PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF THE BOISE RIVER FROM VETERANS MEMORIAL PARKWAY, BOISE TO STAR, IDAHO, OCTOBER 1987 TO MARCH 1988

By S. A. Frenzel

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms in this report are listed below. Constituent concentrations are given in mg/L (milligrams per liter), which is equal to parts per million; µg/L (micrograms per liter), which is equal to parts per billion; µg/g (micrograms per gram), which is equal to parts per million; or g/kg (grams per kilogram), which is equal to parts per thousand. Specific conductance is expressed as µS/cm (microsiemens per centimeter at 25 degrees Celsius).

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
quart (qt)	0.9464	liter
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.590	square kilometer

Temperature in °C (degrees Celsius) can be converted to °F (degrees Fahrenheit) as follows:

$$°F = (1.8)(°C) + 32$$

Water temperatures are reported to the nearest 0.5 °C.

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ABSTRACT

Physical, chemical, and biological characteristics of the Boise River were examined from October 1987 to March 1988 to determine whether trace elements from effluents discharged from two Boise wastewater treatment facilities were detrimental to aquatic communities. Cadmium, chromium, hexavalent chromium, cyanide, lead, nickel, and silver concentrations in the Boise River were less than or near analytical detection levels and were less than chronic toxicity criteria when detectable. Arsenic, copper, and zinc existed in concentrations less than chronic toxicity criteria. Concentrations of trace elements in bottom material from the Boise River generally were small and could not be attributed to effluents discharged from wastewater treatment facilities.

From October to December 1987, mean density of benthic invertebrates colonizing artificial substrates was from 6,100 individuals per substrate downstream from the West Boise wastewater treatment facility to 14,000 individuals per substrate downstream from the Lander Street wastewater treatment facility. From January to March 1988, mean density of benthic invertebrates colonizing artificial substrates in the Boise River was from 7,100 individuals per substrate downstream from the West Boise facility to 10,000 individuals per substrate near Star. Midges, black flies, Baetidae mayflies, and Hydropsychidae caddisflies composed more than 90 percent of the insect population at all sites. Insect communities upstream and downstream from the wastewater treatment facilities were strongly associated, and coefficients of community loss indicated that effluents had benign enriching effects. The numbers of trace-element-intolerant mayflies were not significantly different upstream and downstream from the Lander Street facility from October to December 1987, were significantly larger downstream from the Lander Street facility from January to March 1988, and were significantly larger downstream from the West Boise facility during both sampling periods. Distribution of mayflies indicates that trace-element concentrations in effluents did not adversely affect intolerant organisms in the Boise River.

Densities of native trout were less than 1 fish per 10,760 square feet of stream area upstream and downstream from the Lander Street facility and near Star. The largest native trout density was 7.9 fish per 10,760 square feet within the effluent mixing zone of the West Boise facility. Whitefish densities were from 25 fish per 10,760 square feet near Star to 140 fish per 10,760

square feet upstream from the West Boise facility. Mean condition factors of whitefish were 3.87 and 4.34 upstream and downstream from the Lander Street facility and were 4.30 and 3.58 upstream and downstream from the West Boise facility. Mean condition factor was significantly increased downstream from the Lander Street wastewater treatment facility and was significantly decreased downstream from the West Boise wastewater treatment facility.

INTRODUCTION

The City of Boise operates two municipal WTF's (wastewater treatment facilities) that provide secondary sewage treatment and discharge the treated effluents into the Boise River. The Lander Street WTF discharges effluent immediately downstream from Veterans Memorial Parkway, and the West Boise WTF discharges effluent into the south channel of the Boise River near Eagle Island State Park (fig. 1).

The City's NPDES (National Pollutant Discharge Elimination System) permits proposed in 1987 by the EPA (U.S. Environmental Protection Agency) contained more stringent trace-element criteria than did the recently expired permits. The City requested that EPA modify the permits so that trace-element criteria would be based on site-specific criteria rather than laboratory-derived national criteria, which might not accurately reflect bioavailability or toxicity of a pollutant because of local physical, chemical, or biological characteristics of receiving water. New permits were issued in March 1987 without specific trace-element criteria but included requirements to initiate biomonitoring and to conduct a physical, chemical, and biological evaluation of the effects of the WTF's on the Boise River. The City of Boise undertook the biomonitoring dictated by the permit, and the U.S. Geological Survey, in cooperation with the City of Boise, began a study to determine the physical, chemical, and biological characteristics of the Boise River.

This study focused on biological communities in the Boise River because the Water Quality Act of 1987 emphasized ambient receiving water as the primary measure of pollution control activities; biological communities in receiving water integrate the effects of different pollutant stresses, providing a measure of their aggregate effect (Plafkin and others, EPA, written commun., 1987). Benthic invertebrates have been used as indicators of pollution because (1) they have relatively long life cycles, (2) they are relatively immobile, and (3) individual groups have different ranges of tolerance to a variety of pollutants (Goodnight, 1973).

Trace elements are natural components of the biosphere, and many are essential to sustain life; however, all trace elements are toxic at sufficiently large concentrations. Because many biological communities exist where trace elements occur naturally

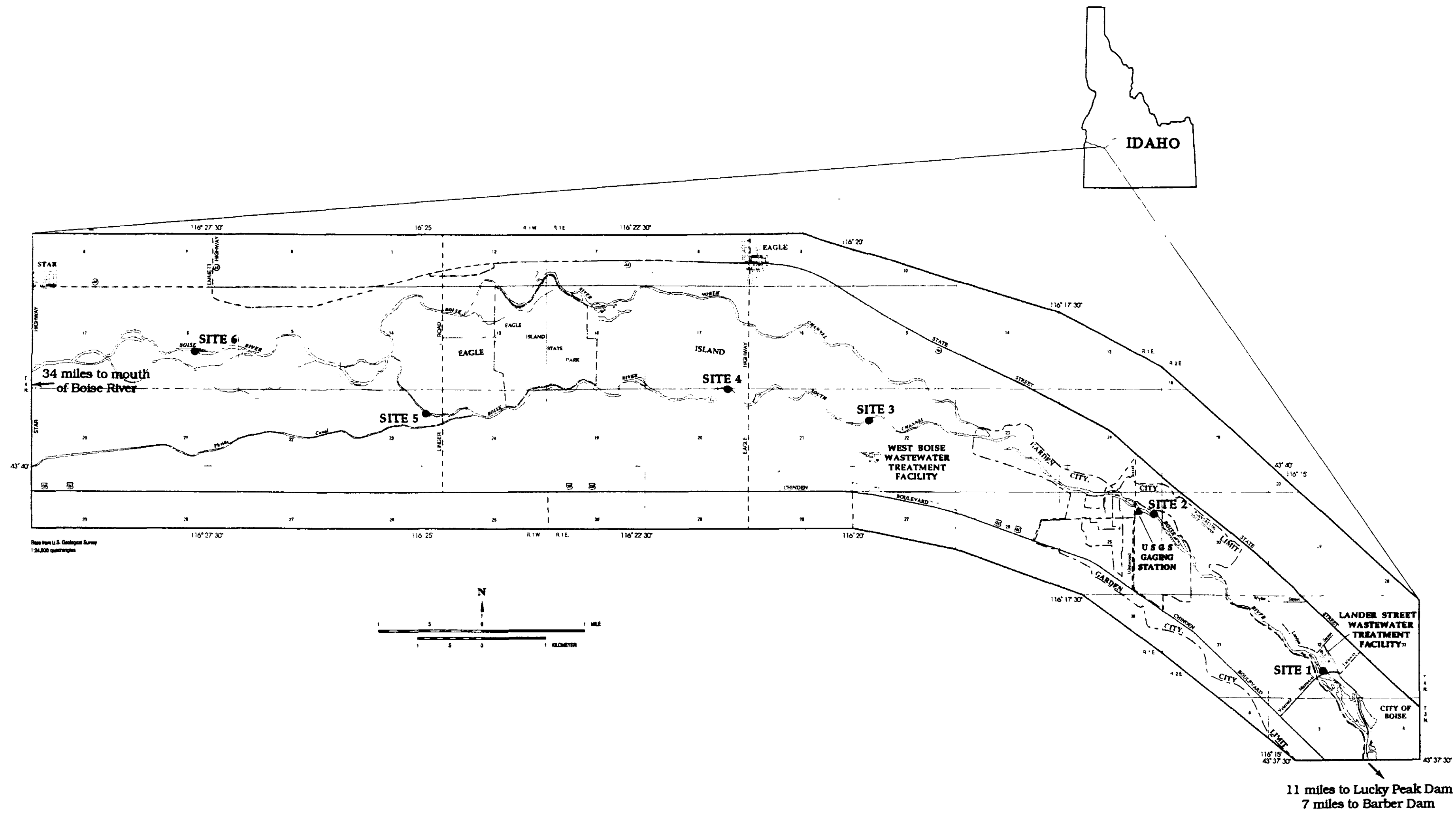

Figure 1.--Study area and data-collection sites.

in near-toxic concentrations, man's activities have a strong potential to adversely affect aquatic ecosystems (Luoma, 1983, p. 1). Whether trace-element concentrations in water or sediment are toxic depends on the bioavailability of the element, which is affected by complex physiological, biochemical, and ecological interactions between organisms and trace elements.

Purpose and Scope

This report describes results of a study to determine the effects of effluent discharges from the Lander Street and West Boise WTF's on the Boise River. The scope of this report includes data collected during the annual low-flow period, October to March, when low streamflows provide the least dilution of effluents and potentially the most toxic conditions in the receiving water. Data were collected during two periods, October to December 1987 and January to March 1988.

Much of the approach used in this study was dictated by the NPDES permit requirements. Data-collection sites were located to minimize changes in water quality or biological characteristics due to influences other than wastewater discharges. Data were collected immediately upstream and downstream from the WTF's where dye injected into the effluent was in equal concentrations across the river. The distance from the point of effluent discharge to the area where effluents are mixed completely is considered the effluent mixing zone. Data also were collected from a site within the effluent mixing zone of the West Boise WTF and downstream from the confluence of the north and south channels of the Boise River near Star. Comparisons of data between sites were made separately for each sampling period because of the high degree of seasonal variability in life stages of invertebrates.

Data reports were published for each sampling period, October to December 1987 (Frenzel and Hansen, 1988a) and January to March 1988 (Frenzel and Hansen, 1988b). Fisheries data were collected for this study during January and February by the Idaho Department of Fish and Game and were reported by Frenzel and Hansen (1988b).

Description of the Study Area

Boise, located in southwest Idaho (fig. 1), has a population of about 107,000; Garden City, which uses Boise's sewage treatment facilities, has a population of about 5,400 (Cenarrusa, 1988, p. 273-274). The Boise River is a popular recreation area and is used by fishermen year round. During the summer, many people float down the river or walk along its banks in the city's various parks.

The Boise River flows westward from its headwaters in the mountains through the city to its mouth at the Snake River at the

Oregon border. Downstream from Boise, the river splits into two channels, forming Eagle Island, and the channels reunite near Star. Drainage area upstream from the U.S. Geological Survey stream-gaging station at Glenwood Street (fig. 1) is about 2,800 mi^2 (Harenberg and others, 1987, p. 325).

Water from spring snowmelt is stored for use during the summer for irrigation and during the nonirrigation season for maintenance of minimum streamflows. The U.S. Bureau of Reclamation has 102,350 acre-ft of storage available in Lucky Peak Reservoir to maintain a minimum release of 80 ft^3/s to the Boise River. The Idaho Department of Fish and Game is allocated 50,000 acre-ft of storage, which is used during the nonirrigation season to achieve a minimum streamflow of 150 ft^3/s (Jarvis, 1985, p. 6). Since the completion of Lucky Peak Dam, streamflow has ranged from 42 to 9,840 ft^3/s. Typically, winter streamflows are at least 150 ft^3/s.

Previous Investigations

Thomas and Dion (1974) studied hydrologic conditions in the Boise River valley and determined that the Boise River generally gained water from ground water, particularly during the nonirrigation season. The Ada Council of Governments (1975, p. 3-5) concluded that low river flows coupled with waste discharged from the Boise metropolitan area had an adverse effect on the physical, chemical, and biological characteristics of the Boise River. The Idaho Department of Health and Welfare (IDHW, 1980) collected water-quality data in 1978 to develop effluent limitations for the City of Boise's WTF's.

Gibson (1975) studied fish populations in the Boise River from Barber Dam to the mouth and observed that mountain whitefish were the only gamefish present in all sections of the river and were most abundant from Barber Dam to Eagle. Resource Systems, Inc. (1983, p. 62) identified fish in the Boise River from Barber Dam to Eagle Island State Park and noted that the following species were common: mountain whitefish (*Prosopium williamsoni)*, rainbow trout (*Salmo gairdneri*), chiselmouth (*Acrocheilus alutaceus*), longnose dace (*Rhinichthys cataractae*), speckled dace (*Rhinichthys osculus*), redside shiner (*Richardsonius balteatus*), bridgelip sucker (*Catastomus columbianus*), and mottled sculpin (*Cottus bairdi*). Reid and Mabbott (1987, p. 31-34) estimated that nearly 51,000 angler hours were expended from March 1, 1986, to January 2, 1987, on the Boise River from Barber Dam to Glenwood Street. Anglers harvested more than 23,000 gamefish, of which 78 percent were hatchery-reared rainbow trout, 10 percent were native rainbow trout, 9 percent were mountain whitefish, 2 percent were native brown trout (*Salmo trutta*), and 1 percent was transplanted steelhead trout (*Salmo gairdneri gairdneri*).

The relative quality of fish habitat in the Boise River was described by Resource Systems, Inc. (1983, p. 63-64). They described habitat in the reach upstream from the Lander Street WTF as good, with islands, side channels, and inflows (fig. 1). Habitat in the reach downstream from Lander Street WTF was described as physically good, but marginal because of sewage effluent, development, and storm runoff. Habitat in the reach upstream and downstream from the West Boise WTF was described as excellent, with pool-riffle diversity, numerous side channels, and extensive tree-canopy cover.

METHODS

Dispersion characteristics of effluent mixing zones were determined from cross-sectional field measurements using fluorometric dye tracing as described by Hubbard and others (1982) and Kilpatrick and Cobb (1984). Before the dye was injected, three cross sections were located downstream from each WTF within the expected mixing zone, which was determined using the equation given by Kilpatrick and Cobb (1984, p. 47). Dye was injected into the effluent from each WTF near the point of discharge using the slug-injection method (Kilpatrick and Cobb, 1984, p. 9-12). Dye clouds were sampled at each cross section 5 to 10 minutes after the leading edge of the cloud was first observed. Samples were collected from five points in each cross section and the dye concentration for each sample was measured using a filter fluorometer. Where dye concentrations were equal at all points in the cross section, the effluents were considered completely mixed with the river.

General areas of data-collection sites were located using results of the dispersion characteristics study. Sites then were selected so that physical characteristics of the river such as velocity, depth, and substrate composition were similar upstream and downstream from WTF's. Site locations shown in figure 1 are:

1) At Veterans Memorial Parkway, immediately upstream from the Lander Street WTF;
2) Above Glenwood Street, downstream from the effluent mixing zone of the Lander Street WTF;
3) South channel, immediately upstream from the West Boise WTF;
4) South channel near Eagle Highway, within the effluent mixing zone of the West Boise WTF;
5) South channel near Linder Road, downstream from the effluent mixing zone of the West Boise WTF;
6) Downstream from the confluence of north and south channels near Star.

Site 4 was added so that water quality within the effluent mixing zone of the West Boise WTF could be examined.

Water-quality samples were collected at all sites using cross-sectional depth-integrated sampling methods (Guy and Norman, 1970, p. 30-32). To prevent trace-element contamination of samples, Teflon[1] or stainless steel sampling equipment was used. At each site, water was composited in a churn splitter and aliquots were withdrawn, processed onsite, and sent for analysis to the U.S. Geological Survey laboratory in Arvada, Colo. Water samples were analyzed for total concentrations of several trace elements. The analytical method used was identical to the method for total-recoverable concentrations specified by the EPA (Jim Schoen, U.S. Geological Survey, oral commun., 1987).

Onsite determinations were made for pH, alkalinity, dissolved oxygen, specific conductance, water temperature, and discharge. Profiles of pH, dissolved oxygen, specific conductance, and water temperature were made at each cross section to determine whether physical and chemical conditions were uniform.

After water samples were collected, bottom-material samples were collected from depositional areas near each cross section. Multiple grab samples were collected using a stainless steel Ponar dredge or quart Teflon bottle and composited. One of the most significant factors controlling bottom-sediment capacity for retaining trace elements is particle size. A positive correlation exists between decreasing particle size and increasing trace-element concentration (Horowitz, 1984, p. 16). Bottom material was wet sieved onsite through a 2.0-mm stainless steel mesh using river water. Material finer than 2.0 mm was sent to the U.S. Geological Survey laboratory where material finer than 0.063 mm was analyzed for aluminum, iron, organic carbon, and several trace elements.

Benthic invertebrates were collected using artificial substrates at sites 1, 2, 3, 5, and 6. Samples of benthic invertebrates from artificial substrates may not be fully representative of the benthic community at a site because of a different microhabitat available than in the natural substrate. However, to assess water pollution, exact duplication of natural conditions is less important than collection of replicate samples at different times and different locations (Beak and others, 1973, p. 231); and, for site comparisons, the replicability of artificial substrates is an advantage (Slack and others, 1986, p. 245).

Substrates consisted of baskets 12 in. by 12 in. by 6 in. made of 5/8-in. mesh wire cloth filled with 3- to 6-in. diameter cleaned river rock. Initial calculations indicated that 10 substrates per site would provide data adequate for statistical comparisons between sites; however, 12 substrates were placed at

[1] Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

each site to account for possible loss of substrates during the colonization period. Because velocity controls occurrence, abundance, and structure of benthic invertebrate communities (Hynes, 1970, p. 200), substrates were placed in riffles of similar velocity, depth, and substrate composition. Within each riffle, a grid was established and the substrates were placed randomly in the grid. Substrates farthest upstream in the grid were placed in the Boise River first and removed last to minimize disturbance upstream from the substrates.

Meier and others (1979, p. 381) reported that numbers of invertebrates colonizing artificial substrates reached a maximum after 39 days, but the number of taxa continued to increase throughout their 60-day study. Shaw and Minshall (1980, p. 264) determined that the number of invertebrates on substrates was stable within 32 days and, in southeastern Idaho, colonization was more rapid in the summer than in the winter. Substrates were left in the Boise River for about 40 days to allow for colonization. All substrates were removed from the river and field processed, but invertebrates from only 10 substrates from each site were enumerated and identified. During substrate removal, a 0.210-mm mesh drift net was placed immediately downstream from the substrate to capture dislodged organisms. Rocks from the substrates were scrubbed to remove invertebrates and material cleaned from the rocks was poured through the drift net. Material retained in the drift net was placed in plastic containers and the containers were filled with 70 percent alcohol.

Invertebrate samples were sorted in the laboratory to remove debris. Because of the large numbers of invertebrates collected from each substrate, subsamples were taken by passing material through a splitter box. Subsamples one-quarter of the original sample size then were passed through a series of sieves. Invertebrates that passed through a 1.0-mm mesh and were retained on a 0.500-mm or 0.250-mm mesh were further subsampled with the splitter box. Only invertebrates retained on a 0.250-mm or larger sieve were identified. Invertebrates were identified to the lowest taxonomic level possible using keys from reports by Usinger (1956), Edmondson (1959), Jensen (1966), Edmunds and others (1976), Baumann and others (1977), Wiggins (1977), and Merritt and Cummins (1984).

A diversity index is a numerical expression based on the numbers and kinds of individuals in the community (Kovalak, 1981, p. 255-256) and is a tool used to assess water quality (Averett, 1981, p. B5). The diversity index for insect families was calculated using the Shannon-Weaver equation (Averett, 1981, p. B4):

$$d = -\Sigma(n_i/n)\log_2(n_i/n) \quad (1)$$

where

d = diversity index or information content of the sample,
n_i = number of individuals in the ith taxa, and
n = number of individuals in the sample.

This diversity index depends on two components: taxonomic richness, and distribution of individuals among the taxa.

Fish populations near WTF's were determined by the Idaho Department of Fish and Game at sites 1, 2, 3, 4, and 6. Site 4, within the effluent mixing zone of the West Boise WTF, was sampled instead of site 5, which did not have a pool-riffle sequence similar to the other sites. During January and February 1988, sites were electrofished and fish populations were estimated using the three-pass removal technique (Terry Holubetz, Idaho Department of Fish and Game, written commun., 1988). Electrofishing sites were about 660 ft long, including riffles upstream and downstream, and were representative of habitat in the area. To allow comparisons between sites, fish densities were calculated per 10,760 ft^2 of stream-surface area. Fish were identified to the species level, and gamefish were measured for total length and weight. Trout were further identified as either native or hatchery reared. Condition factor, an index of well-being, of native trout and whitefish was calculated using the equation from Nielsen and Johnson (1983, p. 296):

$$C = W(10{,}000)/L^3 \quad (2)$$

where

C = condition factor;
W = weight of fish, in pounds; and
L = length of fish, in inches.

Values increase as the fish gains weight relative to length, and larger values indicate healthier fish. Condition factors for fish exposed to stressful conditions such as poor water quality are smaller than factors for fish exposed to optimal conditions.

PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS

Dispersion of Effluent Discharge

On September 29, 1987, Rhodamine WT dye was injected into the effluent discharge from each WTF. Estimated lengths of mixing zones were verified by field-measured dye concentrations. Effluent from the Lander Street WTF was mixed completely with the river about 1.5 mi downstream between Wylie Drive and Glenwood Street, and effluent from the West Boise WTF was mixed completely about 4 mi downstream at Linder Road (fig. 1).

How rapidly an effluent mixes with a stream is a function of the stream gradient, mean velocity, depth, width, volume of streamflow, and method of effluent discharge. The mixing zone for effluent discharged from the West Boise WTF is considerably longer than that for the Lander Street WTF, primarily because of the method of effluent discharge. At the West Boise WTF, effluent is discharged at the side of the channel through a large-diameter open pipe, whereas at the Lander Street WTF, effluent is discharged near the center of the channel through a diffuser. Because streamflow on September 29, 1987, was greater than normal for low-flow periods (fig. 2), the mean width and velocity of the Boise River also were greater and measured mixing-zone lengths were longer than would be experienced at lower flows.

Water Quality

Discharge was measured at each site when water-quality samples were collected (table 1). Discharge generally increased in a downstream direction, probably due to ground-water inflow as well as effluent discharges from the WTF's. Discharge was smaller at site 3 than at site 2 because the river splits into two channels between the sites (fig. 1). During the October 1987 sampling, effluent discharges averaged 14.2 and 11.2 ft^3/s from the Lander Street and West Boise WTF's. During the February 1988 sampling, effluent discharges averaged 14.5 and 9.3 ft^3/s from the Lander Street and West Boise WTF's. Discharge of the Boise River at Glenwood Street ranged from 137 to 200 ft^3/s during the study (fig. 2).

Selected water-quality analyses for samples collected during October 1987 and February 1988 are listed in table 1. Comparisons of data collected during October with data collected during February are not appropriate because of differences in physical conditions and seasonal variability in the biota. Dissolved-oxygen concentrations were from 8.3 to 12.6 mg/L and percent saturations were from 80 to 120. Dissolved-oxygen concentrations and percent saturations were smallest at sites sampled during the morning and were larger at sites sampled during midday. The midday increases were attributed to considerable photosynthetic activity by an abundance of periphyton at all sites. High rates of photosynthesis also can increase pH (Wetzel, 1975, p. 176); the three largest pH values were recorded during midday and corresponded to the largest dissolved-oxygen concentrations (table 1).

Total ammonia concentrations were from 0.02 to 0.72 mg/L (table 1). The smallest value was from site 1, upstream from all wastewater discharges, and the largest value was from site 2, downstream from the Lander Street WTF. The IDHW (1980) observed peak ammonia (NH_3 + NH_4) concentrations of 2.3 mg/L downstream from the Lander Street WTF during the 1978 water year. Ammonia concentrations from the south channel of the Boise River at Linder

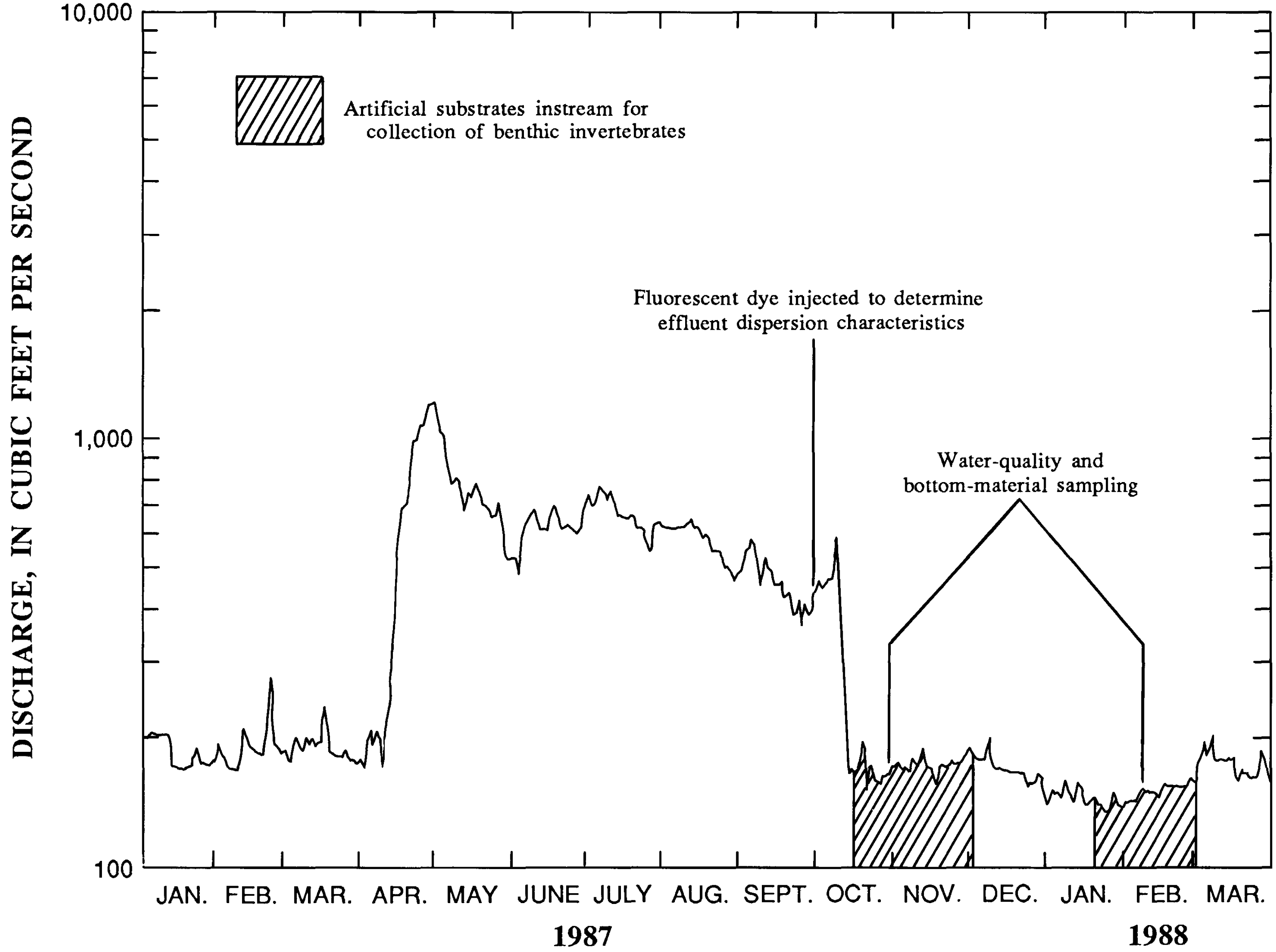

Figure 2.--Mean daily discharge of the Boise River at Glenwood Street and periods of data collection.

Table 1.--Selected water-quality analyses, October 1987 and February 1988

[*, calculated value; <, less than the given value, which is the detection level; --, no data available; hex, hexavalent]

	Sampling sites, Date, Time (24-hour)											
	1		2		3		4		5		6	
Chemical constituents	10/30 0930	2/ 9 1430	10/30 1230	2/ 9 1130	10/29 1225	2/ 9 0930	10/28 1215	2/10 1415	10/29 0920	2/10 1200	10/28 0850	2/10 0930
Onsite Determinations												
Instantaneous discharge (ft^3/s)	147	128	173	147	77.2	61.9	106	73.9	101	99.2	164	236
Dissolved oxygen (mg/L)	9.7	12.0	11.6	10.4	10.0	9.3	8.8	12.6	9.4	10.8	8.3	10.0
Percent saturation*	95	98	120	89	102	80	90	114	94	93	80	85
pH (standard units)	8.0	8.3	8.2	7.8	7.8	7.9	7.6	8.3	8.0	7.8	8.0	7.7
Specific conductance (μS/cm)	124	118	178	175	159	172	288	291	314	293	299	248
Water temperature (°C)	10.5	3.5	13.0	5.0	12.0	5.0	12.5	7.5	11.0	6.0	10.0	5.0
Laboratory Analyses												
Hardness, total (mg/L as $CaCO_3$)*	46	46	52	55	55	56	69	79	95	90	90	66
Ammonia, NH_4, total (mg/L as N)	.04	.02	.52	.72	.22	.62	.26	.28	.22	.39	.18	.20
Chloride, dissolved (mg/L as Cl)	1.2	2.9	5.2	8.0	3.9	7.22	23	10	12	13	12	21
Fluoride, dissolved (mg/L as F)	.50	.50	.70	.70	.60	.70	.60	.60	.60	.60	.50	.70
Aluminum, total (μg/L as Al)	170	240	170	310	170	280	290	350	140	440	80	350
Arsenic, total (μg/L as As)	—	3	—	3	—	3	—	3	—	3	—	3
Cadmium, total (μg/L as Cd)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1
Chromium, total (μg/L as Cr)	2	1	4	<1	3	<1	3	<1	2	1	3	1
Chromium hex, total (μg/L as Cr)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Copper, total (μg/L as Cu)	1	4	4	4	3	5	3	4	2	3	3	5
Cyanide, total (μg/L as CN)	—	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Iron, total (μg/L as Fe)	230	280	250	330	260	300	410	420	230	460	160	370
Lead, total (μg/L as Pb)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Nickel, total (μg/L as Ni)	3	<1	1	<1	1	<1	1	<1	<1	<1	<1	<1
Silver, total (μg/L as Ag)	<1	1	<1	—	<1	<1	<1	<1	<1	<1	<1	<1
Zinc, total (μg/L as Zn)	<10	<10	<10	10	<10	10	20	20	<10	10	<10	20

Road and the Boise River at Star Road during that time were from 0.02 to 0.30 mg/L. Ammonia may be toxic to aquatic organisms, principally in its un-ionized form (NH_3), but its toxicity is affected by other factors, including dissolved oxygen, pH, and temperature (EPA, 1986). The national criteria for total ammonia for the range of pH and temperature measured during this study are shown in table 2. The criteria shown are for chronic toxicity (4-day average concentrations) and are more stringent than criteria for acute toxicity (1-hour average concentrations). None of the ammonia concentrations measured exceeded the criteria, although ammonia concentrations of 0.52 mg/L measured at site 2 in October were near the criteria of 0.63 mg/L because of relatively high pH and water temperature (table 1).

Chloride concentrations generally increased in a downstream direction (table 1). The IDHW (1980) measured chloride concentrations from 3 to 14 mg/L downstream from the Lander Street WTF, from 2 to 13 mg/L at Linder Road, and from 2 to 12 mg/L at Star Road. Peters (1984, p. 20-22) noted that only 20 percent of the chloride from selected streams in the United States could be attributed to human sources, including sewage disposal; however, the importance of human sources may be greater in densely populated areas. Normally, the most important factors influencing chloride are climate and geology.

Fluoride concentrations were from 0.50 to 0.70 mg/L (table 1). Fluoride concentrations increased between sites 1 and 2 probably because of the fluoride concentration in the Lander Street WTF effluent (table 3). Effluent from the West Boise WTF contained total fluoride concentrations that were about the same as the dissolved fluoride concentration in the Boise River upstream from the WTF (tables 1 and 3). The IDHW (1980) reported a maximum fluoride concentration of 1.57 mg/L downstream from the Lander Street WTF; however, they suggested the source of fluoride was geothermal discharge to the river upstream from the WTF.

Total concentrations of aluminum, iron, and several trace elements in water samples collected at all sites are shown in table 1. Most trace-element concentrations were near or less than detection levels. Total concentrations of aluminum, iron, and trace elements also were determined by the City of Boise for treated effluents discharged from the Lander Street and West Boise WTF's (table 3).

Aluminum concentrations in the Boise River were from 80 to 440 µg/L (table 1). Aluminum concentrations during the 1978 water year were as large as 1,000 µg/L downstream from the Lander Street WTF, 700 µg/L at Linder Road, and 600 µ/L at Star Road (IDHW, 1980). The EPA (1986) has not determined a toxicity criteria for aluminum. Aluminum is the third most abundant element in the Earth's outer crust and, in water, commonly is bonded with clay minerals (Hem, 1985, p. 73-74). Effluents discharged from the City's WTF's contained aluminum concentrations similar to those in

Table 2.--Chronic toxicity criteria[1] for total ammonia for salmonids and other sensitive cold-water species

[Ammonia values are in milligrams per liter as nitrogen]

	Water temperature (°C)				
pH	0	5	10	15	20
7.50	2.06	1.97	1.81	1.81	1.23
7.75	1.89	1.81	1.73	1.64	1.15
8.00	1.26	1.18	1.13	1.09	.76
8.25	.72	.67	.64	.62	.44
8.50	.40	.39	.37	.36	.26

[1] U.S. Environmental Protection Agency (1986).

Table 3.--Water-quality analyses for effluents discharged from Lander Street and West Boise wastewater treatment facilities, October 1987 and January 1988[1]

[Concentrations in micrograms per liter, except as noted; <, less than the given value, which is the detection level; --, no data available]

Water-quality constituent	Lander Street		West Boise	
	10/29	1/12	10/29	1/12
Ammonia (total, mg/L as N)	4.08	5.64	0.19	0.05
Fluoride (total, mg/L as F)	2.07	2.85	.72	.74
Aluminum (total, as Al)	160	340	150	130
Arsenic (total, as As)	9	<5	9	<5
Cadmium (total, as Cd)	<1	<5	<1	<5
Chromium (total, as Cr)	<50	<50	<50	<50
Hexavalent chromium (total, as Cr)	<50	<50	<50	<50
Copper (total, as Cu)	30	10	<10	10
Cyanide (total, as CN)	8	--	<5	--
Iron (total, as Fe)	110	130	--	120
Lead (total, as Pb)	<50	<50	<50	<50
Nickel (total, as Ni)	<50	<50	<50	<50
Silver (total, as Ag)	<5	--	<5	--
Zinc (total, as Zn)	78	131	109	81

[1] Kate Parkin, Boise Public Works Department, written commun. (1986).

the Boise River and are not considered a major source of aluminum to the river.

Iron concentrations in the Boise River were from 160 to 460 µg/L (table 1). Iron concentrations during the 1978 water year were as large as 1,500 µg/L downstream from the Lander Street WTF, 450 µg/L at Linder Road, and 570 µg/L at Star Road (IDHW, 1980). The criteria for protection of freshwater aquatic life is 1,000 µg/L total iron (EPA, 1986). Iron is an essential element required by plants and animals and commonly is associated with clays (EPA, 1986). Fully aerated streams with pH between 6.5 and 8.5 should not contain dissolved iron concentrations greater than a few micrograms per liter; higher concentrations generally are due to particulates small enough to pass through a 0.45-µm porosity filter membrane (Hem, 1985, p. 83). Because the analyses shown in table 1 are for total iron concentrations, most iron in the Boise River probably existed as particulates or was associated with suspended sediments. Effluents discharged from the City's WTF's generally contain smaller iron concentrations (table 3) than those in the Boise River and are not considered a major source of iron to the river.

Data collected from the Boise River were compared with similar data collected from several sites representing various sources of trace elements (table 4). Where available, data from sites near Boise were used; however, because data on total concentrations of trace elements commonly are not collected, sites in North Carolina also were compared with the Boise River. Big Jacks Creek near Bruneau is about 60 mi southeast of the study area and drains 253 mi^2 of undeveloped rangeland in southern Idaho. The Snake River at Weiser, Idaho, is about 55 mi northwest of the study area and drains an area of 69,200 mi^2, including the Boise River basin. Much of the Snake River drainage in southern Idaho is public land. Agriculture is the predominant land use on private lands. The Coeur d'Alene River at Enaville is about 275 mi north of the study area and drains 895 mi^2 of ore-rich lands in northern Idaho but is upstream from the South Fork Coeur d'Alene River, which has been severely degraded by mining and smelting processes. Data presented by Simmons and Heath (1982) are from 39 streams in basins that are 90 to 100 percent forested. The French Broad River at Marshall, N.C., drains 1,667 mi^2 of an industrialized basin where water quality has deteriorated as a result of man's activities (Daniel and others, 1982, p. C1). Population in the basin in 1970 was 218,000. The Neuse River at Clayton, N.C., drains 1,129 mi^2. Eighty-three percent of the wastewater discharged to the river is from municipal WTF's (Harned, 1982, p. D6). Population in the basin in 1970 was 284,000.

The IDHW (1980) analyzed samples from the Boise River for trace elements; however, with the exception of zinc, the detection levels of their analyses were larger than those used in this

Table 4.--Range of trace-element concentrations for selected streams

[Total concentrations in micrograms per liter; <, less than the given value, which is the detection level; --, no data available]

Site	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Silver	Zinc
Big Jacks Creek near Bruneau, Idaho, 1978-72[1] 7 samples	2 - 5	<1 - 2	<10 - 20	2 - 29	7 - 21	--	<1 - 1	10 - 80
Snake River at Weiser, Idaho, 1978-82[1] 20 samples	3 - 10	<1 - 5	<10 - <100	1 - 25	2 - 50	1 - 17	<1 - 1	<10 - 40
Coeur d'Alene River at Enaville, Idaho, 1978-80[1] 34 samples	<1 - 10	<1 - 39	3 - 20	<1 - 26	<1 - 880	--	--	<10 - 3,600
Unpolluted rural streams in North Carolina, 1973-78[2] 95 samples	<1 - 3	--	<10 - 20	<1 - 12	<1 - 25	--	--	<5 - 30
French Broad River at Marshall, N.C., 1974-77[3] 9 samples for As and Cd, and 34 samples for Cr, Ca, Pb, and Zn	<1 - 10	<1 - 9	<10 - 90	<10 - 230	<5 - 250	--	--	10 - 6,900
Neuse River at Clayton, N.C., 1974-77[4] 22 samples for As, 23 samples for Cd, and 38 samples for Cu, Pb, and Zn	<1 - 30	<1 - 50	--	2 - 70	2 - 500	--	--	<5 - 1,400

[1] U.S. Geological Survey (1978-82).
[2] Simmons and Heath (1982).
[3] Daniel and others (1982).
[4] Harned (1982).

study, and the trace elements were not detected downstream from the Lander Street WTF, at Linder Road, or at Star Road.

The EPA (1986) determined that toxicity of many trace elements is a function of water hardness. Table 5 shows chronic toxicity criteria for trace elements at each site on the Boise River. The criteria were calculated using hardness data determined as part of the water-quality analyses (table 1). The EPA (1986) noted that, for trace elements, toxicity criteria based on an acid-soluble rather than a total-recoverable method would be more scientifically correct, and that criteria based on total-recoverable methods may be overly protective.

Arsenic concentrations in the Boise River were 3 μg/L at all sites during both sampling periods (table 1). The criteria for protection of freshwater aquatic life is 190 μg/L and is not dependent on hardness (EPA, 1986). Arsenic concentrations in the Boise River were most similar to those in Big Jacks Creek and in unpolluted streams in North Carolina (table 4). The largest arsenic concentration of 30 μg/L (table 4) was from the Neuse River, which was affected by municipal wastewater discharges. Arsenic concentrations in effluents discharged by Boise's WTF's (table 3) at times were greater than those in the river but did not appear to affect arsenic concentrations in the river.

Cadmium concentrations in the Boise River were less than the detection level, except at site 6 in October 1987, when concentrations reached the detection level of 1 μg/L (table 1). The criteria for protection of freshwater aquatic life generally were less than the analytical detection level for cadmium (table 5). Cadmium concentrations in the Boise River generally were smaller than those at the sites listed in table 4. The largest cadmium concentration of 50 μg/L (table 4) was from the Neuse River. Cadmium concentrations in effluents discharged by Boise's WTF's were less than the detection level (table 3) and did not affect cadmium concentrations in the river.

Chromium concentrations in the Boise River were from less than 1 to 4 μg/L (table 1). The criteria for protection of freshwater aquatic life were from 110 to 200 μg/L total chromium (table 5). Chromium concentrations in the Boise River were generally smaller than those at the sites listed in table 4. Chromium concentrations less than detection levels of 10 μg/L were reported for most sites listed in table 4. The largest chromium concentration of 90 μg/L (table 4) was from the French Broad River. Hem (1985, p. 138) noted that concentrations of chromium in water not affected by waste disposal are commonly less than 10 μg/L. Chromium concentrations in effluents discharged by Boise's WTF's were less than the detection level of 50 μg/L (table 3). During October 1987, chromium concentrations in the Boise River increased from 2 μg/L above Lander Street WTF to 4 μg/L below Lander Street WTF (table 1), where the criteria for chromium was 120 μg/L (table 5).

Table 5.--Site-specific chronic toxicity criteria for trace elements, October 1987 and February 1988[1]

[Values, in micrograms per liter, were calculated from hardness data]

Trace element	Site, Date 1		2		3		4		5		6	
	10/30	2/9	10/30	2/9	10/29	2/9	10/28	2/10	10/29	2/10	10/28	2/10
Cadmium	0.62	0.62	0.68	0.71	0.71	0.72	0.85	0.94	1.1	1.0	1.0	0.82
Chromium	110	110	120	130	130	130	150	170	200	190	190	150
Copper	6.1	6.1	6.8	7.1	7.1	7.2	8.6	9.7	11	11	11	8.3
Lead	1.2	1.2	1.4	1.5	1.5	1.5	2.0	2.4	3.0	2.8	2.8	1.9
Nickel	82	82	91	95	95	97	120	130	150	140	140	110
Silver	1.1	1.1	1.3	1.4	1.4	1.5	2.1	2.7	3.7	3.4	3.4	2.0
Zinc	55	55	61	64	64	65	77	87	100	97	97	75

[1] Equations for 4-day average concentrations given in report by U.S. Environmental Protection Agency (1986).

Hexavalent chromium concentrations in the Boise River were less than the detection level of 1 µg/L for all sites (table 1). The criteria for protection of freshwater aquatic life is 11 µg/L total hexavalent chromium (EPA, 1986). Hexavalent chromium commonly is not included in water-quality analyses and was not determined for the sites listed in table 4. Effluents discharged by Boise's WTF's contained less than 50 µg/L of hexavalent chromium and did not appear to increase concentrations in the river.

Copper concentrations in the Boise River were from 1 to 5 µg/L (table 1). The criteria for protection of freshwater aquatic life were from 6.1 to 11 µg/L total copper (table 5). Copper is an essential element in plant and animal metabolism and is used extensively in industry (Hem, 1985, p. 141). Copper concentrations in the Boise River generally were smaller than those shown in table 4. The largest copper concentration of 230 µg/L (table 4) was from the industrial area of the French Broad River. The Neuse River, affected by municipal wastewater discharges, contained copper concentrations as large as 70 µg/L. Copper concentrations in effluents discharged by Boise's WTF's were from less than 10 to 30 µg/L (table 3). On October 29, 1987, copper concentrations in effluent from the Lander Street WTF were 30 µg/L. On October 30, 1987, copper concentrations in the Boise River had increased from 1 µg/L at site 1 to 4 µg/L at site 2 (table 1). There is no reason to assume that effluent quality was substantially different on October 30 than it was on October 29; therefore, the increased copper concentration at site 2 can be attributed, in part, to the Lander Street effluent. On October 30, when copper concentration at site 2 was 4 µg/L, the chronic toxicity criteria for that site was 6.8 µg/L total copper (table 5).

Cyanide concentrations in the Boise River were less than 10 µg/L at all sites (table 1). The criteria for protection of freshwater aquatic life is 5.2 µg/L total cyanide (EPA, 1986). A cyanide concentration of 8 µg/L was measured in the Lander Street effluent during October 1987 (table 3). Smaller detection levels were needed to adequately assess the toxicity of cyanide in the Boise River.

Lead concentrations in the Boise River were less than 5 µg/L at all sites (table 1). The criteria for protection of freshwater aquatic life were from 1.2 to 3.0 µg/L total lead (table 5). Lead concentrations in the Boise River generally were smaller than those at sites listed in table 4, although some concentrations at those sites were less than detection levels. The largest lead concentration of 880 µg/L (table 4) was from the mining area drained by the Coeur d'Alene River. The Neuse River contained lead concentrations as large as 500 µg/L. Effluents discharged from Boise's WTF's contained less than 50 µg/L lead (table 3) and did not increase concentrations in the river enough to be detected. Smaller detection levels were needed to adequately assess the toxicity of lead in the Boise River.

Nickel concentrations in the Boise River were less than or equal to the detection level of 1 µg/L, except at site 1 during October 1987, when the nickel concentration was 3 µg/L (table 1). The criteria for protection of freshwater aquatic life were from 82 to 150 µg/L total nickel (table 5). Data on nickel concentrations commonly are not collected and, of the sites listed in table 4, were available only for the Snake River. Nickel concentrations in the Boise River were smaller than those in the Snake River. Durum and Haffty (1963) reported that the median concentration of dissolved nickel in North American rivers was 10 µg/L. Nickel is an important industrial metal used extensively in corrosion-resistant alloys and can be contributed to the environment in significant amounts by waste disposal (Hem, 1985, p. 139). Effluents discharged from Boise's WTF's contained less than 50 µg/L total nickel (table 3) and did not increase concentrations in the river enough to be detected.

Silver concentrations in the Boise River were less than or equal to the detection level of 1 µg/L (table 1). The criteria for protection of freshwater aquatic life were from 1.1 to 3.7 µg/L total silver (table 5). Data on silver concentrations commonly are not collected and, of the sites listed in table 4, were available only for Big Jacks Creek and the Snake River. Silver concentrations in the Boise River were similar to those in Big Jacks Creek and the Snake River. Silver is used widely and is sufficiently valuable to justify intensive efforts to reclaim it from industrial wastes (Hem, 1985, p. 141). Silver concentrations in effluents discharged from Boise's WTF's were less than 5 µg/L during October 1987 and did not affect silver concentrations in the Boise River.

Zinc concentrations in the Boise River were from less than 10 to 20 µg/L (table 1). During the 1978 water year, zinc concentrations were as large as 39 µg/L downstream from the Lander Street WTF, 13 µg/L at Linder Road, and 54 µg/L at Star Road (IDHW, 1980). The criteria for protection of freshwater aquatic life were from 55 to 100 µg/L total zinc (table 5). When zinc concentrations in the river were 20 µg/L, the criteria was at least 75 µg/L. Zinc concentrations in the Boise River were similar to those in unpolluted streams in North Carolina (table 4). The largest zinc concentration of 6,900 µg/L (table 4) was from the industrial area of the French Broad River. Large amounts of zinc are used industrially, and rainfall and dry fallout probably are major sources of zinc in surface-water runoff, at least in densely populated areas (Hem, 1972, p. 662-663). Effluents discharged from Boise's WTF's contained zinc concentrations from 78 to 131 µg/L (table 3) and may have caused an increase in zinc concentrations in the river.

Trace-element concentrations in the Boise River were small and generally comparable to concentrations in unpolluted streams. Some trace-element concentrations were slightly increased because of effluents discharged from Boise's WTF's but, where detectable, no trace-element concentration exceeded chronic toxicity criteria. Smaller detection levels for some trace elements were needed to adequately assess their toxicity.

Bottom Material

Bottom material was analyzed for concentrations of aluminum, iron, several trace elements, and organic carbon because sediments represent the most concentrated physical pool of trace elements in the aquatic environment and are ingested by many aquatic organisms (Luoma, 1983, p. 12). Organic matter has the ability to concentrate trace elements because of a number of factors including large surface area, high cation exchange capacity, high negative surface charge, and physical trapping (Horowitz, 1984, p. 38). The physical and chemical composition of bottom material can be highly variable. Häkanson and Jansson (1983, p. 45-47) calculated that to insure less than 10 percent error in determining mean organic content of bottom material from River Fyris in Sweden, 26 samples would be needed. They also calculated that 49 samples would be needed to determine cadmium, copper, and lead concentrations with the same accuracy. Bottom material was collected from depositional areas at each site on the Boise River. Sampling only depositional areas, where fine-grained sediments are most abundant, may reduce the variability of trace-element concentrations and the need for large numbers of samples at each site; however, concentrations are representative of depositional areas, not of the entire streambed. Although only one sample was collected at each site, the sample was a composite of multiple grab samples.

Concentrations of aluminum, iron, several trace elements, and organic carbon from bottom material finer than 0.063 mm are shown in table 6. Concentrations of trace elements in bottom material from selected streams or basins were compared with concentrations in the Boise River and are shown in table 7. The irrigation drainage studies listed in table 7 were in response to concerns over irrigation-induced water-quality problems in the Western United States. All data for these studies were collected during 1986-87, grouped together, and treated as a single data set. Reports from which data were obtained are: Knapton and others (1988), Lambing and others (1988), Peterson and others (1988), Radtke and others (1988), Schroeder and others (1988), Stephens and others (1988), and Wells and others (1988). Because methods of sample collection, processing, and analysis were not always specified and may differ from those used in this study, comparisons of data sets are used for gross interpretations, for example, whether concentrations in bottom material are relatively small or large.

Aluminum concentrations were from 890 to 2,800 μg/g and iron concentrations were from 1,500 to 4,000 μg/g in bottom material from the Boise River (table 6). Aluminum and iron are major

Table 6.--Analyses of bottom material finer than 0.063 millimeter, October 1987 and February 1988

[<, less than the given value, which is the detection level]

Constituent	Site 1, 10/30, 0930	Site 1, 2/ 9, 1430	Site 2, 10/30, 1230	Site 2, 2/ 9, 1130	Site 3, 10/29, 1225	Site 3, 2/ 9, 0930	Site 4, 10/28, 1215	Site 4, 2/10, 1415	Site 5, 10/29, 0920	Site 5, 2/10, 1200	Site 6, 10/28, 0850	Site 6, 2/10, 0930
Aluminum (μg/g as Al)	1,800	1,700	890	2,000	1,700	2,200	950	2,800	920	1,400	1,700	1,800
Arsenic (μg/g as As)	3	3	2	3	3	3	2	5	1	2	2	3
Cadmium (μg/g as Cd)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium (μg/g as Cr)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Copper (μg/g as Cu)	2	6	1	7	2	8	1	9	1	4	2	3
Cyanide (μg/g as CN)	<.5	<10	<.5	<10	<.5	<10	<.5	<10	<.5	<10	<.5	<10
Iron (μg/g as Fe)	3,100	2,400	1,800	2,600	2,900	2,500	1,500	4,000	1,800	1,800	2,900	2,500
Lead (μg/g as Pb)	<10	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Nickel (μg/g as Ni)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Zinc (μg/g as Zn)	20	20	10	20	20	30	10	40	10	20	20	20
Carbon, organic (g/kg)	2	1.8	.7	1.8	1.5	6.8	1.2	6.1	1.5	2.6	5.2	2.1

Table 7.—Trace-element concentrations in bottom material from selected streams or basins

[Concentrations in micrograms per gram; median values given where more than one stream or sample; <, less than the given value, which is the detection level; —, no data available; mm, millimeter; *, particle size not defined]

Stream or basin	Particle size	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Mad River near Blue Lake, Calif.[1] 1 sample	Bulk sample	2.7	2	<1	4	11	—	—
	<0.020 mm	4.2	<1	<1	5.8	6.2	—	—
Willamette River and adjacent water, Oregon[2] 44 samples	<2.0 mm	10	.5	72	10	10	—	140
	<.020 mm	10	1	50	40	35	—	200
Coeur d'Alene River at Cataldo, Idaho[3] 1 sample	*	90	48	—	52	2,300	—	1,400
Nationwide median[3] sample size not defined	*	4	1	—	4	16	—	41
Irrigation drainage studies[4] 72 samples	<.063 mm	6.7	<2	58	22	17	24	78

[1] Fuller (1975).
[2] Rickert and others (1977).
[3] Evan Hornig (EPA, written commun., 1987).
[4] Knapton and others (1988); Lambing and others (1988); Peterson and others (1988); Radtke and others (1988); Schroeder and others (1988); Stephens and others (1988); and Wells and others (1988).

components of the Earth's crust and may exist in large concentrations in river sediments. Bottom materials were analyzed for aluminum and iron during three U.S. Department of the Interior irrigation drainage studies (Peterson and others, 1988; Schroeder and others, 1988; and Wells and others, 1988). Aluminum concentrations were from 940 to 90,000 µg/g and iron concentrations were from 350 to 49,000 µg/g in the three areas.

Arsenic concentrations in bottom material from the Boise River were from 1 to 5 µg/g (table 6). Cadmium and chromium concentrations in bottom material from the Boise River were less than detection levels of 1 and 10 µg/g at all sites (table 6). Arsenic, cadmium, and chromium concentrations were similar to those from the sites listed in table 7, except for the Coeur d'Alene River at Cataldo, in northern Idaho, where mining and smelting processes have increased trace-element concentrations in bottom material. Cadmium concentrations were less than the detection level of 2 µg/g in all 72 samples collected during the irrigation drainage studies summarized in table 7. The largest chromium concentration of 72 µg/g (table 7) was the median value for the Willamette River basin in Oregon, which receives urban runoff, municipal wastewater discharges, and industrial discharges principally from the wood and paper industries.

Copper concentrations in bottom material from the Boise River were from 1 to 9 µg/g (table 6). These concentrations were similar to the nationwide median copper concentration and to those from the Mad River near Blue Lake, Calif., where the basin is characterized by dense conifer forests (Fuller, 1975, p. 3). The largest copper concentration of 52 µg/g (table 7) was from the Coeur d'Alene River. Cyanide concentrations in bottom material from the Boise River were less than detection levels of 0.5 µg/g in October 1987 and 10 µg/g in February 1988 (table 6). Data on cyanide concentrations in bottom material from other rivers were not available for comparison. Lead and nickel concentrations in bottom material from the Boise River were less than the detection level of 10 µg/g, except at site 1 in February 1988, when the lead concentration was 10 µg/g (table 6). Lead concentrations were similar to those from the Mad River (table 7). Data on nickel concentrations in bottom material were available only from the irrigation drainage studies, where the median nickel concentration from 72 samples was 24 µg/g. Zinc concentrations in bottom material from the Boise River were from 10 to 40 µg/g (table 6). These concentrations are smaller than any shown in table 7 but near the nationwide median zinc concentration of 41 µg/g. The largest zinc concentration of 1,400 µg/g (table 7) was from the Coeur d'Alene River.

Organic carbon concentrations in bottom material from the Boise River were from 0.7 to 6.8 g/kg (table 6). The smallest concentration was from site 2 during October 1987; the largest concentration was from site 3 during February 1988.

None of the constituents listed in table 6 showed an increased concentration that could be attributed to effluents discharged from the Lander Street and West Boise WTF's. In general, bottom material from the Boise River contained small concentrations of trace elements.

Benthic Invertebrates

Benthic invertebrates were collected from the Boise River to examine whether effluents discharged from Boise's WTF's caused a significant reduction in trace-element-intolerant organisms. Invertebrates were sampled using artificial substrates left in the river from mid-October to early December 1987 and from late January to early March 1988. Complete lists of taxonomic classifications and densities of invertebrates collected from October to December 1987 are in a report by Frenzel and Hansen (1988a) and, for invertebrates collected from January to March 1988, by Frenzel and Hansen (1988b).

October to December 1987

Artificial substrates were placed in the Boise River October 15-16 and were removed November 30 to December 2, 1987. Velocity and depth of the river were measured at each substrate location at the time of placement. Average velocities and depths are shown in table 8; differences between sites 1 and 2 and between sites 3 and 5 probably do not affect colonization.

Mean density of invertebrates colonizing artificial substrates during October to December 1987 was from 6,100 to 14,000 individuals per substrate (fig. 3). The smallest density was from site 5 below the West Boise WTF; the largest density was from site 2 below the Lander Street WTF. Figure 3 also shows the number of insect families identified at each site. The smallest number of insect families was at site 1; the largest number was at site 5. Identification of Diptera (true flies) was not performed below family level; therefore, comparisons of the entire insect community were made at the family level so that each taxa was weighted appropriately. Oligochaeta, Arachnida, Crustacea, and Mollusca also were present in the invertebrate community; however, only insects were used in assessing differences in benthic invertebrate communities between sites.

Family-level diversity of insect communities ranged from 1.55 to 2.06 (fig. 3). The smallest diversity was from site 1; the largest diversity was from site 6. Normal (healthy) communities typically are composed of a few numerically dominant taxa and a larger number of rare taxa (Kovalak, 1981, p. 257). Rare taxa have little influence on the diversity index value; that is, loss of a relatively rare taxa results in only a small reduction in the value of the diversity index. Four families composed more than 90

Table 8.--Average velocity and depth of the Boise River at substrate locations measured on date of placement

[Velocity in feet per second; depth in feet]

Date of placement		Site 1	2	3	5	6
October 15-16, 1987	Velocity	3.23	3.19	1.92	1.79	1.89
	Depth	1.24	1.05	1.35	1.15	1.06
January 21-22, 1988	Velocity	1.97	2.49	2.05	1.50	2.18
	Depth	1.09	1.13	1.15	1.21	.95

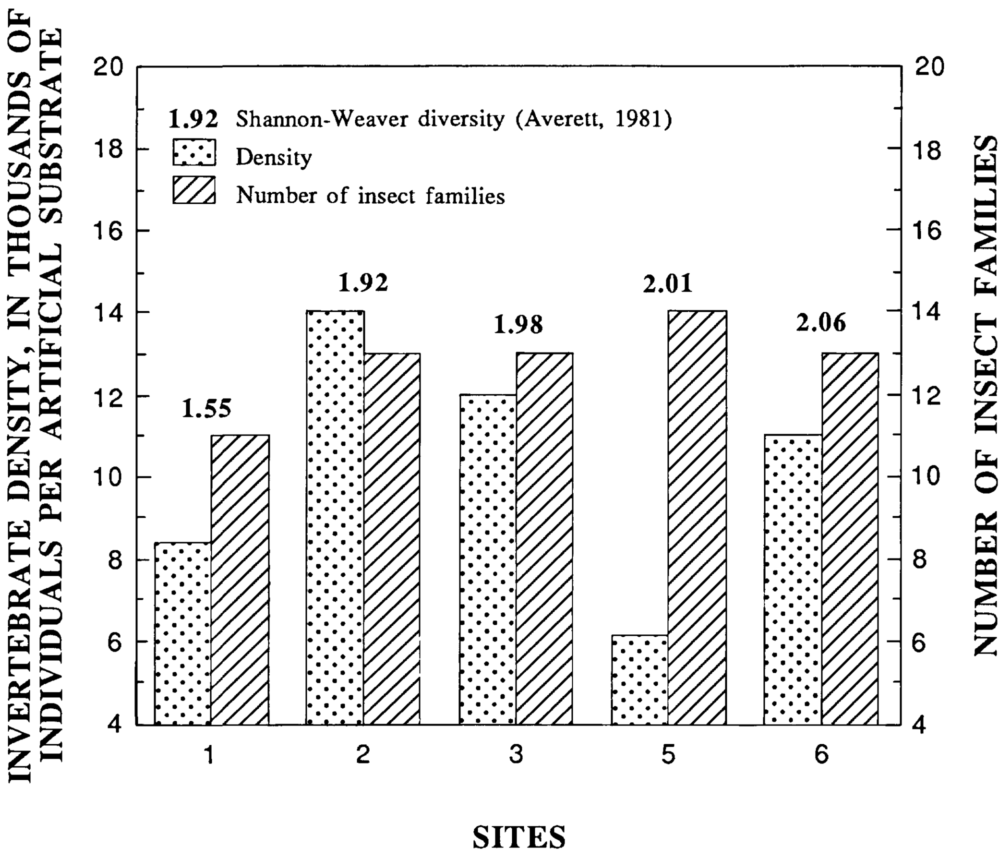

Figure 3.--Mean density of invertebrates, number of insect families, and family-level diversity for communities colonizing artificial substrates, October to December 1987.

percent of the insect population at all sites and 99 percent at site 1 from October to December 1987 (table 9). Chironomidae (midges) and Simuliidae (black flies) belong to the order Diptera (true flies), Baetidae belongs to the order Ephemeroptera (mayflies), and Hydropsychidae belongs to the order Trichoptera (caddisflies). These taxa also were the most abundant insects collected from the Boise River from August 1972 to July 1973. During that time, Diptera, Ephemeroptera, and Trichoptera composed 89 to 99 percent of the insects at all sites (Ada Council of Governments, 1975, p. 41-49).

Each family listed in table 9 contains numerous species, some of which may be tolerant of poor water quality and others which may be intolerant. LaPoint and others (1984, p. 1032) noted that midges can be the most abundant insects in streams with large concentrations of trace elements. In a study of insect communities in the Coeur d'Alene River, true flies, caddisflies, and the mayfly *Baetis tricaudatus* were observed to be tolerant of large trace-element concentrations (Evan Hornig, EPA, written commun., 1987). However, tolerant organisms are present in both clean and polluted water, and only when the presence of tolerant organisms is combined with the absence of intolerant organisms is pollution indicated (Cairns and Dickson, 1971, p. 758). Winner and others (1980, p. 647) hypothesized that habitats heavily polluted by trace elements are dominated by midges; moderately polluted, by midges and caddisflies; and minimally polluted or unpolluted, by caddisflies and mayflies.

Community structure of invertebrates collected from October to December 1987 is shown in figure 4. True flies and mayflies dominated communities at all sites. Mayflies other than Baetidae and stoneflies (Plecoptera) are considered relatively pollution intolerant and were present at all sites; however, at site 6, stoneflies composed less than 1 percent of the total numbers (Frenzel and Hansen, 1988a).

Relative abundance of each insect family collected from sites upstream and downstream from WTF's was compared using Kendall's coefficient of rank correlation, τ , which is a nonparametric test for association (Sokal and Rohlf, 1969, p. 533-537). Where two sites have identical relative abundance, τ is 1; where two sites have exactly opposite relative abundance (the most common taxa at one site is the least common at the other, etc.), τ is -1. The significance of τ was tested to determine the probability of an association occurring by chance. Results of the comparisons are shown in table 10. The strong association of insect communities upstream and downstream from the Lander Street WTF and upstream and downstream from the West Boise WTF indicates that they are from the same population. Probabilities that the associations were by chance are very small. Strong associations of insect communities upstream and downstream from the WTF's indicate that effluents discharged from the WTF's had little effect on community structure.

Table 9.--Mean densities and percentages of total number of insects for the most common families collected from artificial substrates, October to December, 1987

[Densities in number per artificial substrate; percentage in parentheses]

Family	Site 1	Site 2	Site 3	Site 5	Site 6
Chironomidae	1,300 (16)	3,400 (24)	1,700 (14)	2,400 (41)	3,500 (32)
Simuliidae	5,300 (65)	5,700 (41)	5,200 (43)	1,400 (24)	2,400 (22)
Baetidae	910 (11)	3,100 (22)	2,500 (21)	1,500 (26)	3,700 (34)
Hydropsychidae	570 (7)	1,200 (9)	1,800 (15)	370 (6)	730 (7)

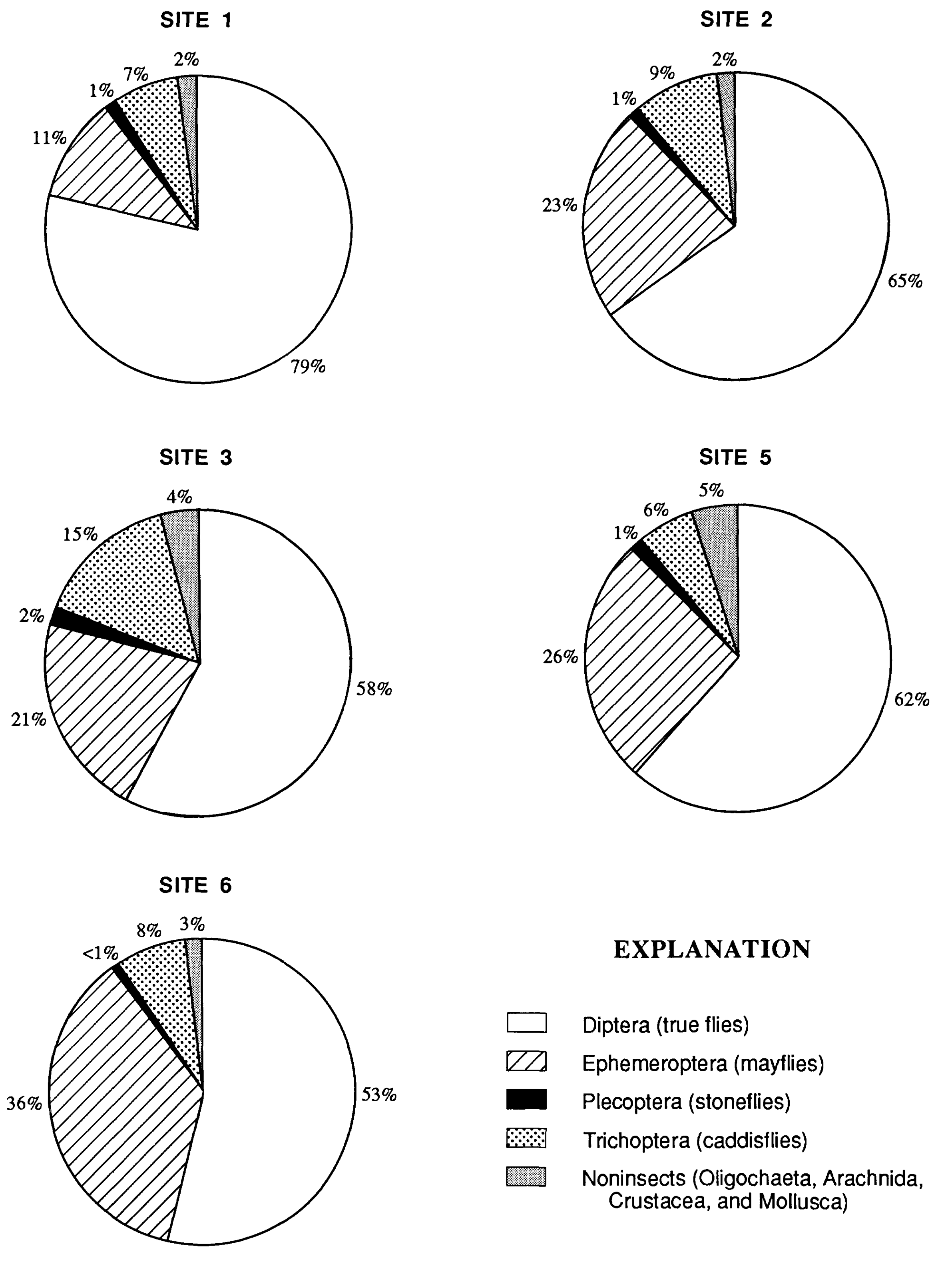

Figure 4.--Community structure of invertebrates, October to December 1987.

Table 10.--Comparison of relative abundance of insect families colonizing artificial substrates upstream and downstream from wastewater treatment facilities, October to December 1987 and January to March 1988

[Kendall's nonparametric test for association performed on mean numbers of each insect family from 10 artificial substrates per site]

Comparison	Kendall's τ	Probability of association by chance
October to December 1987		
Sites 1 and 2	0.633	0.0016
Sites 3 and 5	.714	.0005
January to March 1988		
Sites 1 and 2	.788	<.0004
Sites 3 and 5	.800	<.0004

Courtemanch and Davies (1987, p. 217) stated that many techniques used to evaluate biological communities for effects of wastewater discharge do not discriminate between change and harmful change. They suggested the use of a coefficient of community loss, which discriminates between sites receiving enriching effluents and those receiving stress-inducing effluents:

$$I = (a-c)/b \qquad (3)$$

where

I = coefficient of community loss,
a = number of taxa in the reference community,
c = number of taxa common to both a and b, and
b = number of taxa in the pollution-affected community.

They examined 25 pristine sites where there were no effects, 8 enriched sites where the pollution-affected station was influenced by discharge of treated sewage but dissolved oxygen was always more than 60 percent saturated, 16 organic-stressed sites where dissolved-oxygen saturations were frequently less than 60 percent and organic solids accumulated in the substrate, and 17 toxic-stressed sites where the pollution-affected station was influenced by discharges containing toxic substances. All organic-stressed and toxic-stressed sites had coefficients of community loss values greater than 0.75; enriched sites had values less than 0.35 (Courtemanch and Davies, 1987, p. 219). Coefficients of community loss were calculated using data on insects collected at sites upstream and downstream from WTF's on the Boise River. Coefficients of community loss values were -0.27 for comparison of insect communities upstream and downstream from the Lander Street WTF and -0.08 for insect communities upstream and downstream from West Boise WTF. Negative values result from a larger number of taxa (increased richness) at the downstream site than at the upstream site. Courtemanch and Davies (1987, p. 222) distinguished effluents with a benign enriching effect (values less than 0.4) and those causing harmful displacement of indigenous taxa (values greater than 0.8). Coefficients of community loss indicate that effluents from Boise's WTF's have a benign enriching effect.

Hornig (EPA, written commun., 1987) noted that mayflies other than *Baetis tricaudatus* and stoneflies were severely affected by trace elements. The number of different mayfly taxa identified from the Boise River ranged from 4 at site 1 to 6 at site 5. Mean numbers of mayflies, excluding Baetidae, ranged from 45 per artificial substrate at site 1 to 247 at site 6 (Frenzel and Hansen, 1988a, p. 8). Potential loss of trace-element-intolerant organisms from upstream to downstream from WTF's was examined using a nonparametric analysis of variance, the Wilcoxon two-sample test (Sokal and Rohlf, 1969, p. 391-395), on the sum of the ranks of mayflies, excluding Baetidae (table 11). The null hypothesis (H_o) of each Wilcoxon two-sample test was that the sum of the ranks of mayflies was equal from upstream to downstream from a WTF. The null hypothesis was rejected if the sum of the

Table 11.--Nonparametric analysis of variance of the number of mayflies, excluding Baetidae, on artificial substrates, October to December 1987 and January to March 1988

[Critical Mann-Whitney statistic =68 for α =0.10; H_o: $\Sigma R_1 = \Sigma R_2$, $\Sigma R_3 = \Sigma R_5$; ΣR_i = sum of the ranks of mayflies from 10 artificial substrates at site *i*; WTF, wastewater treatment facility]

Comparison	Sum of ranks		Mann-Whitney statistic	Reject H_o	Significant reduction from upstream to downstream of WTF
October to December 1987					
Sites 1 and 2	ΣR_1 = 108	ΣR_2 = 102	53	No	No
Sites 3 and 5	ΣR_3 = 60.5	ΣR_5 = 149.5	94.5	Yes	No
January to March 1988					
Sites 1 and 2	ΣR_1 = 55	ΣR_2 = 155	100	Yes	No
Sites 3 and 5	ΣR_3 = 55	ΣR_5 = 155	100	Yes	No

ranks of mayflies was significantly different upstream and downstream from a WTF. The probability of falsely rejecting the null hypothesis was set at 10 percent. However, only a significantly smaller sum of the ranks of mayflies downstream from a WTF indicates the possible presence of toxic concentrations of trace elements in the river due to effluent discharge. The sum of the ranks of mayflies colonizing artificial substrates was not significantly different upstream and downstream from the Lander Street WTF and was significantly larger downstream from the West Boise WTF (table 11). Distribution of mayflies indicates that trace-element concentrations in effluents did not adversely affect intolerant organisms in the Boise River.

January to March 1988

Artificial substrates were placed in the Boise River January 21-22 and were removed February 29 to March 2, 1988. Average velocities and depths of the river at artificial substrate locations are shown in table 8. Differences in average velocity between sites 1 and 2 and between sites 3 and 5 probably did not affect colonization because ranges of individual velocity measurements were similar.

Mean density of invertebrates colonizing artificial substrates in the Boise River from January to March 1988 was from 7,100 to 10,000 individuals per artificial substrate (fig. 5). Density was smallest at site 5 and largest at site 6. The number of insect families identified at each site was from 10 at site 3 to 16 at site 5 (fig. 5). The large number of insect families at site 5 was due to several rare taxa; 5 families were represented by only 1 individual per substrate (Frenzel and Hansen, 1988b). Two orders, Odonata (dragonflies and damselflies) and Coleoptera (beetles) were present only at site 5. Family-level diversity of insect communities was from 0.70 at site 1 to 1.93 at site 3 (fig. 5). Diversity was smallest at site 1 due to very large numbers of midges (table 12). Diversity was largest at the site with the smallest number of taxa because individuals were distributed most evenly among the taxa. The four families listed in table 12 composed more than 90 percent of the insect population at all sites and 99 percent at site 6.

Community structure of invertebrates collected from January to March 1988 is shown in figure 6. True flies and mayflies dominated communities at all sites. Mayflies other than Baetidae and stoneflies were present at all sites, although stoneflies composed less than 1 percent of the insect community at sites 1 and 6 (Frenzel and Hansen, 1988b). Relative abundance of each insect family collected from upstream and downstream of WTF's was compared using Kendall's τ (Sokal and Rohlf, 1969, p. 533-537). Insect communities upstream and downstream from each WTF were strongly associated, and probabilities that these associations were by chance were very small (table 10). Results of this comparison indicate that effluents discharged from the Lander

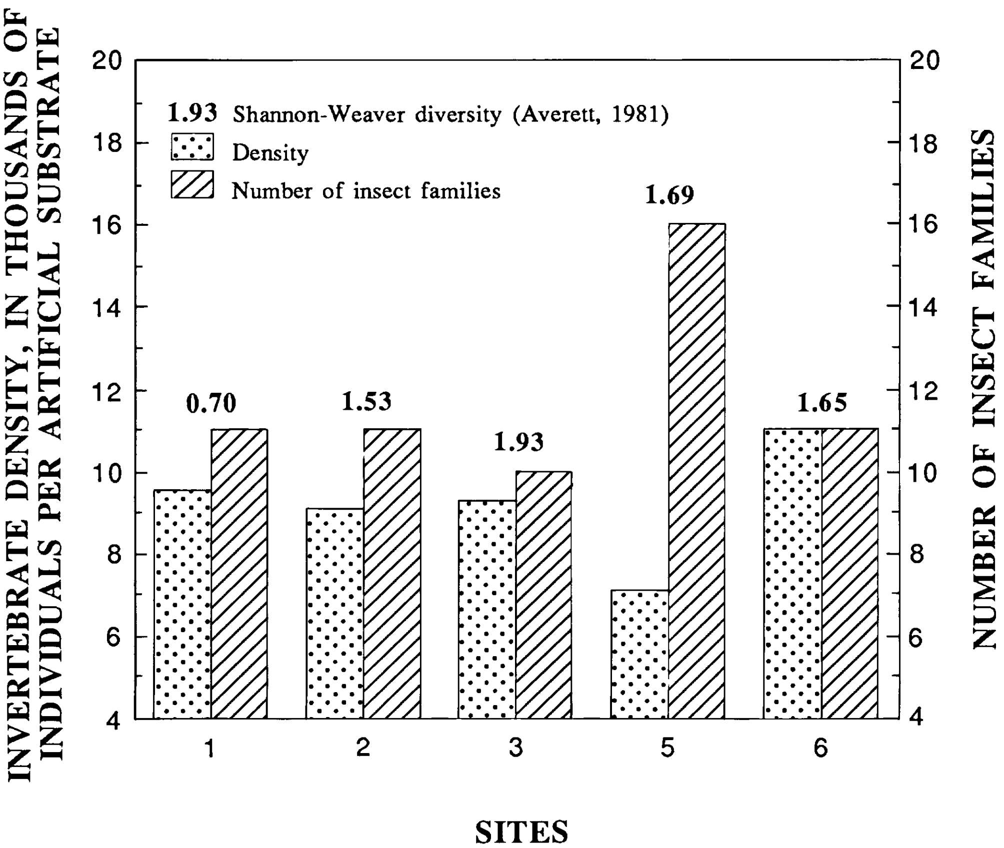

Figure 5.--Mean density of invertebrates, number of insect families, and family-level diversity for communities colonizing artificial substrates, January to March 1988.

Table 12.--Mean densities and percentages of total number of insects for the most common families collected from artificial substrates, January to March, 1988

[Densities in number per artificial substrate; percentage in parentheses]

Family	Site 1	Site 2	Site 3	Site 5	Site 6
Chironomidae	8,000 (89)	6,100 (71)	2,500 (27)	3,200 (48)	4,000 (40)
Simuliidae	220 (2)	400 (5)	3,300 (36)	230 (3)	670 (7)
Baetidae	470 (5)	830 (10)	2,700 (30)	2,700 (40)	5,000 (50)
Hydropsychidae	120 (1)	790 (9)	440 (5)	88 (1)	240 (2)

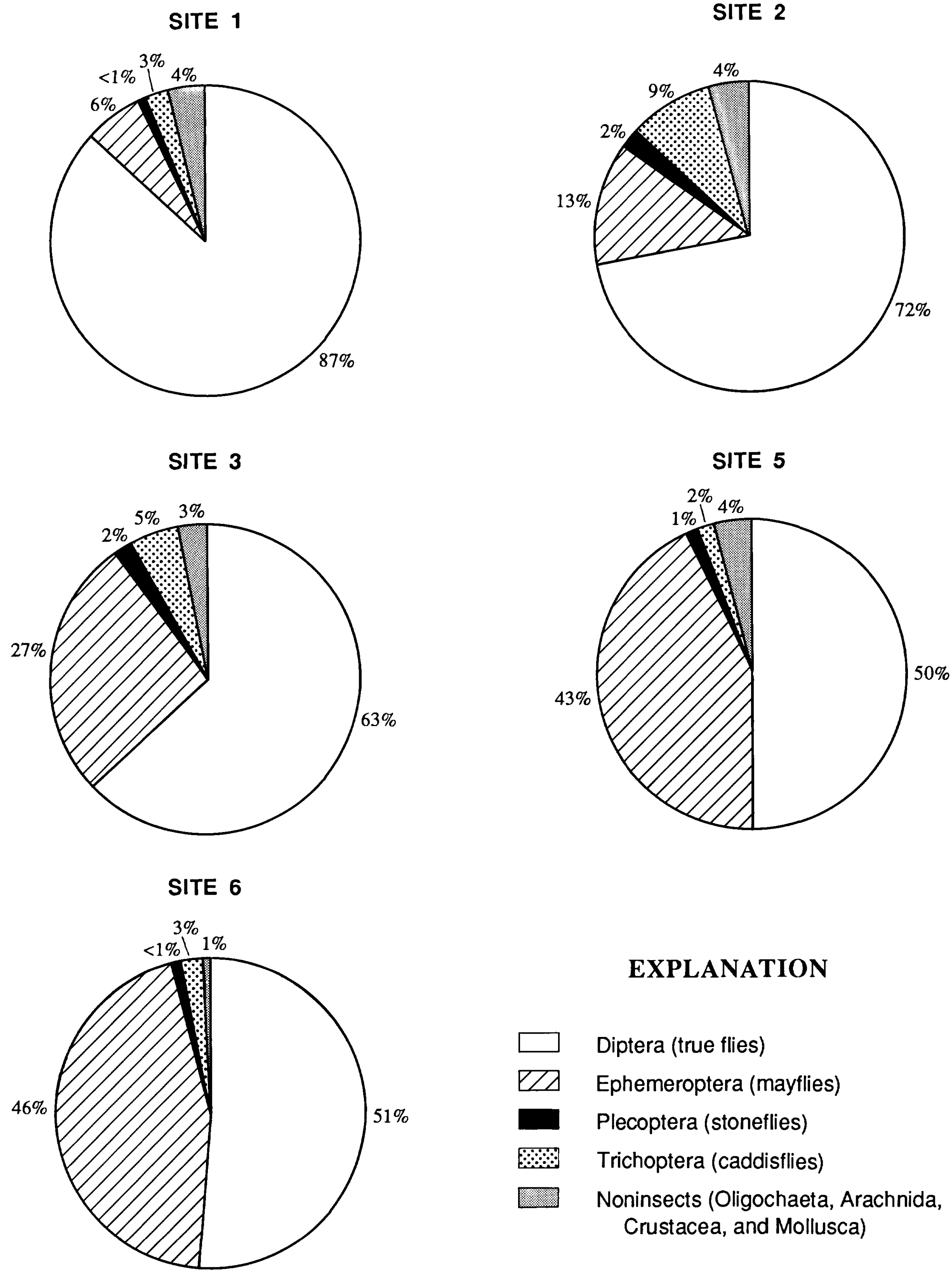

Figure 6.--Community structure of invertebrates, January to March 1988.

Street and West Boise WTF's had little effect on insect community structure.

Coefficient of community loss for insects collected at sites upstream and downstream from the Lander Street WTF was -0.08 and, from upstream to downstream of the West Boise WTF, was -0.42. On the basis of coefficients of community loss (Courtemanch and Davies, 1987, p. 222), effluents discharged by Boise's WTF's had a benign enriching effect.

The number of different taxa of mayflies identified from the Boise River ranged from 3 at site 1 to 6 at sites 5 and 6 (Frenzel and Hansen, 1988b). Numbers of mayflies excluding Baetidae ranged from 28 per artificial substrate at site 3 to 400 at site 5. A nonparametric analysis of variance was conducted on the sum of the ranks of mayflies, excluding Baetidae, at sites upstream and downstream from WTF's. The sum of the ranks of trace-element-intolerant mayflies was significantly larger downstream from the Lander Street and West Boise WTF's (table 11). Distribution of mayflies indicates that trace-element concentrations in effluents did not adversely affect intolerant organisms in the Boise River.

Fish

Fisheries data for the Boise River were collected during January and February 1988 by the Idaho Department of Fish and Game and were reported by Frenzel and Hansen (1988b). Densities of native trout, whitefish, and nongame fish are shown in table 13. Hatchery-reared trout also were present but were not used in any analysis because their length of residence in the river was unknown. Density of native trout was smallest at site 2, largest at site 4, and was less than 1 fish per 10,760 ft^2 at sites 1, 2, and 6. Sites 1 and 2 receive some of the highest trout-fishing pressure in the State (Terry Holubetz, Idaho Department of Fish and Game, written commun., 1988). Whitefish density was smallest at site 6 and largest at site 3. Nongame fish density was smallest at site 3 and largest at site 2. Downstream from the Lander Street WTF, density of native trout was unchanged, density of whitefish increased, and density of nongame fish increased greatly compared with densities upstream from the WTF (table 13). Downstream from the West Boise WTF, density of native trout was unchanged, density of whitefish decreased slightly, and density of nongame fish increased (table 13).

Native trout and whitefish are probably the best fish to use as indicators of environmental quality in the Boise River (Terry Holubetz, Idaho Department of Fish and Game, written commun., 1988). Density of gamefish alone may not be sufficient to show whether water quality has degraded to the point of stressing the fish. To test the relative health of fish communities upstream and downstream from WTF's, an analysis of variance was conducted on condition factors of whitefish at those sites. Whitefish were

Table 13.--Population density of native trout, whitefish, and nongame fish, January and February 1988

[Values are number of fish per 10,760 ft^2 surface area of stream; <, less than]

Fish	Site				
	1	2	3	4	6
Native trout (includes rainbow and brown)	<1	<1	6.9	7.9	<1
Whitefish	30	56	140	100	25
Nongame fish	120	640	54	180	260

chosen for the analysis because their greater abundance compared with abundance of native trout provides increased confidence in statistical comparisons, although both native trout and whitefish had normal to excellent condition factors at all sites (Terry Holubetz, Idaho Department of Fish and Game, written commun., 1988). Gibson (1975, p. 32) determined that the mean condition factor for whitefish in the Boise River from the mouth upstream to Barber Dam was 3.10 during July, August, and October 1974. Mean condition factors of whitefish were 3.87 at site 1 and 4.34 at site 2 during January and February 1988. These mean condition factors were significantly different at $P = 0.003$, which indicates an increase in the relative health of fish communities downstream from the Lander Street WTF.

Mean condition factors of whitefish were 4.30 at site 3 and 3.58 at site 4 and were significantly different at $P < 0.001$, which indicates a decrease in the relative health of fish communities downstream from the West Boise WTF.

SUMMARY AND CONCLUSIONS

Physical, chemical, and biological characteristics of the Boise River were examined to determine whether effluents discharged from Boise's WTF's were detrimental to aquatic communities. Data were collected during the low-flow period from October 1987 to March 1988. Fluorescent dye was injected into effluents discharged from both WTF's to determine the length of effluent mixing zones. Effluent from the Lander Street WTF was mixed completely with the river within 1.5 mi of the point of discharge, and effluent from the West Boise WTF was mixed within 4 mi.

Water samples collected during October 1987 and February 1988 were analyzed for a variety of constituents, including total ammonia and trace-element concentrations. Total ammonia concentrations ranged from 0.02 to 0.72 mg/L and did not exceed chronic toxicity criteria. The smallest total ammonia concentration was at site 1 and the largest was at site 2. Trace elements were analyzed for total concentrations (termed "total-recoverable concentrations" by the EPA). Cadmium, chromium, hexavalent chromium, cyanide, lead, nickel, and silver concentrations in the Boise River were less than or near analytical detection levels and were less than chronic toxicity criteria when detectable. Arsenic concentrations were 3 µg/L and the criteria for arsenic was 190 µg/L. Copper concentrations ranged from 1 to 5 µg/L and the criteria for copper were from 6.1 to 11 µg/L, depending on water hardness. Zinc concentrations ranged from less than 10 to 20 µg/L and the criteria for zinc were from 55 to 100 µg/L, depending on water hardness.

Concentrations of trace elements and organic carbon were determined for bottom material finer than 0.063 mm collected from depositional areas in the Boise River. Cadmium, chromium, cyanide, lead, and nickel concentrations in bottom material were less than or near detection levels. Arsenic concentrations ranged from 1 to 5 μg/g, copper concentrations ranged from 1 to 9 μg/g, and zinc concentrations ranged from 10 to 40 μg/g. Concentrations of trace elements in bottom material from the Boise River generally were small and could not be attributed to effluents discharged from the Lander Street and West Boise WTF's.

Benthic invertebrate communities from 10 artificial substrates per site were examined to determine whether effluents discharged from Boise's WTF's caused a significant reduction in trace-element-intolerant organisms. During October to December 1987, mean density of invertebrates was from 6,100 to 14,000 individuals per substrate. During January to March 1988, mean density of invertebrates was from 7,100 to 10,000 individuals per substrate. Family-level diversity was from 1.55 to 2.06 during October to December 1987, and was from 0.70 to 1.93 during January to March 1988. Communities were dominated by midges, black flies, Baetidae mayflies, and Hydropsychidae caddisflies. These four families composed more than 90 percent of the insect population at all sites. Comparisons of relative abundance of all insect families collected were made using a nonparametric test for association. The strong association of insect communities upstream and downstream from WTF's indicates that effluents had little effect on community structure.

Coefficient of community loss, which discriminates between sites receiving enriching and stress-inducing effluents, was calculated for insect communities upstream and downstream from WTF's. Communities downstream from each WTF indicated benign enriching effects from the effluents.

The numbers of trace-element-intolerant mayflies upstream and downstream from WTF's were compared using a nonparametric analysis of variance. The sum of the ranks of trace-element-intolerant mayflies was not significantly different upstream and downstream from the Lander Street WTF during October to December 1987; was significantly larger downstream from the Lander Street WTF during January to March 1988, and was significantly larger downstream from the West Boise WTF during both sampling periods. Distribution of mayflies indicates that trace-element concentrations in effluents did not adversely affect intolerant organisms in the Boise River.

Fisheries data were collected by the Idaho Department of Fish and Game during January and February 1988. An analysis of variance of condition factors was used to compare the relative health of fish communities upstream and downstream from WTF's. Mean condition factors of whitefish were 3.87 at site 1, 4.34 at site 2, 4.30 at site 3, and 3.58 at site 4. Mean condition factor was significantly increased downstream from the Lander Street WTF and was significantly decreased downstream from the West Boise WTF.

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