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MONTANA DEPARTMENT OF ENVIRONMENTAL QUALITY

Effluent Mixing Characteristics below Four Wastewater-Treatment Facilities in Southwestern Montana, 1997

Water-Resources Investigations Report 99-4026

U.S. Department of the Interior
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By Thomas E. Cleasby and Kent A. Dodge

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U.S. Department of the Interior

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March 1999

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CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS, AND ACRONYMS

Multiply	By	To obtain
acre	0.4047	hectare
acre	4,047	square meter
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
foot per foot	1.0	meter per meter
foot per second (ft/s)	0.3048	meter per second
foot per second squared	0.3048	meter per second squared
foot squared per second	0.09290	meter squared per second
mile (mi)	1.609	kilometer
million gallons per day (MGD)	0.003785	million cubic meters per day

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:

$$°F = 9/5(°C)+32$$

Abbreviated water-quality units used in this report:

µm	micrometer
µS/cm	microsiemens per centimeter at 25 degrees Celsius
mg/L	milligrams per liter
mL	milliliter

Acronyms used in this report:

BOD	biochemical oxygen demand
DMR	discharge monitoring report
EDI	equal discharge increment
EPA	U.S. Environmental Protection Agency
EWI	equal width increment
MDEQ	Montana Department of Environmental Quality
MGD	million gallons per day
NTU	nephelometric turbidity unit
7Q10	7-consecutive day minimum flow having a recurrence interval of 10 years

EFFLUENT MIXING CHARACTERISTICS BELOW FOUR WASTEWATER-TREATMENT FACILITIES IN SOUTHWESTERN MONTANA, 1997

By Thomas E. Cleasby *and* Kent A. Dodge

Abstract

Specific reaches of a receiving body of water may be designated as a mixing zone by the State when establishing water-quality permits for point discharges. This report evaluates the mixing characteristics of receiving streams and the effluent from four wastewater-treatment facilities in southwestern Montana. The mixing zones, sampled in September and October 1997, were the East Gallatin River at Bozeman, Big Pipestone Creek at Whitehall, the Bitterroot River at Darby, and the Bitterroot River at Hamilton. Differing physical and hydrologic characteristics of the receiving streams at each site permitted mixing to be assessed under various conditions of flow and channel morphology. At each site, physical properties and chemical data were collected at multiple points across the stream to determine mixing characteristics at various distances below the wastewater-discharge points. The mixing characteristics were compared to calculated mixing lengths derived from two mixing criteria designed to estimate mixing during low-flow conditions: an equation-derived distance for effluent to achieve one-half width mixing and the distance corresponding to ten times the average stream width. The more restrictive of the two is used by the State to establish a mixing zone for the effluent. The mixing characteristics observed at various distances downstream from wastewater-discharge points during this study may not be directly comparable to estimated mixing lengths because of above-normal flow conditions. Flows were estimated to be from 27 to 47 percent higher than long-term mean September flows and three to eight times higher than the designated low flows for which the one-half width mixing equation was developed. Although flows were higher than normal, several features of mixing were identified that offer insight for future mixing-zone assessments.

Downstream from each wastewater-discharge point, specific conductance was the only physical property to consistently display a lateral variation sufficient to indicate extent of mixing. Of the chemical constituents analyzed, total phosphorus was the most consistent indicator of mixing and corresponded well to the variation in specific conductance. Lateral concentration variations for total phosphorus were observed at all four sites in the transect just downstream from the wastewater-discharge point. Bank-to-bank differences in total phosphorus concentrations in the transect just downstream from each discharge point were variable among the four sites, ranging from relatively minor differences to a nearly three-fold difference. This range of variations was most likely a result of the transect's distance downstream from the wastewater-discharge point and the flow in the receiving stream. To a smaller extent, lateral variations in dissolved chloride and total ammonia concentrations were observed. Other physical properties and chemical constituents analyzed were not consistent, displaying concentrations that were either less than the minimum reporting level, unchanged from bank to bank, or laterally too variable from sample to sample to be useful in determining mixing.

The only chemical concentration to exceed human health standards or aquatic-life criteria was total ammonia. Chronic aquatic-life criteria were exceeded at one or more points in the transects just downstream from the wastewater-discharge points at the Bozeman and Whitehall sites. Total phosphorus concentrations at the Bozeman, Whitehall, and Darby sites were greater than values recommended by the U.S. Environmental Protection Agency to prevent eutrophication. Where mixing across the stream was complete, constituent concentrations downstream from the wastewater-discharge points compared to an upstream reference transect ranged from about 1.5- to 9-fold higher for total phosphorus and about 5- to 30-fold higher for total ammonia.

INTRODUCTION

Mixing zones are specific reaches where wastewater discharged from a point source mixes and is progressively diluted by a receiving body of water. Under the U.S. Environmental Protection Agency's (EPA) Clean Water Act regulations, States may designate a mixing zone when establishing a water-quality permit for a point discharge (U.S. Environmental Protection Agency, 1994). Within a mixing zone, certain water-quality criteria applicable to the receiving water body may be exceeded, but the receiving water body must be in compliance with standards for human health and aquatic life beyond the mixing-zone boundaries. The Montana Department of Environmental Quality (MDEQ) has the responsibility of evaluating and establishing mixing zones at approximately 122 municipal wastewater treatment systems of various designs and sizes which discharge treated wastewater into a receiving water body (M.T. Abrahamson, Montana Department of Environmental Quality, written commun., 1997). The administrative rules of Montana governing the establishment of mixing zones in surface and ground water can be found in MDEQ (1996).

For receiving streams, the mixing zone should not exceed either the stream distance required to disperse effluent across one-half of the cross-sectional area, as calculated by an equation used to determine the one-half width mixing distance, or a distance of 10 times the stream width at a designated critical low flow, whichever is more limiting (Montana Department of Environmental Quality, 1995). For a receiving surface-water body in the area of the mixing zone, the critical low-flow condition used in the equation is defined by the MDEQ as the 7 consecutive day minimum flow having a recurrence interval of 10 years (7Q10 flow). Other factors, such as the existence of drinking water intakes, overlapping mixing zones, biological habitat features such as spawning and nursery areas, and tributaries that serve as migration routes for fish and other aquatic organisms, are considered by the MDEQ when establishing mixing zones for a site.

The rate of lateral mixing can be highly variable from site to site and is affected by the flow rate of the receiving waters, morphology of the receiving stream channel, and stream gradient. Vertical mixing also can be affected by the density of effluent relative to the density of the receiving water. Complete mixing is considered to be achieved when the difference in bank-to-bank values for any parameter is less than 10 percent (Montana Department of Environmental Quality, 1995).

To evaluate mixing characteristics at four sites representing variable hydrologic and morphologic conditions in receiving streams, the USGS, in cooperation with the MDEQ, sampled mixing zones below selected wastewater-treatment facilities in southwestern Montana (fig. 1) during September and October 1997. Because effects on physical properties and constituent concentrations in receiving streams are most pronounced during low flows when dilution capacities are minimal, the late summer-early fall period was selected for sampling. However, flows during 1997 were above normal in western Montana; therefore, conditions during this investigation were not optimal for evaluating mixing characteristics under the hydrologic condition of low flow typically used to establish mixing zones. As a result, the data serve primarily to describe mixing under conditions of above normal streamflow. The data also enable an evaluation of mixing-assessment methods, which may enhance future sampling efforts.

Purpose and Scope

This report evaluates the mixing characteristics of streams receiving the effluent from four wastewater-treatment facilities in southwestern Montana. This initial assessment of mixing is intended to assist the State in evaluating the suitability of criteria currently used to estimate mixing lengths when establishing a mixing zone for wastewater-discharge permits. A second objective was to identify reliable and practical methods and water-quality parameters for improving future mixing zone assessments. Descriptions of the mixing zones, hydrologic conditions, mixing-length calculations, and factors affecting mixing are provided for the following four sites: Bozeman, Whitehall, Darby, and Hamilton (fig. 1).

At each site, water samples were collected for field measurement and laboratory analysis of water-quality parameters from multiple transects (cross sections oriented perpendicular to flow) downstream from the wastewater-discharge point. In addition, one or two transects upstream from the discharge point were sampled as a reference to background water-quality before mixing. The physical and chemical data were evaluated to determine the lateral (bank-to-bank) and longitudinal (downstream) mixing characteristics. The

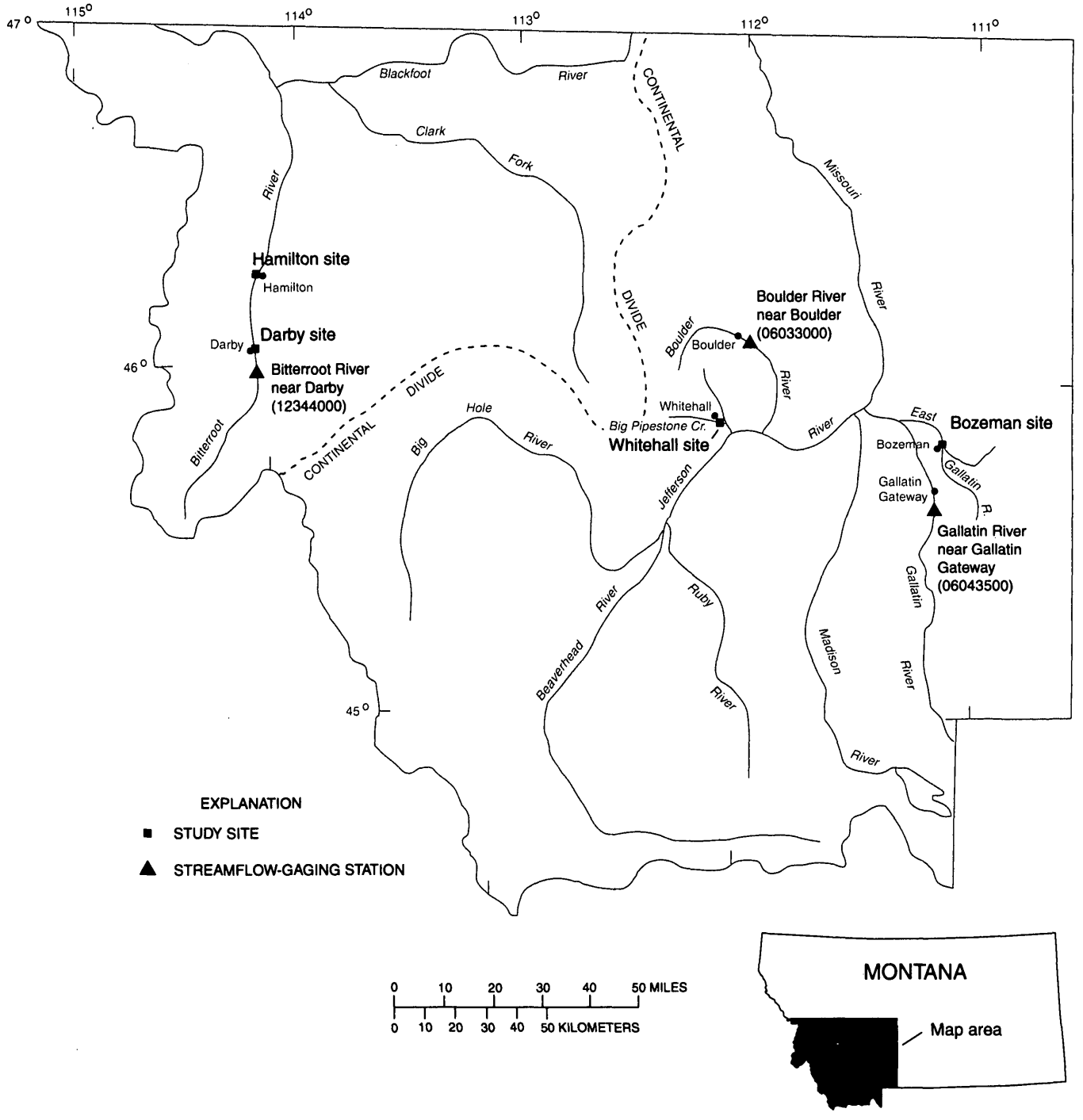


Figure 1. Location of four study sites and selected streamflow-gaging stations in southwestern Montana.

extent of lateral mixing observed at the transects located at varying distances downstream from the discharge point was then compared to calculated mixing lengths derived from two mixing criteria. The two mixing criteria currently used by the State to estimate one-half width mixing lengths are the one-half width mixing length, as calculated by a mixing-length equation (Montana Department of Environmental Quality, 1996), or the distance corresponding to 10 times the average stream width, whichever is the most restrictive.

Methods

A reconnaissance of stream conditions was made at each site before sampling to select appropriate locations for transects. One or two transects upstream from each wastewater-discharge point were selected for sampling to determine background conditions. Two or three transects were selected for sampling downstream from each wastewater-discharge point within the current State-designated mixing zone: one just downstream from the wastewater-discharge point, one near either the calculated one-half width mixing distance (described later) or 10 times the stream width, and one upstream from the current State-designated mixing-zone end point, where complete mixing was indicated by physical properties. Transects were located in areas of relatively uniform depths and velocities to minimize sampling variability associated with turbulence or irregular distribution of flow across the stream.

Discharge was measured at each transect to determine flow distribution across the channel. This information was used to determine the location of equal discharge increment (EDI) sampling verticals across the stream whereby each sample would be discharge-weighted--that is, the sample volume from each vertical would be equal and proportional to the flow (Knapton, 1985). Depending on stream width, as many as 10 sampling verticals in a transect were selected. The samples collected from each vertical were analyzed individually in order to determine lateral variability in water quality.

A depth-integrated water sample was collected with a DH-81 hand-held sampler at each EDI vertical using methods described by Knapton (1985). Field measurements of water-quality properties and field processing of samples were performed using techniques described by Horowitz and others (1994) and Knapton (1985). Water-quality properties of specific conductance, pH, water temperature, and dissolved oxygen were measured onsite with a Hydrolab multiparameter meter at each EDI vertical. Samples for turbidity, bacteria, biological oxygen demand (BOD), and chemical constituents were analyzed in the laboratory. Samples for chemical analyses were composited in a polyethylene churn splitter and aliquots were withdrawn for analyses of constituent concentrations. Acidified samples were preserved onsite with sulfuric acid. Bacteria samples were collected in sterile bottles and chilled.

Water samples were analyzed by the Montana Department of Public Health and Human Services Environmental Laboratory using EPA methods. The EPA methods used were: turbidity, EPA 180.1; biochemical oxygen demand (BOD), EPA 405.1; fecal coliform bacteria, EPA 908C; dissolved chloride, EPA 325.2; total nitrite plus nitrate, EPA 353.2; total ammonia, EPA 350.1; total ammonia plus organic nitrogen, EPA 351.2; and total phosphorus, EPA 365.1. A list of references for methods used is available in EPA (1984). Water-quality data for all sites are presented in tables 2-5 at the back of this report.

Quality Assurance

Quality-assurance procedures used for the collection and field processing of water-quality samples are described by Horowitz and others (1994), Ward and Harr (1990), Edwards and Glysson (1988), Knapton and Nimick (1991), and Knapton (1985). Analytical results for water-quality samples were evaluated for bias and precision using blank and replicate water samples that were submitted from the field and analyzed concurrently in the laboratory with routine samples. Generally, one blank and one replicate water sample was collected at each site.

Blank samples of ultrapure deionized water were analyzed to identify the presence and magnitude of contamination that could originate from sampling or sample processing and potentially bias analytical results. The blank solution was processed through the same sampling equipment using the same handling procedures that were used to collect stream samples. Blank samples were analyzed for the same properties and constituents as those of stream samples to identify the presence of any detectable constituent concentrations (table 6 at the back of this report).

Turbidity values and most constituent concentrations in field blanks were less than the minimum reporting level. Only two constituents exceeded twice the minimum reporting level (typical measurement precision near the detection level), and both exceedances occurred at the Bozeman site. The two constituents were total ammonia plus organic nitrogen (0.70 mg/L as N) and total phosphorus, (0.004 mg/L as P). Concentrations of total ammonia plus organic nitrogen ranged from 0.80 to 2.1 mg/L in stream samples collected before and after the field blank was processed (table 2); therefore, the detectable concentration of 0.70 mg/L in the blank may represent possible field contamination from the previous sample. However, the effect of any contamination bias is difficult to determine because stream values for this constituent were highly variable within a transect, indicating possible poor precision of analytical results. Stream concentrations for total phosphorus collected before and after the field blank ranged from 0.328 to 0.976 mg/L (table 2), whereas the blank concentration was 0.004 mg/L. Consequently, the low concentration in the blank sample relative to stream concentrations indicates negligible bias in total phosphorus concentrations. Detectable values for turbidity, BOD, dissolved chloride, total nitrite plus nitrate, and total ammonia in the blank samples were all less than twice the minimum reporting level.

Analysis of replicate data provides an assessment of the precision (reproducibility) of analytical results. Replicate samples are two or more samples considered to be essentially identical in composition. Replicate samples were collected in the field by splitting a single, composited sample into two samples. Results of replicate analyses are listed in table 7 at the back of this report.

Paired analyses of field replicate samples were used to estimate precision for each parameter, expressed as a relative standard deviation, in percent (table 8 at the back of this report). The relative standard deviations illustrate the overall reproducibility of environmental data that include potential variability from both field and laboratory sources. Relative standard deviations estimated from differences in the paired analytical results for field replicates were within 10 percent for all parameters except total ammonia plus organic nitrogen. A contributing factor to this poor precision may be the small sample size of four used to calculate the statistics. The variability in results for total ammonia plus organic nitrogen, both within a transect and between replicates, may indicate possible instability of this constituent that also could have contributed to its relatively high concentrations in one of the blank samples.

Study Sites

Four wastewater-treatment facilities in southwestern Montana were selected by the MDEQ for this study. Each site had different physical and hydrologic characteristics, which allowed evaluation of mixing under a wide range of flows and channel morphologies. The mixing zones selected for this study were the East Gallatin River at Bozeman, Big Pipestone Creek at Whitehall, Bitterroot River at Darby, and Bitterroot River at Hamilton (fig. 2).

At each of the four wastewater-treatment facilities, three to five transects were sampled. Each transect was assigned a 15-digit station number that represents the approximate latitude and longitude of the transect (first 13 digits) plus a sequence number (last 2 digits). Each sampling point--as many as 10 along a transect--was assigned a sample location identifier. The sample location identifier consists of a letter-number combination (such as A-1), wherein the letter corresponds to the transect and the number identifies the sampling point along that transect. Sampling points along all transects were referenced relative to the left bank (looking downstream), with numbers increasing toward the right bank.

The Bozeman wastewater-treatment facility is a conventional activated sludge system that serves a community of 23,000 (U.S. Bureau of the Census, 1991). The effluent is transported via open channel and is discharged from the left bank into the East Gallatin River. Discharge monitoring report (DMR) data indicated that the average flow through the Bozeman facility in September 1997 was approximately 6 million gallons per day (MGD) (M.T. Abrahamson, Montana Department of Environmental Quality, written commun., 1998). This facility disinfects its treated wastewater with chlorine, then dechlorinates prior to discharge. The State-designated mixing zone extends 4,500 ft downstream from the wastewater-discharge point to the confluence with Sypes Creek. The East Gallatin River has a pool-riffle type channel that is composed of sand, gravel, and cobbles. Banks are mostly steep and vegetated by natural grasses, willows, and cottonwood trees. The stream is highly meander-

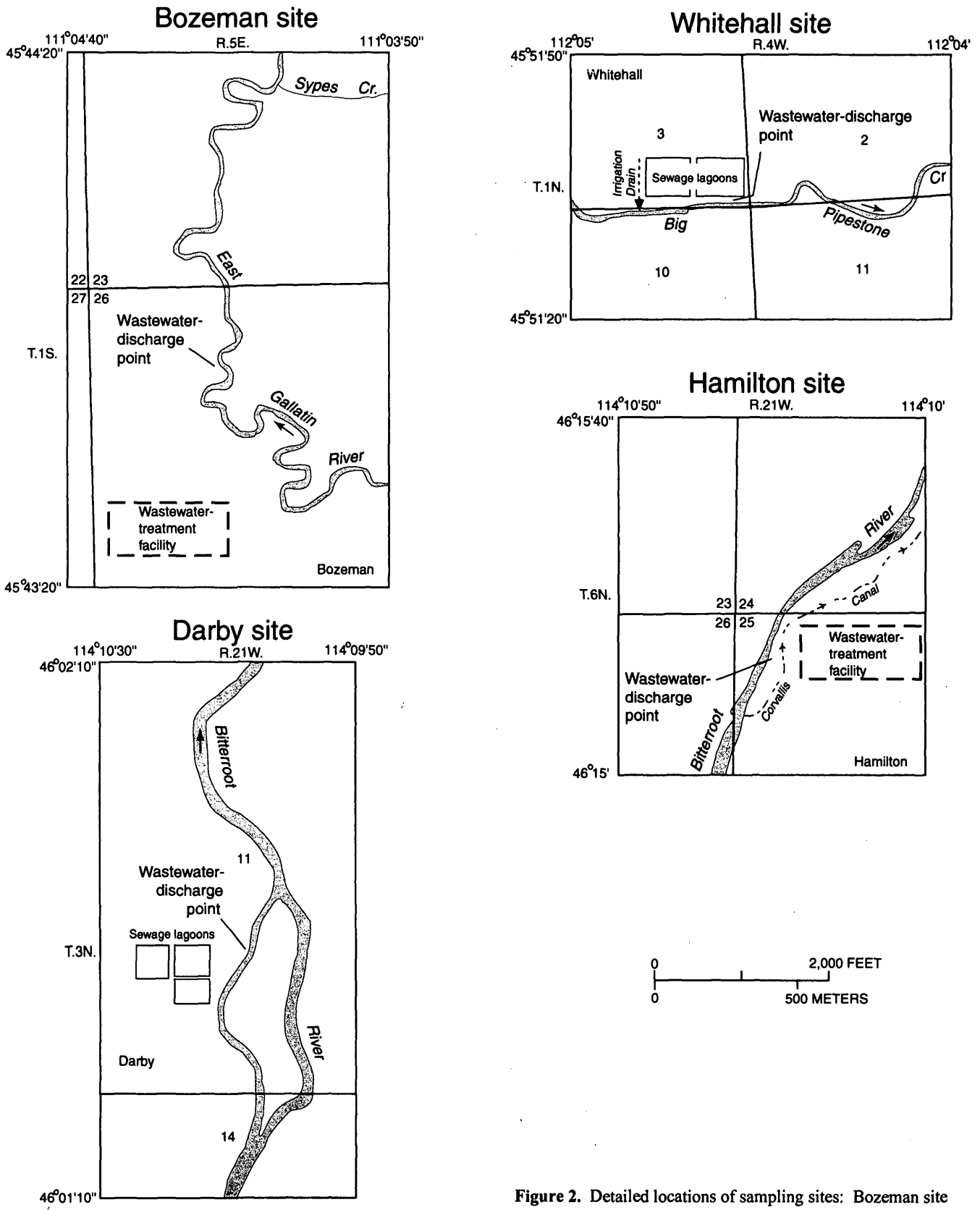


Figure 2. Detailed locations of sampling sites: Bozeman site (East Gallatin River), Whitehall site (Big Pipestone Creek), Darby site (Bitterroot River), and Hamilton site (Bitterroot River).

ing in the general area of the wastewater-discharge point.

The Whitehall wastewater-treatment facility is a facultative lagoon that serves a community of about 1,100 people (U.S. Bureau of the Census, 1991). The facility is composed of two cells having a total surface area of 10.8 acres. Effluent is discharged through a pipe to the left bank of Big Pipestone Creek. DMR data indicated that the average flow through the Whitehall facility in September 1997 was approximately 0.083 MGD (M.T. Abrahamson, written commun., 1998). Treated wastewater is passed through an ultra-violet disinfection unit prior to being discharged. The State-designated mixing zone extends approximately 1,700 ft downstream from the wastewater-discharge point. Big Pipestone Creek is narrow, and heavily vegetated by tall grasses which overhang into the water from both sides. The stream channel is composed mostly of sand and is relatively straight near the facility and slightly to moderately meandering downstream. Both banks are steep and depths are fairly uniform.

The Darby wastewater-treatment facility is a facultative lagoon that serves a community of about 650 people (U.S. Bureau of the Census, 1991). The facility is composed of three cells having a total surface area of 11.6 acres. Effluent is discharged via open channel to the left bank of a side channel of the Bitterroot River. DMR data indicated that the average flow through the Darby facility in September 1997 was approximately 0.058 MGD (M.T. Abrahamson, written commun., 1998). The treated wastewater is not disinfected prior to discharge. The State-designated mixing zone is currently (1997) undetermined for this site. The side channel currently transports little water and may be subject to becoming dry in low-flow years. The side channel rejoins the main channel of the river about 1,000 ft downstream from the wastewater-discharge point. Flow in the side channel at the time of sampling was less than 1 percent of the flow in the main channel of the Bitterroot River. The bed of the side channel is composed of cobbles and gravel. The side channel is slightly meandering with shallow depths and almost stagnant flow velocities. The side channel had abundant algal growth, both above and below the point of wastewater-discharge. The bed of the main channel is composed of boulders and cobbles. The main channel is slightly to moderately meandering, with deep and relatively turbulent flows near the facility.

The Hamilton wastewater-treatment facility is an oxidation-ditch design that serves a community of about 3,000 (U.S. Bureau of the Census, 1991). Effluent is discharged by pipe over the Corvallis Canal and is subsequently released to an open channel for about 50 ft before it enters the Bitterroot River from the right bank. DMR data indicated that the average flow through the Hamilton facility in October 1997 was approximately 0.956 MGD (M.T. Abrahamson, written commun., 1998). Treated wastewater is disinfected with chlorine prior to discharge. The State-designated mixing zone extends 6,500 ft downstream from the discharge point. The Bitterroot River channel is composed of cobbles and boulders and is slightly meandering in the area of the wastewater-treatment facility. Flows were deep and relatively turbulent at the riffles. The right bank consisted of a mostly moderate sloping grade that was vegetated by grasses, willows, and cottonwood trees. Several homes and buildings were located on the right bank. The left bank was nearly vertical, terminating at a plateau about 75 ft above the river.

EFFLUENT MIXING CHARACTERISTICS

This study was intended to describe mixing in State-designated mixing zones during low-flow conditions, when the receiving streams are most vulnerable to water-quality effects from effluent owing to limited dilution capacities. The measurement of mixing patterns was designed to provide data useful for evaluating the predictive capability of the one-half width mixing equation, which utilizes a flow criterion of a 7Q10 flow. The above-normal flows in 1997 precluded a direct assessment of low-flow mixing characteristics; however, water-quality data for selected properties and constituents in the receiving streams were examined to identify lateral and longitudinal mixing characteristics under the given flow conditions. The data also were used to identify exceedances of water-quality standards and the suitability of individual parameters to characterize mixing.

Hydrologic Conditions

During this study, flows were above normal and well above the 7Q10 flows for which the mixing equa-

tion was developed. To provide a relative reference for the flow magnitudes at each site during this study, long-term records at nearby USGS streamflow-gaging stations (fig. 1) were used to compare 1997 mean September flows with long-term mean September flows. Where data were available to determine 7Q10 flows at the site, these flows were compared with flows at the time of sampling. All comparisons between 1997 flows and long-term flows are qualitative and do not take into account flow differences between the gaged sites and sampled sites resulting from intervening tributaries or irrigation withdrawals.

Records for the streamflow-gaging station Gallatin River near Gallatin Gateway (station 06043500) were used for comparison to flows measured in the East Gallatin River at the Bozeman site (fig. 1). This gaging station is 7.3 river mi south of Gallatin Gateway. The East Gallatin River flows into the Gallatin River about 35 river mi downstream from the gaging station. The September 1997 mean flow of 697 ft^3/s of the Gallatin River near Gallatin Gateway was 41 percent higher than the long-term mean September flow of 496 ft^3/s (Shields and others, 1998). The September 1997 mean flow was also more than three times the 7Q10 low flow of 204 ft^3/s at the gaging station, as listed by Shields and White (1981). Accordingly, flows in the nearby East Gallatin River at the Bozeman site at the time of sampling were also presumably several times higher than the 7Q10 flow for the site.

Records for the streamflow-gaging station Boulder River near Boulder (station 06033000) were used for relative comparison of 1997 to long-term flows for Big Pipestone Creek at the Whitehall site (fig. 1). The Boulder River flows into the Jefferson River about 13 river mi downstream from Whitehall, Mont. The September 1997 mean flow of 44 ft^3/s of the Boulder River near Boulder was 47 percent higher than long-term mean September flow of 30 ft^3/s (Shields and others, 1998). The September 1997 mean flow was also about eight times the 7Q10 low flow of 5.5 ft^3/s at the gaging station, as listed by Shields and White (1981). Accordingly, flows in Big Pipestone Creek at the time of sampling were probably several times higher than the 7Q10 flow for the site.

The streamflow-gaging station Bitterroot River near Darby (station 12344000) is about 4.1 river mi upstream from the Darby wastewater-treatment facility (fig. 1); therefore, its records provide a nearly direct indication of flow at the Darby site. Because this gaging station is 23 river mi upstream from the Hamilton site, flows probably can be assumed to be proportional to, though not a direct indication of, long-term flows at Hamilton. The September 1997 mean flow of 442 ft^3/s of the Bitterroot River near Darby was 27 percent higher than the long-term mean September flow of 349 ft^3/s (Shields and others, 1998). Although flows were highly variable throughout the month, they were commonly higher than the mean monthly value. The September 1997 mean flow was almost four times the 7Q10 low flow of 123 ft^3/s at the gaging station, as listed by Waltemeyer and Shields (1982). The flow of the Bitterroot River measured at the Darby site during sampling was 311 ft^3/s, almost three times the 7Q10 flow. Similarly, the flows at Hamilton were possibly as much as three times the 7Q10 flow at that site.

Mixing-length Calculations

The theoretical stream length below a wastewater-discharge point where the effluent has mixed across half the width of the stream (one-half width mixing length) was calculated for the flow conditions at the time of sampling using the mixing equation listed in MDEQ (1996) and shown below in equation 1. The rationale for one-half width mixing of the stream is based on the assumption that, for chronic aquatic-life criteria, only one-half of the instream flow is available for dilution (U.S. Environmental Protection Agency, 1994); therefore, half the stream width serves as a surrogate for half of the flow. The stream characteristics needed for the calculation are average velocity, depth, stream width, channel irregularity, and stream slope. The hydrologic parameters of velocity, depth, and width were obtained from the measurement of streamflow at the most upstream transect of each study site. A qualitative measure of channel irregularity (sinuosity) in the mixing zone was determined onsite from observations of channel meandering and inspection of topographic maps. The slope of the stream in the mixing zone was determined from elevations and channel length obtained from a topographic map.

The one-half width mixing equation is

$$A_{1/2} = \frac{0.4(W/2)^2 V}{L} \quad (1)$$

where

$A_{1/2}$ = stream length, in feet, downstream from the wastewater-discharge point where effluent has mixed across one-half of the width of the stream;

W = average stream width, in feet, at the 7-consecutive day minimum flow having a recurrence interval of 10 years (7Q10 flow);

V = average stream velocity, in feet per second, at the 7Q10 flow downstream from the wastewater-discharge point;

L = lateral dispersion coefficient, in feet squared per second, for the 7Q10 flow downstream from the wastewater-discharge point, as determined from equations 2 and 3.

$$L = CDU \quad (2)$$

where

C = channel irregularity factor just downstream from the wastewater-discharge point.

Values for C defined for various channel types are:

- 0.1 for straight, rectangular streams;
- 0.3 for channelized streams;
- 0.6 for natural channels with moderate meandering;
- 1.0 for streams with significant meandering;
- 1.3 for streams with sharp bends of 90 degrees or more;

D = average stream depth, in feet, at the 7Q10 flow downstream from the wastewater-discharge point; and

U = shear velocity, in feet per second, as determined from equation 3.

$$U = (32.2DS)^{1/2} \quad (3)$$

where

32.2 = acceleration due to gravity, in feet per second squared; and

S = slope, in feet of elevation change per feet of stream-channel length downstream from the wastewater-discharge point.

Hydrologic characteristics measured at each site for the flow conditions at the time of sampling are listed in table 1. These data were used in the one-half width mixing equation (equation 1) to calculate the one-half width mixing length and to calculate the length equal to 10 times the average stream width. Because the more restrictive of the two calculated lengths for 7Q10 flows is used by the State to designate the allowable mixing length, the more restrictive of these two lengths determined for the flow conditions at the time of sampling also was used to locate transects for sampling downstream from wastewater-discharge points. Subsequent evaluation of lateral mixing using physical and chemical data from the transects downstream from the discharge point was used to test the adequacy of the equation for predicting one-half width mixing lengths. However, because flows were substantially higher than 7Q10 flows during the 1997 sampling period, the mixing characteristics may not necessarily be indicative of mixing during lower flows or the accuracy of the mixing equation.

With regard to mixing-length criteria, the one-half width mixing equation (equation 1) and a length of 10 times the stream width provided generally similar estimates of one-half width mixing lengths at the Bozeman and Whitehall sites. The computed one-half width mixing lengths at the Bozeman and Whitehall sites were considerably shorter than the State-designated mixing length (table 1); however, the hydrologic conditions were considerably different from the 7Q10 design flows. The two estimates of one-half width mixing provided by the mixing-length criteria were substantially different at the Hamilton site, with the equation-based estimate resulting in a much greater length that exceeded the State-designated mixing length. There is no designated mixing zone for the Darby site; however, the estimates calculated for the two mixing criteria were also very different in both the side channel and main channel.

The differences between the one-half width mixing lengths calculated by the two mixing-length criteria may result from error in selecting or obtaining values for one or more of the hydrologic characteristics used in the mixing equation. Because most of the characteristics are based on average values or subjective selec-

Table 1. Measured hydrologic characteristics and calculated mixing lengths at four wastewater-treatment facilities in southwestern Montana, 1997

Site	Hydrologic characteristics[1]						Mixing length[1]		
	Discharge, instantaneous[2] (cubic feet per second)	Average stream velocity [3](V) (feet per second)	Average stream depth [3](D) (feet)	Average stream width [3](W) (feet)	Channel irregularity factor [3](C) (dimensionless)	Slope [3](S) (feet per feet)	Calculated one-half width: Mixing equation [3]($A_{1/2}$) (feet)	Calculated one-half width: Ten times average stream width (feet)	State-designated[4] (feet)
Bozeman site	102	1.88	1.30	42	1.0	0.0032	697	420	4,500
Whitehall site	15.7	1.25	1.40	9.5	.6	.0019	46	95	1,700
Darby site (side channel)	.53	.023	.50	21	.6	.0025	17	210	No mixing zone designated
Darby site (main channel)	311	2.30	2.00	108	.6	.0025	5,570	1,080	No mixing zone designated
Hamilton site	685	2.83	1.90	146	.6	.0030	12,400	1,460	6,500

[1]Hydrologic characteristics and calculated mixing lengths were based on 1997 flow conditions at the time of sampling.
[2]Discharge at upstream reference transect.
[3]Abbreviations for components in equations 1, 2, and 3 of this report.
[4]State-designated mixing lengths based on professional judgment.

tion of channel irregularity factors, there could be some inaccuracy in the input values for the equation. Another source of difference between the two estimates could be that the flow conditions in 1997 were too high to be properly utilized in an equation designed for 7Q10 low-flow conditions.

Mixing Zones

All physical, biological, and chemical water-quality data collected for each mixing zone are listed in tables 2-5 at the back of the report. Selected data are shown graphically to illustrate lateral and longitudinal mixing patterns. These patterns are used to assess mixing of effluent in the receiving stream and to evaluate how well the two mixing criteria for estimating one-half width mixing length performed under flow conditions exceeding 7Q10 flows. In addition, selected data are compared to available water-quality standards or reference values to identify exceedances.

Bozeman Site

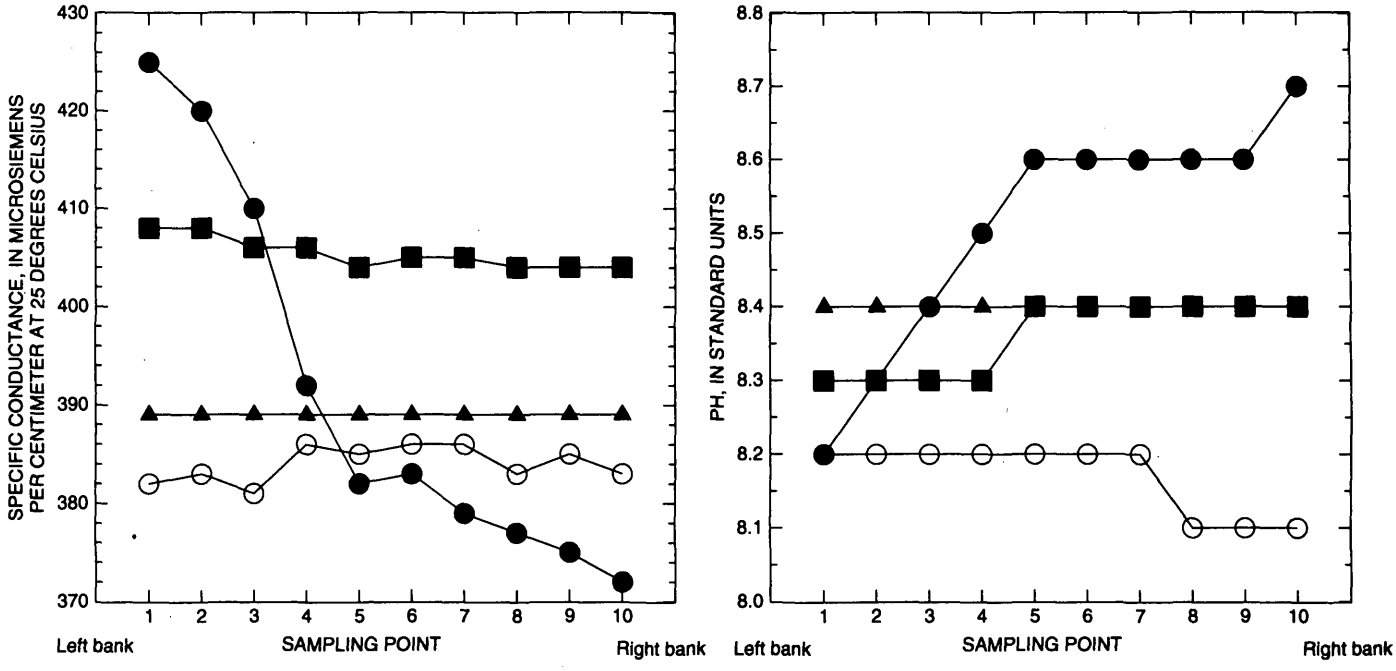
At the Bozeman site (fig. 3), an upstream reference transect (A) was sampled on the East Gallatin River about 80 ft upstream from the wastewater-discharge point, which enters on the left bank. At a flow of 102 ft^3/s, a theoretical mixing length of 10 times the stream width (420 ft) was more restrictive than the length calculated using the one-half width mixing equation (697 ft) at this site (table 1). Therefore, samples were collected at a uniform flow section (transect C) about 400 ft downstream from the wastewater-discharge point. Two sharp meander bends and a riffle with angled turbulent flow occur between the wastewater-discharge point and transect C. Physical properties of water measured at 10 sampling verticals in transect C (fig. 3) were relatively uniform across the stream, indicating that mixing was likely complete. Therefore, both mixing criteria overestimated the length required for one-half width mixing under the existing flow condition.

In an effort to locate the presence and extent of an effluent plume, additional transects upstream and downstream from the first meander bend below the discharge point were measured onsite for physical properties. Downstream from the first meander bend and about 200 ft downstream from the wastewater-discharge point, physical-property values from bank to bank (miscellaneous transect, table 2) differed by less than 4 percent, indicating that mixing probably was complete at this distance. At transect B, upstream from the first meander bend and about 100 ft downstream from the wastewater-discharge point, small but steady changes in specific conductance and pH were observed across the stream, indicating the existence of an effluent plume that was dispersed about halfway across the stream (fig. 3). The most downstream transect (D) was located about 3,500 ft downstream from the wastewater-discharge point, and about 1,000 ft upstream from the State-designated mixing-zone boundary. Physical properties at 10 verticals were mostly uniform at transect (D), indicating that mixing was complete.

Lateral patterns of concentration similar to those for specific conductance and pH were measured for dissolved chloride, total nitrite plus nitrate, total ammonia, and total phosphorus (fig. 3). Concentrations of these constituents were larger at the two downstream transects (C and D), where mixing was complete, than at the upstream reference transect (A). The proportional concentration increase downstream from the wastewater-discharge point relative to the upstream reference conditions varied among the four chemical constituents shown in figure 3. The proportional change was greatest for total phosphorus, which increased about 9-fold at transects C and D compared to concentrations at the upstream reference transect. Increases in the other constituent concentrations ranged from about 2-fold for dissolved chloride to 5-fold for total ammonia.

Turbidity and total ammonia plus organic nitrogen concentrations were inconsistently variable from sampling point to sampling point across each transect and, therefore, were poor indicators of mixing (table 2). All BOD determinations for samples from the Bozeman site were less than the minimum reporting level. Fecal coliform counts were slightly larger at transect B just downstream from the wastewater-discharge point than at the reference transect, but counts for transects farther downstream were similar to upstream reference counts, making the bacteria data inconclusive with regard to mixing or elevated concentrations.

All chemical concentrations at the Bozeman site were less than human health standards (Montana Department of Environmental Quality, 1995) and less



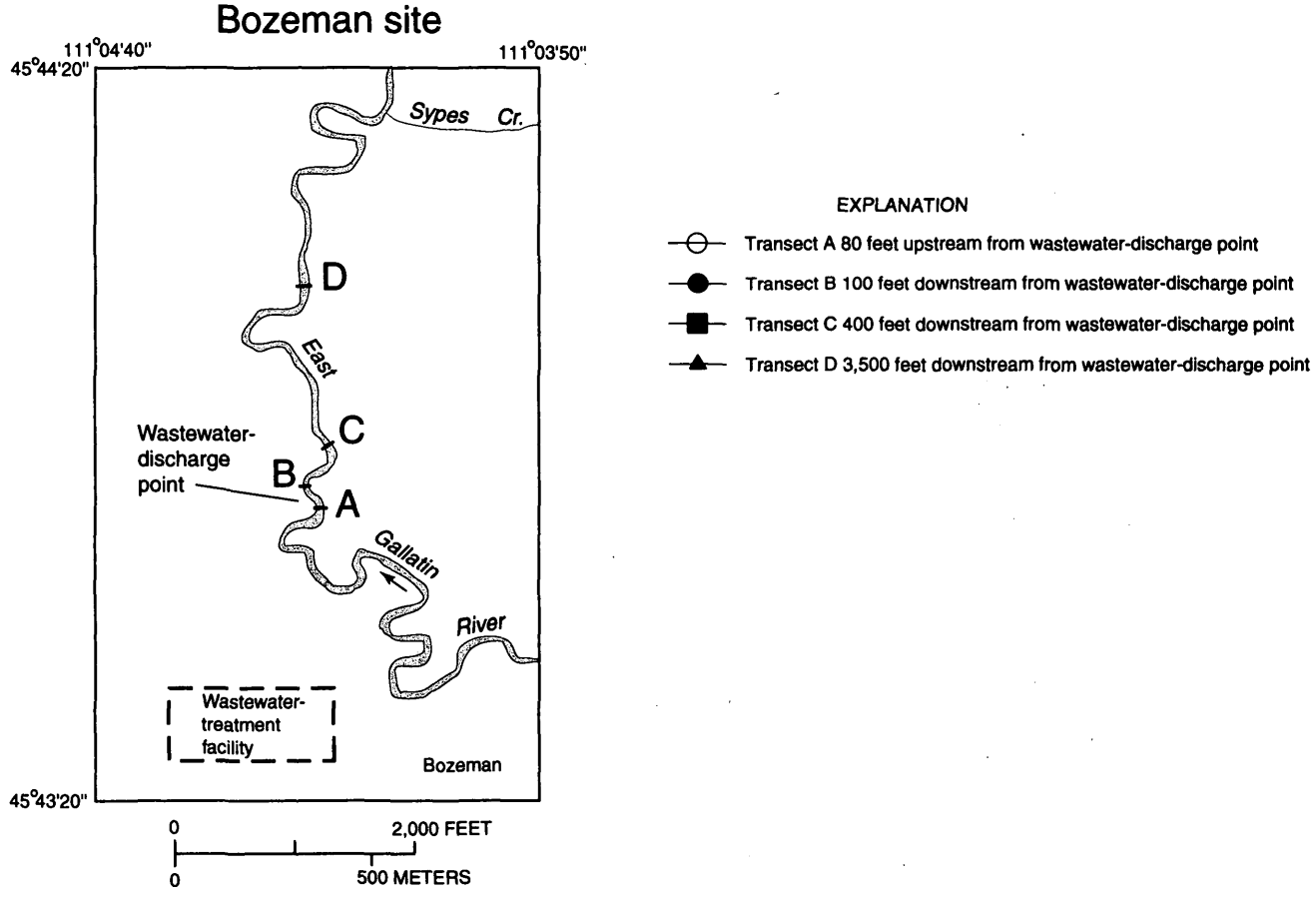


Figure 3. Selected water-quality profiles and corresponding site map of the East Gallatin River near the Bozeman wastewater-treatment facility, September 3, 1997. Left and right bank oriented looking downstream. Sampling-point numbers correspond to the sample location identifiers in table 2. Values less than the minimum reporting level (MRL) were plotted as one-half of the MRL. Each sampling point represents 10 percent of the total flow.

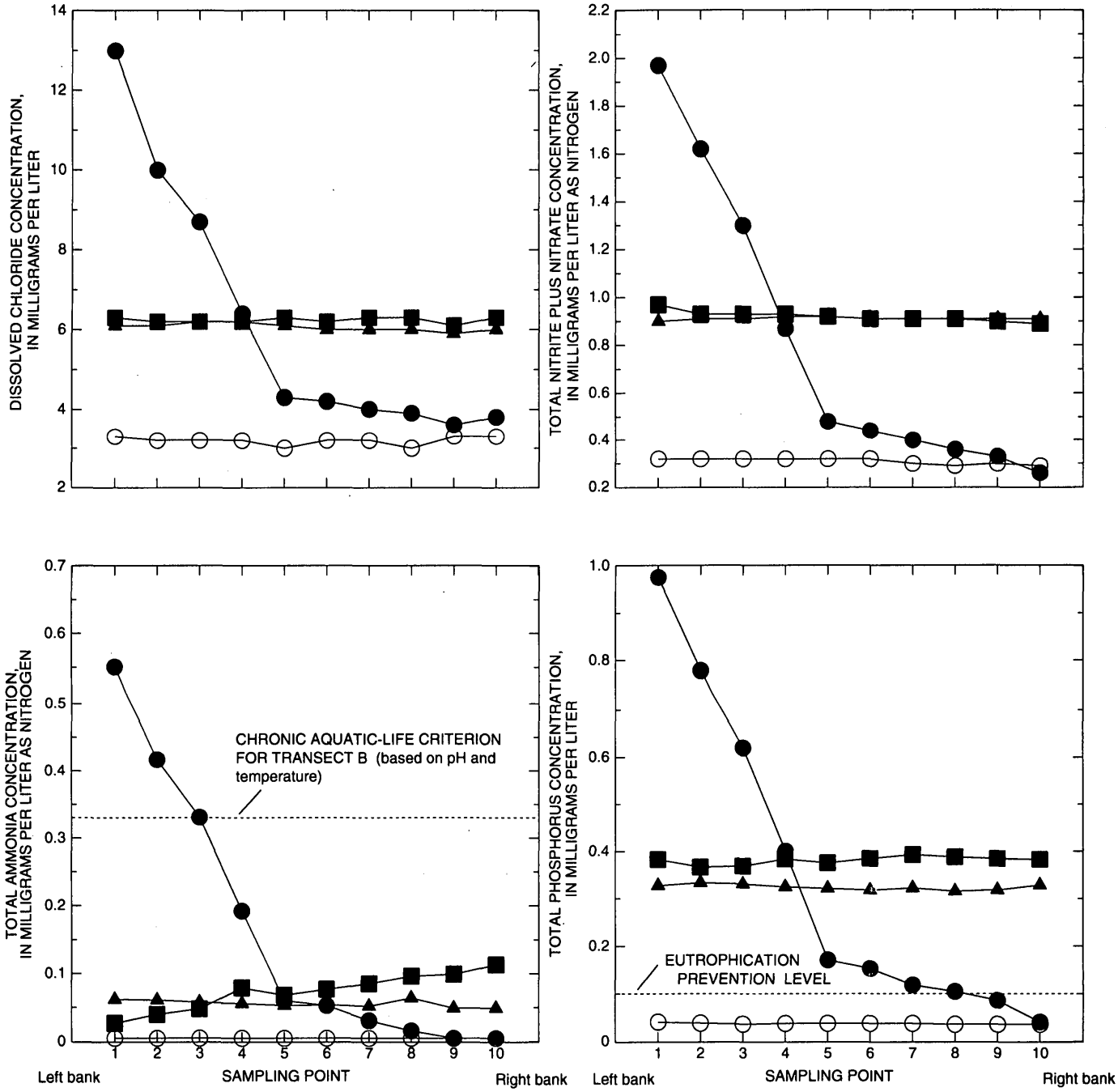


Figure 3. Selected water-quality profiles and corresponding site map of the East Gallatin River near the Bozeman wastewater-treatment facility, September 3, 1997--continued.

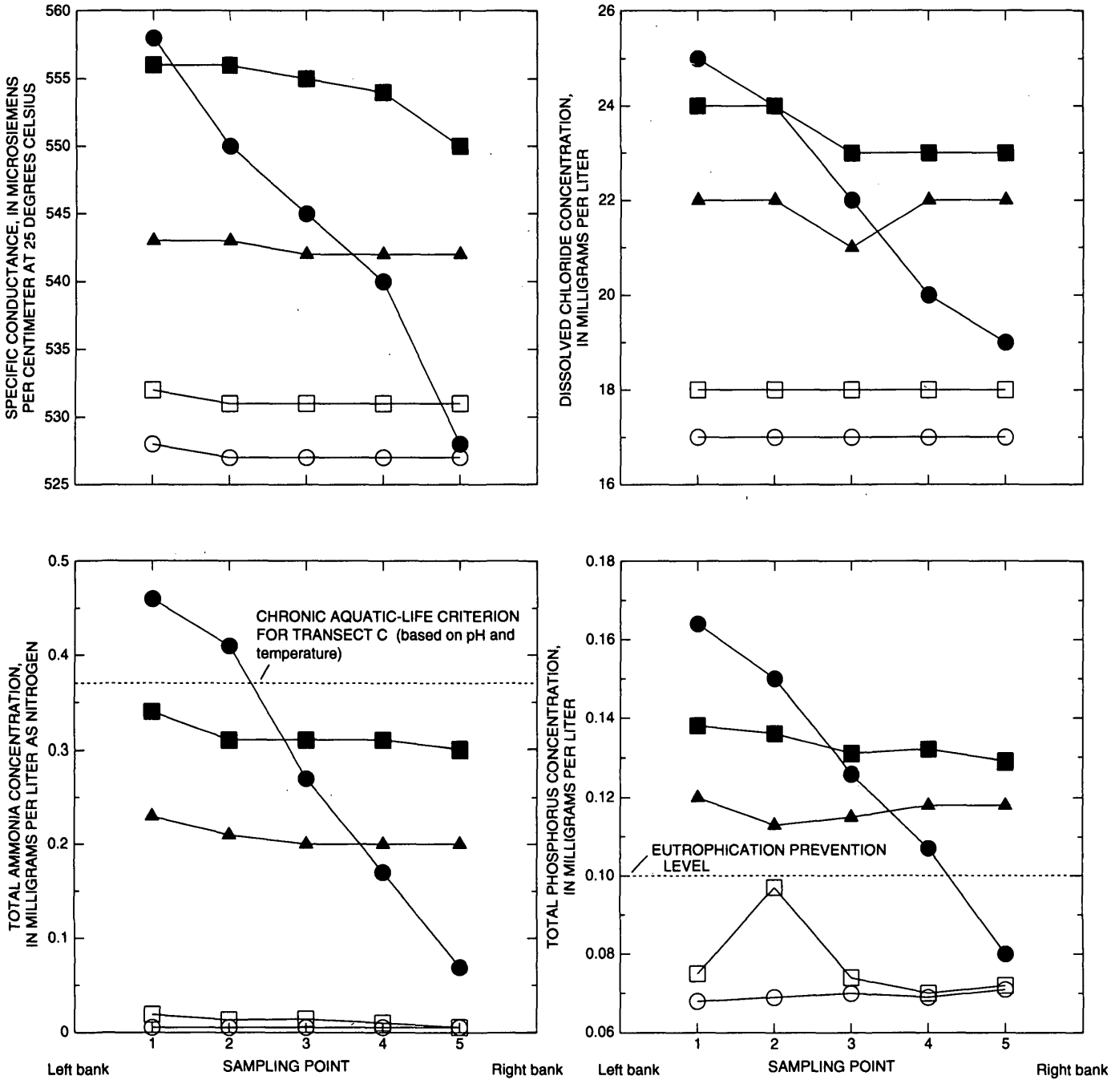
than national chronic aquatic-life criteria (U.S. Environmental Protection Agency, 1986), with the exception of total ammonia. The largest total ammonia concentration at this site (0.551 mg/L as N) occurred in transect B within the effluent plume. Because the aquatic-life criterion for total ammonia varies with pH and water temperature, a value was interpolated (U.S. Environmental Protection Agency, 1986), using the average pH and temperature for transect B. This estimated criterion concentration (0.33 mg/L as N) is plotted for reference on figure 3. Total ammonia concentrations of three samples near the left bank in transect B equaled or exceeded this value, with concentrations decreasing laterally until reaching background concentrations near the right bank.

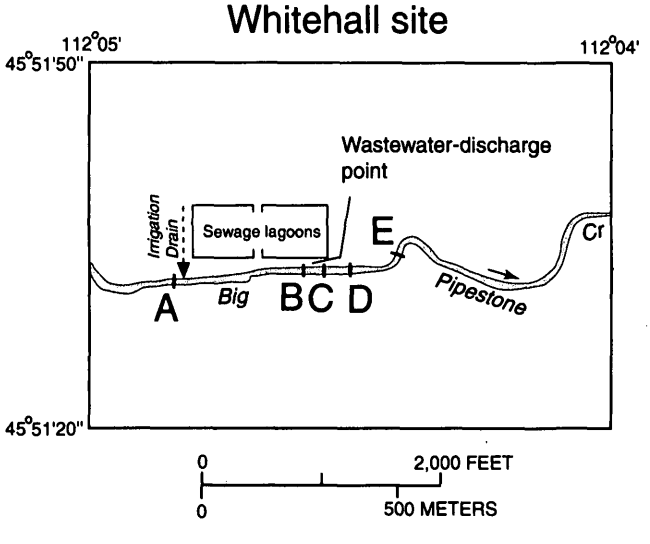
Although no national criterion has been established for phosphorus, EPA (1986) recommends that concentrations be maintained below 0.1 mg/L as P in flowing waters to prevent eutrophication. This recommended level was exceeded in all samples downstream from the wastewater-discharge point, except for the two samples near the right bank in transect B where mixing was incomplete (fig. 3). All total phosphorus concentrations at the upstream reference transect were less than the EPA recommended level.

Whitehall Site

At the Whitehall site (fig. 4), two reference transects (A and B) were sampled on Big Pipestone Creek upstream from the wastewater-discharge point, which enters from the left bank. Transect A was about 80 ft upstream from an irrigation drain that enters Big Pipestone Creek just upstream from the sewage lagoons and 1,000 ft upstream from the wastewater-discharge point. Transect B was about 20 ft upstream from the wastewater-discharge point. Physical properties of water measured at 5 sampling points across each upstream transect were similar; therefore, any effect from irrigation drainage or pond leakage that might affect the determination of wastewater mixing was assumed to be minimal. The most downstream transect (E) was about 1,000 ft downstream from the wastewater-discharge point. One sharp bend and two riffles were between transect E and the wastewater-discharge point. Physical properties of water measured at transect E were relatively uniform across the stream, indicating that mixing probably was complete; therefore, a transect farther downstream was thought to be unnecessary. The calculated one-half width mixing length (46 ft) using the mixing equation was more restrictive than the length equal to 10 times the stream width (95 ft) for this site (table 1); consequently, a transect (C) was sampled at a uniform section about 50 ft downstream from the wastewater-discharge point. Transect C was located in the same pool that received the effluent discharge, with no intervening riffle or meander bend. Specific conductance steadily decreased from left to right bank, indicating that mixing was incomplete at transect C (fig. 4). All sampling points in transect C, with the exception of the one near the right bank, had conductance values elevated relative to the reference transect; thus, it was concluded that the effluent plume had dispersed across most of the channel within the first 50 feet below the discharge point. However, the pH and temperature values were uniform from bank to bank and dissolved-oxygen values showed only slight and variable change (table 3). Assuming that mixing was incomplete at transect C, yet complete at transect E, an additional transect (D) was sampled between them to better define mixing characteristics. Transect D was about 250 ft downstream from the wastewater-discharge point and directly downstream from a riffle, which was the first significant morphological change in the stream channel below the point of wastewater discharge. Physical properties of water sampled at 5 points in transect D were similar, indicating that mixing was probably complete below the riffle.

At transect C, the lateral pattern of concentration for dissolved chloride, total ammonia, and total phosphorus were similar to the specific-conductance gradient (fig. 4), indicating that chemical mixing was not complete at a distance of 50 feet below the wastewater-discharge point, although the effluent plume extended across most of the channel. No substantial lateral differences in concentration for these constituents were detected at the two downstream transects D and E, but concentrations were higher relative to those at upstream reference transects A and B. The proportional concentration increases below the wastewater-discharge point varied among the three chemical constituents (fig. 4). Dissolved chloride concentrations at the two lower transects were only about 1.3 times higher than background concentrations, presumably because of ultra-violet disinfection of wastewater. Total-ammonia concentrations were elevated above





EXPLANATION

- Transect A 1,000 feet upstream from wastewater-discharge point
- Transect B 20 feet upstream from wastewater-discharge point
- Transect C 50 feet downstream from wastewater-discharge point
- Transect D 250 feet downstream from wastewater-discharge point
- Transect E 1,000 feet downstream from wastewater-discharge point

Figure 4. Selected water-quality profiles and corresponding site map of Big Pipestone Creek near the Whitehall wastewater-treatment facility, September 17, 1997. Left and right bank oriented looking downstream. Sampling-point numbers correspond to the sample location identifiers in table 3. Values less than the minimum reporting level (MRL) were plotted as one-half of the MRL. Each sampling point represents 20 percent of total flow.

background concentrations about 30-fold at transect D and about 20-fold at transect E. Increases were smaller for total phosphorus concentrations, which were elevated about 1.5 times the concentrations at the reference transects.

Turbidity values and total ammonia plus organic nitrogen concentrations were laterally variable from sampling point to sampling point across all transects and, therefore, yielded little information on mixing. All BOD concentrations were less than the minimum reporting level at the Whitehall site. Fecal coliform counts at transect C and E downstream from the wastewater-discharge point were virtually the same as those at the upstream reference transect B. Bacteria counts were, however, slightly larger at transect D than at the reference transect B (table 3). Considering that Whitehall disinfects their wastewater prior to discharging (DMR data show <1 fecal coliform/100 mL of wastewater) the higher bacterial counts at transect D may be due to livestock that have direct access to the receiving waters.

All chemical concentrations at the Whitehall site were less than human health standards (Montana Department of Environmental Quality, 1995) and less than national chronic aquatic-life criteria (U.S. Environmental Protection Agency, 1986), with the exception of total ammonia. The highest total ammonia concentration at this site (0.460 mg/L as N) was measured at transect C within the effluent plume 50 feet below the wastewater-discharge point. Using the pH and temperature of transect C, which were uniform from bank to bank, a value of 0.37 mg/L for total ammonia was interpolated from EPA (1986). This pH- and temperature-dependent criterion for total ammonia is plotted on figure 4. Two samples near the left bank in transect C exceeded the ammonia criterion.

The recommended phosphorus concentration of less than 0.1 mg/L as P to prevent eutrophication (U.S. Environmental Protection Agency, 1986) was exceeded in nearly all samples taken below the wastewater-discharge point. The one exception was the sample collected near the right bank in transect C (fig. 4) where mixing was not yet complete. Total phosphorus concentrations were below the EPA recommended level at the upstream reference transects.

Darby Site

At the Darby site (fig. 5), assessment of effluent mixing was complicated by the fact that the Bitterroot River was divided into two channels. The main channel of the river was located across an island, whereas a small side channel having very little flow received the effluent from the wastewater-treatment facility. This side channel rejoined the main channel about 1,000 ft below the discharge point. Therefore, two mixing lengths were evaluated--one for the main channel of the Bitterroot River and one for the side channel that initially receives the effluent. Mixing lengths for each channel were calculated using the hydrologic characteristics of the corresponding channel. A reference transect (A) with 5 sampling points was located in the main channel about 1,000 ft upstream from the confluence of the two channels. A second reference transect (B) with 5 sampling points was located in the side channel about 20 ft upstream from the wastewater-discharge point. Velocities and depths in the side channel were minimal, and the entire channel upstream and downstream from the wastewater-discharge point had dense growths of algae.

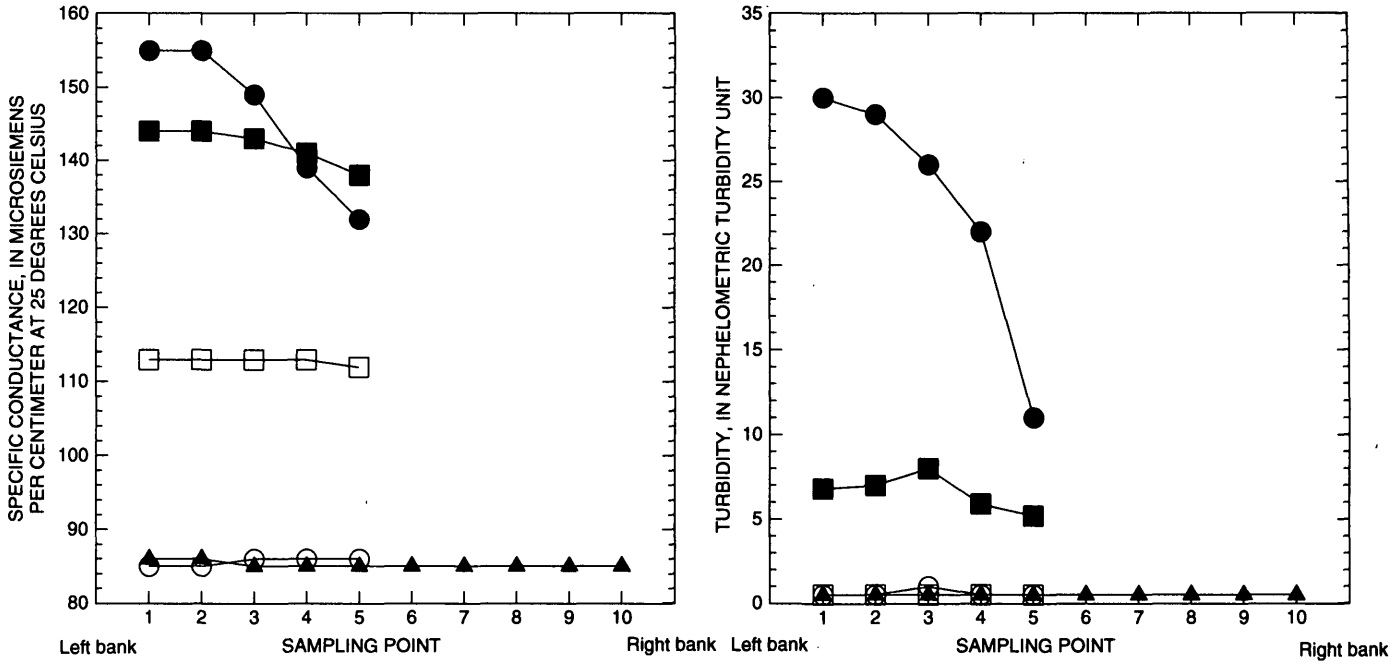
Using hydrologic characteristics of the side channel at the Darby site (table 1), a one-half width mixing length calculated from the mixing equation (17 ft) was much more restrictive than 10 times the stream width (210 ft). Because the wastewater had a lime green color, the incompleteness of mixing was visibly evident for about the first 100 ft downstream from the wastewater-discharge point. Owing to poor sampling conditions of shallow depths and thick algae, the first suitable sampling location in the side channel (transect C) was about 300 ft downstream from the wastewater-discharge point, which was slightly farther than the mixing criterion of 10 times the stream width. Transect C was downstream from two riffles below the wastewater-discharge point. Specific conductance decreased from left to right bank (fig. 5), indicating incomplete mixing at transect C in the side channel. Turbidity at this transect also decreased from left bank to right bank. The lateral variation in specific conductance at transect C, which was near the criterion distance of 10 times the stream width, generally indicates a pattern resembling mixing across one-half the stream; however, all values were higher than those at the reference transect B, which probably implies marginal dispersion of effluent across the entire width. Therefore, the one-half width mixing criterion of 10 times the stream width appears to be reasonably accurate for the low-flow conditions in the side channel.

Transect D was located in the side channel about 1,000 ft downstream from the wastewater-discharge point and immediately upstream from the confluence with the main channel of the river. Specific-conductance and turbidity values at transect D were greater than the upstream reference values measured at transect B, but were more laterally uniform than at transect C, indicating that mixing was largely complete before reaching the main river.

Using hydrologic characteristics for the main channel of the Bitterroot River at the Darby site (table 1), a theoretical one-half width mixing length of 10 times the stream width (1,080 ft) was more restrictive than the one-half width mixing length calculated by the mixing equation (5,570 ft). Owing to unwadable depths, however, the only suitable cross section for sampling in the main channel was about 800 ft downstream from the confluence with the side channel (transect E), which was about 1,800 ft (combined side channel plus main channel distance) downstream from the wastewater-discharge point. No lateral differences in values of physical properties were observed at transect E, and values were comparable to those sampled at the upstream reference transect A (fig. 5).

At transect C in the side channel, 300 ft downstream from the wastewater outlet, concentrations of dissolved chloride, total ammonia, total ammonia plus organic nitrogen, and total phosphorus decreased from left bank to right bank (fig. 5), indicating incomplete mixing. Concentrations of total ammonia at the upstream reference transect (B) and the farthest downstream side-channel transect (D) were greater than values at the intermediate transect C (table 4). This anomalous pattern of ammonia concentrations makes interpretation of ammonia mixing inconclusive and may indicate limited usefulness of this constituent for mixing assessments.

At transect D--the most downstream transect in the side channel--the concentrations of dissolved chloride, total ammonia plus organic nitrogen, and total phosphorus were relatively uniform across the stream (fig. 5); thus, mixing at transect D was indicated to be nearly complete. Dissolved chloride, total ammonia plus organic nitrogen, and total phosphorus concentrations at transect D were elevated about 2-fold to 3-fold above background concentrations at the upstream side-channel reference transect (B). Total ammonia concen-



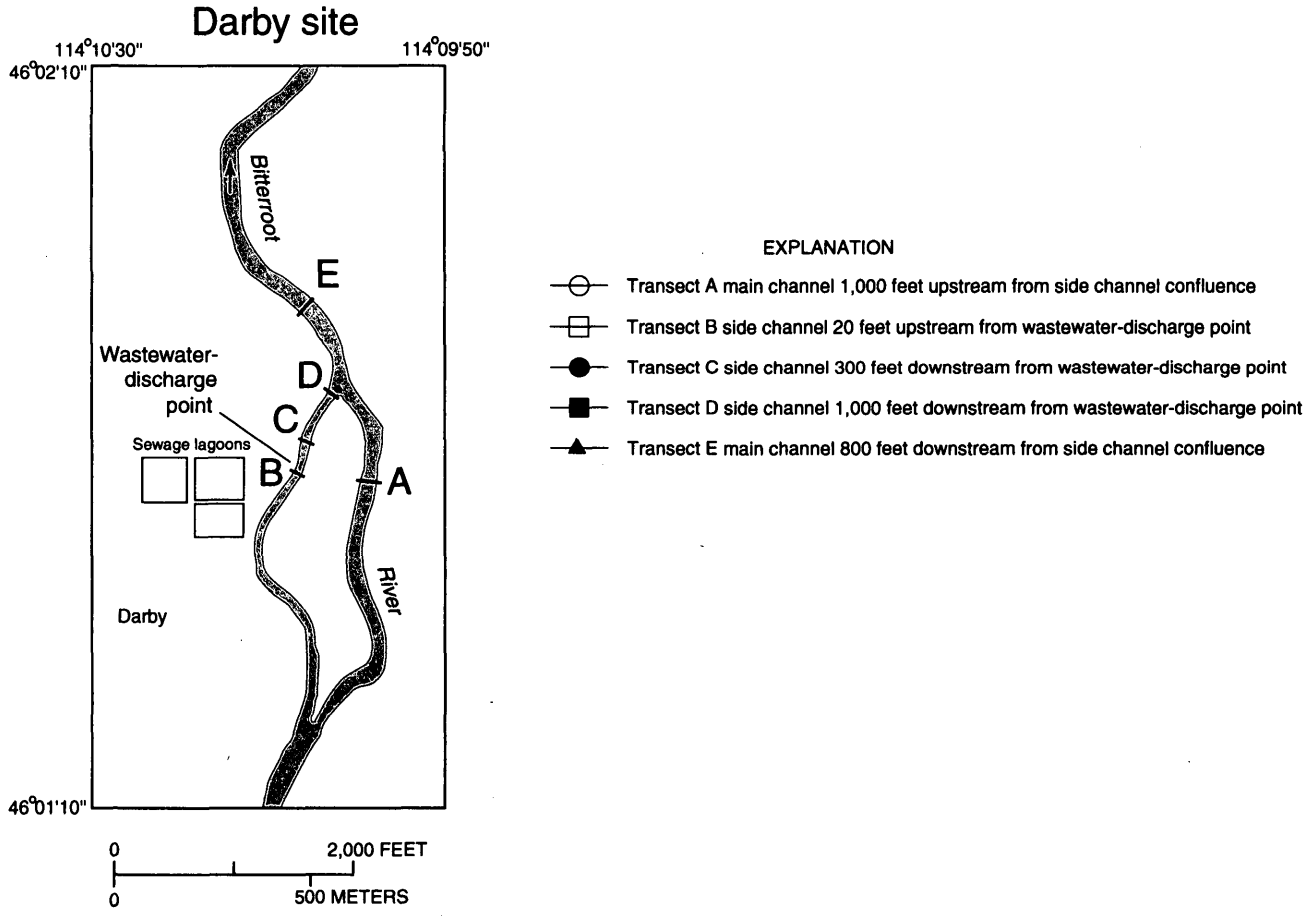


Figure 5. Selected water-quality profiles and corresponding site map of the Bitterroot River near the Darby wastewater-treatment facility, September 30, 1997. Left and right bank oriented looking downstream. Sampling-point numbers correspond to the sample location identifiers in table 4. Values less than the minimum reporting level (MRL) were plotted as one-half of the MRL. Each of the 5 sampling points in transects A-D represents 20 percent of the total flow; each of the 10 sampling points in transect E represents 10 percent of the total flow.

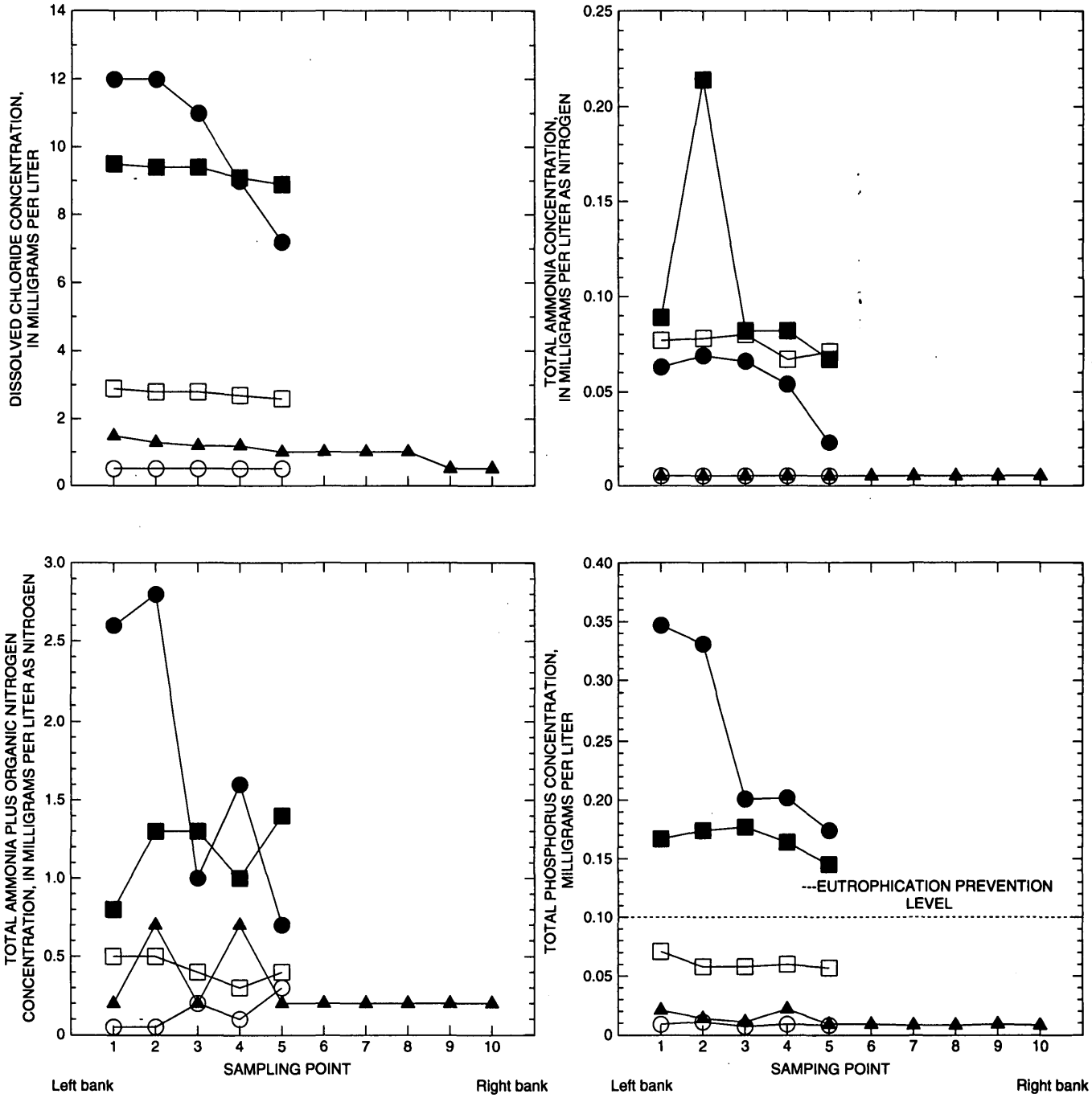


Figure 5. Selected water-quality profiles and corresponding site map of the Bitterroot River near the Darby wastewater-treatment facility, September 30, 1997--continued.

trations at transect D included an anomalous value that makes its usefulness for evaluating mixing questionable.

All BOD and nitrite plus nitrate concentrations at the Darby site were less than the minimum reporting level (table 4). Fecal coliform counts in transects C and D below the wastewater-discharge point were slightly larger than those at the upstream reference (transect B) in the side channel. Bacteria counts were similar at the reference transects in both the main channel (A) and side channel (B).

At the Darby site, chemical concentrations in all water samples were less than human health standards (Montana Department of Environmental Quality, 1995) and less than the national chronic aquatic-life criteria (U.S. Environmental Protection Agency, 1986). The largest total ammonia concentration at this site (0.214 mg/L as N) occurred at transect D (table 4), but was well below the interpolated pH- and temperature-dependent chronic aquatic-life criterion (U.S. Environmental Protection Agency, 1986) concentration of 1.8 mg/L as N.

The phosphorus concentration of less than 0.1 mg/L as P recommended by EPA (1986) to prevent eutrophication was exceeded in all samples from the two transects in the side channel downstream from the wastewater-discharge point (transects C and D). Concentrations were substantially less than the recommended level in all samples from the Bitterroot River main channel (transects A and E) and slightly less in the side-channel reference transect B (fig. 5). The dense algal growths in the shallow water of the side channel above the discharge point may indicate that either the phosphorus or other nutrient concentrations were sufficiently high to stimulate growth.

The characteristics of the water in the side channel were considerably different from those of the main channel. Specific conductance values were elevated and pH values were lower in the upstream side-channel reference transect (B) compared to values in either of the mainstem transects A or E (table 4). Similarly, most concentrations of dissolved chloride, total ammonia, total ammonia plus organic nitrogen, and total phosphorus were larger in the side channel than in the main channel (fig. 5). The dense growth of algae in the side channel may have contributed to the differences in pH and dissolved oxygen between the two channels. A possible reason for the larger chloride and nutrient concentrations in the side channel above the wastewater-discharge point is subsurface leakage from the sewage lagoons, which roughly parallel the side channel. Also, several buildings just upstream from the wastewater outlet may have septic systems that could be affecting the water chemistry in the side channel at the reference transect B.

Hamilton Site

At the Hamilton site (fig. 6), a reference transect (A) was sampled about 100 ft upstream from the wastewater-discharge point, which enters from the right bank of the Bitterroot River. A theoretical one-half width mixing length of 10 times the stream width (1,460 ft) was much more restrictive than the one-half width mixing length (12,400 ft) calculated by the mixing equation for this site (table 1). Therefore, a transect (C) was sampled at a wadable section near the more restrictive estimate of one-half width mixing at about 1,300 ft downstream from the wastewater-discharge point. Transect C was in a straight reach of the river, where most of the flow was along the side of the channel. There was one riffle and a slight bend in the channel between transect C and the wastewater-discharge point. Physical properties at transect C were laterally uniform, with the exception of specific conductance, which was the only physical property to indicate possible incomplete mixing. The change in specific conductance at transect C, however, was small--about 9 percent from bank to bank (fig. 6). However, the lateral pattern of values resembles mixing across one-half of the stream, which may indicate that the criteria of 10 times the stream width is a reasonable estimate for half-width mixing length. The equation-based estimate appears to greatly overestimate one-half width mixing.

In an attempt to better characterize mixing relative to distance below the wastewater-discharge point, a third transect (B) was sampled closer to the discharge point. Transect B was about 600 ft downstream from the wastewater-discharge point, just below a slight bend in the river. Unwadable depths precluded a transect closer to the wastewater-discharge point. Between transect B and the wastewater-discharge point was a riffle and a rock outcrop on the right bank, which constricted the river channel. Specific conductance at transect B varied laterally similar to transect C, and was the only physical property to indicate that mixing was possibly incomplete. The fact that there also was a slight increase in specific conductance from left to right bank at the reference transect A makes it difficult to

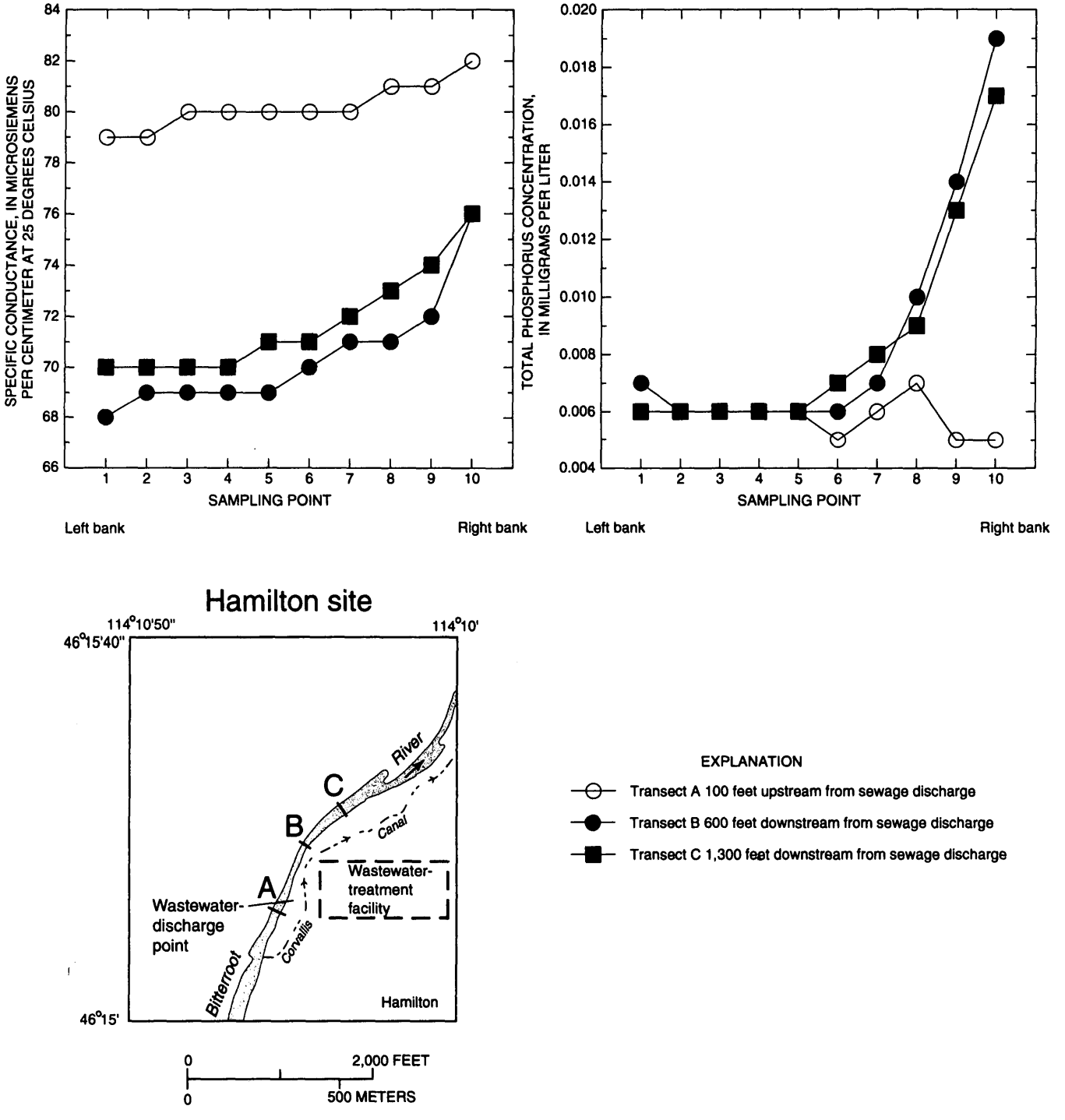


Figure 6. Selected water-quality profiles and corresponding site map of the Bitterroot River near the Hamilton wastewater-treatment facility, October 14-15, 1997. Left and right bank oriented looking downstream. Sampling-point numbers correspond to the sample location identifiers in table 5. Values less than the minimum reporting level (MRL) were plotted as one-half of the MRL. Each sampling point represents 10 percent of the total flow.

clearly assess effluent mixing patterns at transects B and C using this parameter.

Values of specific conductance, pH, and dissolved oxygen were slightly larger at the upstream reference transect A than at transects B and C (table 5); however, the relatively minor differences were possibly caused by diurnal fluctuations within the long time interval between samplings. The upstream reference transect (A) was sampled in the afternoon one day before the two other transects were sampled; transect C was sampled in the morning and transect B around noon.

At the Hamilton site, all but one value each for turbidity and nitrite plus nitrate, all values for BOD, and most values for total ammonia plus organic nitrogen were less than the minimum reporting level (table 5). Except for one value in transect B, ammonia concentrations in all samples downstream from the wastewater outlet were less than the minimum reporting level. In contrast, ammonia concentrations were slightly larger than the minimum reporting level at the upstream reference transect. These minor differences between transects were similar to those observed for physical properties and could be caused by diurnal fluctuations. All fecal-coliform counts were less than 10 colonies per 100 mL, except for the sample taken near the right bank in transect C (table 5). In addition to the effluent discharged to the river, there are several houses and buildings between transects B and C on the right bank that may have septic systems that could have contributed to the higher count.

The only chemical constituent to clearly indicate substantial lateral variations in concentration below the wastewater-discharge point was total phosphorus (fig. 6). At both downstream transects (B and C), the total phosphorus concentration increased from background concentrations near mid-stream to their maximum value at the sampling point nearest the right bank. The lateral increase in total phosphorus concentration was about 3-fold; however, none of the values exceeded the concentration of less than 0.1 mg/L phosphorus as P recommended by EPA (1986) to prevent eutrophication. Chemical concentrations in all water samples at this site were below human health standards (Montana Department of Environmental Quality, 1995) and below the national chronic aquatic-life criteria (U.S. Environmental Protection Agency, 1986).

The existence of a lateral concentration variation for total phosphorus at transect C indicates that mixing was incomplete at a downstream distance of 10 times the stream width (1,300 ft) at the sampled flow of 685 ft^3/s. However, the effluent appeared to be mixed across one-half the width at a distance 600 ft downstream from the wastewater-discharge point at transect B (fig. 6), indicating that the mixing criterion of 10 times the stream width may be reasonable. A distance for complete mixing was not conclusively determined by chemical concentrations, because a lateral variation was still evident for total phosphorus at the most downstream transect 1,300 feet from the wastewater-discharge point. Therefore, the actual distance where complete mixing was achieved probably was farther downstream and the resultant increases in the average constituent concentrations in the transect relative to background concentrations are undetermined. Additional sampling would help to evaluate whether the increases in specific conductivity, bacterial counts, and total phosphorus concentrations at transect C are related to the location of houses and buildings between transects B and C.

FACTORS AFFECTING MIXING ASSESSMENTS

A primary factor affecting effluent mixing is streamflow magnitude of the receiving stream. Flows in September and October 1997 at the Hamilton and Darby mainstem sites on the Bitterroot River were too large to show distinct water-quality changes resulting from the relatively small volumes of wastewater discharge. The large dilution capability at these sites compared to the volume of wastewater being discharged precluded identification of well-defined lateral concentration differences for most parameters, which made mixing determinations difficult at these flows. Although above-normal flows prevented characterization of mixing and concentration effects during low-flow conditions (7Q10) for which the mixing equation was developed, several features of mixing were observed that probably are applicable to future assessments of mixing.

Downstream from each wastewater-discharge point, specific conductance was the only property to consistently display reliable patterns of lateral variation for onsite indication of incomplete mixing.

Although pH values at the Bozeman site indicated lateral variation at the transect downstream from the wastewater-discharge point, the other sites were generally uniform in their bank-to-bank pH values at all transects. Because many variables, such as the stream's acid-neutralizing capacity, diurnal fluctuations in photosynthetic activity, and temperature can affect pH values, this parameter is commonly too inconsistent for assessing mixing. The other physical properties of dissolved oxygen and water temperature are also diurnally variable and, therefore, may be of limited use for determining the extent of mixing.

The slightly higher values of physical properties in the upstream reference transect at the Hamilton site compared to downstream transects were presumably the result of time-dependent measurements being obtained on different days, indicating that sampling should be completed on the same day and within as short a time frame as possible. Because of the time required to measure flow and collect samples, changing the sampling to an equal width increment (EWI) method (Knapton, 1985) could alleviate all but the single flow measurement necessary for the mixing equation. However, because this method is designed for compositing of individual verticals, the volume of sample from individual verticals is not equal and the results for individual verticals do not represent equal increments of discharge. Results from analysis of individual EWI samples can only be used for comparison of lateral concentration differences, and not for lateral variations in load or volumetric assessments of dilution capacity where mixing is incomplete. Where mixing is complete, however, the uniform concentrations can serve as an average value for the cross section to indicate the extent of concentration change relative to background. Consequently, EWI sampling may only be appropriate where spatial differences in concentration, rather than dilution effects, are the primary interest.

Elevated concentrations non-uniformly distributed across the stream were detected for several chemical constituents at transects downstream from the wastewater-discharge point at all four sites. Of the chemical constituents analyzed, total phosphorus was the most consistent indicator of the presence of an effluent plume. A lateral concentration variation for total phosphorus was observed at all four sites in the first transect downstream from the wastewater-discharge point, where mixing was incomplete. The lateral variation in total phosphorus concentration typically corresponded well to the lateral variation in specific conductance values. Lateral variations in dissolved-chloride and total ammonia values also indicated the presence of an effluent plume at all sites except Hamilton. The lateral variations of ammonia plus organic nitrogen concentrations were not consistent, displaying concentrations at one or more sites that were less than the minimum reporting level, unchanged from bank to bank, or too variable from sample to sample to be useful in determining lateral mixing characteristics or the resultant effect of effluent on instream concentrations.

At transects downstream from the wastewater-discharge point where mixing was indicated to be complete, average instream concentrations were greater than background concentrations at the reference transects for almost all constituents. However, most chemical concentrations were below human health standards or aquatic-life criteria, even within identified plumes. The only constituent that reached an aquatic-life criterion level within a plume was total ammonia at the Bozeman and Whitehall sites (figs. 3 and 4). In contrast, total phosphorus concentration exceeded the EPA's recommended value for the prevention of eutrophication at all transects downstream from the wastewater-discharge point except for the Darby (main channel) and Hamilton sites (figs. 3-6).

Owing to the above-normal flows in 1997, assessment of the possible magnitude of constituent concentrations at low flows is difficult. If the wastewater discharge remained constant and streamflows decreased to levels approaching their 7Q10 magnitude, instream concentrations of effluent constituents would likely increase several-fold as a result of decreased dilution and exceedances of water-quality standards or criteria might be expected within the mixing zone.

Mixing was incomplete at the Bozeman and Whitehall sites in transects just downstream from the wastewater-discharge point. At both sites, these transects were located in the same pool that received the wastewater discharge, with no intervening change in flow pattern to facilitate mixing. After encountering a physical change in flow, either by passing through a meander bend or a riffle, mixing occurred quickly, as noted by transects of physical properties below such channel features. Consequently, channel morphology is an important factor in the distance required for mixing. It is not known, however, what effect decreased

depths and velocities during lower flow conditions would have on mixing length.

Physical properties and chemical constituents that were good indicators of mixing at the four sites in southwestern Montana sampled in this study may not be the best indicators in receiving streams having different flow regimes and geological settings, such as eastern Montana rivers. Typically, specific conductance is higher in eastern than in western Montana streams, and differences between the quality of the receiving water and the wastewater may not be sufficient to produce appreciable lateral variations below the wastewater-discharge point.

Land use near the wastewater-treatment facility may also affect concentrations within a mixing zone, in addition to any effects caused by effluent. Other surface- or ground-water inputs to a mixing zone should be considered when evaluating the potential effect from a wastewater-discharge point source. Because of the possible cumulative effects of inputs in a long mixing zone, the ability to attribute instream concentration changes to a sole source can be complicated by overlapping effects from multiple inputs.

POTENTIAL APPROACHES FOR FUTURE MIXING ASSESSMENTS

On the basis of experience obtained from this initial evaluation of effluent mixing characteristics downstream from wastewater treatment facilities, several alternative approaches to sampling and analysis are offered to aid in future mixing assessments. To confirm the effect of effluent mixing on measured instream concentrations, mass loading calculations using samples of the discharged wastewater and upstream reference samples may be useful. Chemical analyses of the discharged wastewater and determination of its discharge rates would allow the computation of constituent loads delivered in the effluent. These loads could be added to upstream loads and used to confirm total loads at transects downstream from the wastewater-discharge point based on the conservation of mass. This type of loading comparison would require EDI sampling. To ensure that upstream reference loads reliably represent background conditions, reference transects should be located at a sufficient distance upstream from the wastewater facility to ensure that there is not influence from subsurface leakage from sewage lagoons or other sources of water. Two upstream reference transects, upgradient and adjacent to lagoons, may also be useful for detecting such subsurface leakage into the receiving stream.

An alternative method for future investigations of mixing zones could be to perform a tracer-injection experiment. For this experiment, a conservative tracer would be continuously injected at a set rate into the discharged wastewater and sampled at transects downstream from the discharge point. The appropriate tracer to be injected would be selected to give the most distinct concentration differences between discharged wastewater containing the tracer and natural stream water. Examples of tracers that could be used are chloride, lithium, bromide, or a dye solution. Using a tracer would eliminate the need for multi-parameter laboratory analyses and thus could be a practical alternative to the methods used in this study. Furthermore, a tracer has the potential, if enough samples are collected, of yielding more definitive results in delineating the edge of a plume owing to greater concentration differences between mixed and unmixed waters.

The results of this initial mixing assessment have provided insight into procedures that can improve sample-collection and analysis, and can reduce some of the uncertainties associated with the assessment of effluent-mixing effects. The following approaches are offered as a general guide for future sampling within mixing zones:

1. Collection of samples during low-flow periods to assess maximum effects of wastewater discharge on instream concentrations;

2. Collection of samples at a sufficient distance upgradient from sewage lagoons to establish a water-quality background reference unaffected by possible subsurface leakage;

3. Collection of samples on the same day and as quickly as possible to minimize the effects of diurnal fluctuations. Use of multiple sampling teams or use of the EWI sampling method if a simple assessment of cross-stream concentration patterns is desired;

4. Collection of samples and determination of discharge rate of wastewater to confirm effluent chemistry and effects on instream concentrations through load calculations and mass balance;

5. Collection of samples upstream and downstream from the first physical change in flow (such as a

riffle or a sharp bend) to evaluate the dispersal effect caused by channel morphology;

6. Use of specific conductance as the primary physical property to identify effluent plumes, unless effluent and instream conductivities are similar. Under such conditions, a multi-parameter meter may be necessary to measure other properties onsite;

7. Restriction of laboratory analyses primarily to total phosphorus; dissolved chloride and total ammonia also may be useful at some sites. Total ammonia plus organic nitrogen concentrations were observed to be too variable for mixing assessments.

SUMMARY AND CONCLUSIONS

Mixing zones are specific reaches where wastewater discharged from a point source mixes and is progressively diluted by a receiving body of water. Mixing zones are designated by the State when establishing water-quality permits for point discharges. The length of a designated mixing zone generally represents the stream distance necessary to disperse effluent across one-half of the cross-sectional area of the stream under low-flow conditions. As a surrogate to one half of the area, one-half of the stream width at the 7Q10 low flow is used as a mixing criterion, which is calculated by the one-half width mixing equation. Alternatively, a distance of 10 times the average stream width at the 7Q10 low flow may be used as the designated one-half width mixing length. The more restrictive of the two estimates is used by the State to establish a mixing zone.

This study was designed to describe mixing characteristics based on the results of water-quality sampling at multiple points across several transects above and below wastewater-discharge points at four treatment facilities in southwestern Montana. The sites selected for this study were the East Gallatin River at Bozeman, Big Pipestone Creek at Whitehall, the Bitterroot River at Darby, and the Bitterroot River at Hamilton. The observed mixing patterns were compared to calculated one-half width mixing lengths to evaluate how well the mixing criteria estimated effluent mixing characteristics. The concentrations measured at each transect were compared to water-quality standards or criteria to identify exceedances. Another objective of this study was to identify reliable and practical procedures for improving future mixing assessments.

Each wastewater-discharge site had different physical and hydrologic characteristics, which allowed an evaluation of mixing under a wide range of flows and channel morphologies. At each site, 3 to 5 transects were sampled upstream and downstream from the wastewater-discharge point. Discharge was measured at each transect to determine flow distribution across the channel to determine the location of equal discharge increment (EDI) sampling verticals. The hydrologic characteristics derived from the flow measurements and channel topography obtained from maps were used to calculate the one-half width mixing length. One of the sampling transects was then located in the vicinity of the one-half width mixing distance. Specific conductance, pH, water temperature, and dissolved oxygen were measured onsite at each vertical, and a depth-integrated water sample was collected for laboratory analysis. Water samples were analyzed for turbidity, BOD, fecal coliform bacteria, dissolved chloride, total nitrite plus nitrate, total ammonia, total ammonia plus organic nitrogen, and total phosphorus.

This study was conducted in September and October 1997. Flows were estimated to be from 27 to 47 percent higher than long-term mean September flows and three to eight times higher than the 7Q10 low flows used in the development of the one-half width mixing equation. Consequently, this study was unable to assess mixing characteristics when dilution capacity of the receiving waters was at a minimum. The one-half width mixing length calculated by the mixing equation was generally similar to the length of 10 times the stream width at two sites, the East Gallatin River at Bozeman and Big Pipestone Creek at Whitehall. The calculated one-half width mixing lengths using the mixing equation and the length of 10 times the stream width at the two sites on the mainstem Bitterroot River were substantially different. The reason for the large differences in one-half width mixing lengths calculated from the two criteria is not known, but may result from either inaccuracy of input values for the equation or from flow conditions too high to be properly utilized in an equation designed for low flows.

Downstream from each wastewater-discharge point, specific conductance was the only property to consistently display a lateral variation for a reliable onsite indication of incomplete mixing. Values of pH, water temperature, and dissolved oxygen displayed little difference from bank to bank at most transects, making these properties less suitable for assessing mixing.

Of the chemical constituents analyzed, total phosphorus was the most consistent indicator of lateral mixing and the presence of an effluent plume. Lateral concentration variations for total phosphorus were observed at all four sites in the transects just downstream from the wastewater-discharge points, where mixing was incomplete. This mixing pattern typically corresponded well to the pattern for specific-conductance values. Bank-to-bank variations in total phosphorus concentrations in the transect just below each wastewater-discharge point were variable among the four sites, ranging from relatively minor differences to a nearly three-fold difference. This range of variations was most likely a result of the transect's distance downstream from the wastewater-discharge point and the flow in the receiving stream. An elevated concentration of total phosphorus persisted at all downstream transects relative to that of the upstream reference transects. Lateral variations in dissolved chloride and total ammonia concentrations also were observed, but to a smaller extent than total phosphorus. Values for other physical and chemical parameters were not consistent, displaying concentrations that were either less than the minimum reporting level, unchanged from bank to bank, or laterally too variable from sample to sample to be useful in determining mixing.

All constituent concentrations measured in this study were less than human health standards. The only chemical concentration to exceed an aquatic-life criterion was total ammonia. Chronic aquatic-life criteria for ammonia were exceeded in the transects just downstream from the wastewater-discharge points at the Bozeman and Whitehall sites. Total phosphorus concentrations at the Bozeman, Whitehall, and Darby (side-channel) sites were greater than the values recommended by EPA to prevent eutrophication. Where mixing across the stream was complete, constituent concentrations downstream from the wastewater-discharge points compared to an upstream reference transect ranged from about 1.5 to 9-fold higher for total phosphorus and about 5- to 30-fold higher for total ammonia. It is uncertain what the effect of effluent mixing would be on instream concentrations during low-flow conditions approaching 7Q10 flows, but it is likely that concentrations would be greater due to less dilution capacity.

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SUPPLEMENTAL DATA

Table 2. Water-quality data for the East Gallatin River near the Bozeman wastewater-treatment facility, September 3, 1997

[Analyses by Montana Department of Public Health and Human Services Environmental Laboratory, Helena, Mont. Sample location identifier: combination of transect letter and sampling-point number. Abbreviations: col/100 mL, colonies per 100 milliliters; °C, degrees Celsius; E, estimated; ft, feet; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; NTU, nephelometric turbidity units. Symbols: <, less than minimum reporting level; --, no data]

Sample location identfier	Transect station number	Date	Time	Location of sampling point along transect (ft from left bank)	Discharge, instantaneous (ft^3/s)	Specific conductance, onsite (µS/cm)	pH, onsite (standard units)	Temperature, water, onsite (°C)	Oxygen, dissolved, onsite (mg/L)
A-1	454344111041501	09-03-97	0955	2.0	10	382	8.2	14.0	9.0
A-2		09-03-97	1000	7.0	10	383	8.2	14.0	9.0
A-3		09-03-97	1005	12.0	10	381	8.2	14.0	9.0
A-4		09-03-97	1010	16.0	10	386	8.2	14.0	9.0
A-5		09-03-97	1015	19.0	10	385	8.2	14.0	9.0
A-6		09-03-97	1020	22.0	10	386	8.2	14.0	9.0
A-7		09-03-97	1025	26.0	10	386	8.2	14.0	8.9
A-8		09-03-97	1030	28.0	10	383	8.1	14.0	8.9
A-9		09-03-97	1035	33.0	10	385	8.1	14.0	8.8
A-10		09-03-97	1040	36.0	10	383	8.1	14.0	8.6
B-1	454346111041601	09-03-97	1615	5.0	11	425	8.2	17.0	10.0
B-2		09-03-97	1610	9.0	11	420	8.3	17.0	10.2
B-3		09-03-97	1605	12.0	11	410	8.4	16.5	10.3
B-4		09-03-97	1600	15.0	11	392	8.5	16.5	10.4
B-5		09-03-97	1555	18.0	11	382	8.6	16.5	10.5
B-6		09-03-97	1550	21.0	11	383	8.6	16.5	10.5
B-7		09-03-97	1545	24.0	11	379	8.6	16.5	10.5
B-8		09-03-97	1540	27.0	11	377	8.6	16.5	10.4
B-9		09-03-97	1535	31.0	11	375	8.6	16.5	10.2
B-10		09-03-97	1530	36.0	11	372	8.7	16.5	10.1
1	Miscellaneous transect downstream from first meander,	09-03-97	1500	6.0	--	396	8.5	16.4	10.9
2	about 200 ft downstream from wastewater-	09-03-97	1501	8.0	--	396	8.5	16.4	10.9
3	discharge point (physical properties only)	09-03-97	1502	10.0	--	397	8.5	16.4	10.9
4		09-03-97	1503	12.0	--	396	8.5	16.4	10.9
5		09-03-97	1504	14.0	--	396	8.5	16.4	10.8
6		09-03-97	1505	17.0	--	401	8.5	16.4	10.8
7		09-03-97	1506	20.0	--	400	8.5	16.4	10.8
8		09-03-97	1507	23.0	--	397	8.5	16.4	10.8
9		09-03-97	1508	26.0	--	397	8.5	16.4	10.8
10		09-03-97	1509	30.0	--	392	8.6	16.4	10.8
11		09-03-97	1510	34.0	--	387	8.6	16.4	10.8
C-1	454349111041401	09-03-97	1230	3.0	12	408	8.3	15.5	10.6
C-2		09-03-97	1235	13.0	12	408	8.3	15.5	10.4
C-3		09-03-97	1240	18.0	12	406	8.3	15.5	10.7
C-4		09-03-97	1245	21.0	12	406	8.3	15.5	10.9
C-5		09-03-97	1250	24.0	12	404	8.4	15.5	11.0
C-6		09-03-97	1255	27.0	12	405	8.4	15.5	11.1
C-7		09-03-97	1300	29.0	12	405	8.4	15.5	11.1
C-8		09-03-97	1305	32.0	12	404	8.4	15.5	11.1
C-9		09-03-97	1310	34.0	12	404	8.4	15.5	11.1
C-10		09-03-97	1315	38.0	12	404	8.4	15.5	11.2
D-1	454401111041601	09-03-97	1840	6.0	12	389	8.4	16.5	8.8
D-2		09-03-97	1845	10.0	12	389	8.4	16.5	8.8
D-3		09-03-97	1850	15.0	12	389	8.4	16.5	8.8
D-4		09-03-97	1855	19.0	12	389	8.4	16.5	8.7
D-5		09-03-97	1900	21.0	12	389	8.4	16.5	8.7
D-6		09-03-97	1905	23.0	12	389	8.4	16.5	8.7
D-7		09-03-97	1910	26.0	12	389	8.4	16.5	8.7
D-8		09-03-97	1915	29.0	12	389	8.4	16.5	8.7
D-9		09-03-97	1920	32.0	12	389	8.4	16.5	8.7
D-10		09-03-97	1925	35.0	12	389	8.4	16.5	8.7

Table 2. Water-quality data for the East Gallatin River near the Bozeman wastewater-treatment facility, September 3, 1997 (Continued)

Sample location identifier	Date	Oxygen, dissolved, onsite (percent saturation)	Turbidity (NTU)	Oxygen demand, biochemical, 5 day at 20 °C (BOD) (mg/L)	Coliform, fecal (col/100 mL)	Chloride, dissolved (mg/L as Cl)	Nitrogen, nitrite plus nitrate, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia plus organic, total (mg/L as N)	Phosphorus, total (mg/L as P)
A-1	09-03-97	102	4.2	<4	--	3.3	0.320	<0.010	0.50	0.041
A-2	09-03-97	102	3.8	<4	89	3.2	.320	<.010	.60	.039
A-3	09-03-97	102	3.5	<4	--	3.2	.320	<.010	1.1	.037
A-4	09-03-97	102	4.6	<4	--	3.2	.320	<.010	.60	.038
A-5	09-03-97	102	3.8	<4	93	3.0	.320	<.010	.50	.038
A-6	09-03-97	102	2.9	--	--	3.2	.320	<.010	.70	.038
A-7	09-03-97	101	3.3	<4	95	3.2	.300	<.010	1.2	.038
A-8	09-03-97	100	2.6	--	--	3.0	.290	<.010	.70	.036
A-9	09-03-97	100	2.7	<4	--	3.3	.300	<.010	.60	.036
A-10	09-03-97	98	2.2	--	--	3.3	.290	<.010	.60	.036
B-1	09-03-97	122	4.1	<4	E170	13	1.97	.551	2.1	.976
B-2	09-03-97	124	4.6	<4	--	10	1.62	.417	1.6	.779
B-3	09-03-97	125	5.2	<4	--	8.7	1.30	.331	.90	.620
B-4	09-03-97	126	5.0	<4	--	6.4	.870	.192	.90	.401
B-5	09-03-97	127	5.1	<4	--	4.3	.480	.060	.40	.171
B-6	09-03-97	127	4.0	<4	--	4.2	.440	.053	.50	.153
B-7	09-03-97	127	4.8	<4	--	4.0	.400	.031	.60	.119
B-8	09-03-97	125	4.5	<4	--	3.9	.360	.016	.90	.105
B-9	09-03-97	123	5.0	<4	--	3.6	.330	<.010	.50	.086
B-10	09-03-97	122	3.5	<4	E120	3.8	.260	<.001	1.0	.041
1	09-03-97	130	--	--	--	--	--	--	--	--
2	09-03-97	130	--	--	--	--	--	--	--	--
3	09-03-97	130	--	--	--	--	--	--	--	--
4	09-03-97	129	--	--	--	--	--	--	--	--
5	09-03-97	129	--	--	--	--	--	--	--	--
6	09-03-97	129	--	--	--	--	--	--	--	--
7	09-03-97	129	--	--	--	--	--	--	--	--
8	09-03-97	129	--	--	--	--	--	--	--	--
9	09-03-97	129	--	--	--	--	--	--	--	--
10	09-03-97	129	--	--	--	--	--	--	--	--
11	09-03-97	129	--	--	--	--	--	--	--	--
C-1	09-03-97	125	3.5	<4	--	6.3	.970	.027	1.8	.383
C-2	09-03-97	123	2.0	--	--	6.2	.930	.040	1.6	.367
C-3	09-03-97	127	3.7	<4	72	6.2	.930	.048	.60	.369
C-4	09-03-97	128	2.6	<4	--	6.2	.930	.079	.60	.384
C-5	09-03-97	130	2.4	<4	65	6.3	.920	.068	1.2	.376
C-6	09-03-97	131	3.7	<4	--	6.2	.910	.077	1.3	.385
C-7	09-03-97	132	3.2	<4	59	6.3	.910	.085	.80	.393
C-8	09-03-97	132	2.2	--	--	6.3	.910	.096	.90	.388
C-9	09-03-97	131	3.5	<4	--	6.1	.900	.099	1.2	.385
C-10	09-03-97	132	2.2	--	--	6.3	.890	.113	.80	.383
D-1	09-03-97	106	4.5	<4	--	6.1	.900	.062	.80	.328
D-2	09-03-97	106	3.5	--	--	6.1	.910	.061	.50	.334
D-3	09-03-97	106	5.0	<4	--	6.2	.910	.058	1.6	.331
D-4	09-03-97	106	2.8	<4	--	6.2	.920	.056	1.1	.325
D-5	09-03-97	106	6.2	<4	--	6.1	.920	.053	.90	.322
D-6	09-03-97	106	4.5	--	--	6.0	.910	.054	.80	.318
D-7	09-03-97	106	6.6	<4	--	6.0	.910	.052	.60	.323
D-8	09-03-97	106	4.4	--	--	6.0	.910	.064	1.0	.316
D-9	09-03-97	106	5.8	<4	--	5.9	.910	.049	1.2	.319
D-10	09-03-97	106	3.4	--	--	6.0	.910	.049	.50	.329

Table 3. Water-quality data for Big Pipestone Creek near the Whitehall wastewater-treatment facility, September 17, 1997

[Analyses by Montana Department of Public Health and Human Services Environmental Laboratory, Helena, Mont. Sample location identifier: combination of transect letter and sampling-point number. Abbreviations: col/100 mL, colonies per 100 milliliters; °C, degrees Celsius; ft, feet; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; NTU, nephelometric turbidity units. Symbols: <, less than minimum reporting level; --, no data]

Sample location identifier	Transect station number	Date	Time	Location of sampling point along transect (ft from left bank)	Discharge, instantaneous (ft^3/s)	Specific conductance, onsite (µS/cm)	pH, onsite (standard units)	Temperature, water, onsite (°C)	Oxygen, dissolved, onsite (mg/L)
A-1	455133112045101	09-17-97	0830	3.0	2.8	528	8.2	10.0	9.3
A-2		09-17-97	0825	5.0	2.8	527	8.2	10.0	9.2
A-3		09-17-97	0820	8.0	2.8	527	8.2	10.0	9.3
A-4		09-17-97	0815	11.0	2.8	527	8.1	10.0	9.2
A-5		09-17-97	0810	14.0	2.8	527	8.2	10.0	9.0
B-1	455133112043601	09-17-97	1050	1.5	3.1	532	8.3	11.0	9.5
B-2		09-17-97	1045	2.5	3.1	531	8.3	11.0	9.4
B-3		09-17-97	1040	4.5	3.1	531	8.3	11.0	9.4
B-4		09-17-97	1035	6.5	3.1	531	8.3	11.0	9.2
B-5		09-17-97	1030	7.5	3.1	531	8.2	11.0	9.0
C-1	455133112043301	09-17-97	1215	1.5	3.2	558	8.4	11.5	9.7
C-2		09-17-97	1210	2.5	3.2	550	8.4	11.5	9.8
C-3		09-17-97	1205	4.5	3.2	545	8.4	11.5	9.9
C-4		09-17-97	1200	6.5	3.2	540	8.4	11.5	9.7
C-5		09-17-97	1155	8.5	3.2	528	8.4	11.5	9.5
D-1	455133112043001	09-17-97	1700	1.0	2.5	556	8.5	13.0	9.0
D-2		09-17-97	1655	3.0	2.5	556	8.5	13.0	9.0
D-3		09-17-97	1650	5.0	2.5	555	8.5	13.0	9.0
D-4		09-17-97	1645	7.0	2.5	554	8.5	13.0	9.0
D-5		09-17-97	1640	10.0	2.5	550	8.5	13.0	8.9
E-1	455134112042501	09-17-97	1430	3.5	3.3	543	8.5	12.5	9.6
E-2		09-17-97	1425	4.5	3.3	543	8.5	12.5	9.6
E-3		09-17-97	1420	5.5	3.3	542	8.5	12.5	9.6
E-4		09-17-97	1415	7.5	3.3	542	8.5	12.5	9.6
E-5		09-17-97	1410	9.5	3.3	542	8.5	12.5	9.5

Table 3. Water-quality data for Big Pipestone Creek near the Whitehall wastewater-treatment facility, September 17, 1997 (Continued)

Sample location identifier	Date	Oxygen, dissolved, onsite (percent saturation)	Turbidity (NTU)	Oxygen demand, biochemical, 5 day at 20 °C (BOD)(mg/L)	Coliform, fecal (col/100 mL)	Chloride, dissolved (mg/L as Cl)	Nitrogen, nitrite plus nitrate, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia plus organic, total (mg/L as N)	Phosphorus, total (mg/L as P)
A-1	09-17-97	98	5.1	<4	--	17	<0.010	<0.010	0.60	0.068
A-2	09-17-97	96	5.3	<4	--	17	<.010	<.010	.30	.069
A-3	09-17-97	98	5.2	<4	--	17	<.010	<.010	.40	.070
A-4	09-17-97	96	5.6	<4	--	17	<.010	<.010	.20	.069
A-5	09-17-97	95	5.4	<4	--	17	<.010	<.010	.20	.071
B-1	09-17-97	101	4.1	<4	--	18	<.010	.019	.70	.075
B-2	09-17-97	101	3.4	<4	280	18	<.010	.013	.30	.097
B-3	09-17-97	100	3.9	<4	--	18	<.010	.014	.50	.074
B-4	09-17-97	99	3.5	<4	290	18	<.010	.010	.40	.070
B-5	09-17-97	96	3.9	<4	--	18	<.010	<.010	.30	.072
C-1	09-17-97	106	3.7	<4	--	25	<.010	.460	1.0	.164
C-2	09-17-97	107	4.3	<4	330	24	<.010	.410	1.0	.150
C-3	09-17-97	107	3.5	<4	--	22	<.010	.270	.60	.126
C-4	09-17-97	106	3.4	<4	300	20	<.010	.170	.40	.107
C-5	09-17-97	103	3.5	<4	--	19	<.010	.069	.40	.080
D-1	09-17-97	101	3.5	<4	--	24	<.010	.340	.90	.138
D-2	09-17-97	101	3.1	<4	--	24	<.010	.310	.80	.136
D-3	09-17-97	101	3.0	<4	430	23	<.010	.310	1.1	.131
D-4	09-17-97	101	3.0	<4	--	23	<.010	.310	.90	.132
D-5	09-17-97	101	3.5	<4	--	23	<.010	.300	.90	.129
E-1	09-17-97	106	5.3	<4	--	22	<.010	.230	.60	.120
E-2	09-17-97	106	3.6	<4	--	22	<.010	.210	.80	.113
E-3	09-17-97	106	3.4	<4	270	21	<.010	.200	.50	.115
E-4	09-17-97	106	4.8	<4	--	22	<.010	.200	.80	.118
E-5	09-17-97	105	3.6	<4	--	22	.010	.200	.50	.118

Table 4. Water-quality data for the Bitterroot River near the Darby wastewater-treatment facility, September 30, 1997

[Analyses by Montana Department of Public Health and Human Services Environmental Laboratory, Helena, Mont. Sample location identifier: combination of transect letter and sampling-point number. Abbreviations: col/100 mL, colonies per 100 milliliters; °C, degrees Celsius; ft, feet; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; NTU, nepelometric turbidity units. Symbols: <, less than minimum reporting level; --, no data]

Sample location identifier	Transect station number	Date	Time	Location of sampling point along transect (ft from left bank)	Discharge, instantaneous (ft^3/s)	Specific conductance, onsite (µS/cm)	pH, onsite (standard units)	Temperature, water, onsite (°C)	Oxygen, dissolved, onsite (mg/L)
A-1	460136114095901	09-30-97	1705	11.0	62	85	8.2	14.0	9.7
A-2		09-30-97	1710	30.0	62	85	8.2	14.0	9.6
A-3		09-30-97	1715	44.0	62	86	8.3	14.0	9.7
A-4		09-30-97	1720	58.0	62	86	8.3	14.0	9.7
A-5		09-30-97	1725	73.0	62	86	8.3	14.0	9.8
B-1	460137114100701	09-30-97	1115	5.0	.11	113	6.6	11.0	5.5
B-2		09-30-97	1110	9.0	.11	113	6.6	11.0	5.3
B-3		09-30-97	1105	12.0	.11	113	6.6	11.0	5.3
B-4		09-30-97	1100	16.0	.11	113	6.6	11.0	5.4
B-5		09-30-97	1055	22.0	.11	112	6.6	11.0	5.3
C-1	460140114100501	09-30-97	1030	4.0	.30	155	7.0	11.0	7.9
C-2		09-30-97	1035	7.0	.30	155	7.0	11.0	8.0
C-3		09-30-97	1040	10.0	.30	149	6.9	11.0	7.8
C-4		09-30-97	1045	13.0	.30	139	6.9	11.0	7.8
C-5		09-30-97	1050	16.0	.30	132	6.9	10.5	7.7
D-1	460143114100201	09-30-97	0900	2.0	.30	144	6.8	9.5	6.2
D-2		09-30-97	0905	4.0	.30	144	6.8	9.5	6.2
D-3		09-30-97	0910	6.0	.30	143	6.8	9.5	6.0
D-4		09-30-97	0915	8.0	.30	141	6.8	9.5	5.9
D-5		09-30-97	0920	10.0	.30	138	6.8	9.5	6.2
E-1	460152114100801	09-30-97	1430	17.0	32	86	8.1	13.0	10.1
E-2		09-30-97	1435	26.0	32	86	8.2	13.0	10.1
E-3		09-30-97	1440	32.0	32	85	8.2	13.0	10.1
E-4		09-30-97	1445	37.0	32	85	8.2	13.0	10.1
E-5		09-30-97	1450	42.0	32	85	8.2	13.0	10.1
E-6		09-30-97	1455	47.0	32	85	8.2	13.0	10.1
E-7		09-30-97	1500	53.0	32	85	8.2	13.0	10.1
E-8		09-30-97	1505	56.0	32	85	8.2	13.0	10.1
E-9		09-30-97	1510	61.0	32	85	8.3	13.0	10.1
E-10		09-30-97	1515	67.0	32	85	8.3	13.0	10.1

Table 4. Water-quality data for the Bitterroot River near the Darby wastewater-treatment facility, September 30, 1997 (Continued)

Sample location identifier	Date	Oxygen, dissolved, onsite (percent saturation)	Turbidity (NTU)	Oxygen demand, biochemical, 5 day at 20 °C (BOD) (mg/L)	Coliform, fecal (col/100 mL)	Chloride, dissolved (mg/L as Cl)	Nitrogen, nitrite plus nitrate, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia plus organic, total (mg/L as N)	Phosphorus, total (mg/L as P)
A-1	09-30-97	108	<1.0	<4	11	<1.0	<0.010	<0.010	<0.10	0.009
A-2	09-30-97	107	<1.0	<4	--	<1.0	<.010	<.010	.10	.011
A-3	09-30-97	109	1.0	<4	20	<1.0	<.010	<.010	.20	.007
A-4	09-30-97	108	<1.0	<4	--	<1.0	<.010	<.010	.10	.009
A-5	09-30-97	109	<1.0	<4	13	<1.0	<.010	<.010	.30	.008
B-1	09-30-97	58	<1.0	<4	--	2.9	<.010	.077	.50	.071
B-2	09-30-97	56	<1.0	<4	16	2.8	<.010	.078	.50	.058
B-3	09-30-97	56	<1.0	<4	15	2.8	<.010	.080	.40	.058
B-4	09-30-97	56	<1.0	<4	15	2.7	<.010	.067	.30	.060
B-5	09-30-97	55	<1.0	<4	--	2.6	<.010	.071	.40	.057
C-1	09-30-97	83	30	<4	99	12	<.010	.063	2.6	.347
C-2	09-30-97	84	29	<4	<20	12	<.010	.069	2.8	.331
C-3	09-30-97	81	26	<4	<20	11	<.010	.066	1.0	.201
C-4	09-30-97	81	22	<4	--	9.0	<.010	.054	1.6	.202
C-5	09-30-97	79	11	<4	60	7.2	<.010	.023	.70	.174
D-1	09-30-97	63	6.8	<4	40	9.5	<.010	.089	.80	.167
D-2	09-30-97	62	7.0	<4	20	9.4	<.010	.214	1.3	.174
D-3	09-30-97	60	8.0	<4	--	9.4	<.010	.082	1.3	.177
D-4	09-30-97	60	5.9	<4	<20	9.1	<.010	.082	1.0	.164
D-5	09-30-97	62	5.2	<4	--	8.9	<.010	.067	1.4	.145
E-1	09-30-97	111	<1.0	<4	--	1.5	<.010	<.010	.20	.021
E-2	09-30-97	111	<1.0	<4	13	1.3	<.010	<.010	.70	.014
E-3	09-30-97	111	<1.0	<4	--	1.2	<.010	<.010	.20	.011
E-4	09-30-97	111	<1.0	<4	--	1.2	<.010	<.010	.70	.022
E-5	09-30-97	111	<1.0	<4	10	1.0	<.010	<.010	.20	.009
E-6	09-30-97	111	<1.0	<4	--	1.0	<.010	<.010	.20	.009
E-7	09-30-97	111	<1.0	<4	--	1.0	<.010	<.010	.20	.008
E-8	09-30-97	112	<1.0	<4	1	1.0	<.010	<.010	.20	.008
E-9	09-30-97	111	<1.0	<4	--	<1.0	<.010	<.010	.20	.009
E-10	09-30-97	111	<1.0	<4	--	<1.0	<.010	<.010	.20	.008

Table 5. Water-quality data for the Bitterroot River near the Hamilton wastewater-treatment facility, October 14-15, 1997

[Analyses by Montana Department of Public Health and Human Services Environmental Laboratory, Helena, Mont. Sample location identifier: combination of transect letter and sampling-point number. Abbreviations: col/100 mL, colonies per 1-- milliliters; °C, degrees Celsius; ft, feet; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; NTU, nepelometric turbidity units. Symbols: <, less than minimum reporting level; --, no data]

Sample location identifier	Transect station number	Date	Time	Location of sampling point along transect (ft from left bank)	Dis-charge, instan-taneous (ft^3/s)	Specific conduc-tance, onsite (µS/cm)	pH, onsite (standard units)	Temper-ature, water, onsite (°C)	Oxygen, dissolved, onsite (mg/L)
A-1	461511114102701	10-14-97	1500	9.0	68	79	8.2	9.0	11.0
A-2		10-14-97	1505	32.0	68	79	8.2	9.0	11.0
A-3		10-14-97	1510	41.0	68	80	8.2	9.0	11.1
A-4		10-14-97	1515	51.0	68	80	8.2	9.0	11.1
A-5		10-14-97	1520	58.0	68	80	8.2	9.0	11.1
A-6		10-14-97	1525	70.0	68	80	8.2	9.0	11.0
A-7		10-14-97	1530	82.0	68	80	8.2	8.5	11.1
A-8		10-14-97	1535	97.0	68	81	8.2	8.5	11.0
A-9		10-14-97	1540	110	68	81	8.2	8.5	11.0
A-10		10-14-97	1545	129	68	82	8.2	8.5	11.0
B-1	461518114102301	10-15-97	1300	18.0	64	68	8.0	9.0	10.2
B-2		10-15-97	1305	36.0	64	69	8.1	9.0	10.2
B-3		10-15-97	1310	56.0	64	69	8.1	9.0	10.2
B-4		10-15-97	1315	66.0	64	69	8.1	9.0	10.3
B-5		10-15-97	1320	77.0	64	69	8.1	9.0	10.3
B-6		10-15-97	1325	83.0	64	70	8.1	9.0	10.3
B-7		10-15-97	1330	90.0	64	71	8.1	9.0	10.3
B-8		10-15-97	1335	103	64	71	8.1	9.0	10.3
B-9		10-15-97	1340	115	64	73	8.1	9.0	10.4
B-10		10-15-97	1345	133	64	76	8.0	9.0	10.3
C-1	461522114101801	10-15-97	0900	10.0	68	70	7.4	7.0	10.1
C-2		10-15-97	0905	21.0	68	70	7.4	7.0	10.1
C-3		10-15-97	0910	27.0	68	70	7.4	7.0	10.1
C-4		10-15-97	0915	38.0	68	70	7.4	7.0	10.0
C-5		10-15-97	0920	47.0	68	71	7.4	7.0	10.1
C-6		10-15-97	0925	54.0	68	71	7.4	7.0	10.1
C-7		10-15-97	0930	69.0	68	72	7.4	7.0	10.0
C-8		10-15-97	0935	77.0	68	73	7.3	7.0	10.0
C-9		10-15-97	0940	94.0	68	74	7.3	7.0	10.0
C-10		10-15-97	0945	129	68	76	7.3	7.0	10.1

Table 5. Water-quality data for the Bitterroot River near the Hamilton wastewater-treatment facility, October 14-15, 1997 (Continued)

Sample location identifier	Date	Oxygen, dissolved, onsite (percent saturation)	Turbidity (NTU)	Oxygen demand, biochemical, 5 day at 20 °C (BOD) (mg/L)	Coliform, fecal (col/100 mL)	Chloride, dissolved (mg/L as Cl)	Nitrogen, nitrite plus nitrate, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia plus organic, total (mg/Las N)	Phosphorus, total (mg/L as P)
A-1	10-14-97	107	<1.0	<4	--	1.4	0.030	0.012	<0.10	0.006
A-2	10-14-97	107	<1.0	<4	--	1.4	<.010	.016	.10	.006
A-3	10-14-97	108	<1.0	<4	--	1.3	<.010	.014	<.10	.006
A-4	10-14-97	108	<1.0	--	--	1.3	<.010	.015	<.10	.006
A-5	10-14-97	108	<1.0	<4	2	1.2	<.010	.016	<.10	.006
A-6	10-14-97	106	<1.0	<4	--	1.3	<.010	.016	<.10	.005
A-7	10-14-97	107	<1.0	<4	--	1.3	<.010	.014	.40	.006
A-8	10-14-97	107	<1.0	--	6	1.4	<.010	.014	<.10	.007
A-9	10-14-97	107	<1.0	<4	--	1.3	<.010	.015	<.10	.005
A-10	10-14-97	107	<1.0	<4	--	1.5	<.010	.014	<.10	.005
B-1	10-15-97	99	<1.0	<4	--	1.4	<.010	.011	<.10	.007
B-2	10-15-97	99	<1.0	<4	4	1.4	<.010	<.010	<.10	.006
B-3	10-15-97	99	<1.0	<4	--	1.4	<.010	<.010	<.10	.006
B-4	10-15-97	100	<1.0	<4	--	1.5	<.010	<.010	<.10	.006
B-5	10-15-97	100	<1.0	<4	--	1.4	<.010	<.010	<.10	.006
B-6	10-15-97	100	<1.0	<4	--	1.4	<.010	<.010	.10	.006
B-7	10-15-97	100	<1.0	<4	2	1.5	<.010	<.010	<.10	.007
B-8	10-15-97	100	<1.0	<4	--	1.5	<.010	<.010	<.10	.010
B-9	10-15-97	100	<1.0	<4	9	1.7	<.010	<.010	.10	.014
B-10	10-15-97	99	<1.0	<4	--	1.7	<.010	<.010	<.10	.019
C-1	10-15-97	93	<1.0	<4.0	--	1.4	<.010	<.010	<.10	.006
C-2	10-15-97	93	<1.0	<4.0	6	1.3	<.010	<.010	<.10	.006
C-3	10-15-97	92	<1.0	<4.0	--	1.1	<.010	<.010	<.10	.006
C-4	10-15-97	92	<1.0	<4.0	--	1.1	<.010	<.010	.30	.006
C-5	10-15-97	92	<1.0	<4.0	6	1.3	<.010	<.010	<.10	.006
C-6	10-15-97	93	<1.0	<4.0	--	1.3	<.010	<.010	<.10	.007
C-7	10-15-97	92	1.1	<4.0	--	1.1	<.010	<.010	<.10	.008
C-8	10-15-97	92	<1.0	<4.0	48	1.2	<.010	<.010	<.10	.009
C-9	10-15-97	92	<1.0	<4.0	--	1.3	<.010	<.010	.20	.013
C-10	10-15-97	92	<1.0	<4.0	--	1.5	<.010	<.010	.30	.017

Table 6. Chemical analyses of field blanks for water samples

[Analyses by Montana Department of Public Health and Human Services Environmental Laboratory, Helena, Mont. Abbreviations: °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; NTU, nephelometric turbidity units. Symbols: <, less than minimum reporting level; --, no data]

Date	Time	Specific conductance, onsite (µS/cm)	pH, onsite (standard units)	Turbidity, onsite (NTU)	Oxygen demand, biochemical, 5 day at 20 °C (BOD) (mg/L)	Chloride, dissolved (mg/L as Cl)	Nitrogen, nitrite plus nitrate, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia plus organic, total (mg/L as N)	Phosphorus total (mg/L as P)
09-03-97	1730	3	4.7	<1.0	--	<1.0	<0.010	<0.010	0.70	0.004
09-30-97	1400	1	5.2	<1.0	<4.0	1.0	<.010	<.010	.20	.001
10-15-97	0800	2	5.2	<1.0	<4.0	<1.0	<.010	.016	<.10	<.001
10-15-97	0805	2	5.2	--	--	--	--	--	<.20	--

Table 7. Chemical analyses of field replicates for water samples

[Analyses by Montana Department of Public Health and Human Services Environmental Laboratory, Helena, Mont. Abbreviations: °C, degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units. Symbols: <, less than minimum reporting level; --, no data]

Transect station number	Location	Date	Time
454346111041601	Bozeman site, transect B	09-03-97	1615
		09-03-97	1620
455133112043601	Whitehall site, transect B	09-17-97	1050
		09-17-97	1055
460137114100701	Darby site, transect B	09-30-97	1115
		09-30-97	1120
461511114102701	Hamilton site, transect A	10-14-97	1545
		10-14-97	1550
		10-14-97	1555

Transect station number	Date	Turbidity, onsite (NTU)	Oxygen demand, biochemical, 5 day at 20 °C (BOD) (mg/L)	Chloride, dissolved (mg/L as Cl)	Nitrogen, nitrite plus nitrate, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia plus organic, total (mg/L as N)	Phosphorus, total (mg/L as P)
454346111041601	09-03-97	4.1	<4	13	1.97	0.551	2.1	0.976
	09-03-97	3.5	--	12	1.97	.555	1.3	1.06
455133112043601	09-17-97	4.1	<4	18	<.010	.019	.70	.075
	09-17-97	4.2	<4	18	<.010	.021	.20	.076
460137114100701	09-30-97	<1.0	<4	2.9	<.010	.077	.50	.071
	09-30-97	<1.0	<4	2.8	<.010	.074	.50	.071
461511114102701	10-14-97	<1.0	<4	1.5	<.010	.014	<.10	.005
	10-14-97	<1.0	<4	1.4	<.010	.016	<.10	.006
	10-14-97	--	--	--	--	--	<.20	--

Table 8. Precision of chemical analyses of field replicates for water samples

[Analyses by Montana Department of Public Health and Human Services Environmental Laboratory, Helena, Mont. Abbreviations: °C, degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units]

Property or constituent and reporting unit	Number of replicate pairs	Standard deviation	Relative standard deviation (percent)
Turbidity, onsite (NTU)	4	0.22	9.8
Oxygen demand, biochemical, 5 day at 20 °C (BOD) (mg/L)	3	.0	.0
Chloride, dissolved (mg/L)	4	.36	4.1
Nitrogen, nitrite plus nitrate, total (mg/L)	4	.0	.0
Nitrogen, ammonia, total (mg/L)	4	.002	1.2
Nitrogen, ammonia plus organic, total (mg/L)	4	.33	49.0
Phosphorus, total (mg/L)	4	.03	10.0

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