygen, conductivity, pH, stream velocity at site, flow gauge measurements. Alkalinity, suspended solids, total phosphorus, total soluble phosphorus, soluble reactive phosphorus, ammonia-nitrogen, nitrate plus nitrite-nitrogen, Kjeldahl-nitrogen zinc, chlorine, chloride, calcium hardness.
	10	2	"	½ m & 1 m Grab	Phytoplankton
		2	"	"	Fecal coliforms
		3	"	Rock Basket Samplers	Periphyton, id./dry weight
		3	"	"	Macroinvertebrates
		3	"	Rock Basket Samplers	Chlorophyll a (Periphyton)
		2		½ m & 1 m Grab	Chlorophyll a (Plankton)

5) An urban runoff study should be coordinated with the river investigation.

6) Along with the investigation into urban runoff, potential increases in runoff and ways to reduce the adverse effects of that runoff should be assessed. Toxicity bioassays should be performed to assess the toxicity of the urban runoff to the aquatic organisms.

7) Studies into the effects that the constituents of urban runoff will have on zinc stress and toxicity currently observed in the river are needed.

8) Analysis of heavy metals should be performed.

It must be mentioned that the frequency and intensity of the comprehensive study will be dependent upon financial and personnel contraints. The upper Spokane River area contains some of the most valuable aquatic resources in the state. This portion of the valley is also in a rapid expansion mode, and these data are necessary to make informed management decisions.

If monetary constraints do not allow for retention of the ten established stations, it is recommended that key stations in the following areas be maintained:

1. Stateline, RM 95.2 (RK 153.2), to Barker, RM 90.4 (RK 145.5), to determine water quality and nutrient loading before groundwater exchange;
2. two stations from RM 90.4 (RK 145.5) to RM 85.8 (RK 138.1) to establish loading by groundwater;
3. one station near Upriver Dam or Greene St., RM 82.4 (RK 132.6) to RM 78.2 (RK 125.8);

4. one station at Gonzaga, RM 75.5 (RK 121.5), and one near Hangman Creek, RM 72.6 (RK 116.9), to show nutrient additions made to river flow through the city of Spokane.

In time, it may be necessary to conduct a study that would only define the direct impacts of the Liberty Lake STP effluent upon the water quality of the Spokane River. In order to identify those possible effects, a minimum of four sampling stations should be established at Harvard I RM 93.1 (RK 149.8), Harvard II RM 92.2 (RK 148.4), Barker RM 90.4 (RK 145.5), and Sullivan RM 87.9 (RK 141.5). Mid-river as well as shoreline locations should be sampled at each station to better define and interpret the extent of the impacts resulting from the effluent. Table 9 summarizes the water quality sampling program.

Table 9. Recommended Water Quality Sampling Program Summary for Liberty Lake STP Effluent Impacts

Number of Locations	Number of Samples per Location	Sampling Frequency	Method of Collection	Physical Chemical Parameters/ Biological Parameters
4	4	Biweekly May-Sept; Monthly Oct-April	½ m Grab & Mid-Channel Composite	Analyzed temperature, dissolved oxygen, conductivity, pH, stream velocity at site, flow gauge measurements. Alkalinity, suspended solids, total phosphorus, total soluble phosphorus, soluble reactive phosphorus, ammonia-nitrogen, nitrate plus nitrite-nitrogen, Kjeldhal-nitrogen zinc, chlorine, chloride, calcium, hardness.
4	2	"	½ m & 1 m Grab	Phytoplankton
	3	"	½ m Grab & Mid-Channel Composite	Fecal coliforms
	3	"	Rock Basket Samplers	Periphyton, id./dry weight
	3	"	"	Macroinvertebrates
	3	"	"	Chlorophyll a (Periphyton)
	3	"	½ m & 1 m Grab & Mid-Channel Composite	Chlorophyll a (Plankton)

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