WATER-QUALITY AND TRANSPORT CHARACTERISTICS OF SUSPENDED SEDIMENT AND TRACE ELEMENTS IN STREAMFLOW OF THE UPPER CLARK FORK BASIN FROM GALEN TO MISSOULA, MONTANA, 1985-90

By John H. Lambing

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CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS, AND ACRONYMS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer
part per million	1	microgram per gram
square mile (mi^2)	2.59	square kilometer
ton (short)	907.2	kilogram
ton per day (ton/d)	907.2	kilogram per day

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the following equations:

$$°C = 5/9\ (°F - 32)$$
$$°F = 9/5\ (°C) + 32$$

Abbreviated water-quality units used in this report:

µg/L	micrograms per liter
mg/L	milligrams per liter
µS/cm	microsiemens per centimeter at 25 °C

Acronyms used in this report:

MCL	Maximum Contaminant Level
SMCL	Secondary Maximum Contaminant Level

Water-year definition:

A water year is the 12-month period October 1 through September 30. It is designated by the calendar year in which it ends.

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ABSTRACT

An estimated 100 million tons of tailings enriched in arsenic, cadmium, copper, lead, and zinc was supplied to the upper Clark Fork between 1880 and 1982 from mining, milling, and smelting of mineral ores near Butte and Anaconda, Montana. Large quantities of the tailings have been transported downstream and deposited along the flood plain and in Milltown Reservoir. Public water-supply contamination and fishkills attributed to large concentrations of trace elements derived from the tailings caused the U.S. Environmental Protection Agency to designate the mine-impacted areas as Superfund sites. In response to the need for information that can be used to guide resource management and remedial cleanup decisions, this report describes the water-quality and transport characteristics of suspended sediment and trace elements in the Clark Fork and selected tributaries from Galen to Missoula, Montana, for 1985-90.

A surface-water sampling program conducted during 1985-90 documented suspended-sediment and trace-element concentrations throughout a wide range of hydrologic conditions. Four stations on the Clark Fork mainstem and four major tributaries were sampled periodically for water quality to assess spatial differences among sites. In addition, three of the mainstem and one of the tributary sites were operated as daily sediment stations to describe temporal variability and quantify the suspended-sediment loads transported past various points of the basin.

For mainstem stations, the median suspended-sediment concentration increased from 8 mg/L (milligrams per liter) near Galen to 24 mg/L at Turah Bridge, near Bonner, a distance of 112.5 river miles. The median concentration for the tributaries ranged from 9 mg/L in the Blackfoot River to 43 mg/L in Flint Creek.

Maximum concentrations of arsenic equaled or exceeded the Maximum Contaminant Level (MCL) of 50 µg/L (micrograms per liter) specified in Primary Drinking-Water Regulations established by the U.S. Environmental Protection Agency. The exceedances in concentration occurred at three mainstem stations upstream from Milltown Reservoir and at Flint Creek. However, all other concentrations were less than the MCL, indicating that exceedances of the arsenic regulation are probably infrequent. The largest concentration of arsenic was 200 µg/L in the Clark Fork at Deer Lodge. All concentrations of cadmium were less than the MCL of 10 µg/L. Maximum concentrations of lead exceeded the MCL of 50 µg/L at two mainstem stations upstream from Milltown Reservoir and in the tributary Flint Creek; however, all other samples had lead concentrations less than the MCL. The largest lead concentration was 200 µg/L at the Clark Fork at Deer Lodge.

Trace-element concentrations were compared to aquatic-life criteria to identify the existence of water-quality conditions that could cause acute or chronic toxicity. The results indicate minimal toxic potential from arsenic, with only one sample (200 µg/L) exceeding the criterion for chronic toxicity. Dissolved copper concentrations exceeded chronic and acute criteria at the upper three mainstem stations, with the maximum exceedance (120 µg/L) occurring during a fishkill in the Clark Fork at Deer Lodge. Maximum total-recoverable copper concentrations exceeded both acute and chronic toxicity criteria at all sampling stations; exceedances were common at several stations. Maximum concentrations of dissolved lead exceeded the chronic criteria at one mainstem and all four tributary stations, but commonly were less than the minimum reporting level. Maximum concentrations of total-recoverable lead exceeded the chronic criteria at every station, and were near the acute criteria at two mainstem stations and in Flint Creek. Total-recoverable lead concentrations exceeded chronic criteria in more than 50 percent of the samples at one mainstem station and at three of the four tributary stations. The only sample (230 µg/L) with dissolved zinc in excess of the acute criteria was collected from the mainstem at Deer Lodge during a fishkill. The maximum concentrations of total-recoverable zinc at three mainstem and two tributary stations exceeded both acute and chronic criteria; however, all other samples had concentrations less than the criteria.

Average annual loads of suspended sediment and trace elements for water years 1985-90 were estimated on the basis of relations between selected constituents. The results indicate that the Clark Fork supplied a greater load of every constituent to Milltown Reservoir compared to the Blackfoot River. The arsenic, copper, and zinc loads contributed by the Clark Fork equaled or exceeded 80 percent of the total load input to the reservoir. Mass-balance calculations for Milltown Reservoir indicate that, except for arsenic and manganese, constituent loads showed net gains during the period. An average of 16,300 tons of suspended sediment was deposited annually during water years 1985-90. Net deposition of copper was the largest of the trace elements--about 23 tons annually. Trace-element net losses were estimated at an average annual rate of 0.8 ton of arsenic and 10 tons of manganese.

INTRODUCTION

The Clark Fork of the Columbia River, which drains west-central Montana, originates at the confluence of Silver Bow Creek and Warm Springs Creek (fig. 1). A large deposit of copper ore was discovered at Butte near the headwaters of Silver Bow Creek in 1880. The predominantly sulfide ores of arsenic, copper, lead, and zinc were intensively mined and subsequently milled and smelted at numerous locations between Butte and Anaconda. Vast quantities of mine tailings were produced and deposited over large areas along Silver Bow Creek and near the Anaconda smelting operations. The mine tailings contain concentrations of arsenic, cadmium, copper, lead, and zinc that are 10 to 100 times expected background values (Andrews, 1987). Early efforts to retain the mine tailings in ponds were often limited or unsuccessful, and large quantities of the tailings either were dumped directly or were eroded into the headwater tributaries of the Clark Fork. An estimated 100 million tons of tailings was supplied to the Clark Fork during the period of mining from 1880 to 1982 (Andrews, 1987).

The tailings have been transported various distances downstream and have mixed with the natural sediment of the Clark Fork. Some of the contaminated sediment has been deposited over extensive areas of the upper mainstem channel and flood plain. Widespread tailings deposits in the channel and flood plain are continually resuspended and transported downstream by bed scour, lateral channel cutting, and overland erosion. Soluble salts of trace elements within the deposits either can be flushed directly into the streams by surface runoff or can leach through the flood-plain soils to the alluvial aquifer. A recent study by Moore and others (1989) indicates that bank sediment in the upper Clark Fork mainstem is greatly enriched in arsenic, copper, lead, and zinc compared to bank sediment in Clark Fork tributaries.

Sediment enriched with trace elements has degraded the water quality of the upper Clark Fork to varying degrees since the late nineteenth century. A series of three settling ponds (Warm Springs Ponds) were built near the mouth of Silver Bow

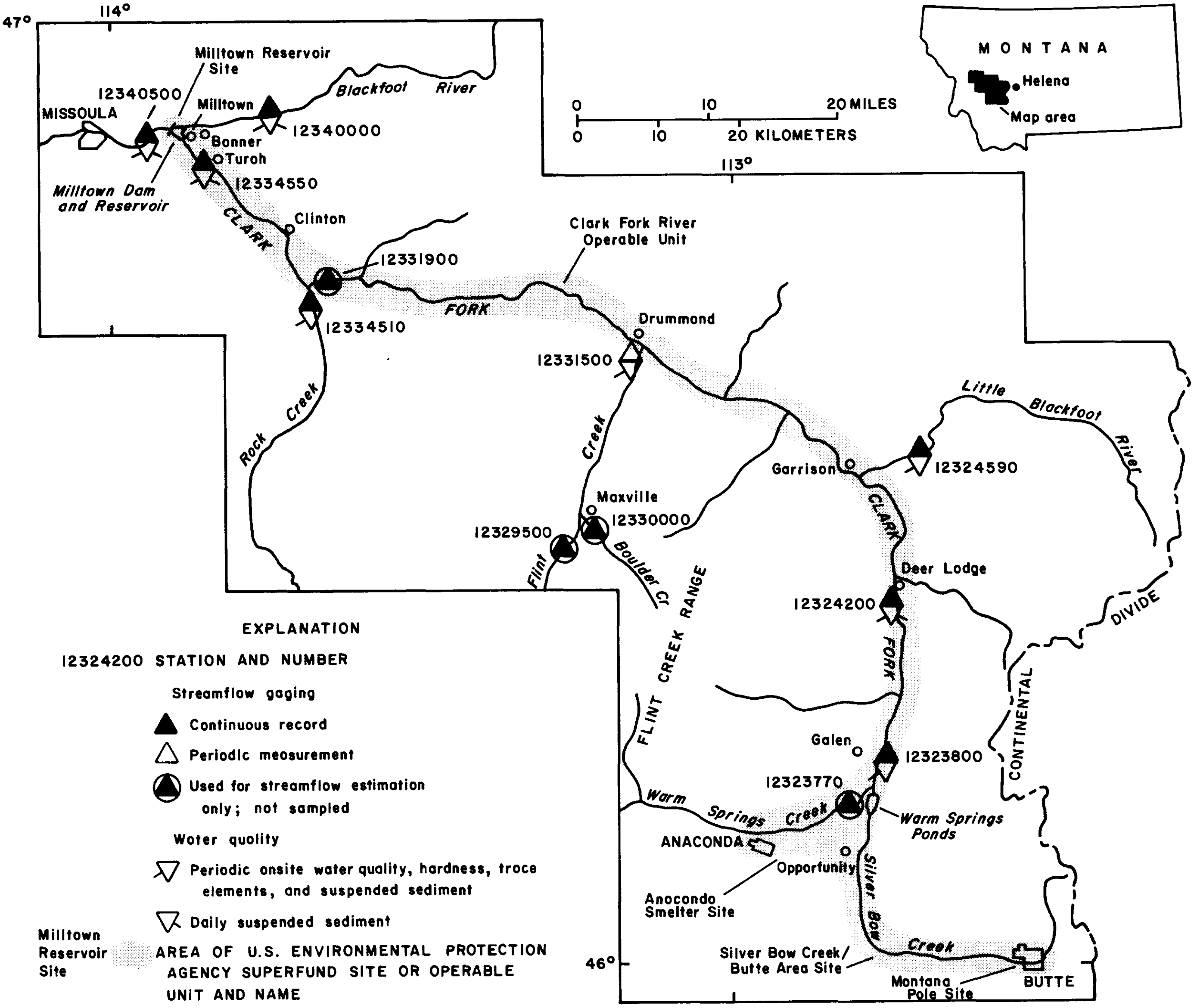

Figure 1.--Location of study area.

Creek between 1911 and 1959 to capture tailings eroded from the upper part of the basin. Beginning in 1975, lime was added at the inlet of the ponds to induce precipitation of metals and thereby increase settling efficiency. This treatment of Silver Bow Creek significantly improved the water quality of the upper Clark Fork, although additional tailings are introduced periodically during high flows that exceed the storage capacity of the settling ponds; during these high flows, untreated water of Silver Bow Creek is routed through a channel that bypasses the ponds. In spite of these improvements, tailings within the river system are a persistent source of potential toxicity to aquatic life, as manifested by periodic fishkills and suppressed trout populations (Phillips, 1985). Additionally, human health may be at risk from water-supply contamination as a result of widely distributed mine wastes that come in contact with surface-water and ground-water sources.

A large quantity of tailings has been transported from upstream mining areas and deposited in Milltown Reservoir, a small hydroelectric impoundment located about 97 river miles downstream from Deer Lodge. Created by the construction of Milltown Dam in 1907, the reservoir has been accumulating tailings-laden sediment for more than 80 years. The contaminated sediment on the reservoir bottom was the source for arsenic migration into an underlying aquifer utilized by Milltown as a source of public water supply (Woessner and others, 1984). As a result, the U.S. Environmental Protection Agency required replacement of the community's water supply. The quantity of potentially toxic trace elements transported past Milltown prior to the dam's construction and the quantity that has moved through the impoundment are largely undetermined. However, data collected by Johns and Moore (1985) have documented trace-element enrichment in the sediment of downstream reservoirs.

Large-scale mining operations in Butte ceased in 1982, but widespread public concern has been expressed about the potential effects of mine tailings distributed throughout the upper Clark Fork basin. As a result of the continuing threat to the water resources of the upper Clark Fork, the U.S. Environmental Protection Agency has designated three areas (fig. 1) impacted by mine tailings from Butte to Milltown Dam as National Priority List sites that are eligible for study and remedial cleanup provided by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA, commonly known as the Superfund Act). A fourth site, Montana Pole, was designated on the basis of organic-waste contamination resulting from creosote treatment of wooden poles during the mining period. The entire length of the Clark Fork from the confluence of Warm Springs and Silver Bow Creeks to Milltown Reservoir is incorporated within the Milltown Reservoir Site and is designated the "Clark Fork River Operable Unit." The four Superfund sites in the upper Clark Fork basin collectively form a contiguous area from Butte to Milltown Reservoir (fig. 1).

In response to the need for a water-quality data base to guide resource management and remedial cleanup decisions, a data-collection program to document suspended-sediment and trace-element concentrations in the upper Clark Fork basin was begun by the U.S. Geological Survey in March 1985. The data were collected in cooperation with the State of Montana, the Montana Power Company, and the U.S. Environmental Protection Agency. Upon completion of almost 6 years of data collection, the U.S. Environmental Protection Agency provided funding for the Geological Survey to analyze and interpret the data.

Purpose and Scope

This report describes the water-quality and transport characteristics of suspended sediment and trace elements in streamflow of the Clark Fork and selected tributaries from Galen to Missoula, Mont. Water-quality data for periodic samples, which were collected during a wide range of hydrologic conditions, are described in terms of spatial and temporal variability, are compared to environmental criteria, and are used to show relations between selected constituents. The relations between constituents are used to estimate annual loads of suspended sediment and trace elements. Those results then are used to describe transport characteristics and to identify source areas.

The surface-water quality of the upper Clark Fork basin is characterized by data collected from March 1985 through October 1990. Constituent loads were estimated for the complete period of water years 1985-90. Data for streamflow, onsite water quality, suspended sediment, and trace elements were collected periodically at seven water-quality sampling stations upstream from Milltown Reservoir and at one station downstream from the reservoir. Four of these stations also were operated either continually or intermittently as daily suspended-sediment stations.

The data analyzed in this report were not collected as part of an ongoing interpretive project, but rather as part of a baseline data-collection program. As a result of intermittent funding and changing data-collection objectives, the periods of record are variable and gaps exist in the data base. This report represents an effort to assess conditions in the upper Clark Fork basin from 1985 through 1990 using the available data.

Description of Study Area

Topography and Drainage

The upper Clark Fork basin lies west of the Continental Divide in west-central Montana. It is located within the Rocky Mountains physiographic province, which is characterized by rugged mountains and intermontane valleys. The drainage area of the Clark Fork basin upstream from Missoula is about 6,000 mi^2. In the study area, the Clark Fork valley is about 90 mi long and ranges in elevation from about 4,800 ft near Galen to about 3,200 ft near Missoula.

From Galen to Deer Lodge, the topography is dominated by a broad valley about 5 mi wide that is bordered by high, dissected terraces that rise 200 to 1,000 ft above the river. The north-trending valley is flanked on the east by mountains along the Continental Divide and on the west by the Flint Creek Range. Elevations range from about 8,600 ft along the Continental Divide to about 10,000 ft in the Flint Creek Range. Near Garrison, the Clark Fork turns northwesterly and flows through a narrow valley that is generally less than 1 mi wide downstream from Drummond. This valley is bordered by mountains having elevations generally less than 7,500 ft. The valley of Flint Creek is similar to but smaller than the broad valley of the upper Clark Fork. Valleys of the other tributaries are generally narrower than that of Flint Creek and are bordered closely by various mountain ranges.

From Galen to Missoula, four major tributaries enter the mainstem Clark Fork--Little Blackfoot River, Flint Creek, Rock Creek, and Blackfoot River. Other, smaller tributaries having perennial flow primarily drain areas of the Flint Creek Range. Numerous intermittent tributaries drain the lower mountain slopes on both sides of the Clark Fork valley. Flows of most of the perennial streams in the study area are seasonally decreased by irrigation withdrawals.

Climate

The climate of the study area ranges from semiarid in the broad valleys to humid alpine in the mountains. More than 70 percent of the annual precipitation in the broad valleys generally occurs between April and September, with May and June being the wettest months. The average annual precipitation in the broad valleys ranges from about 12 to 14 in. (U.S. Department of Agriculture, 1981, sheet 8). Most of the precipitation in the mountains occurs as snow from December through April, although rainfall can be substantial in May and June. Average annual precipitation in the mountains ranges from about 20 to 60 in., depending on elevation. The average valley temperatures range from 20 °F in January to 63 °F in July (National Oceanic and Atmospheric Administration, 1988).

General Geology

A regional geologic map that includes the study area was prepared by Alt and Hyndman (1980). The geology of the Deer Lodge Valley, which includes approximately the valley from Opportunity to Garrison, was described in detail by Konizeski and others (1968). The glacial geology of the entire study area was described by Alden (1953).

In general, the geology consists of bedrock mountains surrounding valleys underlain by Tertiary and Quaternary sediments. The highland areas consist mostly of metasedimentary rocks of Precambrian age and sedimentary rocks of Paleozoic and Mesozoic age. A few areas along the Continental Divide east of Deer Lodge are underlain by Cretaceous to Tertiary granite and Tertiary volcanic rocks.

The broad valleys of Flint Creek and the Clark Fork near Deer Lodge are underlain by as much as 5,500 ft of Upper Cretaceous and Tertiary sediments. The high valley terraces formed on Tertiary sediments in the Deer Lodge and Flint Creek valleys are remnants of an erosional surface created during late Pliocene or early Pleistocene time. A veneer of glacial deposits derived from ice caps that formed on the Flint Creek Range during the Quaternary Period underlies the west side of the Deer Lodge Valley. Glacial outwash and moraines are most extensive near the mouths of tributaries draining the east slopes of the Flint Creek Range. Glacial deposits also occur in the Flint Creek valley. Quaternary alluvium, which occurs near all streams, is normally fine to coarse grained and thin in the smaller tributaries. Quaternary alluvium ranges in thickness from about 25 ft in the Deer Lodge Valley to 300 ft in the narrow valley upstream from the confluence with Rock Creek.

DATA COLLECTION AND ANALYSIS

The primary objective of data collection was to document suspended-sediment and trace-element concentrations during a wide range of hydrologic conditions. Daily mean suspended-sediment concentrations were determined at selected stations to describe temporal variability and to quantify the annual mass (load) of sediment transported past various points in the basin. Because many trace elements are strongly associated with suspended sediment, a secondary objective was to identify relations between suspended sediment and trace elements and subsequently to estimate annual trace-element loads.

Sampling Locations

Four locations on the upper Clark Fork mainstem and four on major tributaries (fig. 1) were sampled periodically for water quality. Three of the mainstem stations and one tributary station also were operated for measurement of daily suspended-sediment concentrations. With the exception of Flint Creek, all stations had continuous-record streamflow gages that were operated concurrently during the water-quality sampling period. The sampling locations, type of data collected, and periods of record are identified in table 1.

Table 1.--*Types and periods of data collection at sampling stations*

[--, no data; P, present (October 1990)]

		Type and period of data collection		
Station number (fig. 1)	Station name	Continuous-record streamflow	Periodic water quality[1]	Daily suspended sediment
12323800	Clark Fork near Galen	07/88-P	07/88-P	--
12324200	Clark Fork at Deer Lodge	10/78-P	03/85-P	03/85-09/86, 04/87-P
12324590	Little Blackfoot River near Garrison	10/72-P	03/85-P	--
12331500	Flint Creek near Drummond	08/90-P	03/85-P	--
12334510	Rock Creek near Clinton	10/72-P	03/85-P	--
12334550	Clark Fork at Turah Bridge, near Bonner	05/86-P	03/85-P	03/85-P
12340000	Blackfoot River near Bonner	10/39-P	03/85-P	07/86-04/87, 06/88-P
12340500	Clark Fork above Missoula	03/29-P	10/89-P	07/86-04/87, 06/88-P

[1] Onsite water-quality measurements; laboratory analyses of hardness, selected trace elements, and suspended sediment.

Design of Sampling Program

Sampling stations were selected to provide sufficient geographic coverage of the upper Clark Fork basin to identify water-quality characteristics at the upper and lower ends of the mainstem and of the four major tributaries. The reach along the Clark Fork from Galen to Deer Lodge represents areas of abundant flood-plain tailings and brackets the area of occurrence of recent fishkills. Stations upstream and downstream from Milltown Reservoir enabled determination of a mass-balance analysis for suspended sediment. The tributaries, which were sampled near their mouths, represent the cumulative contribution from their entire basins.

Sampling frequency was generally limited to five to eight samples per year at each station. Efforts were made to document water quality during both short-duration runoff and more stable flow. However, because of known occurrences of toxicity to aquatic organisms during storm runoff, sampling was typically intensified during high flows caused by snowmelt or rainfall to document the short-lived maximum concentrations of suspended sediment and trace elements. This effort to identify worst-case conditions during periods of runoff precluded a routine sampling schedule at fixed time intervals.

Methods of Sample Collection, Processing, and Analysis

Periodic water-quality samples were collected using standard methods of the U.S. Geological Survey as described by Guy and Norman (1970), U.S. Geological Survey (1977), and Knapton (1985). All water samples were collected by depth integration at multiple verticals across the stream to account for vertical and horizontal variability of constituent distribution throughout the cross-sectional area of the stream. Suspended-sediment samples from the daily sediment stations listed in table 1 were collected by depth integration at a single vertical near mid-stream. Sampling equipment consisted of standard U.S. Geological Survey depth integrating suspended-sediment samplers. The samplers were equipped with nylon nozzles and were coated with a non-metallic epoxy paint to prevent trace-element contamination.

Onsite sample processing, including filtration and acidification, and onsite measurements of various water-quality properties were performed according to standard methods as described by U.S. Geological Survey (1977) and Knapton (1985). Onsite measurements included specific conductance, pH, water temperature, bicarbonate, carbonate, and total alkalinity.

Periodic suspended-sediment samples were analyzed for concentration and particle-size distribution (percent finer than 0.062 mm diameter) at the U.S. Geological Survey sediment laboratory in Helena, Mont. Single-vertical samples collected at the daily sediment stations were analyzed only for concentration. Particle-size analyses for multiple size classes were performed at the U.S. Geological Survey sedimentation laboratory in Iowa City, Iowa. Methods for sediment analysis are described by Guy (1969).

Periodic chemical samples were analyzed for hardness and trace-element concentration by the U.S. Geological Survey's National Water Quality Laboratory in Denver, Colo., using methods described by Fishman and Friedman (1989). Hardness was determined by analysis of calcium and magnesium concentrations. Dissolved and total-recoverable concentrations were determined for arsenic, cadmium, copper, iron, lead, manganese, and zinc. Digestion methods for total-recoverable analyses are described by Fishman and Friedman (1989, p. 50-51).

Quality Assurance

The general objectives of quality assurance for data-collection programs of the U.S. Geological Survey are that (1) data-collection activities follow Geological Survey approved methods, and (2) data analysis and interpretation procedures are documented and capable of being verified. Within this general framework are specific actions to assure the quality of the collected data. These procedures are documented in various publications and internal memoranda. Methods and associated quality control for sample collection and processing are described by Ward and Harr (1990), Guy and Norman (1970), Knapton (1985), and Knapton and Nimick (1991). The National Water Quality Laboratory is responsible for providing quality control of the analyses performed within its facility and within laboratories performing contract analyses. Standard procedures used by the laboratory for sample handling and quality assurance are described by Friedman and Erdmann (1982) and Jones (1987). Techniques for analysis of inorganic constituents are described by Fishman and Friedman (1985). Laboratory methods for sediment analysis are described by Guy (1969).

Quality assurance of laboratory data was documented by test samples that consisted of either a duplicate set of stream samples or blank samples of distilled water submitted at a proportion equivalent to about 15 percent of the total number of samples. Duplicate samples were collected in such a manner that the water from each of the two sets was considered to be essentially identical in composition. Independent analyses of duplicate samples can indicate the precision (repeatability) of analytical results. All but one of the duplicate samples were subsamples split from the original volume of sampled water. One duplicate sample was collected sequentially by repeating the sampling procedure to obtain a second discrete and independent sample volume. The sequential duplicate sample provided verification of both sampling procedure and analytical precision. All blank samples of distilled water, except one, were passed through all sample-processing equipment to detect possible contamination from non-environmental sources (field blank). One blank sample of distilled water was collected from the distillation unit of the Helena Office support laboratory and was analyzed directly without processing through equipment (shelf blank) to assure the quality of distilled water used for rinsing of all equipment and sample bottles. Results of the analyses for duplicate samples submitted to the National Water Quality Laboratory are listed in table 28 at the back of this report. Results of the analyses for blank samples are listed in table 29 at the back of this report.

All sample bottles, standard solutions, and acid preservatives were provided by the National Water Quality Laboratory and were subject to their internal quality control as described in Bench-Level Protocols on file in the Quality Control Office of the laboratory. In addition, selected analytical schedules, requirements for sample treatments, and required sample bottles are described in the laboratory's analytical services catalog (Pritt and Jones, 1989). All samples collected in cooperation with the U.S. Environmental Protection Agency were handled and transported to the laboratory in accordance with "chain-of-custody" procedures to provide documentation of sample identification, handling, shipment, and receipt.

Water-quality data stored in computerized data bases of the U.S. Geological Survey are subjected to various quality-assurance procedures. Within the laboratory, quality-control measures are applied regarding sample handling, analytical equipment, and measurement accuracy. Each analysis is checked for chemical logic according to ionic balance and calculated values. As the data are entered into the laboratory data base, the values of selected constituents are compared to national water-quality standards. Data that exceed national water-quality standards are identified for verification. Data are also verified for consistency as they are entered. Within the District Office, the data are further verified and laboratory reruns are requested as necessary. Prior to publication, the data receive final technical review and approval by the project chief and the District Water-Quality Specialist.

Results of all sample analyses are stored in the national Water Data Storage and Retrieval System (WATSTORE) data base of the U.S. Geological Survey (1983). The primary file used to store all water-quality analyses in this system is the Water Quality File. This data base allows thorough documentation of the data in a nationally consistent manner and allows the data to be readily retrieved.

STREAMFLOW CHARACTERISTICS

Streamflow can significantly affect the processes that control water quality and the rate of constituent transport through the surface-water system. The large variability of streamflow, both day-to-day and year-to-year, can greatly affect the magnitude and duration of various water-quality conditions. Water-quality characteristics defined by samples collected during a period of one to several years are commonly used to estimate long-term average conditions. Recognition of how well streamflow characteristics during a specific sampling period represent long-term hydrologic conditions can give insight to data interpretation. One means of obtaining a long-term perspective is by comparing study-period flow statistics with long-term statistics, if such data are available.

In the upper Clark Fork, two continuous-record streamflow-gaging stations have been in operation for more than 50 years. A measure of long-term average streamflow conditions of the basin is derived from the record of these two stations. The Clark Fork above Missoula has daily streamflow data for March 1929-present. Because this is the most-downstream station in the study area, the record at this station should adequately describe the long-term average combined streamflow of the upper basin. Streamflow at this station is affected by irrigation, industrial and domestic demands, and natural hydrologic variation. Comparison of flow-duration curves for water years 1985-90 and 1930-90 indicates how streamflow characteristics during the short-term study differed from long-term average conditions. The percentage of time that streamflow of a given magnitude was equaled or exceeded during the two periods is shown in figure 2. Most streamflows during water years

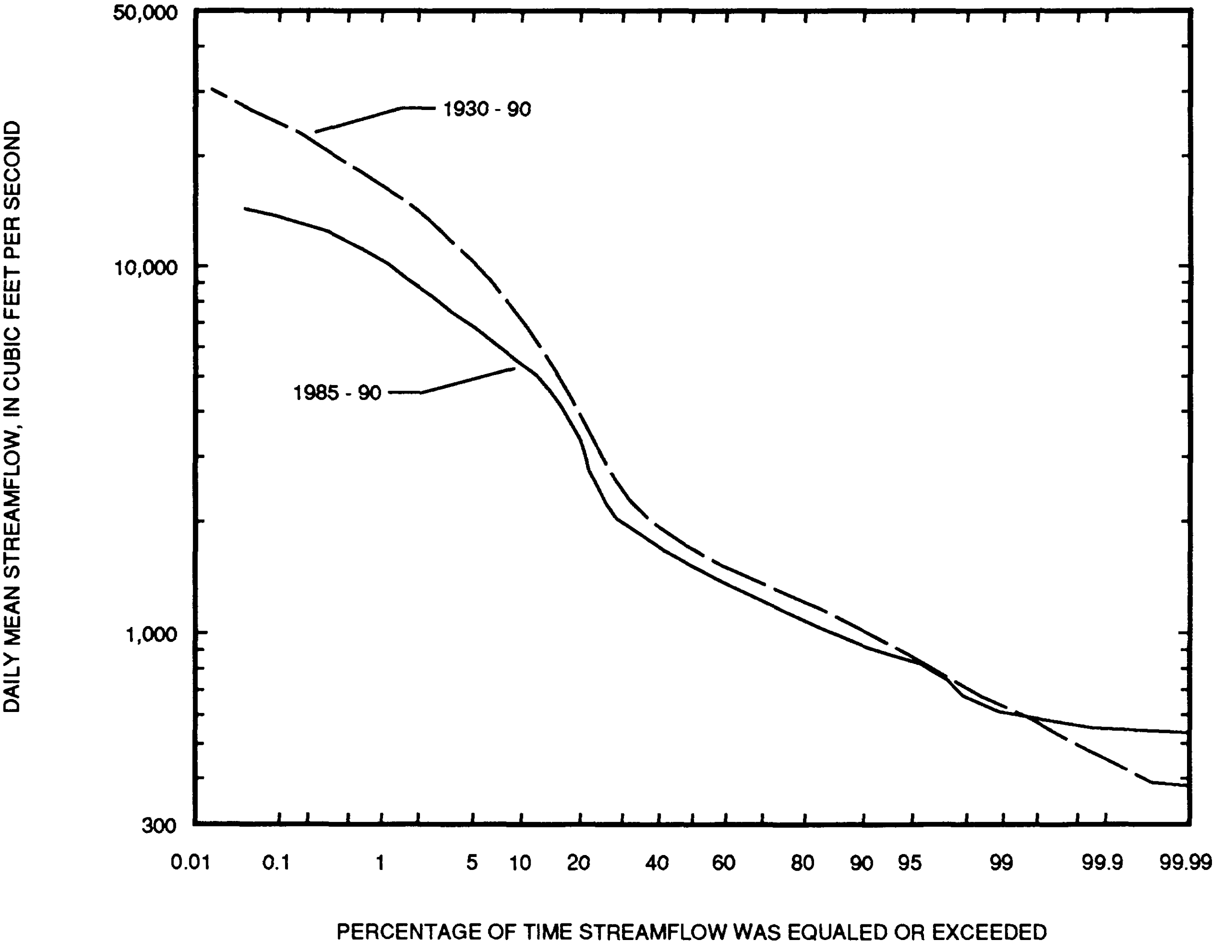

Figure 2.--Comparison of streamflow-duration characteristics for the Clark Fork above Missoula, water years 1985-90 and 1930-90.

1985-90 were less than those during the long-term period, especially at the higher range. Only at the very low range was the streamflow greater during the study period than during the long-term period (an effect of the 1930's drought). The increasing divergence of the two curves at the higher range indicates that substantially smaller runoff peaks occurred during the study period than during the long-term average period.

The Blackfoot River near Bonner has streamflow data for October 1939-present. This station record characterizes a tributary basin that is relatively unaffected by large-scale water development. Thus, the streamflow record for the two periods should reflect differences caused primarily by natural hydrologic variation rather than by cultural effects. The flow-duration characteristics of the Blackfoot River during water years 1985-90 and 1940-90 (fig. 3) are essentially the same as for the Clark Fork above Missoula. The lack of large runoff peaks during the study period is evidenced by the divergence of the curves at the higher range. Throughout the mid-range of flow record, streamflows during the study period were slightly less than those during the long-term period, whereas at the very low range, streamflows during the study period were greater than those during the long-term period. The very low flows for 1940-90, unlike the Clark Fork above Missoula, were the result of an intermittent series of droughts in the Blackfoot River basin.

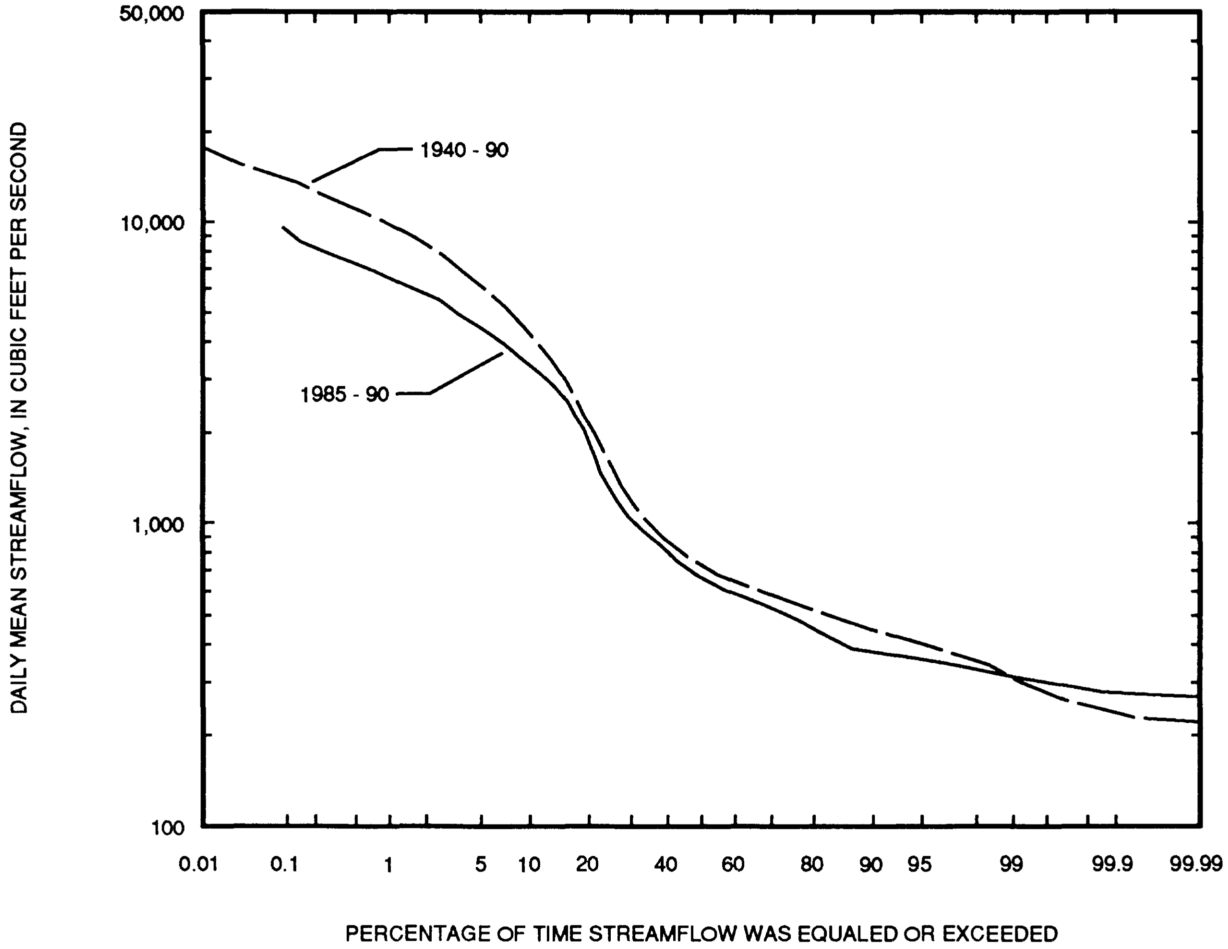

Figure 3.--Comparison of streamflow-duration characteristics for the Blackfoot River near Bonner, water years 1985-90 and 1940-90.

Streamflow records of less than 20 years are available for the Clark Fork at Deer Lodge (12 years), Little Blackfoot River near Garrison (18 years), and Rock Creek near Clinton (18 years). These records also indicate generally less streamflow during water years 1985-90 than during the period of record.

Streamflow records for the Clark Fork near Galen, Flint Creek near Drummond, and Clark Fork at Turah Bridge, near Bonner are short term (less than 5 years). Daily streamflow record is available for only part of the 1985-90 sampling period for the Clark Fork near Galen (July 1988-October 1990). Available daily streamflow record is very short for Flint Creek near Drummond (August-October 1990). Streamflow record for the Clark Fork at Turah Bridge, near Bonner is available for most of the sampling period (May 1986-October 1990). Streamflow data during the ungaged periods of water years 1985-90 were estimated by regression relations with nearby streamflow-gaging stations using techniques described by Parrett and others (1989). Comparisons of constituent-transport characteristics were made using streamflow record for a common base period (water years 1985-90).

Daily streamflow records for the Clark Fork near Galen were extended from July 1988 back to October 1984 (1985 water year) by developing a relation between concurrent daily streamflow of Warm Springs Creek at Warm Springs (station 12323770) and the Clark Fork near Galen during water years 1989 and 1990. This relation then was applied to the Warm Springs Creek record from October 1984 to July 1988 to estimate daily flows of the Clark Fork near Galen. The technique used for streamflow extension, as described by Hirsch (1982), is an alternative to ordinary least-squares regression and is referred to as MOVE.1 (Maintenance of Variance Extension, Type 1). The MOVE.1 curve-fitting technique tends to maintain the variance of the unextended records, unlike ordinary least-squares regression, which commonly results in smaller variances. In this study, the curve fitting was improved by seasonal segregation of the data base to account for variable streamflow effects observed during periods of irrigation and snowmelt.

Daily streamflow records for Flint Creek near Drummond were estimated entirely for water years 1985-90. The record of daily streamflow was generated by the concurrent-measurement method described by Parrett and others (1989). Although no continuous streamflow record was available until August 1990, instantaneous streamflow was measured during all sampling visits. These periodic values were correlated with the concurrent combined streamflow of two upstream stations--Flint Creek at Maxville (station 12329500) and Boulder Creek at Maxville (station 12330000). The estimates made using the concurrent-measurement method were based on the MOVE.1 curve-fitting technique. Seasonal segregation of the data base also was used for Flint Creek near Drummond to improve the curve fitting. An example of the MOVE.1 curve-fitting technique used to estimate daily streamflow record for Flint Creek near Drummond is shown in figure 4.

Daily streamflow records for the Clark Fork at Turah Bridge, near Bonner were estimated for the ungaged period October 1984-April 1986. The streamflow data were calculated as the sum of daily mean streamflows from two upstream stations--Clark Fork near Clinton (station 12331900) and Rock Creek near Clinton (station 12334510).

Monthly and annual streamflow characteristics for all sampling stations, including those with partly or entirely estimated daily streamflow records, are summarized in table 2. For stations having streamflow record prior to 1985, the average monthly and annual streamflow values for the period of record are also given as a reference to long-term conditions. For comparative purposes, the long-term record is assumed to represent "normal" conditions.

According to table 2, annual flows for water years 1985-90 were less than long-term annual flows. The less than normal annual flows during the study period can be adequately accounted for by less than normal annual precipitation and subsequently decreased runoff. The data in table 2 also indicate that the April-June spring runoff generally peaked earlier during the study period than during the long-term record. Possible explanations could be less snow combined with greater than normal temperatures in early spring that caused accelerated thawing of the snowpack, less than normal rainfall during late spring, or both. As a result of an earlier spring runoff, streamflows commonly receded to base flow by early summer.

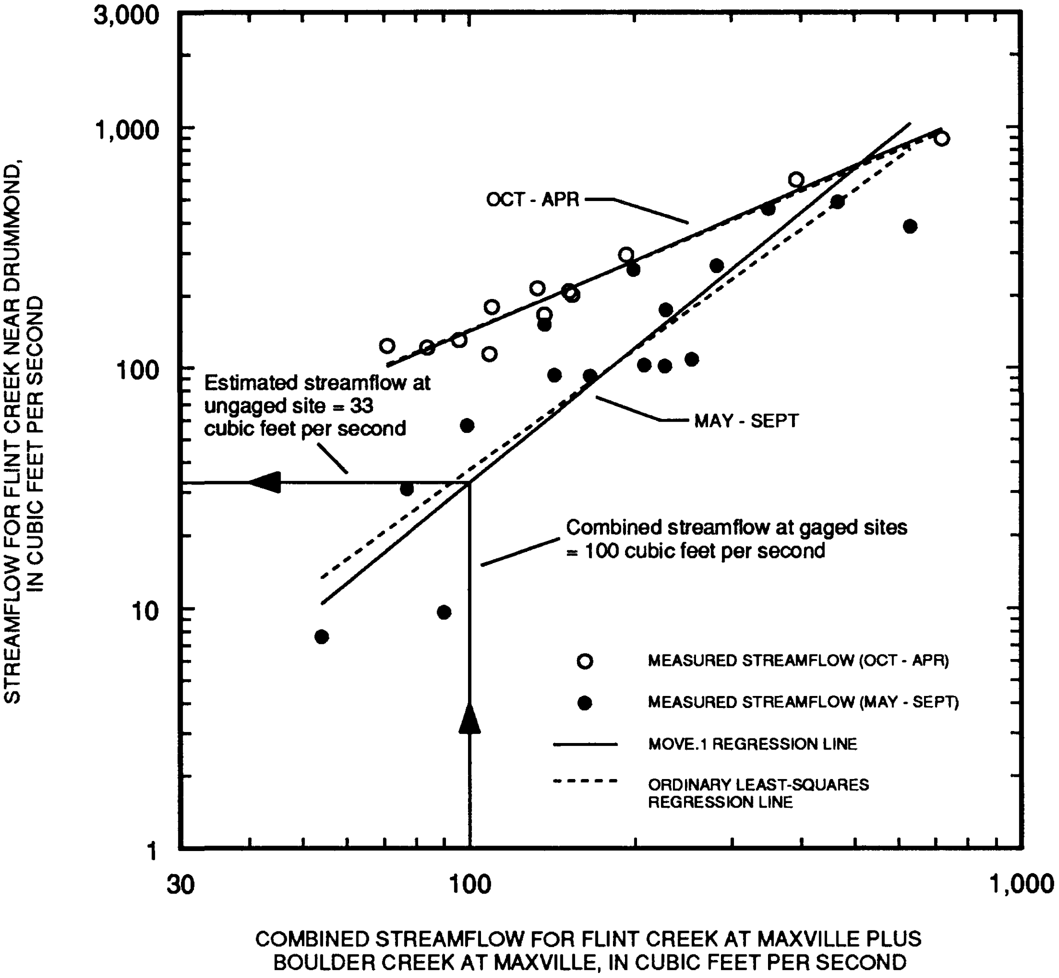

Figure 4.--Example of seasonal streamflow relations defined by the Maintenance of Variance Extension, Type 1 (MOVE.1) and ordinary least-squares curve-fitting techniques.

The implications of less than normal streamflow during the study period cannot be strictly quantified. However, knowledge of streamflow characteristics can provide a realistic perspective when evaluating transport characteristics of sediment or other constituents. Because constituent discharge is directly related to water discharge, the assumption that estimated average loads during the study period are somewhat less than actual long-term average loads is probably reasonable. The assumption is especially important when considering that extreme high flows of the magnitude that periodically occurred during the long-term record did not occur during the 1985-90 study period. Transport characteristics are as yet undefined for maximum flow conditions, which may be essential to accurate estimates of long-term constituent loads.

WATER QUALITY CHARACTERISTICS

All water-quality data collected from March 1985 through September 1989 and the corresponding summary statistics have been published (Lambing, 1987, 1988, 1989, 1990). In addition, all data through September 1990 are included in "Water-Resources Data" reports (U.S. Geological Survey, issued annually), which are published by water year. All the water-quality data periodically collected from March 1985 through October 1990 are statistically summarized in table 30 at the back of this report. The water-quality characteristics based on those data are presented in the following sections.

Table 2.--*Mean monthly and annual streamflow during water years 1985-90 and long-term periods at sampling stations*

[ft^3/s, cubic feet per second]

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual
Clark Fork near Galen													
1985-90 mean streamflow, in ft^3/s	83	88	78	86	79	124	146	191	189	42	30	53	1,189
1985-90 mean streamflow, in percent of annual	7.0	7.4	6.6	7.2	6.6	10.4	12.3	16.1	15.9	3.5	2.5	4.5	100
Clark Fork at Deer Lodge													
1985-90 mean streamflow, in ft^3/s	222	225	198	208	224	261	277	280	254	89	67	153	2,458
1979-90 mean streamflow, in ft^3/s	266	269	251	243	277	297	316	448	510	218	103	193	3,391
1985-90 mean streamflow, in percent of normal	83	84	79	86	81	88	88	62	50	41	65	79	72
1985-90 mean streamflow, in percent of annual	9.0	9.2	8.1	8.5	9.1	10.6	11.3	11.4	10.3	3.6	2.7	6.2	100
1979-90 mean streamflow, in percent of annual	7.8	7.9	7.4	7.2	8.2	8.8	9.3	13.2	15.0	6.5	3.0	5.7	100
Little Blackfoot River near Garrison													
1985-90 mean streamflow, in ft^3/s	68	66	53	49	65	122	275	317	196	76	41	49	1,377
1973-90 mean streamflow, in ft^3/s	74	73	69	68	82	119	244	560	431	135	62	59	1,976
1985-90 mean streamflow, in percent of normal	92	90	77	72	79	103	113	57	45	56	66	83	70
1985-90 mean streamflow, in percent of annual	4.9	4.8	3.8	3.6	4.7	8.9	20.0	23.0	14.2	5.5	3.0	3.6	100
1973-90 mean streamflow, in percent of annual	3.7	3.7	3.5	3.5	4.2	6.0	12.4	28.3	21.8	6.8	3.1	3.0	100
Flint Creek near Drummond													
1985-90 mean streamflow, in ft^3/s	136	123	106	94	106	127	169	126	163	45	31	27	1,253
1985-90 mean streamflow, in percent of annual	10.8	9.8	8.4	7.5	8.5	10.2	13.5	10.0	13.0	3.6	2.5	2.2	100
Rock Creek near Clinton													
1985-90 mean streamflow, in ft^3/s	234	207	155	144	161	239	614	1,240	1,140	410	249	247	5,040
1973-90 mean streamflow, in ft^3/s	260	233	200	188	189	244	525	1,550	1,820	716	322	276	6,523
1985-90 mean streamflow, in percent of normal	90	89	78	77	85	98	117	80	63	57	77	89	77
1985-90 mean streamflow, in percent of annual	4.6	4.1	3.1	2.9	3.2	4.7	12.2	24.6	22.6	8.1	5.0	4.9	100
1973-90 mean streamflow, in percent of annual	4.0	3.6	3.1	2.9	2.9	3.7	8.0	23.8	27.9	11.0	4.9	4.2	100

Table 2.--*Mean monthly and annual streamflow during water years 1985-90 and long-term periods at sampling stations*--Continued

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual
						Clark Fork at Turah Bridge, near Bonner							
1985-90 mean streamflow, in ft^3/s	870	847	731	701	795	1,050	1,670	2,200	1,970	806	544	721	12,905
1985-90 mean streamflow, in percent of annual	6.7	6.6	5.7	5.4	6.2	8.1	13.0	17.0	15.3	6.2	4.2	5.6	100
						Blackfoot River near Bonner							
1985-90 mean streamflow, in ft^3/s	603	636	553	506	506	910	2,480	3,840	2,970	1,040	644	621	15,309
1940-90 mean streamflow, in ft^3/s	655	644	598	553	595	759	2,010	4,940	5,010	1,830	832	671	19,097
1985-90 mean streamflow, in percent of normal	92	99	92	92	85	120	123	78	59	57	77	93	80
1985-90 mean streamflow, in percent of annual	3.9	4.2	3.6	3.3	3.3	5.9	16.2	25.1	19.4	6.8	4.2	4.1	100
1940-90 mean streamflow, in percent of annual	3.4	3.4	3.1	2.9	3.1	4.0	10.5	25.9	26.2	9.6	4.4	3.5	100
						Clark Fork above Missoula							
1985-90 mean streamflow, in ft^3/s	1,460	1,470	1,270	1,200	1,300	1,970	4,070	5,980	4,920	1,840	1,170	1,300	27,950
1930-90 mean streamflow, in ft^3/s	1,590	1,580	1,440	1,340	1,480	1,860	3,760	8,070	8,480	3,210	1,500	1,430	35,740
1985-90 mean streamflow, in percent of normal	92	93	88	90	88	106	108	74	58	57	78	91	78
1985-90 mean streamflow, in percent of annual	5.2	5.3	4.5	4.3	4.6	7.0	14.6	21.4	17.6	6.6	4.2	4.7	100
1930-90 mean streamflow, in percent of annual	4.4	4.4	4.0	3.8	4.2	5.2	10.5	22.6	23.7	9.0	4.2	4.0	100

Suspended Sediment

Suspended sediment was sampled to describe the variability and magnitude of concentrations and quantities transported in the upper Clark Fork basin. Knowledge of sediment characteristics is important because of known chemical associations of sediment with the particulate form of trace elements (Horowitz, 1985). Suspended-sediment samples were collected concurrently with all periodic water-quality samples to identify possible relations between suspended-sediment and trace-element concentrations.

Periodic Samples

The availability and physical and chemical characteristics of suspended sediment can vary geographically as a result of differences in geology, topography, vegetation, climate, and land use. These factors cumulatively affect the supply of sediment to the surface-water system. Streamflow characteristics, in turn, control the capacity of the stream to transport the available sediment supply. Because the concentration and transport of sediment are directly related to the magnitude of streamflow, continuous streamflow record can indicate the temporal variability of sediment concentration at a given site.

A commonly used graphical method to display the statistical distribution of data is the boxplot. The boxplot illustrates the minimum and maximum concentrations plus selected percentiles that describe the percentage of samples having concentrations equal to or less than an indicated value. When boxplots for individual sites are presented in one illustration, both the individual site characteristics and the geographic variability between sites are demonstrated.

The statistical distributions of suspended-sediment concentrations in water samples collected periodically during 1985-90 are shown in figure 5. The stations are grouped to illustrate the downstream variation along the Clark Fork mainstem and the relative characteristics of water contributed to the mainstem from the major tributaries. For general discussion, the median concentration is used to compare the central tendencies of concentrations at the stations. These comparisons are limited to some extent because the sample sizes differ between stations (table 30) and the timing of sampled runoff events may not represent equivalent hydrologic conditions. However, the distribution of samples throughout various ranges of streamflow magnitude is similar for these stations. Therefore, general differences in characteristics can be identified and can be assumed to represent actual variability in sediment occurrence between stations.

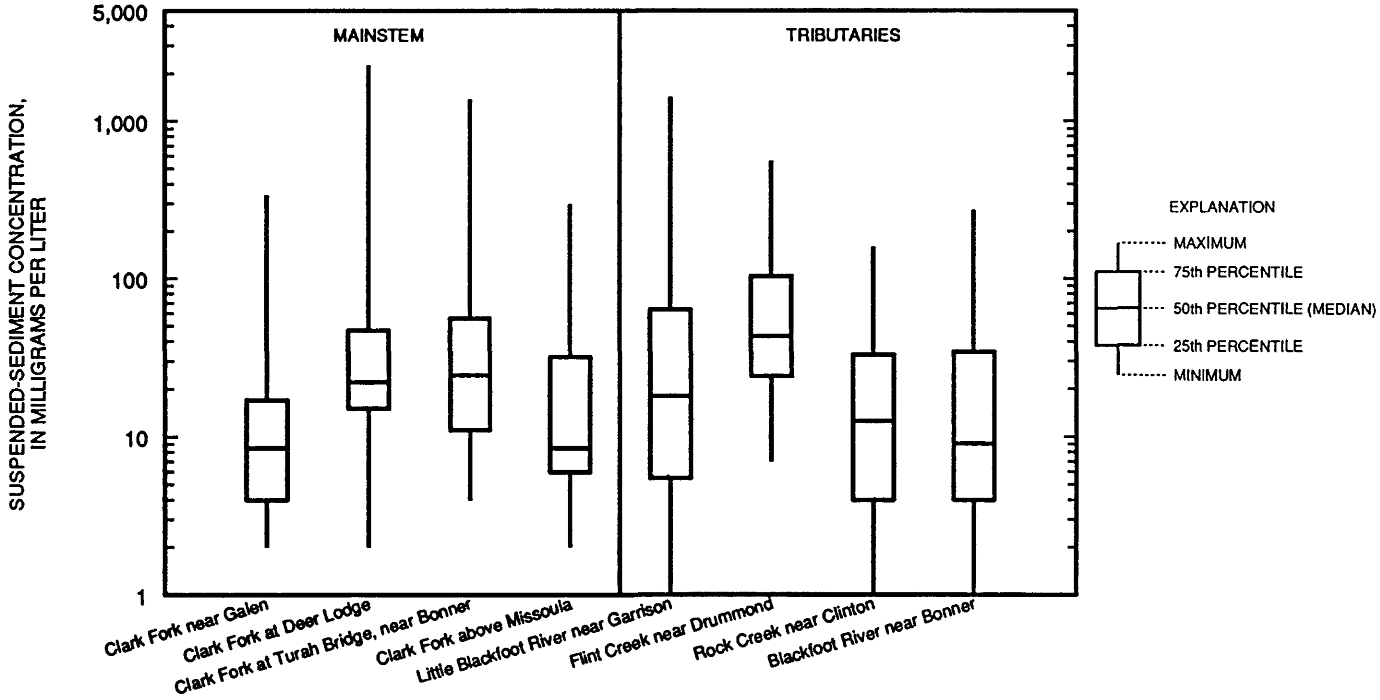

Figure 5.--Statistical distribution of suspended-sediment concentrations in water samples collected periodically during 1985-90.

For mainstem stations, the median suspended-sediment concentration increased from 8 mg/L near Galen to 22 mg/L at Deer Lodge, a distance of 21.5 river miles. The median concentration was 24 mg/L at the next downstream mainstem station at Turah Bridge, near Bonner, a distance of 91.0 river miles. Although three of the four major tributaries enter the Clark Fork between Deer Lodge and Turah Bridge, median concentration changes little between the upstream and downstream ends of this reach. The median decreased to 8 mg/L in the Clark Fork above Missoula, presumably because of partial sediment deposition in Milltown Reservoir and dilution by the Blackfoot River. The pattern of increase then decrease is similar for the other percentiles. Minimum concentrations for the mainstem stations were all 4 mg/L or less. Maximum concentrations in the mainstem ranged from 297 mg/L above Missoula to 2,250 mg/L at Deer Lodge. Maximum concentrations generally occurred during snowmelt or storm runoff. Concentrations during runoff commonly change substantially within a short time; therefore, conclusions drawn about the supply of sediment to the stream from direct comparisons of instantaneous maximum concentrations may be inappropriate.

The variation of suspended-sediment concentration for the tributaries is shown in figure 5. Overall, suspended-sediment concentrations in Flint Creek were notably larger compared to the other tributaries and the mainstem. The median for the tributaries ranged from 9 mg/L in the Blackfoot River to 43 mg/L in Flint Creek, nearly a five-fold difference. Minimum concentrations were 1 mg/L in all tributaries except Flint Creek, where it was 7 mg/L. Maximum concentrations in the tributaries ranged from 157 mg/L in Rock Creek to 1,410 mg/L in the Little Blackfoot River. The periodic samples indicate that Flint Creek commonly sustains larger sediment concentrations than the other tributaries during most flow conditions. In general, the sediment concentrations in the mainstem were intermediate to those measured in the tributaries.

Relations between Suspended-Sediment Concentration and Streamflow

Suspended-sediment concentration is subject to large variability depending on hydrologic conditions during sample collection. Such variability can invalidate direct comparisons between stations if the range of hydrologic conditions sampled or the period of record is not similar. To account for differences due to short-term fluctuations in hydrologic conditions or dissimilar periods of record, relations between hydrologic variables, such as suspended-sediment concentration and streamflow, can be identified for each station. These relations, if significant, describe the response of one variable to the change in a related variable. These relations then can be assumed to represent the general response of sediment concentrations to a wide range of hydrologic conditions. Comparison of the relations for each station commonly gives more insight into differences in sediment characteristics than direct comparison of measured instantaneous values.

Equations describing the relation between suspended-sediment concentration and streamflow were developed using Kendall's Tau nonparametric regression (Kendall, 1975). This method was chosen on the basis of a comparison of suspended-sediment loads estimated by several methods to actual loads measured at daily sediment stations. A discussion of the method selection is presented in the section "Estimation of Constituent Loads."

Regression estimates for the daily sediment stations were improved by segregating samples by season, then deriving separate equations for each season. Two seasons, February-April and May-January, were selected. These seasons include periods of distinctly different runoff and sediment-transport conditions: low-elevation valley snowmelt and high-elevation mountain snowmelt/rainfall runoff. Seasonal segregation was not possible for the periodic stations because of insufficient numbers of samples during late summer and winter. Additional samples more uniformly dispersed throughout the year might identify seasonal variability and thereby enhance the reliability of sediment estimation.

Equations for estimating suspended-sediment concentration from streamflow are presented in table 3. The original data were logarithmically transformed prior to regression analysis. All equations are log-linear and have an attained significance level less than 0.001. Standard errors of estimate for suspended-sediment concentration range from 64 to 122 percent.

Trace Elements

Trace elements are of concern in the Clark Fork basin because of their potential toxicity to human health and aquatic life. The large quantities of mine tailings in the upper reaches of the mainstem and in less extensive areas of tributary basins represent a persistent source of contaminant supply to the stream. Upon entering the surface-water system either by erosion of contaminated sediments

Table 3.--*Equations for estimating suspended-sediment concentration*

[Tau, Kendall's rank correlation coefficient; p, attained significance level; SE, standard error of estimate, in percent; SED, sediment concentration, in milligrams per liter; Q, streamflow, in cubic feet per second. <, less than]

Station	Equation	Tau	p	SE
Clark Fork near Galen	$SED = 0.0562(Q)^{1.10}$	0.64	<0.0001	100
Clark Fork at Deer Lodge:				
February-April	$SED = 0.000955(Q)^{1.88}$	.67	<.0001	94
May-January	$SED = 0.118(Q)^{1.02}$	.45	<.0001	122
Little Blackfoot River near Garrison	$SED = 0.00288(Q)^{1.53}$	.70	<.0001	116
Flint Creek near Drummond	$SED = 0.671(Q)^{0.829}$	.52	<.0001	106
Rock Creek near Clinton	$SED = 0.00141(Q)^{1.36}$	.66	<.0001	86
Clark Fork at Turah Bridge, near Bonner:				
February-April	$SED = 0.00123(Q)^{1.47}$	.58	<.0001	85
May-January	$SED = 0.00447(Q)^{1.15}$	.57	<.0001	70
Blackfoot River near Bonner:				
February-April	$SED = 0.00537(Q)^{1.08}$	.71	<.0001	70
May-January	$SED = 0.00129(Q)^{1.24}$	.68	<.0001	64
Clark Fork above Missoula:				
February-April	$SED = 0.00138(Q)^{1.25}$	.74	.0005	84
May-January	$SED = 0.00316(Q)^{1.02}$	.52	<.0001	76

or by discharge of contaminated ground water, the trace elements could attain concentrations that pose serious risk to either public drinking-water supplies or the viability of aquatic organisms through either acute or chronic toxicity. Acute toxicity is manifested by widespread death to large numbers of the aquatic population within a relatively short time as a result of rapid and large increases in trace-element concentrations. Several such episodes during 1985-90 killed thousands of trout and presumably other sensitive organisms. Chronic toxicity is manifested by suppression of normal biological functions over a long time as a result of trace-element concentrations that consistently exceed biological thresholds for impairment. Chronic toxicity does not cause death directly, but can affect the growth, reproduction, or other biological activities necessary to sustain a healthy population of aquatic organisms.

Regulations for trace-element concentrations in public drinking-water supplies have been established to protect human health (U.S. Environmental Protection Agency, 1989a). Primary Drinking-Water Regulations, which are reported as Maximum Contaminant Levels (MCL's), are legally enforceable for public drinking-water supplies. Secondary Drinking-Water Regulations, which are reported as Secondary Maximum Contaminant Levels (SMCL's), have been established to protect the esthetic qualities of drinking water (U.S. Environmental Protection Agency, 1989b). In addition, criteria for trace-element concentrations in water that would provide protection to a diverse range of aquatic organisms have been established (U.S. Environmental Protection Agency, 1986). These criteria are referred to as aquatic-life criteria.

Drinking-water regulations and aquatic-life criteria for trace elements are summarized in table 4. Because the degree of toxicity to aquatic life of cadmium, copper, lead, and zinc varies with the ambient hardness of the water, toxicity needs to be calculated on a site-specific basis. To provide a uniform basis for comparison, three levels of hardness have been included in the table along with the corresponding criteria for the trace element. The three levels represent the

Table 4.--*Drinking-water regulations and aquatic-life criteria for trace elements*

[MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level; --, no regulation or criterion available. Reported regulations and criteria apply to total-recoverable concentrations]

	Maximum concentration established for indicated regulation or criteria, in micrograms per liter				
			Freshwater aquatic-life criteria		
Element	Primary Drinking-Water Regulation (MCL)[1]	Secondary Drinking-Water Regulation (SMCL)[2]	Acute toxicity[3]	Chronic toxicity[3]	Hardness[4]
Arsenic	50	--	[5]360	[5]190	--
Cadmium	10	--	2.2	0.8	60
	--	--	4.8	1.3	120
	--	--	9.5	2.1	220
Copper	--	1,000	11	7.6	60
	--	--	21	14	120
	--	--	37	23	220
Iron	--	300	--	1,000	--
Lead	50	--	43	1.7	60
	--	--	103	4.0	120
	--	--	223	8.7	220
Manganese	--	50	--	--	--
Zinc	--	5,000	76	69	60
	--	--	137	124	120
	--	--	228	207	220

[1] U.S. Environmental Protection Agency (1989a).

[2] U.S. Environmental Protection Agency (1989b).

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

[4] Hardness, in milligrams per liter as calcium carbonate, is used to calculate aquatic-life criteria for selected trace elements. Equations for hardness-dependent criteria are reported by the U.S. Environmental Protection Agency (1986).

[5] Aquatic-life criteria reported for arsenic are for trivalent arsenic. Trivalent-arsenic concentrations are not directly comparable to the arsenic concentrations measured in this study, but represent the most conservative criteria to assess potential toxicity.

general range of median values measured at the sampling stations. The stations and hardness values used to calculate the aquatic-life criteria for cadmium, copper, lead, and zinc are:

Station	Hardness, in milligrams per liter as calcium carbonate
Clark Fork near Galen	220
Clark Fork at Deer Lodge	220
Clark Fork at Turah Bridge, near Bonner	120
Clark Fork above Missoula	120
Little Blackfoot River near Garrison	120
Flint Creek near Drummond	120
Rock Creek near Clinton	60
Blackfoot River near Bonner	60

Comparison of Periodic-Sample Concentrations to Drinking-Water Regulations

MCL's for drinking water have been established by the U.S. Environmental Protection Agency for three of the trace elements analyzed in this study--arsenic, cadmium, and lead. The statistical distribution of total-recoverable concentrations of these trace elements in water samples collected periodically during 1985-90 at each sampling station is shown in figures 6 to 8, respectively. The

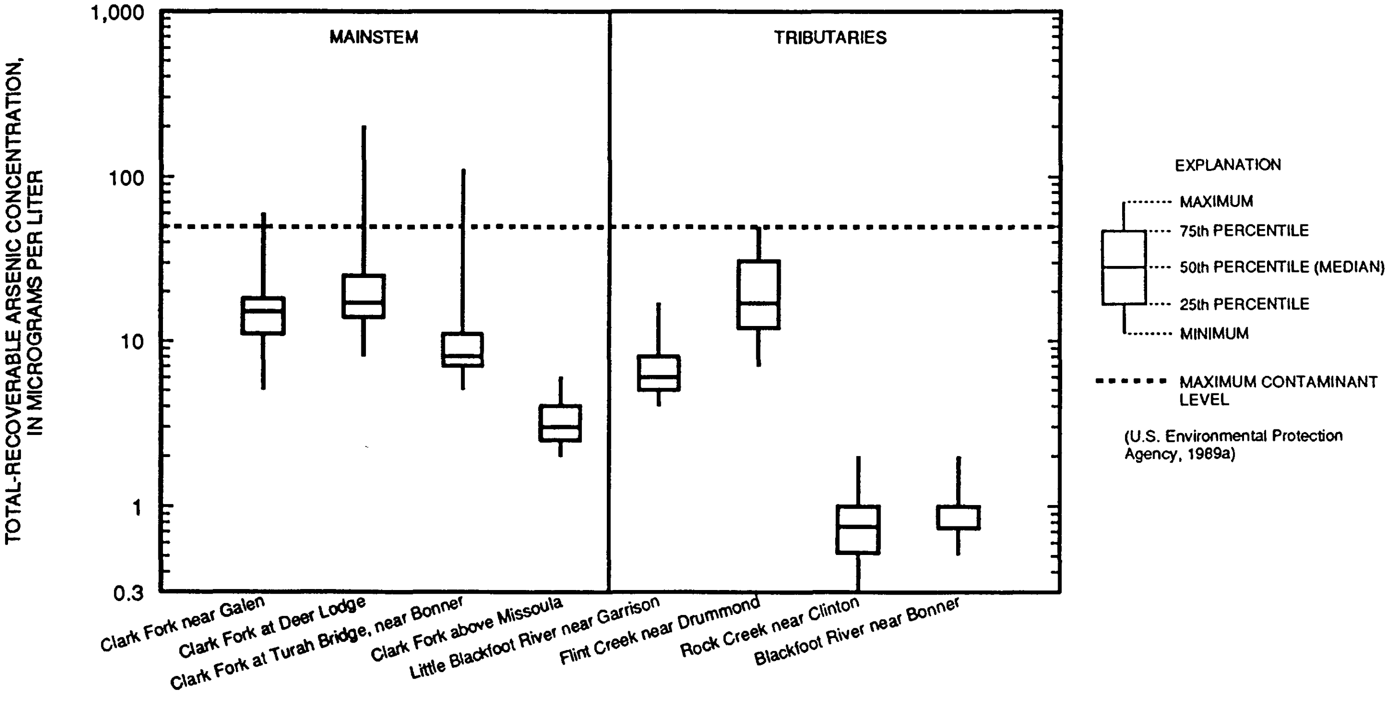

Figure 6.--Statistical distribution of total-recoverable arsenic concentrations in water samples collected periodically during 1985-90 compared to the Maximum Contaminant Level for public drinking-water supplies.

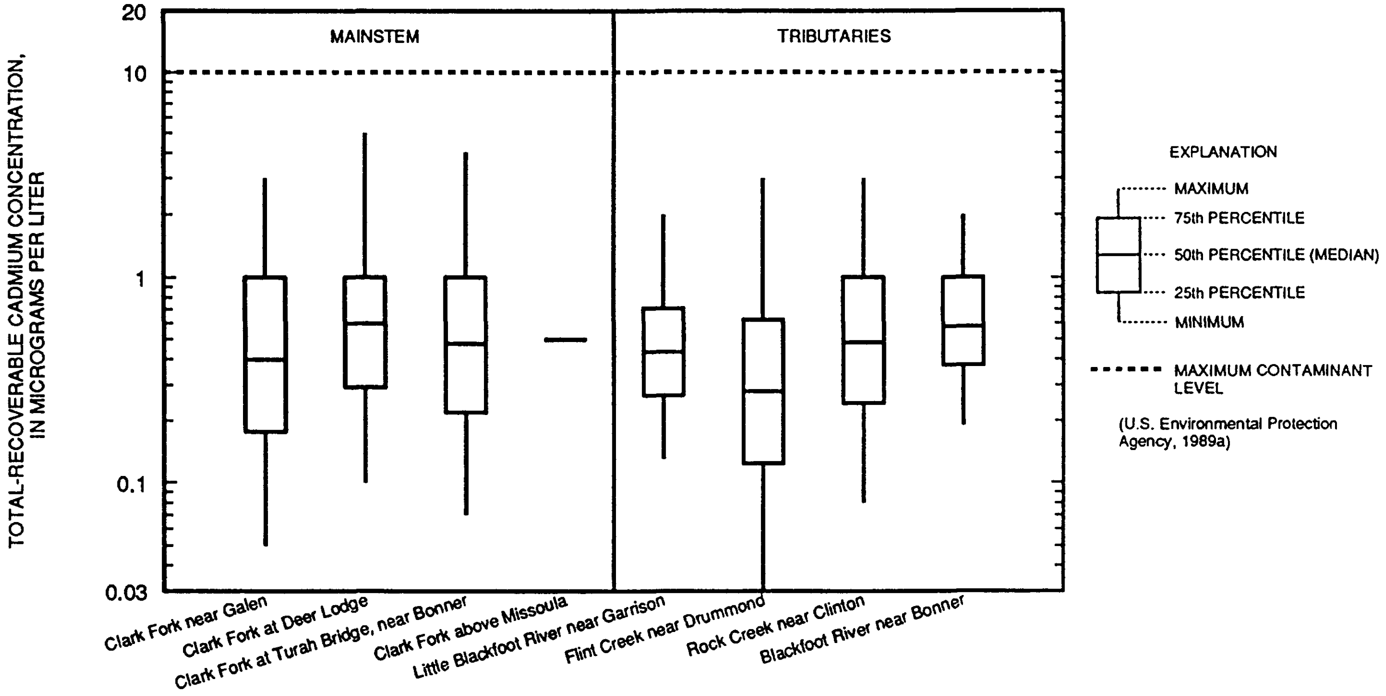

Figure 7.--Statistical distribution of total-recoverable cadmium concentrations in water samples collected periodically during 1985-90 compared to the Maximum Contaminant Level for public drinking-water supplies.

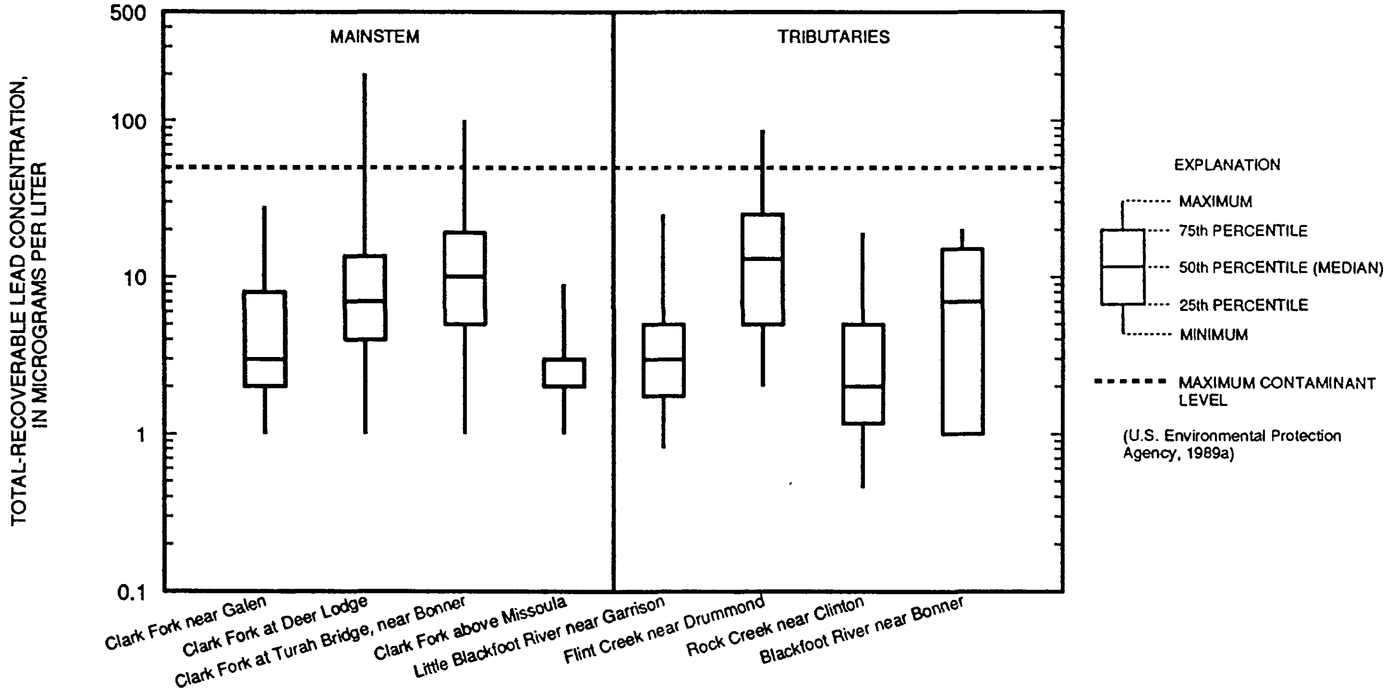

Figure 8.--Statistical distribution of total-recoverable lead concentrations in water samples collected periodically during 1985-90 compared to the Maximum Contaminant Level for public drinking-water supplies.

percentile distribution of values less than the minimum reporting level of 1 µg/L was estimated by log-probability regression (Helsel and Cohn, 1988). For some boxplots, a predominance of identical concentrations analyzed in the samples results in overlay of percentile lines, giving a modified box. A single horizontal line indicates that concentrations of all samples were identical. The MCL for drinking water for each trace element is also graphed to provide a reference to the proportion of samples that exceeded the established protective concentration.

The concentrations graphed in figures 6-8 represent only those instantaneous conditions that were present at the time of sampling. Unsampled short-term fluctuations in concentration may not be completely represented by the periodic samples; therefore, comparisons of measured concentrations to established protective concentrations are intended to illustrate only general water-quality characteristics at the stations.

The distribution of total-recoverable arsenic concentrations and the MCL of 50 µg/L are shown in figure 6. Maximum concentrations for the three upstream Clark Fork stations and Flint Creek either equaled or exceeded the MCL to varying degrees. The exceedances were greatest on the Clark Fork at Deer Lodge (maximum concentration of 200 µg/L) and at Turah Bridge, near Bonner (maximum concentration of 110 µg/L). Except for the maximum concentrations at these four stations, all other concentrations were less than the MCL, which indicates that the arsenic MCL for drinking water at the sampling stations is exceeded infrequently. Along the mainstem, concentrations increased from Galen to Deer Lodge, than decreased downstream. Arsenic concentrations in Rock Creek and the Blackfoot River were commonly less than 1 µg/L. Of the tributaries, Flint Creek had the largest arsenic concentrations, which, other than the maximum, were similar to those for the Clark Fork at Deer Lodge.

The distribution of total-recoverable cadmium concentrations and the MCL of 10 µg/L are shown in figure 7. All cadmium concentrations for 1985-90 were less than the MCL, and most were less than the minimum reporting level of 1 µg/L. These data indicate that exceedances of the cadmium MCL for drinking water are unlikely. No distinct differences in cadmium concentrations were noted among the stations.

The distribution of total-recoverable lead concentrations and the MCL of 50 µg/L are shown in figure 8. The two mainstem stations at Deer Lodge and at Turah Bridge, near Bonner, plus the tributary Flint Creek, had maximum concentrations that exceeded the lead MCL for drinking water. The exceedance was greatest for the Clark Fork at Deer Lodge (maximum concentration of 200 µg/L). With the exception of these three maximum values, all lead concentrations were less than the MCL. Similar to arsenic, lead concentrations increased in the mainstem from Galen to Deer Lodge. In contrast to arsenic, however, lead concentrations increased at the next downstream mainstem station at Turah Bridge, near Bonner. Farther downstream, concentrations decreased in the Clark Fork above Missoula. Flint Creek had the largest lead concentrations of the tributaries.

SMCL's for drinking water have been established for four of the trace elements analyzed in this study--copper, iron, manganese, and zinc. Because the effects of these trace elements on drinking water relate to esthetic, rather than health effects, the SMCL's are generally large relative to other criteria. Although some maximum concentrations of copper, manganese, and zinc were larger than SMCL's, only total-recoverable iron concentrations commonly exceeded the 300-µg/L SMCL at all stations.

Comparison of Periodic-Sample Concentrations to Aquatic-Life Criteria

Aquatic-life criteria have been established for six of the trace elements analyzed in this study--arsenic, cadmium, copper, iron, lead, and zinc. The statistical distribution of concentrations of these trace elements in water samples collected periodically during 1985-90 at each sampling station is shown in figures 9-14, respectively. The percentile distribution of values less than the minimum reporting level of 1 µg/L for arsenic, cadmium, and lead or 3 µg/L for iron and zinc was estimated by log-probability regression (Helsel and Cohn, 1988). One-half

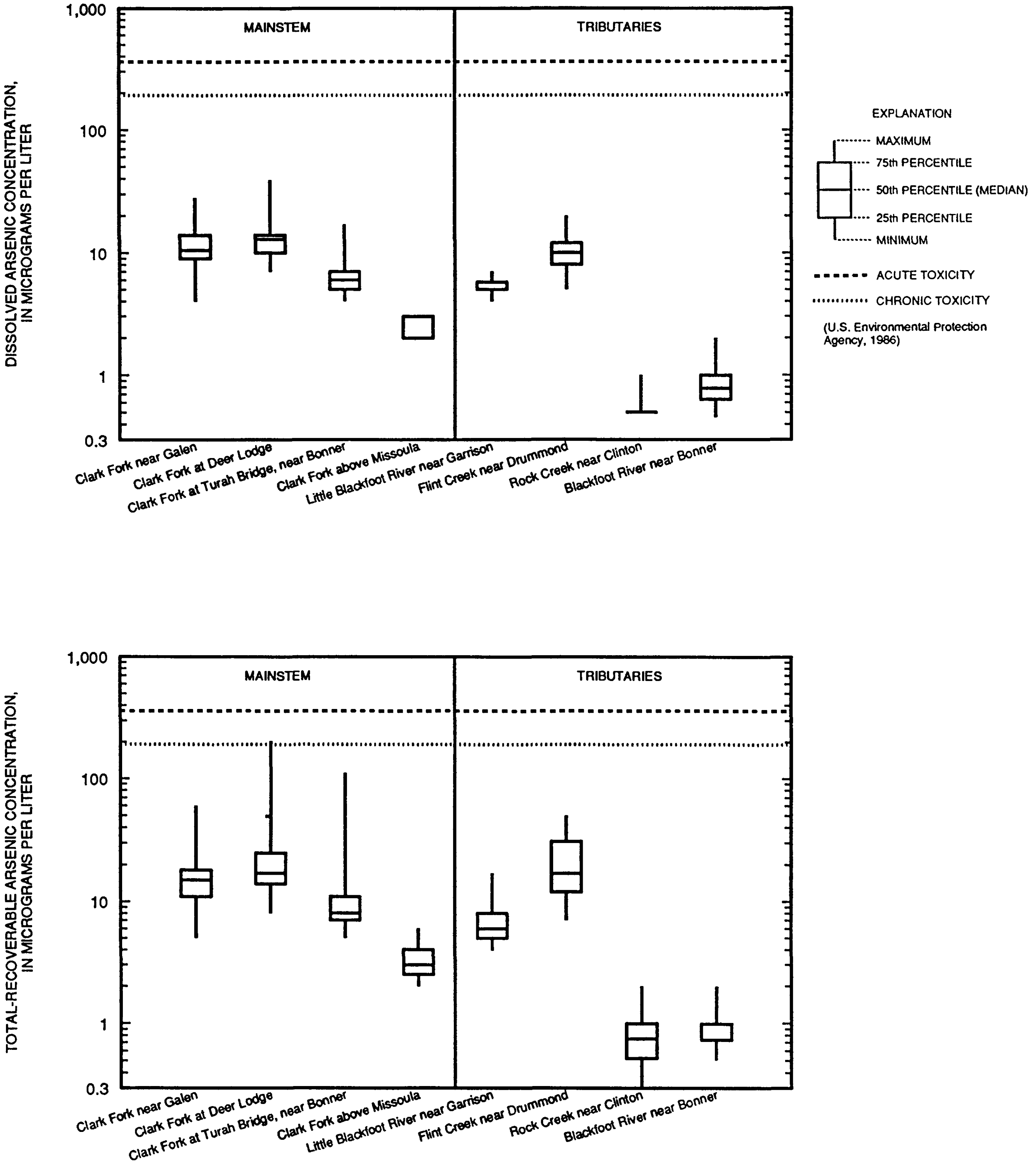

Figure 9.--Statistical distribution of dissolved and total-recoverable arsenic concentrations in water samples collected periodically during 1985-90 compared to aquatic-life criteria for acute and chronic toxicity.

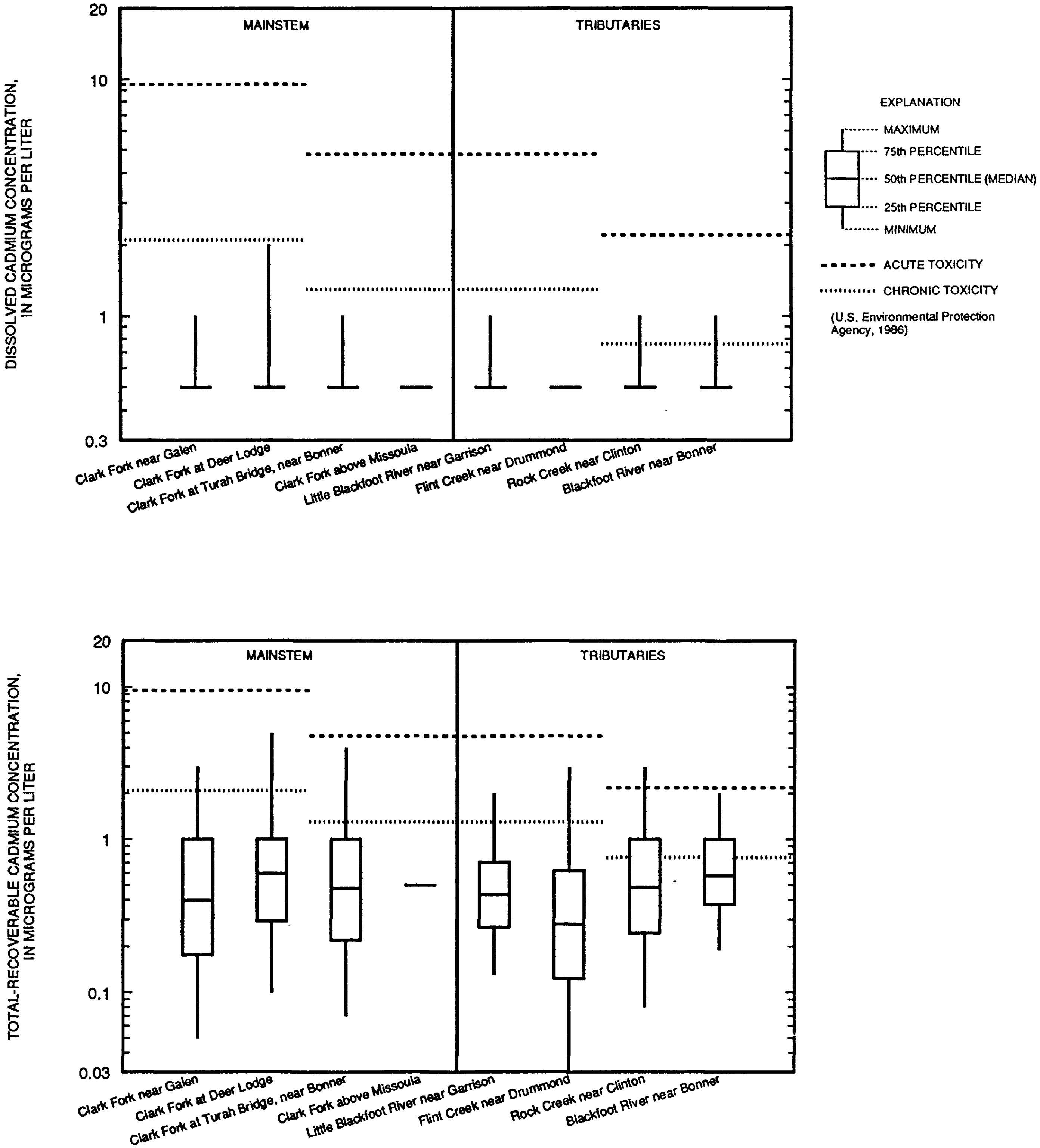

Figure 10.--Statistical distribution of dissolved and total-recoverable cadmium concentrations in water samples collected periodically during 1985-90 compared to aquatic-life criteria for acute and chronic toxicity. Variable criteria result from differences in water hardness among the stations (see table 4).

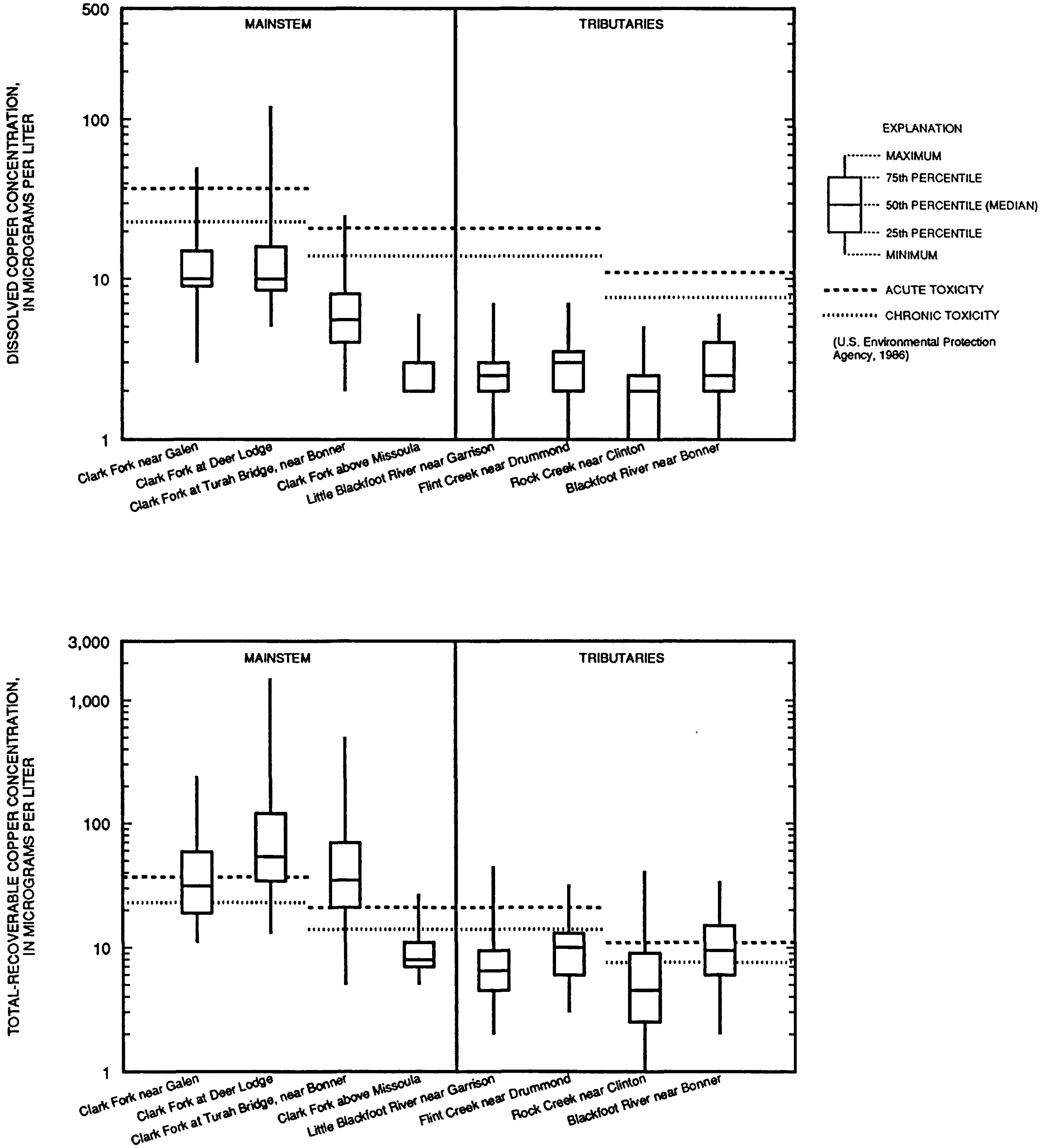

Figure 11.--Statistical distribution of dissolved and total-recoverable copper concentrations in water samples collected periodically during 1985-90 compared to aquatic-life criteria for acute and chronic toxicity. Variable criteria result from differences in water hardness among the stations (see table 4).

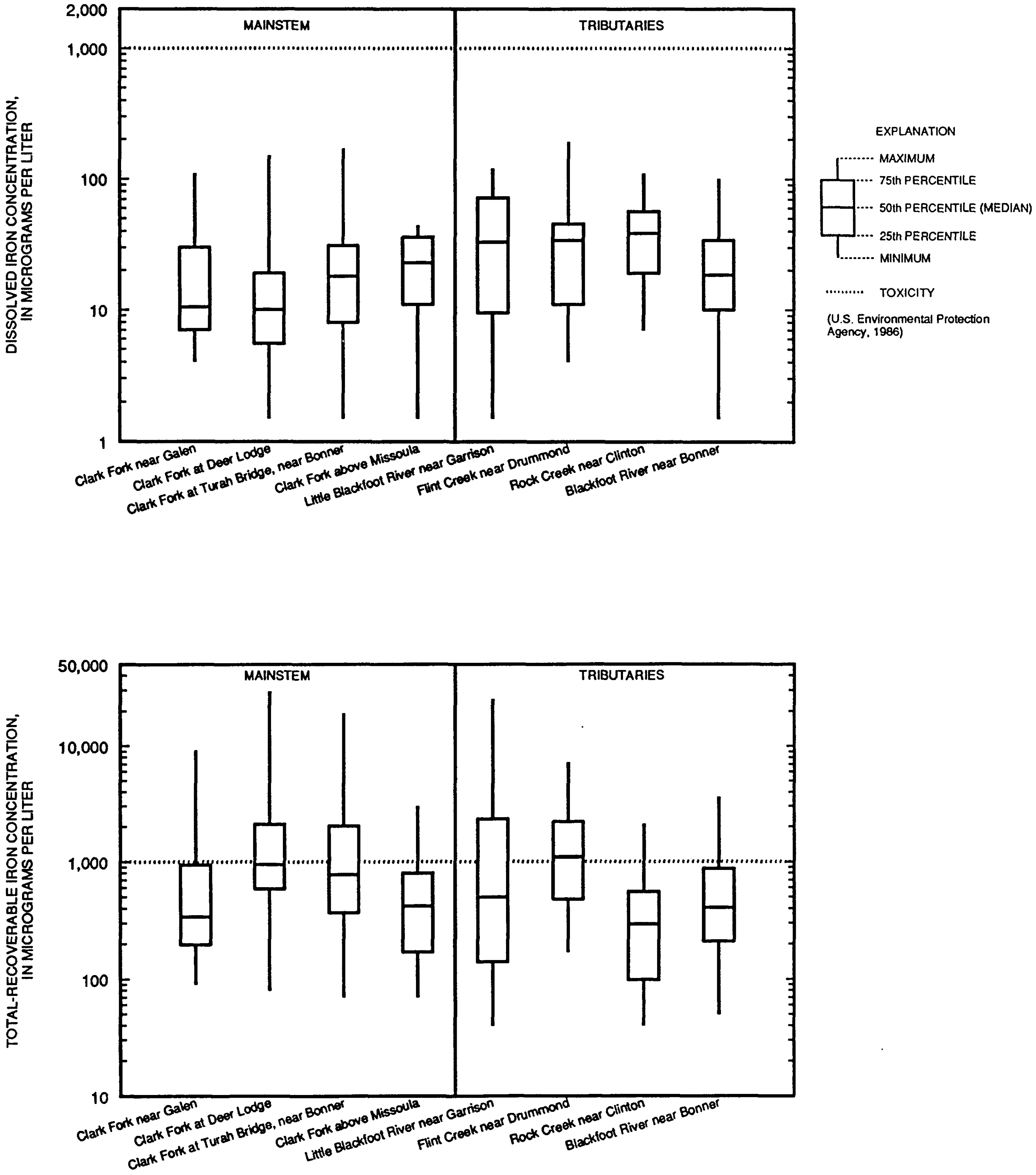

Figure 12.--Statistical distribution of dissolved and total-recoverable iron concentrations in water samples collected periodically during 1985-90 compared to aquatic-life criteria for toxicity.

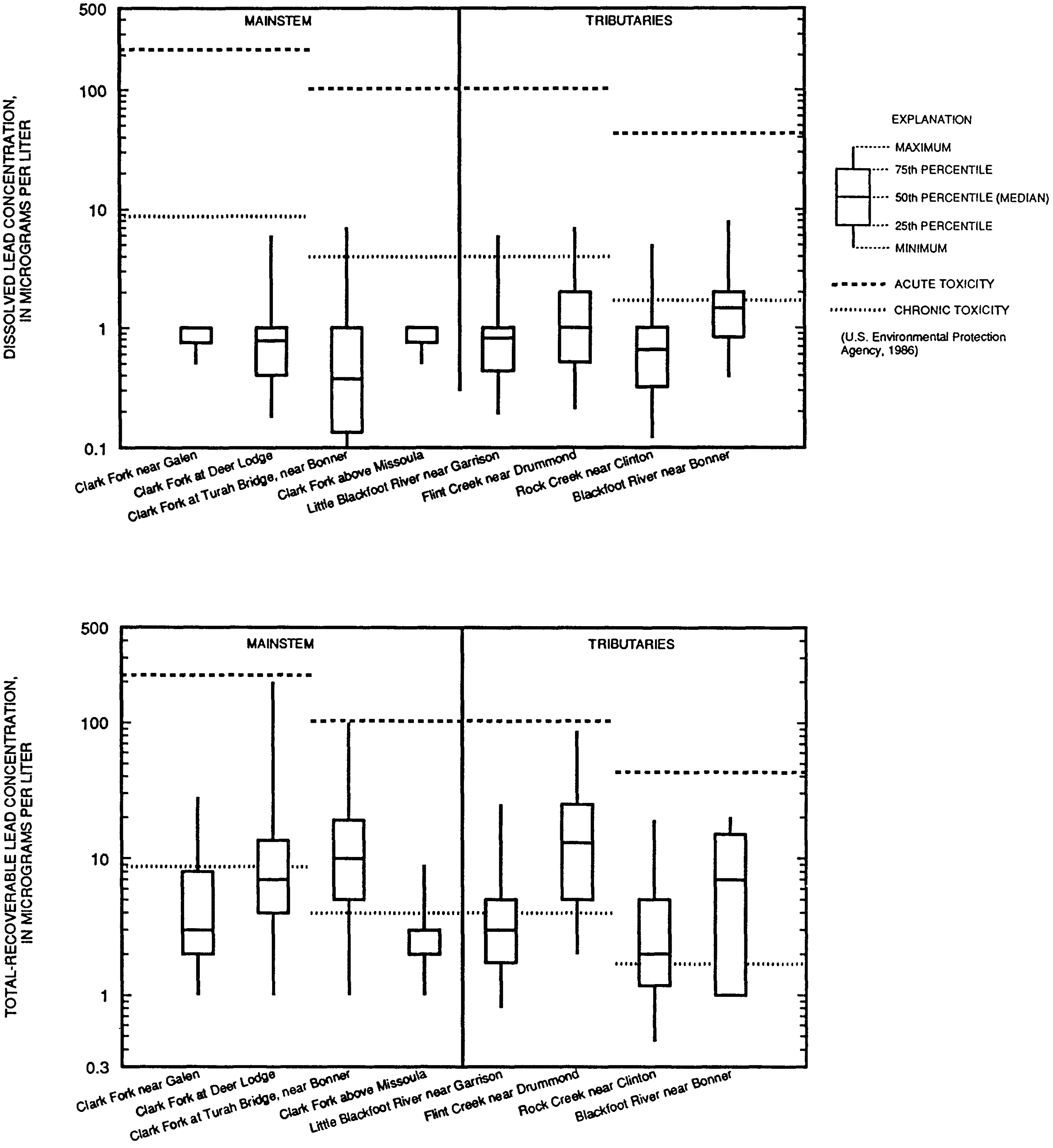

Figure 13.--Statistical distribution of dissolved and total-recoverable lead concentrations in water samples collected periodically during 1985-90 compared to aquatic-life criteria for acute and chronic toxicity. Variable criteria result from differences in water hardness among stations (see table 4).

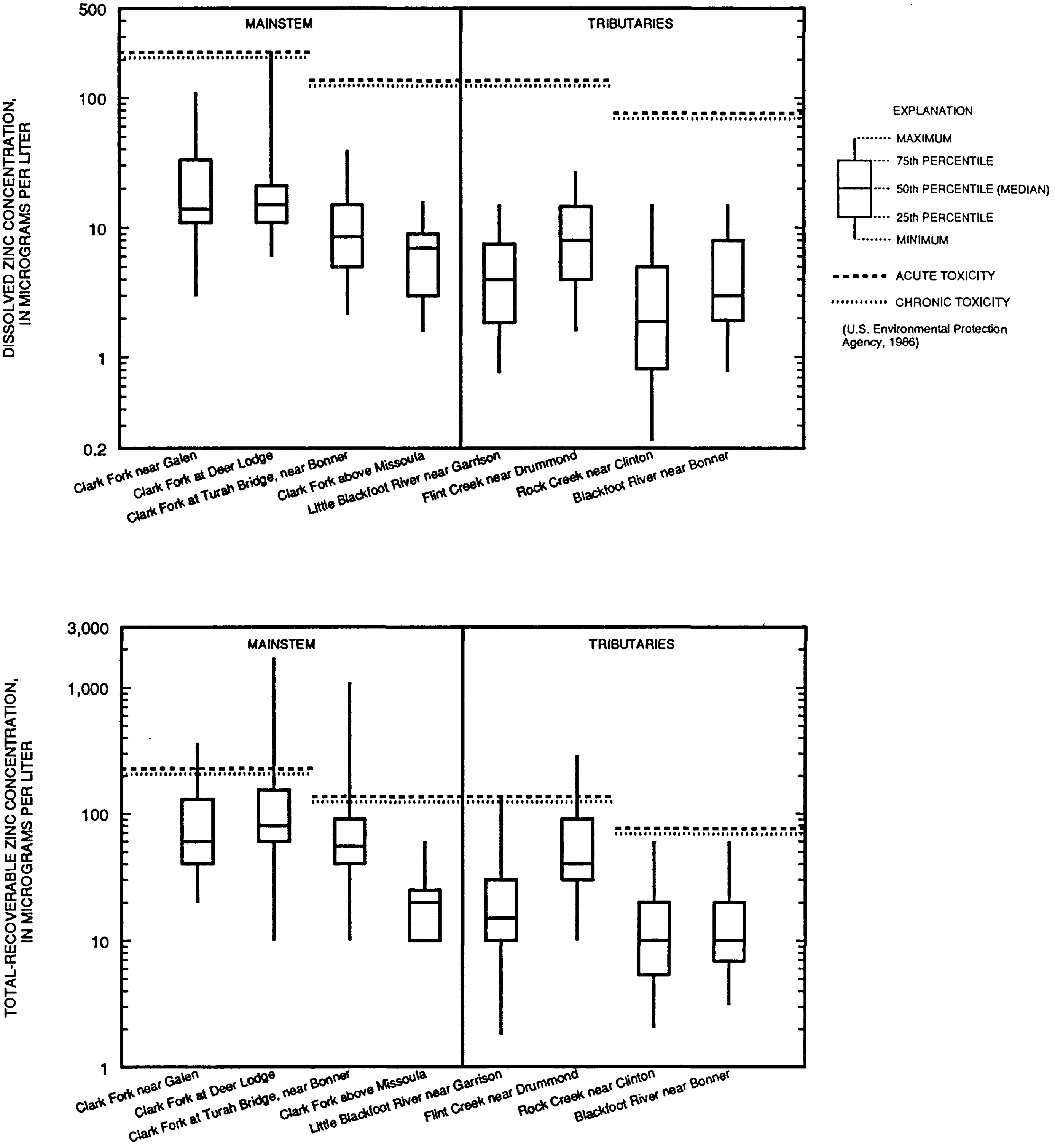

Figure 14.--Statistical distribution of dissolved and total-recoverable zinc concentrations in water samples collected periodically during 1985-90 compared to aquatic-life criteria for acute and chronic toxicity. Variable criteria result from differences in water hardness among stations (see table 4).

the minimum reporting level was used to plot the percentile distribution for arsenic and cadmium where the number of samples having concentrations greater than the minimum reporting level was insufficient to estimate a log-probability distribution. The aquatic-life criteria for each trace element are also graphed to provide a reference to the proportion of samples that exceeded the established protective concentration. For those trace elements whose toxicity varies with hardness (table 4), variable site-specific aquatic-life criteria are plotted.

Criteria for the protection of freshwater aquatic life generally are sufficiently small to protect the most sensitive organisms, rather than just a particular species. These conservative criteria are intended to afford the greatest degree of protection to the entire biological community. Because tolerances of aquatic organisms to trace elements can vary greatly either among species or within the same species acclimated to different environmental conditions, aquatic-life criteria are considered to be only a general reference to potential toxicity. National criteria reported by the U.S. Environmental Protection Agency (1986) apply to total-recoverable concentrations. However, because the criteria are subject to ongoing research and refinement, both dissolved and total recoverable trace-element concentrations in this report are compared to aquatic-life criteria.

The distribution of dissolved and total-recoverable arsenic concentrations relative to the aquatic-life criteria for acute (360 µg/L) and chronic (190 µg/L) toxicity are shown in figure 9. All dissolved and total-recoverable arsenic concentrations measured during 1985-90, except one, were less than criteria for toxicity. The exception was the maximum total-recoverable arsenic concentration of 200 µg/L for the Clark Fork at Deer Lodge, which slightly exceeded the chronic criterion. Most arsenic concentrations were substantially less than criteria, thereby indicating minimal potential for adverse effects to aquatic life from arsenic.

Dissolved and total-recoverable cadmium concentrations relative to aquatic-life criteria are shown in figure 10. Because cadmium toxicity varies with water hardness (table 4), three levels of criteria are shown for hardnesses of 220, 120, and 60 µg/L in downstream order. Evaluations of the toxic potential of cadmium to aquatic life are complicated by the fact that the criteria for chronic toxicity, especially for waters having little hardness, are very near or less than the minimum reporting level of 1 µg/L. Consequently, the precision limits of the analytical method may not provide a sufficient level of accuracy to conclusively determine if criteria actually were exceeded. Given this limitation, cadmium data are evaluated only in general terms.

Almost all dissolved cadmium concentrations were less than the minimum reporting level (fig. 10). Total-recoverable cadmium was also at or less than the minimum reporting level in most samples, with the 75th percentile concentration at all stations being 1 µg/l or less. Several maximum concentrations of total-recoverable cadmium were greater than 1 µg/L, with the largest being 5 µg/L for the Clark Fork at Deer Lodge. The maximum total-recoverable concentrations for the three upstream mainstem stations exceeded the chronic toxicity criteria. The maximum total-recoverable concentrations for all tributaries exceeded the chronic criteria, and the maximum concentration of 3 µg/L in Rock Creek exceeded the acute criterion. Whether these exceedances represent actual toxic potential is uncertain, because of the possibility of reported values being affected by analytical imprecision for concentrations near the minimum reporting level. The small cadmium criteria, coupled with a predominance of concentrations less than the minimum reporting level, make evaluations of cadmium toxicity generally inconclusive.

Dissolved and total-recoverable copper concentrations relative to aquatic-life criteria are shown in figure 11. The hardness-dependent criteria for copper are reported in table 4. Copper is of particular concern in the Clark Fork basin because fishkills in the upper reaches of the mainstem have been at least partly attributed to copper toxicity (Phillips, 1985, p. 57). The specific cause of acute toxicity may include several environmental factors, but the data on copper are instructive with respect to established criteria.

The maximum dissolved copper concentrations for the periodic samples exceeded both acute and chronic toxicity criteria only at the three upstream mainstem stations (fig. 11). The boxplots show that maximum total-recoverable copper concentrations were in exceedance of both acute and chronic toxicity criteria at all mainstem and tributary stations. At several stations, total-recoverable copper concentrations exceeded the criteria in more than 50 percent of the samples. The largest dissolved and total-recoverable concentrations were measured in the Clark Fork mainstem from Galen to Turah Bridge, near Bonner. The Clark Fork above Missoula had copper concentrations similar to those of the tributaries.

The large number of samples in which total-recoverable copper concentrations exceeded criteria for both acute and chronic toxicity clearly indicates a persistent source of copper in the sediment of the upper Clark Fork basin, especially along the upper mainstem. Acute toxicity in the form of fishkills has been observed several times in recent years at the two mainstem stations near Galen and at Deer Lodge. No similar acute toxicity has been observed at the other stations, although all maximum total-recoverable copper concentrations exceeded the acute criteria. In fact, no acute toxicity was observed at the upper mainstem stations during the occurrence of maximum total-recoverable concentrations, which sometimes greatly exceeded the acute criteria. Because the maximum total-recoverable concentrations commonly occur during runoff when much sediment is suspended and streamflows are large, dead organisms may be difficult to observe. Even then, a significant fishkill is unlikely to be completely undetected although less extensive episodes of lethality may occur. Therefore, acute toxicity is probably not widespread during high flow when total-recoverable copper concentrations are large. However, the potential for chronic toxicity as a result of large total-recoverable concentrations cannot be discounted, but is difficult to infer because of the many ways in which chronic effects can be manifested.

The correlation of maximum dissolved copper concentrations to the occurrence of acute toxicity may offer some insight to the applicability of aquatic-life criteria. The maximum dissolved copper concentration measured during 1985-90 was 120 µg/L in the Clark Fork at Deer Lodge during a fishkill on July 12, 1989, in the mainstem reach upstream from Deer Lodge. This concentration is more than three times greater than the acute toxicity criterion. By comparison, the maximum total-recoverable copper concentration, also measured at Deer Lodge but on a different date (March 10, 1989), was 1,500 µg/L--more than 40 times the acute criterion. No fishkill was observed when the total-recoverable concentration was 1,500 µg/L, thereby indicating that the aquatic-life criterion for acute toxicity may be more applicable to dissolved rather than total-recoverable concentrations of trace elements.

Dissolved and total-recoverable copper attained maximum concentrations under different hydrologic conditions. These conditions may have been partly responsible for the degree of toxicity. The maximum dissolved concentration occurred during summer low-flow conditions. An intense rainstorm in the upper mainstem had caused rapid dissolution and flushing of metal salts from tailings along the flood plain into the stream. Localized and short-lived suppression of pH to toxic or stressful levels also could have been partly responsible for the acute toxicity. The maximum total-recoverable concentration occurred during spring snowmelt runoff when much of the winter ice cover on the stream was undergoing breakup and both streamflow and suspended-sediment concentrations were relatively large. In general, the conditions responsible for acute toxicity are presumably of short duration as indicated by relatively small copper concentrations the day after the fishkill (July 13, 1989) in the Clark Fork near Galen.

The acute criteria also were exceeded by dissolved copper at the Clark Fork near Galen and the Clark Fork at Turah Bridge, near Bonner. No known fishkills were associated with these minor exceedances, which occurred during snowmelt runoff. The lack of fishkills may indicate either that corresponding factors associated with summer low flow contribute to acute toxicity or that the acute criterion provides a conservative margin of safety.

Specific effects of the dissolved and total-recoverable phases of copper on chronic toxicity are not known. However, chronic effects are believed to be present to variable degrees along the mainstem as evidenced by significant decreases in trout populations along various reaches of the Clark Fork (Phillips, 1985).

The distribution of dissolved and total-recoverable iron concentrations relative to the aquatic-life criterion are shown in figure 12. The criterion of 1,000 µg/L (U.S. Environmental Protection Agency, 1986) is not identified as representing either acute or chronic toxicity, but for discussion is assumed to represent chronic toxicity. All concentrations of dissolved iron were considerably less than the criterion. In contrast, the maximum total-recoverable iron concentrations exceeded 1,000 µg/L at all sites, some by very large margins. The maximum total-recoverable iron concentration was 29,000 µg/L in the Clark Fork at Deer Lodge. Because iron has limited solubility in aerated waters, it is strongly associated with suspended sediment and shows large increases in total-recoverable concentration during runoff. The biological effect of large concentrations of iron is not well understood, and iron is not generally implicated as a direct cause of toxicity. However, hydrous iron oxides are known to concentrate certain trace elements in aquatic systems (Horowitz, 1985) and may contribute indirectly to toxicity.

The distribution of dissolved and total-recoverable lead concentrations relative to aquatic-life criteria are shown in figure 13. The hardness-dependent criteria for lead are reported in table 4. Dissolved lead concentrations at all stations were commonly less than the minimum reporting level of 1 µg/L. The maximum dissolved lead concentrations at several stations exceeded the chronic toxicity criteria. The greatest percentage of exceedances for dissolved lead occurred in the Blackfoot River near Bonner, where more than 25 percent of the samples had lead concentrations greater than the chronic criterion. However, whether the number of exceedances represents a serious toxic potential for lead is uncertain because the criteria are so close to the minimum reporting level.

Maximum concentrations of total-recoverable lead exceeded the chronic criteria at every station (fig. 13). Most notable is the fact that at the Clark Fork at Turah Bridge, near Bonner and at three of the four tributaries, more than 50 percent of the samples exceeded the lead criteria for chronic toxicity. The largest maximum total-recoverable lead concentration (200 µg/L) was measured at Clark Fork at Deer Lodge; there, the concentration was more than 20 times the chronic criterion and was nearly at the acute criterion. Also, the Clark Fork at Turah Bridge, near Bonner and Flint Creek near Drummond had maximum concentrations near the acute criterion. The relatively large percentage of samples at some stations that exceeded chronic criteria indicate the presence of a persistent source of lead in the basin upstream from those stations.

The distribution of dissolved and total-recoverable zinc concentrations relative to aquatic-life criteria are shown in figure 14. The hardness-dependent criteria for zinc are reported in table 4. Because the difference between chronic and acute criteria for zinc is small, the two levels of potential toxicity relative to the distribution of sample concentrations are difficult to distinguish. In general, dissolved zinc concentrations in the mainstem decrease in a downstream direction and, except for one sample, were at concentrations less than the criteria. The exception was the sample collected from the Clark Fork at Deer Lodge during the fishkill on July 12, 1989. In that sample, the dissolved zinc concentration was 230 µg/L, which slightly exceeded the acute criterion and may have been responsible for the lethal effects either directly or in combination with the effects of other metals. Dissolved zinc concentrations in the tributaries were largest in Flint Creek, but were substantially less than criteria at all tributary stations.

The maximum total-recoverable zinc concentrations measured at three mainstem and two tributary stations exceeded criteria for both acute and chronic toxicity. However, total-recoverable zinc concentrations in all other samples were less than either criteria. As with copper, the maximum total-recoverable zinc concentrations in the mainstem greatly exceeded acute criteria during several periods of runoff, but no evidence of widespread biological mortality was observed at those times. This similar biological response to the dissolved and total-recoverable phases of copper and zinc may support the conclusion that criteria for acute toxicity may be more applicable to dissolved rather than total-recoverable concentrations of trace elements.

Relations between Trace Elements and Suspended Sediment

Trace-element concentrations during various hydrologic conditions can be estimated from mathematical relations developed between sampled concentrations of trace elements and a related constituent, such as suspended sediment. Use of such correlations are advantageous when the related constituent can be measured more readily and inexpensively. When suspended-sediment concentrations are measured daily or estimated from a continuous record of streamflow, the duration as well as the magnitude of trace-element concentrations can be estimated. Estimates of the duration of trace-element concentrations may be useful in evaluating potential impacts by providing a measure of the persistence of degraded conditions in the aquatic environment.

Many trace elements are strongly bound to sediment by various sorption mechanisms (Horowitz, 1985). Therefore, statistically significant relations commonly exist between the concentrations of trace elements and suspended sediment. The strength of association with sediment varies among the trace elements, with the greater correlations existing for those that are most strongly bound to the sediment. As an example of trace element-sediment association, the median concentrations of dissolved and total-recoverable copper for each of the sampling stations are shown in figure 15. The difference in height between the paired bars indicates the proportion of the element that is in the suspended phase, which is substantial for total-recoverable copper. In general, the median percentage of copper in suspension ranged from 50 percent in Rock Creek to more than 80 percent in the Clark Fork at Deer Lodge and Clark Fork at Turah Bridge, near Bonner. On the basis of similar graphs presented by Lambing (1990, p. 13-15), trace elements

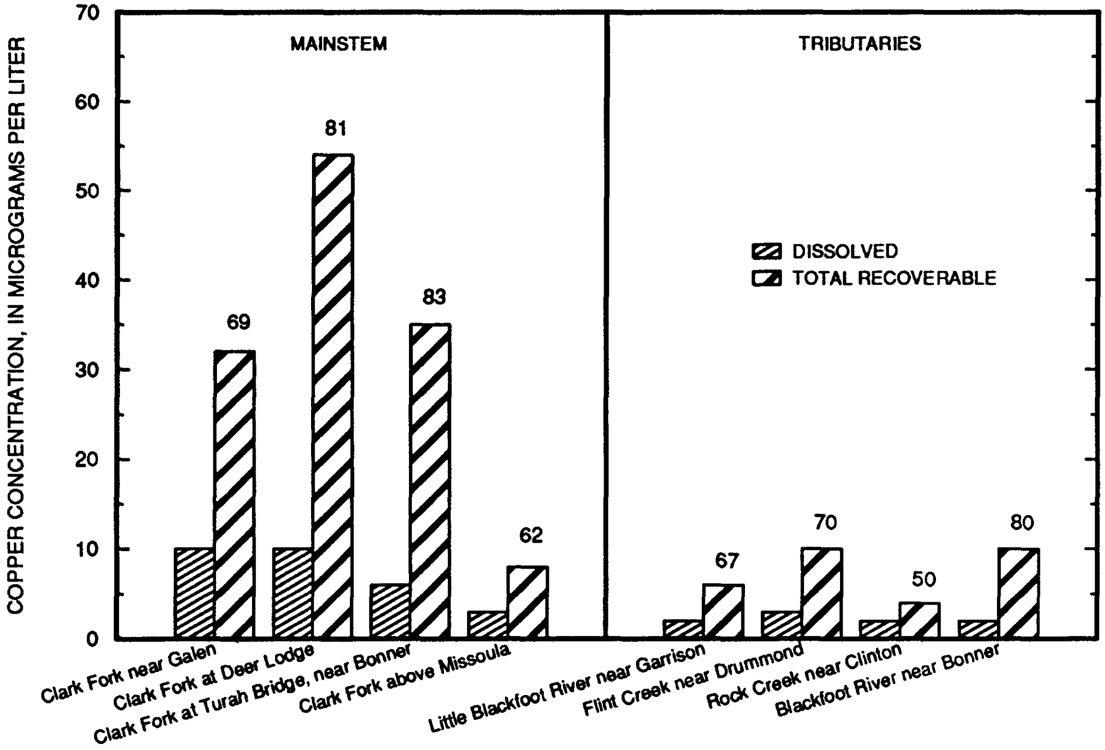

Figure 15.--Median concentrations of dissolved and total-recoverable copper in water samples collected periodically during 1985-90. Number above bar represents the percentage of total-recoverable copper that is in suspension.

strongly associated with suspended sediment are copper, iron, lead, manganese, and zinc. Arsenic is generally less strongly bound to sediment, as indicated by relatively small differences between dissolved and total-recoverable concentrations.

Equations for estimating total-recoverable trace-element concentrations from suspended-sediment concentrations are presented in tables 5-10. The relations between trace-element and suspended-sediment concentrations were developed using ordinary least-squares regression. This procedure was chosen because of its smaller variance relative to nonparametric regression when residuals are normally distributed. Unlike sediment-streamflow relations, which are supply controlled and are affected by processess such as hysteresis, the trace element-sediment relations are chemically controlled by the trace-element content of the sediment.

The original data were logarithmically transformed prior to regression analysis. All equations are log-linear, and with few exceptions, have an attained significance level equal to or less than 0.05. Because relations between total-recoverable cadmium and suspended-sediment concentrations were not significant owing to the predominance of values less than minimum reporting level, they are not included in the tables. Development of seasonal relations was not attempted because of an insufficient number and seasonal distribution of trace-element samples. Ranges of standard errors of estimate, in percent, for trace-element concentrations are: arsenic, 22-43; copper, 30-83; iron, 27-52; lead, 58-129; manganese, 29-70; and zinc, 34-79.

The relations presented in tables 5-10 can be used as a measure of the expected response of total-recoverable trace-element concentration to changes in suspended-sediment concentration. The source of the stream sediment is a major factor controlling the trace-element content and presumably is responsible for the relatively large scatter in some relations (as indicated by small R^2 values). Sediment originating from tailings-laden channel or flood-plain sources would be expected to have larger trace-element concentrations than that derived from upland sources. Although trace-element concentrations vary with sediment sources, the relations are informative for distinguishing relative differences in response characteristics between stations.

Comparison of equation slopes among the stations supports the general spatial patterns observed in the boxplots of trace-element concentrations. The greater the slope, as indicated by an increase in magnitude of the exponent, the greater the increase in trace-element concentration for a given increase in suspended-sediment concentrations. For all the trace elements, the slopes of the equations are consistently large for the Clark Fork at Deer Lodge. Also, the slopes are large for most trace elements for the Clark Fork at Turah Bridge, near Bonner. Flint Creek commonly has the largest slopes of the tributaries. A downstream pattern in slopes is evident for the mainstem stations for all the trace elements. The equation slope increases in the 21.5 river miles from Galen to Deer Lodge, but is only slightly different 91.0 river miles downstream from Deer Lodge to Turah Bridge. From Turah Bridge to above Missoula, the equation slope decreases substantially as the Clark Fork passes through Milltown Reservoir and receives inflow from the Blackfoot River. In general, the trace element-sediment relations for the Clark Fork above Missoula are more similar to those of the Blackfoot River than those of the Clark Fork at Turah Bridge, near Bonner.

Estimated Duration of Exceedance of Aquatic-Life Criteria

The regression relations between trace-element and suspended-sediment concentrations (tables 5-10) were used to estimate the suspended-sediment concentration at which the total-recoverable trace-element concentration would equal the aquatic-life criteria. A duration analysis of daily mean suspended-sediment concentrations then was used to determine the percentage of time (as represented by the percentage of days during water years 1985-90) that the daily suspended-sediment concentrations equaled or exceeded this level. Duration statistics for suspended-sediment concentrations were estimated from daily values generated by the sediment-streamflow relations (table 3) for sites where a daily sediment record was not available.

Table 5.--*Equations for estimating total-recoverable arsenic concentration*

[R^2, coefficient of determination; p, attained significance level; SE, standard error of estimate, in percent; AS, arsenic concentration, in micrograms per liter; SED, suspended-sediment concentration, in milligrams per liter. <, less than]

Station	Equation	R^2	p	SE
Clark Fork near Galen	$AS = 7.29(SED)^{0.326}$	0.62	<0.001	40
Clark Fork at Deer Lodge	$AS = 3.93(SED)^{0.426}$	.69	<.001	41
Little Blackfoot River near Garrison	$AS = 3.79(SED)^{0.173}$	.69	<.001	22
Flint Creek near Drummond	$AS = 3.14(SED)^{0.454}$	.83	<.001	24
Rock Creek near Clinton	$AS = 0.446(SED)^{0.210}$	.35	.002	43
Clark Fork at Turah Bridge, near Bonner	$AS = 1.96(SED)^{0.415}$	.71	<.001	39
Blackfoot River near Bonner	$AS = 0.500(SED)^{0.187}$	.29	.004	42
Clark Fork above Missoula	$AS = 2.27(SED)^{0.111}$	.18	[1].199	34

[1] Regression relation not statistically significant.

Table 6.--*Equations for estimating total-recoverable copper concentration*

[R^2, coefficient of determination; p, attained significance level; SE, standard error of estimate, in percent; CU, copper concentration, in micrograms per liter; SED, suspended-sediment concentration, in milligrams per liter. <, less than]

Station	Equation	R^2	p	SE
Clark Fork near Galen	$CU = 10.2(SED)^{0.531}$	0.81	<0.001	40
Clark Fork at Deer Lodge	$CU = 3.95(SED)^{0.736}$	.80	<.001	54
Little Blackfoot River near Garrison	$CU = 2.38(SED)^{0.326}$	.67	<.001	44
Flint Creek near Drummond	$CU = 1.32(SED)^{0.493}$	.77	<.001	32
Rock Creek near Clinton	$CU = 1.71(SED)^{0.430}$	.42	.001	83
Clark Fork at Turah Bridge, near Bonner	$CU = 2.65(SED)^{0.686}$	.75	<.001	62
Blackfoot River near Bonner	$CU = 4.13(SED)^{0.257}$	.44	.002	61
Clark Fork above Missoula	$CU = 3.81(SED)^{0.312}$	.68	.002	30

Table 7.--*Equations for estimating total-recoverable iron concentration*

[R^2, coefficient of determination; p, attained significance level; SE, standard error of estimate, in percent; FE, iron concentration, in micrograms per liter; SED, suspended-sediment concentration, in milligrams per liter. <, less than]

Station	Equation	R^2	p	SE
Clark Fork near Galen	$FE = 69.2(SED)^{0.803}$	0.95	<0.001	29
Clark Fork at Deer Lodge	$FE = 23.4(SED)^{1.01}$	.94	<.001	37
Little Blackfoot River near Garrison	$FE = 29.5(SED)^{0.952}$	.97	<.001	31
Flint Creek near Drummond	$FE = 25.7(SED)^{0.942}$	.92	<.001	33
Rock Creek near Clinton	$FE = 45.7(SED)^{0.729}$	.82	<.001	52
Clark Fork at Turah Bridge, near Bonner	$FE = 18.2(SED)^{0.995}$	.96	<.001	32
Blackfoot River near Bonner	$FE = 28.2(SED)^{0.852}$	.86	<.001	51
Clark Fork above Missoula	$FE = 34.7(SED)^{0.881}$	.96	<.001	27

Table 8.--*Equations for estimating total-recoverable lead concentration*

[R^2, coefficient, of determination; p, attained significance level; SE, standard error of estimate, in percent; PB, lead concentration, in micrograms per liter; SED, suspended-sediment concentration, in milligrams per liter. <, less than]

Station	Equation	R^2	p	SE
Clark Fork near Galen	$PB = 1.18(SED)^{0.555}$	0.70	<0.001	59
Clark Fork at Deer Lodge	$PB = 0.330(SED)^{0.831}$	.82	<.001	58
Little Blackfoot River near Garrison	$PB = 1.51(SED)^{0.303}$	.34	.003	93
Flint Creek near Drummond	$PB = 0.482(SED)^{0.809}$	.74	<.001	60
Rock Creek near Clinton	$PB = 1.60(SED)^{0.288}$	.17	.046	115
Clark Fork at Turah Bridge, near Bonner	$PB = 0.931(SED)^{0.612}$	.58	<.001	88
Blackfoot River near Bonner	$PB = 4.54(SED)^{0.085}$	.01	[1] .570	129
Clark Fork above Missoula	$PB = 1.04(SED)^{0.315}$	.39	.039	59

[1] Regression relation not statistically significant.

Table 9.--*Equations for estimating total-recoverable manganese concentration*

[R^2, coefficient of determination; p, attained significance level; SE, standard error of estimate, in percent; MN, manganese concentration, in micrograms per liter; SED, supended-sediment concentration, in milligrams per liter. <, less than]

Station	Equation	R^2	p	SE
Clark Fork near Galen	$MN = 115(SED)^{0.449}$	0.76	<0.001	39
Clark Fork at Deer Lodge	$MN = 22.4(SED)^{0.652}$	.82	<.001	45
Little Blackfoot River near Garrison	$MN = 5.01(SED)^{0.715}$	.89	<.001	50
Flint Creek near Drummond	$MN = 13.8(SED)^{0.731}$	.90	<.001	29
Rock Creek near Clinton	$MN = 7.36(SED)^{0.361}$	.41	.001	69
Clark Fork at Turah Bridge, near Bonner	$MN = 5.73(SED)^{0.780}$	.93	<.001	32
Blackfoot River near Bonner	$MN = 4.89(SED)^{0.582}$	.62	<.001	70
Clark Fork above Missoula	$MN = 12.6(SED)^{0.479}$	.83	<.001	31

Table 10.--*Equations for estimating total-recoverable zinc concentration*

[R^2, coefficient of determination; p, attained significance level; SE, standard error of estimate, in percent; ZN, zinc concentration, in micrograms per liter; SED, suspended-sediment concentration, in milligrams per liter. <, less than]

Station	Equation	R^2	p	SE
Clark Fork near Galen	$ZN = 26.3(SED)^{0.413}$	0.53	0.001	63
Clark Fork at Deer Lodge	$ZN = 6.47(SED)^{0.702}$	.80	<.001	52
Little Blackfoot River near Garrison	$ZN = 4.25(SED)^{0.442}$	.70	<.001	58
Flint Creek near Drummond	$ZN = 3.33(SED)^{0.680}$	.80	<.001	41
Rock Creek near Clinton	$ZN = 4.81(SED)^{0.350}$	.34	.003	79
Clark Fork at Turah Bridge, near Bonner	$ZN = 3.57(SED)^{0.751}$	.91	<.001	34
Blackfoot River near Bonner	$ZN = 5.62(SED)^{0.263}$	.22	.017	78
Clark Fork above Missoula	$ZN = 11.0(SED)^{0.197}$	.18	[1] .192	64

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[1] Regression relation not statistically significant.

Duration estimates were made only for total-recoverable trace-element concentrations that are directly applicable to aquatic-life criteria for chronic toxicity (U.S. Environmental Protection Agency, 1986). Aquatic-life criteria for acute toxicity were not considered because of the inability of the relations to estimate the occurrence of short-lived changes in concentration that typically are responsible for lethal effects. MCL's for drinking water also were not considered because the Primary Drinking-Water Regulations are legally enforceable and require direct sampling and analysis. A graphical example of the procedure is shown in figures 16 and 17. The estimated percentages of time that total recoverable trace-element concentrations exceeded aquatic-life criteria for chronic toxicity during water years 1985-90 are listed in table 11.

The procedure for estimating the percentage of time that criteria are exceeded provides a very generalized measure of the duration of potentially toxic condi-

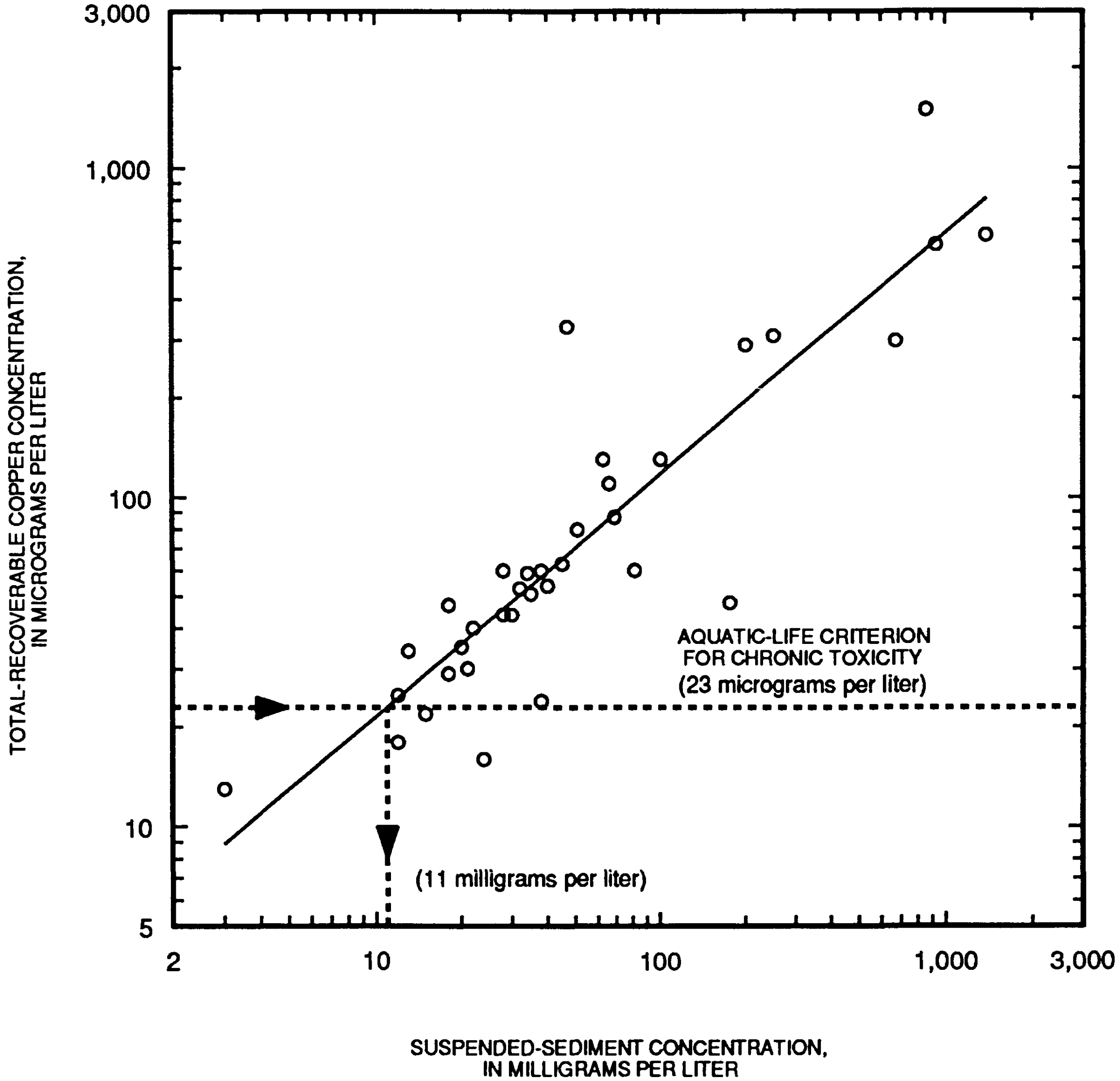

Figure 16.--Example of estimating the suspended-sediment concentration at which the total-recoverable copper concentration is equal to the aquatic-life criterion for chronic toxicity. Relation between total-recoverable copper and suspended-sediment concentrations is for the Clark Fork at Deer Lodge, 1985-90.

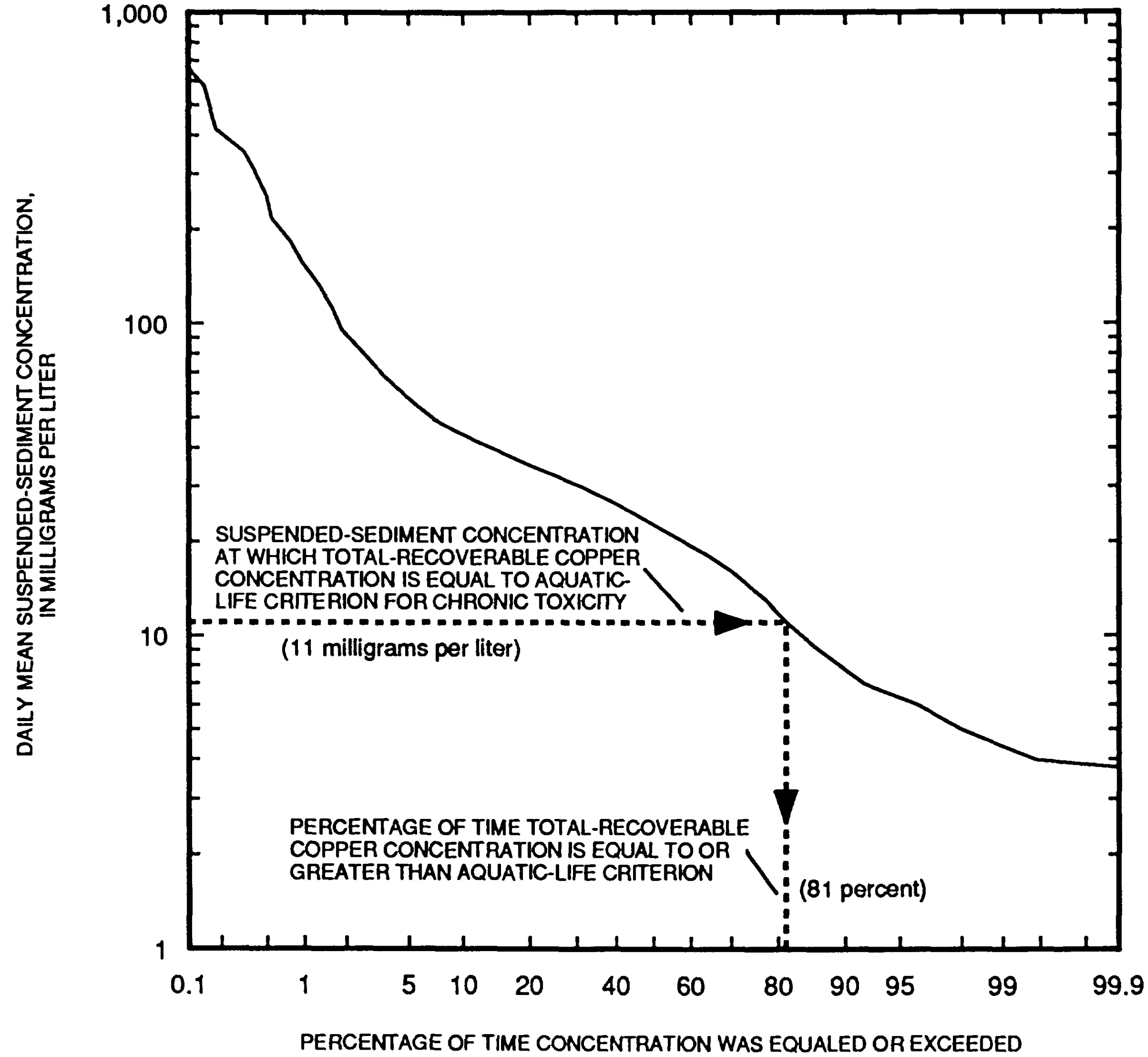

Figure 17.--Examples of estimating the percentage of time that total-recoverable copper concentration is equal to or greater than the aquatic-life criterion for chronic toxicity. Percentage is based on duration statistics of daily mean suspended-sediment concentration for the Clark Fork at Deer Lodge, water years 1985-90.

tions. These estimates are intended to provide relative comparisons between stations and are not intended to be accurate measures of actual duration at specific sites. Such duration estimates may be useful in assessing biological responses to variable lengths of exposure to degraded water quality.

The percentages of time that trace-element concentrations exceeded chronic toxicity criteria during water years 1985-90 were generally small, with the exception of total-recoverable copper and lead at some stations. Criteria exceedances less than 0.1 percent of the time indicate negligible potential for chronic toxicity. As an arbitrary reference, stations where criteria exceedances occur no more than about 5 percent of the time probably represent a situation where only several days per year exhibit potential chronic toxicity, presumably during peak streamflows. The margin of error in the estimates of exceedance may also make these small percentages generally insignificant. Stations where exceedances occur

Table 11.--*Estimated percentage of time that total-recoverable trace-element concentrations exceeded aquatic-life criteria for chronic toxicity during water years 1985-90*

[--, regression relation not statistically significant. <, less than; >, greater than]

Station	Aquatic-life criteria[1] for chronic toxicity, in micrograms per liter	Estimated suspended-sediment concentration at criteria, in milligrams per liter	Estimated percent of time criteria exceeded
Arsenic			
Clark Fork near Galen	190	22,000	<0.1
Clark Fork at Deer Lodge	190	9,000	<.1
Little Blackfoot River near Garrison	190	>100,000	<.1
Flint Creek near Drummond	190	8,400	<.1
Rock Creek near Clinton	190	>100,000	<.1
Clark Fork at Turah Bridge, near Bonner	190	61,000	<.1
Blackfoot River near Bonner	190	>100,000	<.1
Clark Fork above Missoula	190	--	--
Copper			
Clark Fork near Galen	23	5	71
Clark Fork at Deer Lodge	23	11	81
Little Blackfoot River near Garrison	14	230	<.1
Flint Creek near Drummond	14	120	1
Rock Creek near Clinton	7.6	32	3
Clark Fork at Turah Bridge, near Bonner	14	11	59
Blackfoot River near Bonner	7.6	11	24
Clark Fork above Missoula	14	65	3
Iron			
Clark Fork near Galen	1,000	28	3
Clark Fork at Deer Lodge	1,000	41	12
Little Blackfoot River near Garrison	1,000	40	2
Flint Creek near Drummond	1,000	49	12
Rock Creek near Clinton	1,000	69	.6
Clark Fork at Turah Bridge, near Bonner	1,000	56	6
Blackfoot River near Bonner	1,000	66	1
Clark Fork above Missoula	1,000	45	7
Lead			
Clark Fork near Galen	8.7	37	1
Clark Fork at Deer Lodge	8.7	51	7
Little Blackfoot River near Garrison	4.0	25	6
Flint Creek near Drummond	4.0	14	82
Rock Creek near Clinton	1.7	--	--
Clark Fork at Turah Bridge, near Bonner	4.0	11	59
Blackfoot River near Bonner	1.7	--	--
Clark Fork above Missoula	4.0	72	3
Zinc			
Clark Fork near Galen	207	150	<.1
Clark Fork at Deer Lodge	207	140	1
Little Blackfoot River near Bonner	124	2,100	<.1
Flint Creek near Drummond	124	200	.2
Rock Creek near Clinton	69	2,000	<.1
Clark Fork at Turah Bridge, near Bonner	124	110	2
Blackfoot River near Bonner	69	14,000	<.1
Clark Fork above Missoula	124	--	--

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[1] Criteria for copper, lead, and zinc vary with water hardness (see table 4).

more than 10 percent of the time might represent a situation where selected trace-element concentrations are increased periodically in response to short-lived hydrologic conditions. Stations where criteria are exceeded more than 50 percent of the time indicate a persistent occurrence of concentrations that could put the health of the aquatic community at risk. Stations with frequent exceedances of chronic criteria might also experience large peak concentrations that could, at times, exceed acute criteria.

Total-recoverable concentrations of arsenic, iron, and zinc rarely exceeded criteria for chronic toxicity. Arsenic and zinc concentrations consistently were less than the criteria at all stations. Iron, not generally regarded as a toxic constituent, exceeded criteria at a frequency ranging from less than 1 to 12 percent of the time. No estimate was made of the frequency at which cadmium exceeded criteria, because relations between cadmium and suspended sediment were not statistically significant and minimum reporting levels were near or greater than some of the hardness-dependent criteria.

Only total-recoverable copper and lead concentrations exceeded chronic toxicity criteria more than 50 percent of the time at some stations (table 11). Copper concentrations were commonly greater than criteria at the three upper mainstem stations. The frequency of exceedance for copper in the mainstem increased from Galen to Deer Lodge, then decreased downstream at Turah Bridge, near Bonner. For these three stations, the percentage of time that copper concentrations exceeded criteria ranged from 59 percent at Turah Bridge, near Bonner to 81 percent at Deer Lodge. The percentage of time that copper concentrations exceeded criteria in the Clark Fork above Missoula was 3 percent--much less than that of the mainstem stations upstream from Milltown Reservoir. The only tributary that showed a relatively frequent occurrence of copper concentrations in excess of the criteria was the Blackfoot River, where criteria were exceeded 24 percent of the time.

The duration characteristics of total-recoverable lead concentrations were substantially different from those of copper. Lead concentrations at the two mainstem stations near Galen and at Deer Lodge were greater than criteria less than 10 percent of the time. In contrast, lead concentrations exceeded the criteria in the Clark Fork at Turah Bridge, near Bonner 59 percent of the time. This increase in concentration at Turah Bridge, near Bonner indicates that there may be substantial sources of lead other than the Clark Fork basin upstream from Deer Lodge. Evidence supporting a source of lead other than the upper mainstem might be the duration characteristics for lead concentrations in Flint Creek near Drummond, where the concentrations exceeded criteria 82 percent of the time.

Trace-Element Content of Suspended Sediment

The trace-element and suspended-sediment concentrations determined from periodic water-quality samples can be used to indirectly estimate the quantity of trace element per unit mass of sediment. This type of measurement excludes the diluting or concentrating effect of streamflow volumes, and indicates the trace-element content of the particulate matter suspended in the stream. Knowledge of the trace-element content of sediment at various locations in the basin can assist in determining the chemical characteristics of sediment sources upstream from the sampling station. This information, in turn, can be used to identify areas of the basin that contain sediments having a relatively large trace-element content with respect to reference concentrations from areas less likely to contain contaminated sediments.

The trace-element content of suspended sediment as used in this report is not strictly equivalent to direct analysis of the sediment by chemical extraction methods. Direct analysis of sediment to determine trace-element concentration is the preferred method. In the absence of such data, the indirect computation can provide useful information for comparisons between stations. Data describing the distribution of trace elements in the channel and flood-plain sediments of the Clark Fork and selected tributaries determined by direct analysis are presented in Moore (1985).

In the indirect method, the dissolved trace-element concentration was subtracted from the total-recoverable concentration measured in the water sample (one-half the minimum reporting level was substituted for concentrations reported as less than a given minimum reporting level). The difference was assumed to represent the concentration of the trace element that was attached directly to the sediment suspended in the water. The concentration of the trace element in suspension was then divided by the suspended-sediment concentration measured in the water sample. This value was multiplied by 1,000 to give a mass-ratio concentration in micrograms of trace element per gram of suspended sediment (parts per million).

Bar graphs in figures 18-23 illustrate the variation in trace-element content of suspended sediment at the sampling stations during 1985-90. Median concentrations were plotted to represent the general trace-element characteristics of fluvial sediment at each station, and then the between-site geographic variation was compared. Cadmium was not plotted because median concentrations of suspended cadmium were less than the minimum reporting level at all stations.

The assessment of whether fluvial sediments at individual sites are enriched with trace elements is not quantitative, but can be made in a relative sense by comparing values from individual sites with values from sites believed to be generally uncontaminated. For this discussion, two sites were assumed to have relatively uncontaminated sediments and thus were used as references for comparison--Rock Creek near Clinton and the Blackfoot River near Bonner. Rock Creek has had minimal cultural development, whereas the Blackfoot River basin has had isolated areas of intensive mining. The small areal extent of mining in the upper Blackfoot River basin relative to the overall basin size probably results in minimal effect on the trace-element content of the fluvial sediments sampled near the mouth of the basin. Although these two stations should provide a suitable index of assumed background concentrations, natural geologic variation between basins may be a factor in observed differences that are not directly attributable to the effects of mining.

The most obvious characteristic in the graphs is the consistent downstream decrease in trace-element content of suspended sediment along the mainstem (with the exception of iron in the Clark Fork above Missoula). The decreases presumably occur as a function of distance from the Butte-Anaconda mining and smelting district and result from a gradual mixing of contaminated tailings with cleaner downstream channel and tributary sediments. Although concentrations decreased, the three mainstem stations upstream from Milltown Reservoir commonly contained larger concentrations than the background index stations on Rock Creek and the Blackfoot River. Trace-element concentrations of the suspended sediment in the Clark Fork above Missoula were similar to those of the index tributaries as a result of deposition of a part of the sediment load in Milltown Reservoir and dilution from Blackfoot River sediments.

The arsenic, manganese, and zinc content in the suspended sediment significantly decreased in the 21.5-mi reach of mainstem between Galen and Deer Lodge. Although geochemical processes were not investigated in this study, the decreases in the concentration may be caused by dissolution of particulate-bound trace elements or dilution by sediments containing much smaller trace-element concentrations.

Trace-element content of suspended sediment in the tributaries was variable, and the smallest concentrations were not always at the index stations on Rock Creek and the Blackfoot River. Among the tributaries, the most significant differences were the elevated concentrations of arsenic and lead in the suspended sediment of Flint Creek relative to the reference concentrations. The arsenic concentration in Flint Creek sediment was similar to that of the Clark Fork at Deer Lodge. The lead concentration in Flint Creek sediment was only slightly smaller than that of the Clark Fork near Galen, where the median lead concentration in sediment was the largest of all the stations. Most trace-element concentrations of sediment in the Little Blackfoot River were similar to those of the index tributaries.

Because the trace-element content of suspended sediment is calculated indirectly, the most important information is not the actual value of the estimate,

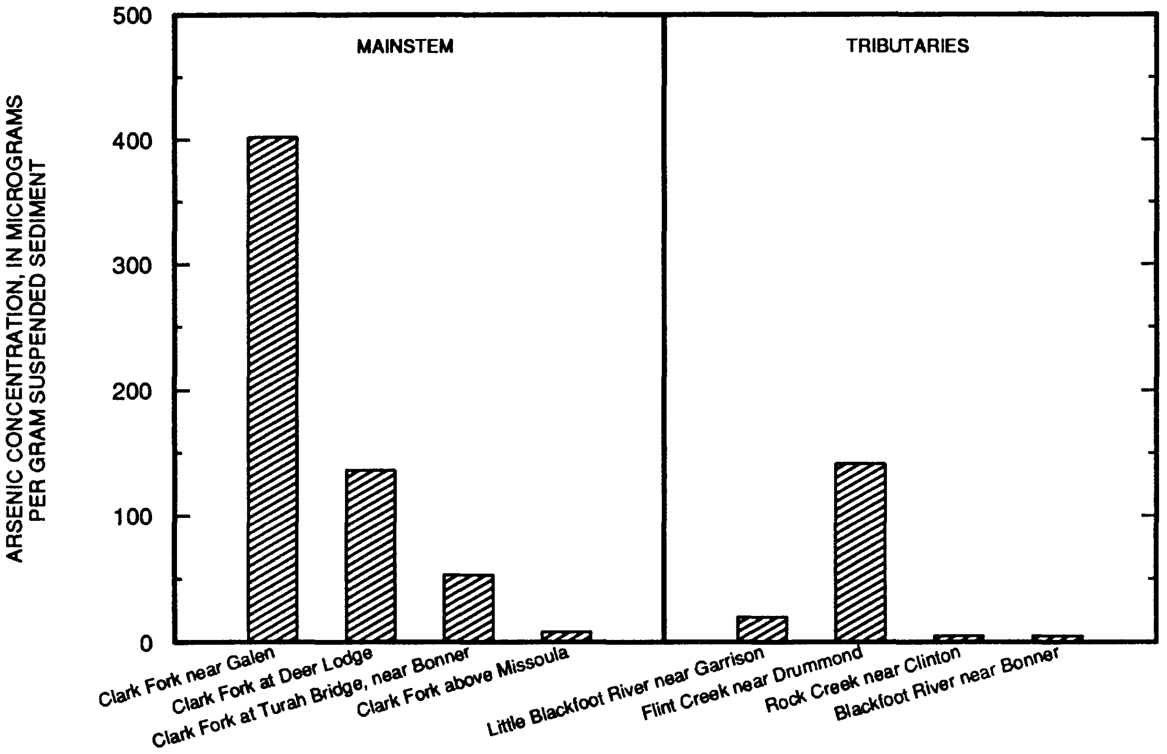

Figure 18.--Median concentrations of arsenic in suspended sediment, 1985-90.

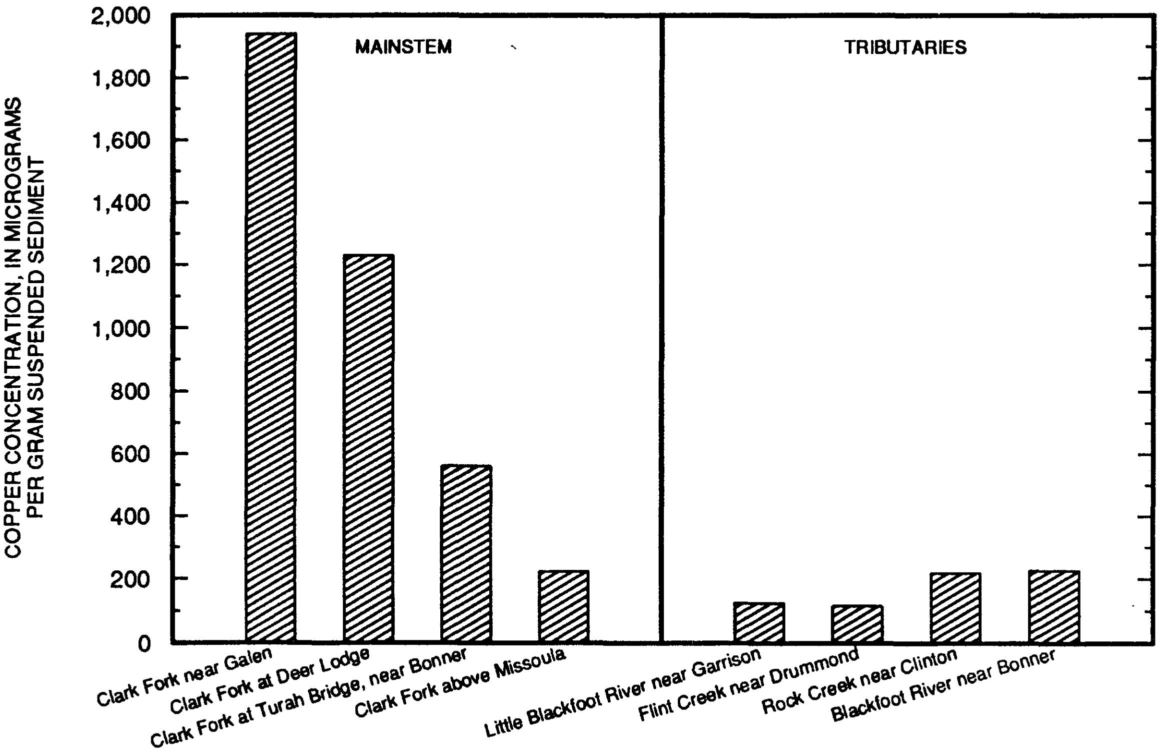

Figure 19.--Median concentrations of copper in suspended sediment, 1985-90.

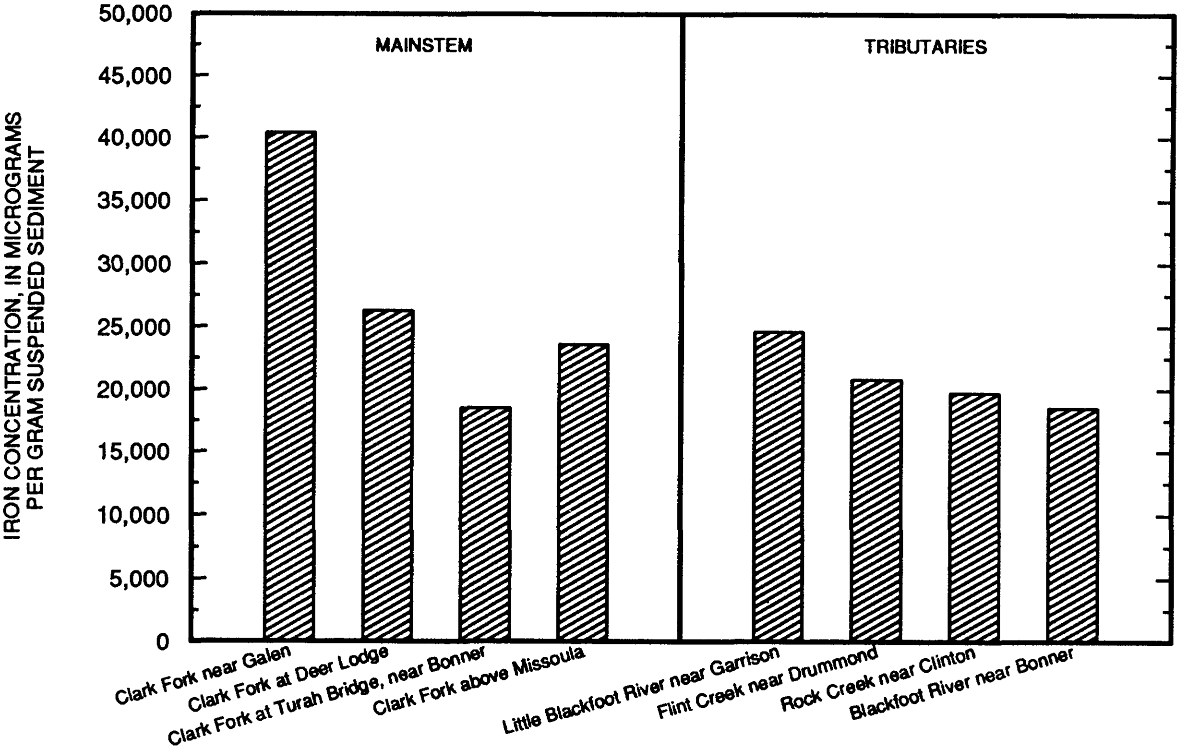

Figure 20.--Median concentrations of iron in suspended sediment, 1985-90.

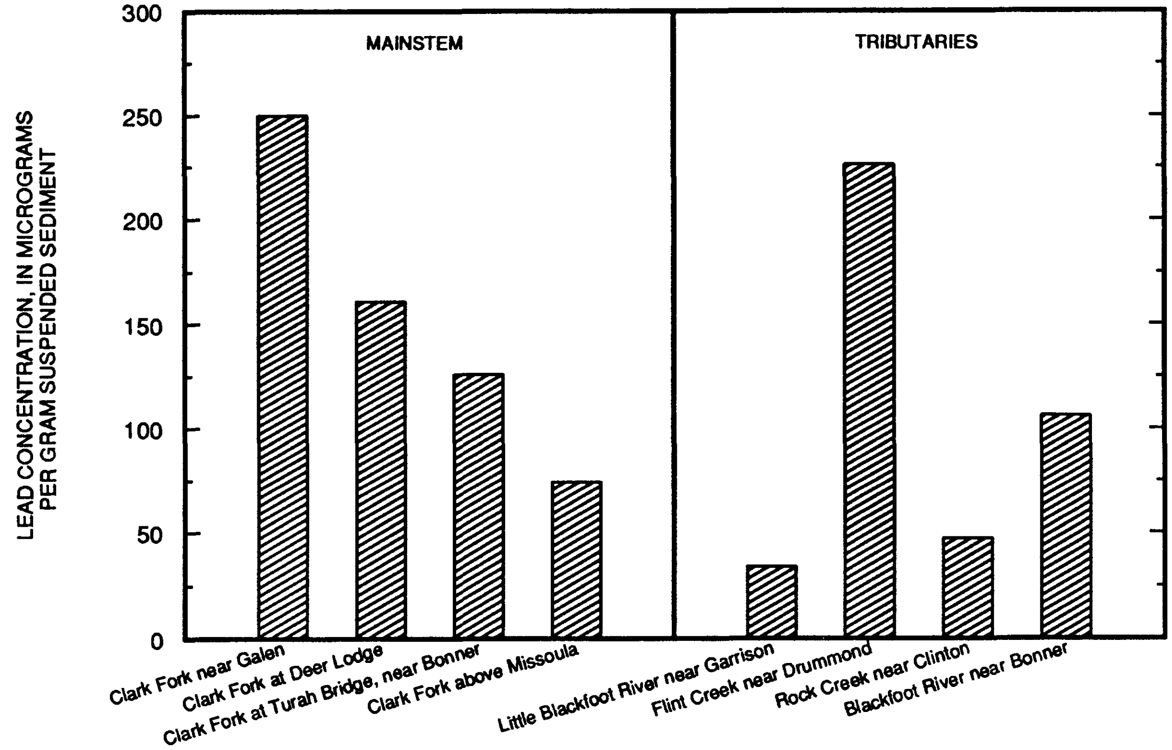

Figure 21.--Median concentrations of lead in suspended sediment, 1985-90.

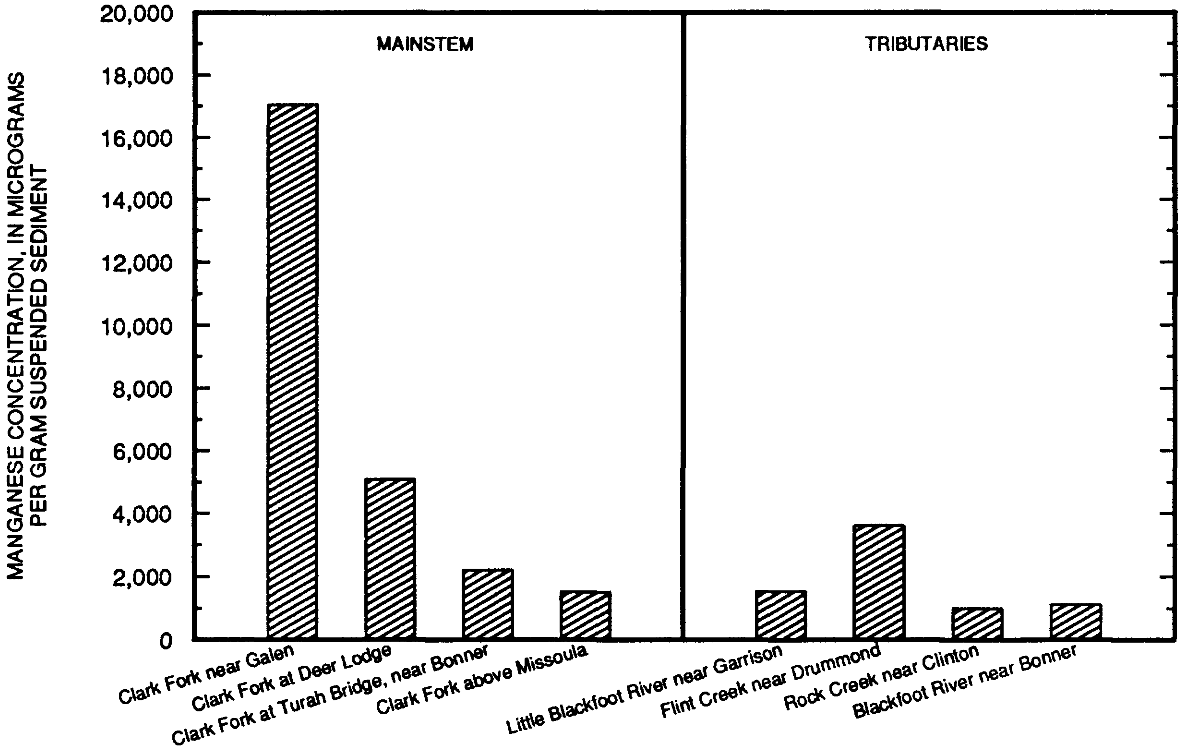

Figure 22.--Median concentrations of manganese in suspended sediment, 1985-90.

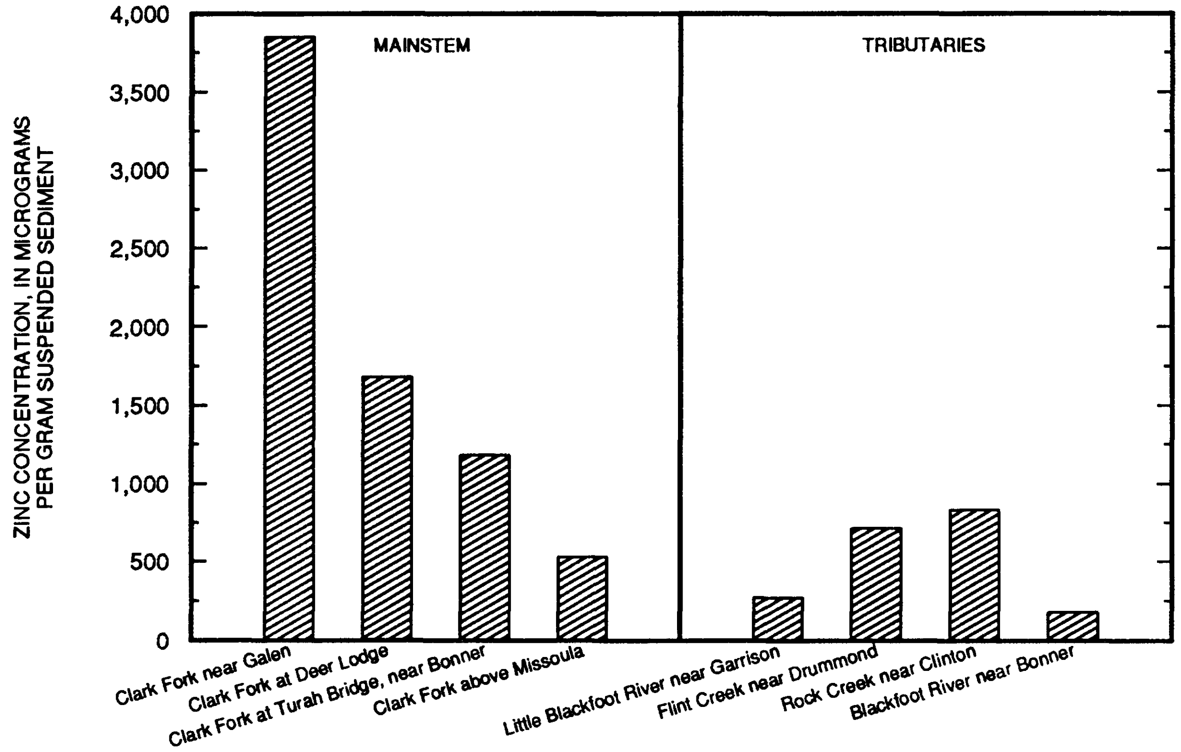

Figure 23.--Median concentrations of zinc in suspended sediment, 1985-90.

but rather the relative magnitude, which can be used to identify either anomalous characteristics or consistent patterns of geographic variability. Although the trace-element content of the sediment can indicate areas of potential contamination, its effect on water quality is a function of the quantity of sediment that is supplied to the surface-water system. This quantity is controlled by the physical characteristics of sediment stability and the erosional capacity of runoff to entrain the available sediment. To quantify the sediment and trace-element inputs to the hydrologic system, and therefore assess the relative importance of specific source areas, the constituent loads transported annually past various points in the basin need to be determined.

Estimation of Constituent Loads

One objective of this study was to examine the data obtained during the 1985-90 sampling period for adequacy in estimating annual constituent loads contributed from various parts of the upper Clark Fork basin. The procedure chosen to estimate constituent loads involved the development of regression relations that could be used to describe transport rates (discharge) for suspended sediment and trace elements. The regression relations were used with daily streamflow records to compute daily loads for constituents transported past the sampling stations. The estimated daily loads for water years 1985-90 were summed to determine an average annual load for each constituent. These loads then were used to describe the downstream variation along the mainstem, tributary contributions, and a mass balance of constituent transport through Milltown Reservoir.

Suspended Sediment

Suspended-sediment discharge (transport rate) was computed from streamflow and suspended-sediment concentration according to the equation:

$$Qs = Q \cdot C \cdot K \qquad (1)$$

where:

Qs = suspended-sediment discharge, in tons per day;
Q = streamflow, in cubic feet per second;
C = suspended-sediment concentration, in milligrams per liter; and
K = units conversion constant (0.0027).

Daily suspended-sediment discharge was determined for the four stations listed in table 1 as having daily sediment data. Sediment samples were collected at a frequency that enabled computation of daily mean suspended-sediment concentration according to procedures described by Porterfield (1972). The daily mean suspended-sediment concentrations were integrated with the continuous streamflow record to compute a daily suspended-sediment discharge. However, the record of daily suspended-sediment discharge for each of the four daily sediment stations was not complete for the entire 1985-90 sampling period. Meaningful comparison of annual constituent loads between stations required that all stations have a common base period and that the base period be of sufficient length to encompass a wide range of annual hydrologic variation. Therefore, in this study, the base period selected for evaluation of constituent transport was water years 1985-90. To obtain a common base period for comparison of long-term average loads, values for the unsampled parts of the base period at the daily sediment stations (see table 1) needed to be estimated. In addition, those stations that were not sampled on a daily basis also required estimates of annual sediment loads for the base period to enable assessment of the long-term averages and relative load contributions to the basin.

Selection of the most appropriate statistical method to estimate sediment discharge was based on a comparison of various regression estimates to actual daily sediment discharge determined for the four daily sediment stations. Only complete years of sediment record were used in evaluating regression accuracy to assure that the full range of seasonal variability was considered. Comparison of regression estimates to the record from daily sediment stations allowed a rigorous examination of year-to-year and seasonal variation and included the effects of short-term fluctuations in sediment concentration. The best estimation techniques were those that produced statistically significant equations, reasonable accuracy of the annual load, realistic seasonal distribution of loads, normally distributed residuals about the regression line, and an unbiased mean error of the estimated annual loads. The method of estimation judged to be suitable for describing sediment characteristics at daily sediment stations was also used for non-daily stations.

Regression analysis was performed on data from periodic samples collected during 1985-90. Testing of various regression methods indicated that the best statistical results were obtained by linear regression of logarithmically transformed values of streamflow and suspended-sediment discharge. However, annual loads estimated by ordinary least-squares regression for the four daily sediment stations consistently overestimated actual loads (mean error range of +3 to +23 percent). The overestimation presumably was the result of a disproportionate number of samples collected during runoff conditions, which caused a predominance of values representing short-term conditions of increased suspended-sediment concentrations. Because ordinary least-squares regression gives a mean description of the response variable, the large concentrations measured during runoff conditions caused a large positive bias in the estimates. To minimize the effect of bias, a regression method that provided a median, rather than a mean, description of the response variable was tested. Kendall's Tau nonparametric regression (Kendall, 1975) produced greater accuracy of estimated long-term loads, a more representative seasonal distribution of estimated monthly loads, and unbiased mean error of the estimates (mean error range of -1.5 to +3 percent). Therefore, Kendall's Tau nonparametric regression was used to develop predictive equations for estimating suspended-sediment discharge. The regression relations determined by ordinary least-squares and Kendall's Tau methods are compared graphically in figure 24.

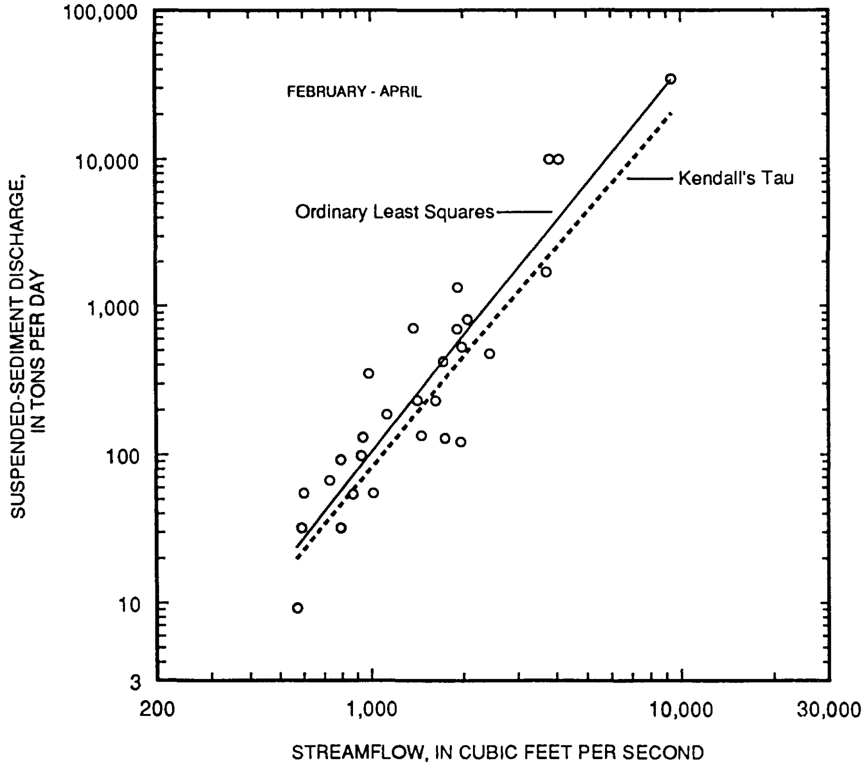

Figure 24.--Comparison of linear regression relations for estimating suspended-sediment discharge for the Clark Fork at Turah Bridge, near Bonner, 1985-90, by ordinary least-squares and Kendall's Tau (Kendall, 1975) methods.

Equations for estimating suspended-sediment discharge at all the sampling stations are presented in table 12. A distinct difference in seasonal relations was evident for all four daily sediment stations; therefore, seasonal equations were developed separately for two seasons--February through April and May through January. Substantially different sediment-transport characteristics of early-spring valley snowmelt compared to late-spring mountain snowmelt were primarily responsible for the seasonal differences. The data were insufficient to develop seasonal equations for the other stations. All equations in table 12 are log-linear and have an attained significance level equal to or less than 0.0001. Standard errors of estimate for suspended-sediment discharge range from 64 to 122 percent. The equations were applied to the daily streamflow record to estimate daily values of suspended-sediment discharge for unsampled periods at the daily sediment stations and for the entire base period (water years 1985-90) at the other stations.

Table 12.--*Equations for estimating suspended-sediment discharge*

[Tau, Kendall's rank correlation coefficient; p, attained significance level; SE, standard error of estimate, in percent; SEDQ, sediment discharge, in tons per day; Q, streamflow, in cubic feet per second. <, less than]

Station	Equation	Tau	p	SE
Clark Fork near Galen	$SEDQ = 0.000145(Q)^{2.11}$	0.82	<0.0001	100
Clark Fork at Deer Lodge:				
February-April	$SEDQ = 0.00000269(Q)^{2.89}$	.77	<.0001	94
May-January	$SEDQ = 0.000309(Q)^{2.02}$	.70	<.0001	122
Little Blackfoot River near Garrison	$SEDQ = 0.00000741(Q)^{2.53}$	.76	<.0001	116
Flint Creek near Drummond	$SEDQ = 0.00166(Q)^{1.83}$	.69	<.0001	106
Rock Creek near Clinton	$SEDQ = 0.00000417(Q)^{2.37}$	.77	<.0001	86
Clark Fork at Turah Bridge, near Bonner:				
February-April	$SEDQ = 0.00000316(Q)^{2.47}$	.72	<.0001	85
May-January	$SEDQ = 0.0000141(Q)^{2.15}$	.75	<.0001	70
Blackfoot River near Bonner:				
February-April	$SEDQ = 0.0000110(Q)^{2.09}$	.82	<.0001	70
May-January	$SEDQ = 0.00000355(Q)^{2.24}$	.81	<.0001	64
Clark Fork above Missoula:				
February-April	$SEDQ = 0.00000288(Q)^{2.25}$	.81	.0001	84
May-January	$SEDQ = 0.0000100(Q)^{2.02}$	.74	<.0001	76

Trace Elements

Relations for estimating total-recoverable trace-element discharge were developed from the periodic samples to enable calculation of annual and average long-term loads at the sampling stations. Prior to defining the relations for trace-element discharge, the total recoverable trace-element concentrations from periodic samples were converted to trace-element discharge by the following equation:

$$Qt = Q \cdot C \cdot K \qquad (2)$$

where:

Qt = trace-element discharge, in tons per day;
Q = streamflow, in cubic feet per second;
C = trace-element concentration, in micrograms per liter; and
K = units conversion constant (0.0000027).

Suspended-sediment discharge was used as the explanatory variable in the relations because of the strong association of some trace elements to suspended sediment. Because suspended-sediment discharge incorporates both streamflow and suspended-sediment concentration, it would reasonably explain more variation in the response of trace-element discharge than either variable alone. Kendall's Tau nonparametric regression was used to develop the predictive equations for trace-element discharge to minimize the potential bias associated with the suspended-sediment data. An example of the relation between total-recoverable copper discharge and suspended-sediment discharge using both ordinary least-squares and Kendall's Tau regression is shown in figure 25.

Equations for estimating total recoverable trace-element discharge at all the sampling stations are presented in tables 13-18. All equations are log-linear, and

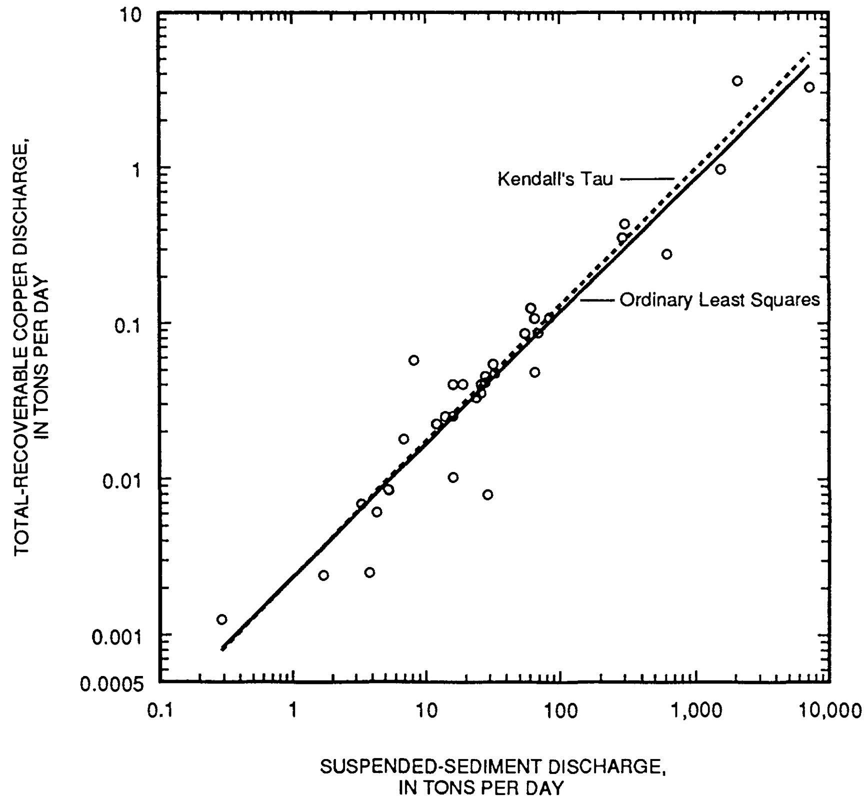

Figure 25.--Comparison of linear regression relations for estimating total-recoverable copper discharge for the Clark Fork at Deer Lodge, 1985-90, by ordinary least-squares and Kendall's Tau (Kendall, 1975) methods.

Table 13.--*Equations for estimating total-recoverable arsenic discharge*

[Tau, Kendall's rank correlation coefficient; p, attained significance level; SE, standard error of estimate, in percent; ASQ, arsenic discharge, in tons per day; SEDQ, suspended-sediment discharge, in tons per day. <, less than]

Station	Equation	Tau	p	SE
Clark Fork near Galen	$ASQ = 0.00263(SEDQ)^{0.551}$	0.82	<0.0001	37
Clark Fork at Deer Lodge	$ASQ = 0.00138(SEDQ)^{0.671}$	.81	<.0001	52
Little Blackfoot River near Garrison	$ASQ = 0.00126(SEDQ)^{0.467}$	.87	<.0001	26
Flint Creek near Drummond	$ASQ = 0.000912(SEDQ)^{0.698}$	.88	<.0001	31
Rock Creek near Clinton	$ASQ = 0.000245(SEDQ)^{0.492}$	.77	<.0001	46
Clark Fork at Turah Bridge, near Bonner	$ASQ = 0.00209(SEDQ)^{0.549}$	.85	<.0001	38
Blackfoot River near Bonner	$ASQ = 0.000513(SEDQ)^{0.487}$	.78	<.0001	40
Clark Fork above Missoula	$ASQ = 0.00427(SEDQ)^{0.401}$	.82	<.0001	30

Table 14.--*Equations for estimating total-recoverable copper discharge*

[Tau, Kendall's rank correlation coefficient; p, attained significance level; SE, standard error of estimate, in percent; CUQ, copper discharge, in tons per day; SEDQ, suspended-sediment discharge, in tons per day. <, less than]

Station	Equation	Tau	p	SE
Clark Fork near Galen	$CUQ = 0.00575(SEDQ)^{0.699}$	0.92	<0.0001	37
Clark Fork at Deer Lodge	$CUQ = 0.00234(SEDQ)^{0.873}$	.82	<.0001	58
Little Blackfoot River near Garrison	$CUQ = 0.00115(SEDQ)^{0.555}$	.83	<.0001	44
Flint Creek near Drummond	$CUQ = 0.000525(SEDQ)^{0.725}$	.85	<.0001	42
Rock Creek near Clinton	$CUQ = 0.000813(SEDQ)^{0.658}$	.75	<.0001	86
Clark Fork at Turah Bridge, near Bonner	$CUQ = 0.00240(SEDQ)^{0.836}$	.80	<.0001	45
Blackfoot River near Bonner	$CUQ = 0.00295(SEDQ)^{0.559}$	.77	<.0001	67
Clark Fork above Missoula	$CUQ = 0.00617(SEDQ)^{0.514}$	.85	<.0001	31

Table 15.--*Equations for estimating total-recoverable iron discharge*

[Tau, Kendall's rank correlation coefficient; p, attained significance level; SE, standard error of estimate, in percent; FEQ, iron discharge, in tons per day; SEDQ, suspended-sediment discharge, in tons per day. <, less than]

Station	Equation	Tau	p	SE
Clark Fork near Galen	$FEQ = 0.0501(SEDQ)^{0.861}$	0.94	<0.0001	28
Clark Fork at Deer Lodge	$FEQ = 0.0245(SEDQ)^{0.995}$	.89	<.0001	37
Little Blackfoot River near Garrison	$FEQ = 0.0269(SEDQ)^{0.962}$	.94	<.0001	31
Flint Creek near Drummond	$FEQ = 0.0229(SEDQ)^{0.994}$	.95	<.0001	33
Rock Creek near Clinton	$FEQ = 0.0589(SEDQ)^{0.795}$	.87	<.0001	50
Clark Fork at Turah Bridge, near Bonner	$FEQ = 0.0257(SEDQ)^{1.01}$	.91	<.0001	32
Blackfoot River near Bonner	$FEQ = 0.0224(SEDQ)^{0.920}$	.86	<.0001	51
Clark Fork above Missoula	$FEQ = 0.0398(SEDQ)^{0.939}$	.96	<.0001	25

Table 16.--*Equations for estimating total-recoverable lead discharge*

[Tau, Kendall's rank correlation coefficent; p, attained significance level; SE, standard error of estimate, in percent; PBQ, lead discharge, in tons per day; SEDQ, suspended-sediment discharge, in tons per day. <, less than]

Station	Equation	Tau	p	SE
Clark Fork near Galen	$PBQ = 0.000468(SEDQ)^{0.733}$	0.81	<0.0001	58
Clark Fork at Deer Lodge	$PBQ = 0.000240(SEDQ)^{0.905}$	.77	<.0001	58
Little Blackfoot River near Garrison	$PBQ = 0.000692(SEDQ)^{0.540}$	.70	<.0001	88
Flint Creek near Drummond	$PBQ = 0.000331(SEDQ)^{0.930}$	.85	<.0001	64
Rock Creek near Clinton	$PBQ = 0.00115(SEDQ)^{0.520}$	.58	<.0001	126
Clark Fork at Turah Bridge, near Bonner	$PBQ = 0.00110(SEDQ)^{0.780}$	.71	<.0001	89
Blackfoot River near Bonner	$PBQ = 0.00407(SEDQ)^{0.467}$	.50	.0004	139
Clark Fork above Missoula	$PBQ = 0.000776(SEDQ)^{0.624}$	.71	.0031	64

Table 17.--*Equations for estimating total-recoverable manganese discharge*

[Tau, Kendall's rank correlation coefficient; p, attained significance level; SE, standard error of estimate, in percent; MNQ, manganese discharge, in tons per day; SEDQ, suspended-sediment discharge, in tons per day. <, less than]

Station	Equation	Tau	p	SE
Clark Fork near Galen	$MNQ = 0.0692(SEDQ)^{0.599}$	0.90	<0.0001	39
Clark Fork at Deer Lodge	$MNQ = 0.0112(SEDQ)^{0.828}$	.84	<.0001	52
Little Blackfoot River near Garrison	$MNQ = 0.00309(SEDQ)^{0.799}$	.93	<.0001	38
Flint Creek near Drummond	$MNQ = 0.00741(SEDQ)^{0.858}$	.92	<.0001	31
Rock Creek near Clinton	$MNQ = 0.00603(SEDQ)^{0.573}$	.76	<.0001	58
Clark Fork at Turah Bridge, near Bonner	$MNQ = 0.00603(SEDQ)^{0.827}$	.90	<.0001	30
Blackfoot River near Bonner	$MNQ = 0.00347(SEDQ)^{0.769}$	.86	<.0001	69
Clark Fork above Missoula	$MNQ = 0.0174(SEDQ)^{0.646}$	.89	<.0001	28

Table 18.--*Equations for estimating total-recoverable zinc discharge*

[Tau, Kendall's rank correlation coefficient; p, attained significance level; SE, standard error of estimate, in percent; ZNQ, zinc discharge, in tons per day; SEDQ, suspended-sediment discharge, in tons per day. <, less than]

Station	Equation	Tau	p	SE
Clark Fork near Galen	$ZNQ = 0.00912(SEDQ)^{0.617}$	0.82	<0.0001	57
Clark Fork at Deer Lodge	$ZNQ = 0.00437(SEDQ)^{0.806}$	.82	<.0001	55
Little Blackfoot River near Garrison	$ZNQ = 0.00151(SEDQ)^{0.654}$	.77	<.0001	63
Flint Creek near Drummond	$ZNQ = 0.00166(SEDQ)^{0.834}$	.91	<.0001	50
Rock Creek near Clinton	$ZNQ = 0.00257(SEDQ)^{0.620}$	.72	<.0001	79
Clark Fork at Turah Bridge, near Bonner	$ZNQ = 0.00355(SEDQ)^{0.799}$	.89	<.0001	33
Blackfoot River near Bonner	$ZNQ = 0.00417(SEDQ)^{0.558}$	.69	<.0001	81
Clark Fork above Missoula	$ZNQ = 0.0170(SEDQ)^{0.447}$	.64	.0081	63

have an attained significance level equal to or less than 0.01. Equations are not presented for cadmium because of the predominance of concentrations less than the minimum reporting level. The equations were applied to either the actual or the estimated daily record of suspended-sediment discharge of all sampling stations for water years 1985-90 to compute a daily record of trace-element discharge. Ranges of standard errors of estimate, in percent, for trace-element discharge are: arsenic, 26-52; copper, 31-86; iron, 25-51; lead, 58-139; manganese, 28-69; and zinc, 33-81.

TRANSPORT CHARACTERISTICS OF CONSTITUENT LOADS

Estimates of suspended-sediment and trace-element loads can be used to describe the proportion of total constituent load contributed from various source areas in the upper Clark Fork basin. Knowledge of the load contributions from individual source areas can provide a basin-wide perspective to assess the relative importance of each source area. In addition, the determination of annual loads at stations upstream and downstream from Milltown Reservoir enables calculation of a mass balance of suspended-sediment and trace-element loads transported through the reservoir.

Constituent Source Areas

In this study, the density of sampling stations was insufficient for detailed assessment of point or local sources; therefore, constituent source areas throughout the upper basin were delineated only generally. The estimated constituent loads are not intended to represent absolute values, but rather to provide a relative comparison between stations to indicate the importance of various source areas. Also, the estimated loads represent only water years 1985-90, and extrapolation of transport rates outside this period may produce erroneous results if either hydrologic or physical conditions within the basin are not similar.

The estimated average annual suspended-sediment load for water years 1985-90 for each of the mainstem and tributary sampling stations is given in table 19. The mainstem and tributary source areas are considered to represent the entire watershed upstream from the sampling station. Loads along the mainstem can be compared to those discharged from gaged tributary basins to determine the proportion of change attributable to individual tributaries. If the assumption is made that loads are additive in a downstream direction, then the cumulative contribution from other sources within the intervening reaches between mainstem stations also can be determined. The contributions from sources within the intervening reach (sediment from ungaged tributaries and the channel and flood plain of the mainstem) are assumed to equal the difference in load between mainstem stations, minus any load contributed by a gaged tributary. The average annual load input to Milltown Reservoir was calculated as the sum of the average annual loads discharged by the Clark Fork at Turah Bridge, near Bonner and the Blackfoot River near Bonner.

In the same manner as suspended sediment, the estimated daily trace-element loads for water years 1985-90 were summed to calculate average annual loads of total-recoverable trace elements, except cadmium (tables 20-25). Also, the contribution of loads from various source areas was determined as described for suspended sediment. Because the total-recoverable concentrations used to compute the trace-element loads include the dissolved phase of the trace element, groundwater discharge to the Clark Fork in intervening reaches could potentially contribute to the loads.

Several general characteristics can be identified from the tables of average annual suspended-sediment and trace-element loads. The annual loads at the three mainstem stations upstream from Milltown Reservoir increased in a downstream direction, indicating that net transport rates are greater than depositional rates. This condition does not imply that localized or temporary deposition does not occur in the 112.5-mi reach between Galen and Turah Bridge, only that a larger net quantity of material was moved out of the major source areas than was deposited along the channel or flood plain. A notable feature of the relative magnitude of annual loads is that the unmeasured sources within the intervening reaches generally

Table 19.--*Estimated average annual suspended-sediment loads, water years 1985-90*

Location	Annual suspended-sediment load, in tons Mainstem station	 Tributary station	 Other sources[1]
Clark Fork near Galen	1,442		
Intervening reach (21.5 miles)			7,007
Clark Fork at Deer Lodge	8,449		
Little Blackfoot River near Garrison		1,977	
Flint Creek near Drummond		4,709	
Rock Creek near Clinton		8,466	
Intervening reach (91.0 miles)			19,572
Clark Fork at Turah Bridge, near Bonner	43,173		
Blackfoot River near Bonner		32,273	
Input to Milltown Reservoir (Clark Fork at Turah Bridge, near Bonner plus Blackfoot River near Bonner)	75,446		
Clark Fork above Missoula	59,187		

[1] Include sediment from ungaged tributaries and the channel and flood plain in the intervening reach between mainstem stations.

Table 20.--*Estimated average annual total-recoverable arsenic loads, water years 1985-90*

Location	Annual arsenic load, in tons Mainstem station	 Tributary station	 Other sources[1]
Clark Fork near Galen	1.6		
Intervening reach (21.5 miles)			1.7
Clark Fork at Deer Lodge	3.3		
Little Blackfoot River near Garrison		0.6	
Flint Creek near Drummond		1.6	
Rock Creek near Clinton		.2	
Intervening reach (91.0 miles)			1.4
Clark Fork at Turah Bridge, near Bonner	7.1		
Blackfoot River near Bonner		1.0	
Input to Milltown Reservoir (Clark Fork at Turah Bridge, near Bonner plus Blackfoot River near Bonner)	8.1		
Clark Fork above Missoula	8.9		

[1] Include trace elements from ungaged tributaries, the channel and flood plain, and ground-water discharge in the intervening reach between mainstem stations.

Table 21.--*Estimated average annual total-recoverable copper loads, water years 1985-90*

Location	Annual copper load, in tons Mainstem station	 Tributary station	 Other sources[1]
Clark Fork near Galen	4.5		
Intervening reach (21.5 miles)			7.2
Clark Fork at Deer Lodge	11.7		
Little Blackfoot River near Garrison		0.6	
Flint Creek near Drummond		1.0	
Rock Creek near Clinton		1.5	
Intervening reach (91.0 miles)			22.4
Clark Fork at Turah Bridge, near Bonner	37.2		
Blackfoot River near Bonner		8.1	
Input to Milltown Reservoir (Clark Fork at Turah Bridge, near Bonner plus Blackfoot River near Bonner)	45.3		
Clark Fork above Missoula	22.4		

[1] Include trace elements from ungaged tributaries, the channel and flood plain, and ground-water discharge in the intervening reach between mainstem stations.

Table 22.--*Estimated average annual total-recoverable iron loads, water years 1985-90*

Location	Annual iron load, in tons Mainstem station	 Tributary station	 Other sources[1]
Clark Fork near Galen	53		
Intervening reach (21.5 miles)			149
Clark Fork at Deer Lodge	202		
Little Blackfoot River near Garrison		46	
Flint Creek near Drummond		106	
Rock Creek near Clinton		191	
Intervening reach (91.0 miles)			645
Clark Fork at Turah Bridge, near Bonner	1,190		
Blackfoot River near Bonner		442	
Input to Milltown Reservoir (Clark Fork at Turah Bridge, near Bonner plus Blackfoot River near Bonner)	1,630		
Clark Fork above Missoula	1,610		

[1] Include trace elements from ungaged tributaries, the channel and flood plain, and ground-water discharge in the intervening reach between mainstem stations.

Table 23.--*Estimated average annual total-recoverable lead loads, water years 1985-90*

Location	Annual lead load, in tons Mainstem station	Tributary station	Other sources[1]
Clark Fork near Galen	0.4		
Intervening reach (21.5 miles)			1.0
Clark Fork at Deer Lodge	1.4		
Little Blackfoot River near Garrison		0.4	
Flint Creek near Drummond		1.2	
Rock Creek near Clinton		1.3	
Intervening reach (91.0 miles)			8.0
Clark Fork at Turah Bridge, near Bonner	12.3		
Blackfoot River near Bonner		7.3	
Input to Milltown Reservoir (Clark Fork at Turah Bridge, near Bonner plus Blackfoot River near Bonner)	19.6		
Clark Fork above Missoula	5.0		

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[1] Include trace elements from ungaged tributaries, the channel and flood plain, and ground-water discharge in the intervening reach between mainstem stations.

Table 24.--*Estimated average annual total-recoverable manganese loads, water years 1985-90*

Location	Annual manganese load, in tons Mainstem station	Tributary station	Other sources[1]
Clark Fork near Galen	45.6		
Intervening reach (21.5 miles)			1.4
Clark Fork at Deer Lodge	47.0		
Little Blackfoot River near Garrison		3.0	
Flint Creek near Drummond		21.3	
Rock Creek near Clinton		8.1	
Intervening reach (91.0 miles)			9.3
Clark Fork at Turah Bridge, near Bonner	88.7		
Blackfoot River near Bonner		28.5	
Input to Milltown Reservoir (Clark Fork at Turah Bridge, near Bonner plus Blackfoot River near Bonner)	117		
Clark Fork above Missoula	127		

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[1] Include trace elements from ungaged tributaries, the channel and flood plain, and ground-water discharge in the intervening reach between mainstem stations.

Table 25.--*Estimated average annual total-recoverable zinc loads, water years 1985-90*

Location	Annual zinc load, in tons Mainstem station	 Tributary station	 Other sources[1]
Clark Fork near Galen	6.2		
Intervening reach (21.5 miles)			10.6
Clark Fork at Deer Lodge	16.8		
Little Blackfoot River near Garrison		1.0	
Flint Creek near Drummond		4.4	
Rock Creek near Clinton		4.1	
Intervening reach (91.0 miles)			18.1
Clark Fork at Turah Bridge, near Bonner	44.4		
Blackfoot River near Bonner		11.4	
Input to Milltown Reservoir (Clark Fork at Turah Bridge, near Bonner plus Blackfoot River near Bonner)	55.8		
Clark Fork above Missoula	44.1		

[1] Include trace elements from ungaged tributaries, the channel and flood plain, and ground-water discharge in the intervening reach between mainstem stations.

accounted for a substantial proportion of the downstream increases in load. Thus, there are significant sources in addition to the upper basin and the four major tributaries. The available data cannot distinguish the specific sources within the intervening reaches that contribute to the increase. Better delineation of actual source areas would require a larger number of sampling stations along the mainstem or on additional tributaries.

Because Milltown Reservoir is the first mainstem impoundment on the Clark Fork, it has accumulated large quantities of sediment and trace elements derived from upstream areas of the watershed. This accumulation process continues, although presumably at a rate that is less than that prior to construction of the Warm Springs Ponds when tailings were largely uncontained. Past distribution of large quantities of mine tailings along the upper mainstem channel, plus smaller quantities dispersed within tributary basins, are potential sources of trace elements to the reservoir. The average annual loads of suspended sediment and trace elements calculated for water years 1985-90 can be used to indicate the percentage of the total load discharged to the reservoir from various source areas (table 26).

Comparison of the average annual loads input to Milltown Reservoir by the Clark Fork and the Blackfoot River indicates that the Clark Fork basin supplied a greater load of every constituent, even though streamflow of the Clark Fork was slightly less than that of the Blackfoot River during water years 1985-90. The suspended-sediment load of the Clark Fork was 1.3 times greater than that of the Blackfoot River, yet the trace-element loads ranged from 1.7 times greater for lead to 7.1 times greater for arsenic.

The percentages listed in table 26 can be used to compare the proportion of annual load contributed to Milltown Reservoir by the various source areas or to identify anomalous characteristics. Comparison of the corresponding percentages of suspended sediment and trace elements may indicate areas having potentially con-

Table 26.--*Percentage of average annual suspended-sediment and total-recoverable trace-element loads discharged to Milltown Reservoir from various source areas, water years 1985-90*

	Percent of average annual load discharged to Milltown Reservoir						
		Trace element					
Station	Suspended sediment	Arsenic	Copper	Iron	Lead	Manganese	Zinc
Clark Fork near Galen	1.9	20	9.9	3.2	2.0	39	11
Intervening reach (21.5 miles)	9.3	21	16	9.2	5.1	1.2	19
Clark Fork at Deer Lodge	11	41	26	12	7.1	40	30
Little Blackfoot River near Garrison	2.6	6.8	1.3	2.8	2.0	2.6	1.8
Flint Creek near Drummond	6.2	20	2.2	6.5	6.1	18	7.9
Rock Creek near Clinton	11	3.1	3.3	12	6.6	6.9	7.3
Intervening reach (91.0 miles)	26	17	49	39	40	8.0	33
Clark Fork at Turah Bridge, near Bonner	57	88	82	73	63	76	80
Blackfoot River near Bonner	43	12	18	27	37	24	20

taminated sediments. Of the two basins contributing load to Milltown Reservoir, the Clark Fork contributed a substantially larger proportion of trace elements to Milltown Reservoir than did the Blackfoot River. The trace-element input from the Clark Fork at Turah Bridge, near Bonner ranged from 63 percent of the lead to 88 percent of the arsenic that entered Milltown Reservoir. Arsenic, copper, and zinc supplied by the Clark Fork equaled or exceeded 80 percent of the total quantity entering the reservoir. The fact that the Clark Fork supplied only 57 percent of the suspended sediment yet 63-88 percent of the trace-element load indicates that the sediments within its basin are enriched in trace-element content relative to those of the Blackfoot River.

Source areas within the upper Clark Fork basin contributed variable quantities of individual trace elements. For arsenic, the Clark Fork near Galen, the most upstream station and nearest to the headwater mining areas, contributed 20 percent of the load entering Milltown Reservoir. A nearly equal quantity was added to the Clark Fork in the 21.5-mi reach from Galen to Deer Lodge, presumably from the visually contaminated channel and flood-plain sediments. The three major tributaries between Deer Lodge and Turah Bridge, near Bonner collectively contributed 30 percent, with Flint Creek individually accounting for 20 percent of the arsenic load. The contribution of arsenic was substantially greater from Flint Creek than from any of the other tributaries, including the much larger Blackfoot River. A quantity nearly equivalent to that of Flint Creek (17 percent) was contributed by sources in the 91.0-mi reach of mainstem between Deer Lodge and Turah Bridge, near Bonner.

The percentage of copper contributed by the Clark Fork near Galen was almost 10 percent of Milltown Reservoir's average annual load, and that of the 21.5-mi intervening reach to Deer Lodge was 16 percent. The three major tributaries between Deer Lodge and Turah Bridge, near Bonner contributed only minor quantities--about 1-3 percent. A notably large proportion (49 percent) of the reservoir's annual copper load was derived from the 91.0-mi reach between Deer Lodge and Turah Bridge, near Bonner. This result is somewhat surprising given that the fishkills attributed to copper toxicity occur primarily upstream from Deer Lodge. However, because fishkills are caused by a rapid, short-term flush of trace element into the stream during low-flow conditions, annual loads alone are probably not a good criterion to assess potential acute toxicity. In addition, the relatively long length of mainstem channel that contributes sediment, in combination with the basins of the ungaged tributaries in this reach, provides a large source area.

Iron loads derived from various sources showed spatial trends similar to those of copper. Iron transported past the Clark Fork near Galen represented about 3 percent of the annual load input to Milltown Reservoir. Slightly more than 9 percent was added in the mainstem reach from Galen to Deer Lodge. The three tributaries between Deer Lodge and Turah Bridge, near Bonner collectively added about 21 percent, whereas the Blackfoot River added 27 percent. The 91.0-mi intervening reach added the largest quantity of iron (39 percent) to the reservoir.

Lead contributions to Milltown Reservoir showed relatively uniform inputs from the upper basin and tributaries. The lead added to the Clark Fork from the 21.5-mi reach between Galen and Deer Lodge was more than double the quantity passing Galen, although the two sources combined contributed only about 7 percent of the total load to the reservoir. Contributions from the three tributaries ranged from about 2 to 7 percent for a cumulative total of about 15 percent. The largest contribution (40 percent) was from the 91.0-mi intervening reach between Deer Lodge and Turah Bridge, near Bonner. A nearly equivalent quantity of lead (37 percent) was contributed by the Blackfoot River. The percentage of trace-element load contributed by the Blackfoot River was larger for lead than any of the other trace elements.

Manganese contributions from the various source areas exhibited much different spatial patterns than the other trace elements. The largest manganese contribution to Milltown Reservoir from a single source (39 percent) was the load passing the Clark Fork near Galen. In contrast, a small quantity of slightly more than 1 percent entered the Clark Fork between Galen and Deer Lodge. This atypical characteristic may be the result of geochemical reactions occurring within the 21.5-mi intervening reach. One aspect of the water chemistry indicating a geochemical response is that, on the basis of median concentrations, about 50 percent of the total-recoverable manganese at Galen was in the dissolved phase whereas only about 15 percent of the total-recoverable manganese at Deer Lodge was dissolved. Similar to arsenic, Flint Creek contributed a much larger percentage of the manganese load (18 percent) than did the Little Blackfoot River and Rock Creek. The 91.0-mi intervening reach between Deer Lodge and Turah Bridge, near Bonner contributed only 8 percent of the reservoir's manganese load.

The contributions of zinc from the source areas in the upper Clark Fork basin were similar to those of copper. Eleven percent of Milltown Reservoir's zinc load passed the Clark Fork near Galen. Nearly twice that quantity (19 percent) was added in the 21.5-mi reach between Galen and Deer Lodge. The tributary contributions between Deer Lodge and Turah Bridge, near Bonner were about 2-8 percent, for a cumulative total of about 17 percent, which was about double the percentage of copper contributed by these tributaries. The load contributed from sources in the 91.0-mi reach between Deer Lodge and Turah Bridge, near Bonner comprised 33 percent of the average annual zinc load entering the reservoir. The proportion of zinc (20 percent) contributed by the Blackfoot River was similar to that of copper.

In general, the Clark Fork basin upstream from Galen supplied a significant quantity of arsenic and manganese, and moderate quantities of copper and zinc. The 21.5-mi reach of the mainstem between Galen and Deer Lodge was also a significant source of trace elements, contributing substantial quantities of arsenic, copper, and zinc. With the exception of Flint Creek, which contributed relatively large quantities of arsenic and manganese, the three tributaries entering the Clark Fork between Deer Lodge and Turah Bridge, near Bonner generally contributed only small to moderate quantities of most trace elements. A major source for several trace elements was the 91.0-mi reach of mainstem between Deer Lodge and Turah Bridge, near Bonner. The unmeasured sources within this reach contributed substantial loads of suspended sediment and every trace element except manganese. The largest proportion of the reservoir's average annual load of copper, iron, lead, and zinc originated from this intervening reach of mainstem, exclusive of the loads discharged by the three major tributaries in this reach. It may not be surprising that a 91.0-mi channel that contains historically deposited tailings would be a major source area; however, the proportion attributable to channel sediments, ungaged tributaries, and ground water is unknown. The Blackfoot River, the largest source of streamflow in the study area, contributed only moderate quantities of most trace elements, but a significant quantity of lead.

Mass Balance of Constituent Loads in Milltown Reservoir

Annual mass balance of suspended sediment and trace elements, in tons, was estimated for Milltown Reservoir for water years 1985-90 (table 27). Mass balance was calculated by subtracting the annual output from the annual input. Annual input to the reservoir was calculated as the sum of the annual loads for the Clark Fork at Turah Bridge, near Bonner and the Blackfoot River near Bonner. Annual output from the reservoir was the annual load determined for the Clark Fork above Missoula. The annual balance is reported as either a positive value indicating net gain (deposition) or a negative value indicating net loss (erosion) from the reservoir. Results from individual years are summed to provide a net average for water years 1985-90.

Table 27.--*Estimated annual mass balance of suspended-sediment and total-recoverable trace-element loads in Milltown Reservoir, water years 1985-90*

[+, net gain; -, net loss]

Water year	Mass balance of load, in tons						
		Trace element					
	Suspended sediment	Arsenic	Copper	Iron	Lead	Manganese	Zinc
1985	+ 27,100	+ 0.9	+ 26.8	+ 333	+ 16.2	+ 13.2	+ 18.2
1986	+ 53,600	+ 0.4	+ 51.8	+1,080	+ 24.0	+ 31.8	+ 39.7
1987	- 17,400	- 3.2	+ 0.4	- 653	+ 6.4	- 61.5	- 14.6
1988	+ 5,100	- 0.8	+ 8.8	- 43	+ 8.5	- 14.4	- 0.6
1989	+ 11,300	- 1.2	+ 27.8	- 454	+ 17.0	- 19.1	+ 15.9
1990	+ 17,900	- 0.7	+ 21.9	- 143	+ 15.6	- 10.1	+ 11.6
Net total	+ 97,600	- 4.6	+137.5	+ 120	+ 87.7	- 60.1	+ 70.2
Net average	+ 16,300	- 0.8	+ 22.9	+ 20	+ 14.6	- 10.0	+ 11.7

The loads for individual years indicate the large year-to-year variation. Part of the variation is the result of annual hydrologic conditions within the basin; however, some of the variation may be the result of intermittent construction on Milltown Dam during 1986-89 that likely disturbed part of the reservoir's bottom sediment. Another factor that complicates the estimation of mass balance is that the regression relations for trace-element discharge for the Clark Fork above Missoula are based on only 1 year of trace-element sampling (October 1989-October 1990). Therefore, extrapolation of these relations to previous water years may result in an unknown degree of error. Given these limitations, the estimates of mass balance need to be used with caution, and are intended to provide only a gross measure of the net gains or losses of constituent loads during the period of study.

All constituents showed net gains in the reservoir during the pre-construction period of water years 1985 and 1986. In water year 1987, the first full year of data collection following the start of construction activities, all constituents except copper and lead showed net losses from the reservoir. Arsenic, iron, and manganese continued to show net losses during every subsequent year of the sampling period. Copper and lead exhibited net gains during all years of the period, whereas zinc showed variable patterns of gain and loss. The wide range of variability between net gains and losses may reflect numerous factors such as limited storage capacity of the reservoir that is subject to occasional scouring of bottom sediment during high flow, disturbance of bottom sediment by dam operation and construction, geochemical effects causing either precipitation or dissolution of trace elements, and differential movement of sediment on the basis of particle size.

Short-term losses of sediment and trace-elements associated with occurrences of scouring during high flows or disturbance are difficult to quantify, but may represent a substantial part of the annual mass balance. Potential geochemical effects might be inferred from the concentrations of iron and manganese. The median dissolved concentrations of iron and manganese at the Clark Fork above Missoula are larger than those at Turah Bridge, near Bonner, even though considerable dilution is provided by the Blackfoot River. Dissolution of particulate iron and manganese could result in loss of dissolved load from the reservoir, even though suspended sediment may be deposited. The median percentage of suspended sediment finer than sand (0.062 mm diameter) increased from 69 percent in the Clark Fork at Turah Bridge, near Bonner to 88 percent in the Clark Fork above Missoula (table 30). This increase in the percentage of fine sediment downstream from Milltown Reservoir implies that part of the coarse sediment was depositing in the reservoir.

The net average mass balance for water years 1985-90 indicates that, except for arsenic and manganese, constituent loads showed net deposition in Milltown Reservoir. An average of 16,300 tons of suspended sediment was deposited annually in the reservoir during water years 1985-90. Of the trace elements, copper was deposited in the greatest quantity (about 23 tons annually). Average annual trace-element losses from the reservoir were about 0.8 ton of arsenic and 10 tons of manganese.

Deposition of sediment and attached trace elements is the probable physical process that accounts for the generally smaller loads transported downstream from the reservoir, although other processes previously described may result in net losses in individual years. The net loss of arsenic and manganese loads from the reservoir is difficult to explain from a physical-transport perspective, and may involve either geochemical processes within the reservoir, construction activities, or estimation error. The loss of arsenic load may be attributable to the characteristic of arsenic occurring primarily in the dissolved phase. Because most of the dissolved arsenic likely would pass through Milltown Reservoir, any additional arsenic mobilized into solution by geochemical processes acting on reservoir bottom sediments could add to the dissolved load passing through the reservoir. Manganese is more likely than arsenic to occur in the particulate phase and might be expected to follow the depositional pattern of suspended sediment and the other trace elements more closely. Iron also is bound strongly to sediment but showed negligible deposition during the period. The effects of specific processes on trace-element transport through the reservoir are undefined by the available data.

SUMMARY AND CONCLUSIONS

Vast quantities of tailings have been produced by large-scale mining, milling, and smelting of mineral ores in the upper Clark Fork basin of west-central Montana. The headwater area of the Clark Fork basin between Butte and Anaconda supplied an estimated 100 million tons of tailings to the Clark Fork during the period of mining from 1880 to 1982. These tailings contain concentrations of arsenic, cadmium, copper, lead, and zinc that are 10 to 100 times the expected background values. The tailings have been transported various distances downstream, have been deposited along the flood plain and in Milltown Reservoir, and are continually resuspended and transported by erosional processes. Similar processes have occurred at a smaller scale in several tributary basins of the upper Clark Fork.

The tailings discharged from mining areas have gradually mixed with the natural sediments of the basin, causing sediments to be enriched in trace-element content and the water quality of the upper Clark Fork to be degraded. Improvements in water quality were achieved by the construction of settling ponds to capture tailings, but storm runoff over flood-plain tailings deposits continues to periodically cause fishkills. Tailings dispersed throughout the basin are a persistent source of potential toxicity to aquatic life. In addition, at least one public water supply near Milltown Reservoir was abandoned because of arsenic contamination. Because contaminated sediments continue to pose a potential hazard to the water resources of the upper Clark Fork, the U.S. Environmental Protection Agency designated the tailings-impacted areas from Butte to Milltown Dam as Superfund National Priority List sites.

A data-collection program was conducted from March 1985 to October 1990 by the U.S. Geological Survey to document suspended-sediment and trace-element concentrations during a wide range of hydrologic conditions in surface water of the upper Clark Fork basin. Four stations along the Clark Fork mainstem and four stations on major tributaries were sampled periodically for water quality to provide sufficient geographic coverage to assess spatial differences among sites. In addition, three of the mainstem and one of the tributary sites were operated as daily sediment stations to describe temporal variability and to quantify the suspended-sediment loads transported past various points in the basin.

Comparison of streamflow-duration characteristics indicates that streamflow during water years 1985-90 was consistently less than normal (based on long-term records), especially at the higher range. An implication of the less-than-normal flows is that average annual loads estimated for suspended sediment and trace elements for water years 1985-90 may underestimate actual long-term average loads.

For mainstem stations, the median suspended-sediment concentration increased from 8 mg/L near Galen to 24 mg/L at Turah Bridge, near Bonner, a distance of 112.5 river miles. The median concentration for the tributaries ranged from 9 mg/L in the Blackfoot River to 43 mg/L in Flint Creek.

The statistical distribution of concentrations of arsenic in water samples indicates that maximum concentrations of total-recoverable arsenic at the three mainstem stations upstream from Milltown Reservoir and in Flint Creek either equaled or exceeded the MCL of 50 µg/L specified in Primary Drinking-Water Regulations of the U.S. Environmental Protection Agency. The maximum total-recoverable arsenic concentration was 200 µg/L in the Clark Fork at Deer Lodge. Of the tributaries, Flint Creek had the largest arsenic concentrations, with values similar to those for the Clark Fork at Deer Lodge. However, except for these maximum values, other samples had concentrations less than the MCL. This condition indicates that exceedances of the established protective concentration for arsenic in drinking water are probably infrequent at the sampling stations.

All concentrations of total-recoverable cadmium were less than the MCL of 10 µg/L. Most samples had concentrations less than the minimum reporting level of 1 µg/L, indicating that exceedances of the MCL for cadmium are unlikely.

Maximum total-recoverable lead concentrations measured in water samples from two mainstem stations, at Deer Lodge and at Turah Bridge, near Bonner, and from the tributary Flint Creek exceeded the MCL of 50 µg/L. The largest concentration of total-recoverable lead was 200 µg/L in the Clark Fork at Deer Lodge. With the exception of these three maximum values, all other samples had lead concentrations less than the MCL.

Dissolved and total-recoverable trace-element concentrations were compared to aquatic-life criteria to identify the existence of water-quality conditions that could cause acute or chronic toxicity. All but one of the arsenic concentrations were less than the criteria for toxicity. Only the 200-µg/L maximum concentration of arsenic in the Clark Fork at Deer Lodge was slightly in excess of the criterion for chronic toxicity. Most of the arsenic concentrations were substantially less than the criteria, thereby indicating minimal potential for adverse effects to aquatic life from arsenic.

All cadmium concentrations were less than the MCL of 10 µg/L, and most were less than 1 µg/L. Evaluations of the toxic potential of cadmium to aquatic life are complicated by the fact that the critera for chronic toxicity, especially for waters having little hardness, are very near or less than the minimum reporting level of 1 µg/L. Consequently, the precision limits of the analytical method may not provide a sufficient level of accuracy to conclusively determine if criteria actually were exceeded.

Maximum dissolved copper concentrations in water samples exceeded both acute and chronic toxicity criteria at the three upper mainstem stations. Maximum total-recoverable copper exceeded both acute and chronic toxicity criteria at all mainstem and tributary stations; more than 50 percent of the samples from several stations exceeded criteria. The large number of samples in which total-recoverable copper concentrations exceeded aquatic-life criteria indicates a persistent source of copper in the sediment of the upper Clark Fork basin, especially along the upper mainstem. The maximum dissolved copper concentration (120 µg/L) was measured in the Clark Fork at Deer Lodge during a fishkill in the Clark Fork upstream from Deer Lodge. Although this concentration was more than three times greater than the acute toxicity criterion, much larger total-recoverable copper concentrations have been measured (maximum of 1,500 µg/L) without an observed fishkill. The variable response of aquatic organisms to the different phases of copper might indicate that criteria for acute toxicity may be more applicable to dissolved rather than total-recoverable concentrations.

All concentrations of dissolved iron were considerably less than the criterion. However, maximum concentrations of total-recoverable iron exceeded the criterion at all sites, some by very large margins (maximum of 29,000 µg/L in the Clark Fork at Deer Lodge). Iron is strongly associated with sediment and shows large increases in total-recoverable concentrations during runoff, but its biological effects are not well understood.

Dissolved lead concentrations were commonly less than the minimum reporting level of 1 µg/L, although the maximum dissolved concentrations measured at one mainstem and all four tributary stations exceeded criteria for chronic toxicity. Similar to cadmium, whether these exceedances represent a serious toxic potential for dissolved lead is uncertain, because the criteria are so close to the minimum reporting level. Maximum concentrations of total-recoverable lead exceeded chronic criteria at every station. Notably, at one mainstem station and at three of the four tributaries, more than 50 percent of the samples exceeded chronic criteria. Maximum total-recoverable lead concentration was nearly at the acute criteria in the mainstem at Deer Lodge and at Turah Bridge, near Bonner and in Flint Creek. The relatively large percentage of samples that exceeded criteria for chronic toxicity indicates the presence of a persistent source of lead in the mainstem and some tributary basins.

Except for one sample, dissolved zinc concentrations were less than aquatic-life criteria. Dissolved zinc in a sample collected from the Clark Fork at Deer Lodge during a fishkill had a concentration of 230 µg/L, which exceeded the criterion for acute toxicity and may have been responsible for the lethal effects either directly or in combination with the effects of other metals. The maximum total-recoverable zinc concentrations at three mainstem and two tributary stations exceeded both acute and chronic criteria; however, all other samples had concentrations less than the criteria. Similar to copper, the maximum concentrations of total-recoverable zinc were not associated with acute toxicity, which supports the possibility that acute effects are primarily attributable to dissolved concentrations.

Equations defining the relation between total-recoverable trace-element and suspended-sediment concentrations were used to estimate the sediment concentrations at which trace elements are present in concentrations equal to or greater than aquatic-life criteria. Application of this relation to duration statistics of daily suspended-sediment concentrations provides a means to estimate a frequency, in percentage of time, that criteria for chronic toxicity are exceeded. Such estimates, however, are intended to provide relative comparisons between stations and are not intended to be accurate measures of actual duration at specific sites. Comparison of exceedance estimates may be useful in assessing biological responses to variable lengths of exposure to degraded water quality.

The percentages of time that trace-element concentrations exceeded criteria for chronic toxicity were generally small, with the exception of total-recoverable copper and lead at some stations. The duration of exceedance of chronic criteria was negligible for arsenic and zinc. No estimate was available for cadmium because of the predominance of concentrations less than the minimum reporting level. Only copper and lead concentrations exceeded chronic criteria more than 50 percent of the time at some stations. Copper was estimated to be in excess of chronic criteria at the three upper mainstem stations from 59 percent of the time at Turah Bridge, near Bonner to 81 percent of the time at Deer Lodge. This exceedance decreased to 3 percent in the Clark Fork above Missoula. The only tributary that showed a relatively frequent occurrence of copper concentrations in excess of the criteria was the Blackfoot River, where criteria were exceeded 24 percent of the time.

The exceedance characteristics of lead were substantially different from those of copper. Sample concentrations from the two upper mainstem stations near Galen and at Deer Lodge exceeded chronic criteria for lead less than 10 percent of the time. In contrast to the general pattern of downstream decreases in concentration, the exceedance frequency increased to 59 percent of the time at the next downstream station at Turah Bridge, near Bonner. Part of this effect may be due to Flint Creek, which exceeded the chronic criteria for lead 82 percent of the time.

Trace-element content of suspended-sediment was computed indirectly from concurrent concentrations of trace elements and suspended sediment. In general, the trace-element content consistently decreased downstream along the mainstem, presumably as a function of distance from the headwater mining areas. Concentrations of trace elements in the tributaries were variable. The most significant differences among the tributaries were the elevated concentrations of arsenic and lead in the sediment of Flint Creek.

To quantify and compare the inputs of suspended sediment and total-recoverable trace elements to the surface-water system, constituent loads transported annually past the sampling stations were estimated for water years 1985-90. Estimates were made by regression relations applied to daily values of either streamflow or suspended-sediment discharge. The estimated daily loads were summed for the period to compute an average annual load for each constituent. Both the average annual loads, in tons, and the proportion of the total load contributed to Milltown Reservoir, in percent, were determined. These data were used for comparisons between source areas.

The average annual loads computed for the Clark Fork and the Blackfoot River indicate that the Clark Fork basin supplied a greater load to Milltown Reservoir of every constituent, even though streamflow was slightly less in the Clark Fork than in the Blackfoot River during water years 1985-90. The suspended-sediment load of the Clark Fork was 1.3 times greater than that of the Blackfoot River, yet the trace-element loads ranged from 1.7 times greater for lead to 7.1 times greater for arsenic. By percentage, the trace-element input from the Clark Fork ranged from 63 percent of the lead to 88 percent of the arsenic that entered Milltown Reservoir.

Arsenic, copper, and zinc supplied by the Clark Fork equaled or exceeded 80 percent of the total quantity entering the reservoir. The fact that the Clark Fork supplied only 57 percent of the suspended sediment yet 63-88 percent of the trace-element load indicates that the sediments within its basin are enriched in trace-element content compared to those of the Blackfoot River.

Source areas within the upper Clark Fork basin contributed variable quantities of individual trace elements. Arsenic was derived from three main sources, each contributing about 20 percent of Milltown Reservoir's total load. These source areas were the mainstem basin upstream from Galen, the 21.5-mi intervening reach between Galen and Deer Lodge, and Flint Creek. Most notable was the relatively large contribution from the short reach between Galen and Deer Lodge, where the flood plain is visibly contaminated with tailings. The contribution of arsenic was substantially greater from Flint Creek than from any of the tributaries, including the much larger Blackfoot River.

A somewhat different geographic distribution of sources is evident for copper. Even though the Clark Fork basin upstream from Galen plus the reach between Galen and Deer Lodge accounted for a substantial percentage of Milltown Reservoir's annual load (26 percent), the Little Blackfoot River, Flint Creek, and Rock Creek contributed only minor quantities (about 1-3 percent). The largest load of copper (49 percent) was contributed from the 91.0-mi intervening reach between Deer Lodge and Turah Bridge, near Bonner.

Iron loads from various source areas showed spatial trends similiar to those of copper. The largest quantities of iron contributed to Milltown Reservoir were derived from the Blackfoot River (27 percent) and the 91.0-mi intervening reach between Deer Lodge and Turah Bridge, near Bonner (39 percent).

Lead contributions to Milltown Reservoir were relatively uniform from the upper basin and tributaries. The entire watershed upstream from Deer Lodge supplied only 7 percent, and three tributaries between Deer Lodge and Turah Bridge, near Bonner supplied an additional 15 percent. The largest contribution was from the 91.0-mi reach between Deer Lodge and Turah Bridge, near Bonner, which supplied 40 percent of the annual load of lead. A nearly equivalent quantity of lead (37 percent) was supplied by the Blackfoot River.

Manganese loads exhibited spatial patterns unlike most of the other trace elements. The largest contribution (39 percent) was supplied from the basin upstream from Galen, whereas only a negligible quantity (1 percent) was added in the 21.5-mi reach between Galen and Deer Lodge. Flint Creek also contributed a substantial quantity (18 percent), but the 91.0-mi reach between Deer Lodge and Turah Bridge, near Bonner supplied only 8 percent of Milltown Reservoir's manganese load.

Zinc contributions from various sources are similar to those of copper. The basin upstream from Deer Lodge supplied about 30 percent of Milltown Reservoir's annual load, which is similar to the quantity (33 percent) supplied from the 91.0-mi reach between Deer Lodge and Turah Bridge, near Bonner. A larger percentage of zinc load compared to copper load was discharged from the three tributaries between Galen and Deer Lodge, which cumulatively contributed about 17 percent of the annual zinc load to the reservoir. The percentage of zinc load (20) added by the Blackfoot River was similar to that of copper.

The annual mass balance of constituent loads in Milltown Reservoir indicates that, except for arsenic and manganese, constituent loads showed net gains (deposition). The net loss (erosion) of arsenic and manganese loads from the reservoir is difficult to explain from a physical-transport perspective, and may involve geochemical processes within the reservoir, construction activities, or estimation error. An average of 16,300 tons of suspended sediment was deposited annually during water years 1985-90. Of the trace elements, copper deposition was largest (about 23 tons annually). Trace-element losses were estimated at an average annual rate of about 0.8 ton of arsenic and 10 tons of manganese. The effects of specific processes on trace-element transport through Milltown Reservoir are undefined by the available data.

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SUPPLEMENTAL DATA

Table 28.--*Results of analyses for duplicate samples*

[Unless otherwise specified, all duplicate samples were subsamples split onsite from a churn splitter. µg/L, micrograms per liter; <, less than minimum reporting level]

Station number	Date	Arsenic, total-recoverable (µg/L as As)	Arsenic, dissolved (µg/L as As)	Cadmium, total-recoverable (µg/L as Cd)	Cadmium, dissolved (µg/L as Cd)	Copper, total-recoverable (µg/L as Cu)	Copper, dissolved (µg/L as Cu)	Iron, total-recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Lead, total-recoverable (µg/L as Pb)	Lead, dissolved (µg/L as Pb)	Manganese, total-recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)	Zinc, total-recoverable (µg/L as Zn)	Zinc, dissolved (µg/L as Zn)
12323800	05-10-89	28	19	<1	<1	59	12	1,200	18	17	<1	490	81	130	12
		32	19	1	<1	63	12	1,200	19	14	4	580	82	100	23
	06-09-89	18	12	<1	<1	33	11	650	25	6	1	300	79	100	9
		18	13	<1	<1	36	9	630	20	8	1	310	11	100	<3
	08-17-89	14	10	<1	<1	13	9	120	9	2	1	170	110	20	13
		13	10	<1	<1	14	7	140	8	2	<1	170	110	30	15
	04-02-90	17	11	<1	<1	35	13	330	6	3	<1	310	160	50	11
		20	11	<1	<1	25	10	360	9	3	<1	310	160	50	29
	10-24-90	5	4	<1	<1	16	3	230	4	1	<1	180	110	40	10
		5	4	<1	<1	17	4	240	10	4	<1	180	110	30	23
12324200	04-15-86	16	10	<1	<1	51	7	640	11	6	<1	210	57	70	15
		15	11	<1	<1	56	7	670	12	5	<1	190	57	80	19
	04-29-87	12	12	<1	<1	34	8	380	5	<5	<5	220	18	40	20
		12	13	1	<1	35	8	370	10	<5	<5	230	10	40	20
	07-10-87	15	14	<1	<1	29	12	580	4	5	<5	130	40	40	14
		17	14	1	<1	31	12	610	20	5	<5	140	40	40	10
	09-02-87[1]	15	14	<1	<1	25	9	160	4	6	<5	90	26	20	9
		12	14	<1	<1	27	9	200	3	5	<5	90	26	20	8
	04-20-88	26	13	1	<1	110	19	2,000	8	11	<5	480	20	130	14
		24	14	1	<1	120	16	2,700	10	12	<5	490	23	150	16
	03-07-89	66	30	2	<1	590	47	19,000	120	80	<5	1,600	93	590	43
		81	28	2	1	560	50	20,000	110	75	<5	1,500	94	590	38
12324590	04-15-86	5	5	<1	<1	6	4	310	33	1	<1	30	8	<10	8
		5	5	<1	<1	7	4	290	32	2	<1	20	5	<10	<3
	04-16-90	7	5	<1	<1	6	2	2,000	35	5	<1	120	6	20	4
		8	4	<1	<1	6	2	2,200	24	6	<1	110	5	20	5
12331500	04-15-86	11	7	<1	<1	9	3	600	62	9	1	110	23	30	6
		11	7	<1	<1	8	3	540	60	7	<1	100	22	20	<3
	07-19-87	15	11	<1	<1	7	2	480	9	<5	<5	160	34	30	4
		16	11	<1	<1	6	9	510	9	<5	<5	150	34	20	3
12334510	04-15-86	<1	<1	<1	<1	3	1	150	50	1	<1	10	<1	<10	3
		<1	<1	<1	<1	4	1	110	49	3	<1	<10	<1	<10	<3
	04-20-89	1	<1	<1	<1	2	2	540	54	6	<5	20	2	<10	<3
		1	<1	<1	<1	<1	3	540	55	<5	<5	20	3	10	6
	05-30-90	1	<1	<1	<1	4	2	900	63	3	<1	30	3	<10	<3
		<1	<1	<1	<1	3	1	950	60	2	<1	30	3	<10	<3
12334550	04-16-86	7	5	<1	<1	36	4	410	19	11	<1	50	7	40	5
		6	5	<1	<1	30	5	400	16	10	<1	50	7	40	<3
	05-28-87	7	5	<1	<1	18	16	530	18	<5	<5	40	5	40	<3
		7	4	<1	<1	18	15	470	30	<5	<5	30	<10	40	10
	05-17-88	6	9	<1	<1	42	10	780	22	7	<5	80	5	50	7
		6	9	<1	<1	36	13	750	24	8	<5	70	5	50	6
	02-24-89	7	5	<1	<1	16	3	370	6	<5	<5	80	5	40	10
		7	5	2	1	16	4	370	8	<5	<5	70	5	40	12
	01-10-90	6	5	<1	<1	23	2	680	10	5	<1	100	6	60	6
		5	6	<1	<1	20	2	650	11	6	<1	110	7	60	21
	03-21-90	9	6	<1	<1	40	5	1,800	18	6	<1	160	10	80	20
		9	6	<1	<1	41	5	1,600	10	5	<1	160	10	70	9
12340000	04-16-86	1	<1	<1	<1	34	3	240	32	11	<1	10	1	<10	<3
		1	<1	<1	<1	48	3	100	28	12	<1	10	<1	<10	<3
	05-08-89	1	<1	<1	<1	18	3	1,600	28	15	2	90	5	20	3
		2	1	<1	<1	16	2	1,400	51	14	1	90	14	10	<3
12340500	12-28-89	3	3	<1	<1	7	2	70	<3	3	<1	30	15	20	10
		3	3	<1	<1	6	2	70	7	3	<1	40	15	20	12
	07-25-90	3	2	<1	<1	5	3	190	11	1	1	40	20	10	3
		3	2	<1	<1	5	3	200	10	2	2	40	20	10	5

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[1] Sequential duplicate sample (two independent samples obtained by repeating sampling procedure).

Table 29.--*Results of analyses for blank samples of distilled water*

[FB, field blank consisting of distilled water passed through processing equipment in the field; SB, shelf blank consisting of distilled water obtained from the distillation unit at the Helena Office support laboratory and submitted for analysis without processing through equipment; µg/L, micrograms per liter; <, less than minimum reporting level]

Sample type	Date	Arsenic, total-recoverable (µg/L as As)	Arsenic, dissolved (µg/L as As)	Cadmium, total-recoverable (µg/L as Cd)	Cadmium, dissolved (µg/L as Cd)	Copper, total-recoverable (µg/L as Cu)	Copper, dissolved (µg/L as Cu)	Iron, total-recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Lead, total-recoverable (µg/L as Pb)	Lead, dissolved (µg/L as Pb)	Manganese, total-recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)	Zinc, total-recoverable (µg/L as Zn)	Zinc, dissolved (µg/L as Zn)
FB	06-01-88	<1	<1	<1	<1	3	1	10	<3	<5	<5	<10	<1	<3	<10
FB	04-07-89	<1	<1	<1	<1	3	1	<10	3	<5	<5	<10	<1	30	<3
FB	04-24-90	<1	<1	<1	<1	2	<1	40	<3	1	<1	10	<1	<10	<3
SB	06-06-90	<1	<1	<1	<1	2	<1	<10	<3	1	<1	<10	<1	<10	<3

Table 30.--*Statistical summary of streamflow and water-quality data for periodic samples, March 1985 through October 1990*

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; ton/d, tons per day; mm, millimeter; <, less than minimum reporting level[1]; --, indicates insufficient data greater than minimum reporting level to compute statistic]

Parameter and unit of measure	Descriptive statistics				Percent of samples in which values were less than or equal to those shown				
	Number of samples	Maximum	Minimum	Mean	95	75	Median 50	25	5
<u>12323800--Clark Fork near Galen. Period of record: July 1988-October 1990</u>									
Streamflow, instantaneous (ft^3/s)	22	370	21	144	365	254	96	59	22
Specific conductance, onsite (µS/cm)	19	670	225	477	670	590	496	380	225
pH, onsite (standard units)	19	8.8	7.5	8.1	8.8	8.2	8.1	7.9	7.5
Temperature, water (°C)	21	22.5	.0	10.0	22	15.7	10.0	4.2	.0
Hardness, total (mg/L as $CaCO_3$)	18	300	96	209	300	252	220	155	96
Alkalinity, onsite (mg/L as $CaCO_3$)	17	143	49	97	143	120	91	83	49
Arsenic, total-recoverable (µg/L as As)	18	60	5	19	60	18	15	11	5
Arsenic, dissolved (µg/L as As)	18	28	4	12	28	14	10	8	4
Cadmium, total-recoverable (µg/L as Cd)	18	3	<1	[2].72	3	1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	18	1	<1	--	1	<1	<1	<1	<1
Copper, total-recoverable (µg/L as Cu)	18	240	11	53	240	60	31	18	11
Copper, dissolved (µg/L as Cu)	18	50	3	14	50	15	10	9	3
Iron, total-recoverable (µg/L as Fe)	18	9,200	90	1,110	9,200	945	340	197	90
Iron, dissolved (µg/L as Fe)	18	110	4	23	110	30	10	7	4
Lead, total-recoverable (µg/L as Pb)	18	28	<5	[2]7	28	8	3	2	<5
Lead, dissolved (µg/L as Pb)	18	1	<1	[2]1	1	1	<5	<1	<1
Manganese, total-recoverable (µg/L as Mn)	18	1,400	80	431	1,400	572	320	195	80
Manganese, dissolved (µg/L as Mn)	18	360	33	172	360	237	155	80	33
Zinc, total-recoverable (µg/L as Zn)	18	360	20	97	360	145	60	40	20
Zinc, dissolved (µg/L as Zn)	18	110	3	30	110	33	14	10	3
Sediment[3] concentration (mg/L)	22	338	2	31	305	17	8	3	2
Sediment[3] discharge (ton/d)	22	338	.17	25	303	11	2	.5	.2
Sediment[3] (percent finer than 0.062 mm)	21	97	65	80	96	85	81	72	65
<u>12324200--Clark Fork at Deer Lodge. Period of record: March 1985-October 1990</u>									
Streamflow, instantaneous (ft^3/s)	69	1,920	23	269	752	320	210	111	49
Specific conductance, onsite (µS/cm)	58	642	262	524	628	583	549	478	347
pH, onsite (standard units)	33	8.5	7.4	8.0	8.4	8.2	8.0	7.8	7.4
Temperature, water (°C)	68	23.0	.0	9.6	20.0	14.8	10	4.6	.0
Hardness, total (mg/L as $CaCO_3$)	25	270	120	220	267	250	230	195	132
Alkalinity, onsite (mg/L as $CaCO_3$)	31	196	71	134	188	156	135	115	75
Arsenic, total-recoverable (µg/L as As)	35	200	8	29	144	25	17	14	8
Arsenic, dissolved (µg/L as As)	35	39	7	14	31	14	13	10	7
Cadmium, total-recoverable (µg/L as Cd)	35	5	<1	[2]1	3	1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	35	2	<1	--	1	<1	<1	<1	<1
Copper, total-recoverable (µg/L as Cu)	35	1,500	13	154	803	130	54	34	15
Copper, dissolved (µg/L as Cu)	35	120	5	16	61	17	10	8	5
Iron, total-recoverable (µg/L as Fe)	35	29,000	80	3,790	26,600	2,100	950	580	136
Iron, dissolved (µg/L as Fe)	35	150	<3	[2]20	120	19	10	5	<3
Lead, total-recoverable (µg/L as Pb)	35	200	<5	[2]21	100	14	7	4	<5
Lead, dissolved (µg/L as Pb)	35	6	<1	[2]1	5	1	<5	<1	<1
Manganese, total-recoverable (µg/L as Mn)	35	4,600	50	522	2,360	490	230	170	66
Manganese, dissolved (µg/L as Mn)	35	400	<1	[2]55	210	57	35	22	<10
Zinc, total-recoverable (µg/L as Zn)	35	1,700	10	196	955	170	80	60	18
Zinc, dissolved (µg/L as Zn)	35	230	6	23	85	22	15	11	6
Sediment[3] concentration (mg/L)	69	2,250	2	122	896	48	22	14	3
Sediment[3] discharge (ton/d)	69	8,690	.29	319	1,810	32	11	4	.8
Sediment[3] (percent finer than 0.062 mm)	60	99	41	71	91	81	72	58	45

Table 30.--*Statistical summary of streamflow and water-quality data for periodic samples, March 1985 through October 1990*--Continued

Parameter and unit of measure	Descriptive statistics				Percent of samples in which values were less than or equal to those shown				
	Number of samples	Maximum	Minimum	Mean	95	75	Median 50	25	5
12324590--Little Blackfoot River near Garrison. Period of record: March 1985-October 1990									
Streamflow, instantaneous (ft^3/s)	27	2,080	35	396	1,660	495	310	84	35
Specific conductance, onsite (µS/cm)	24	300	120	206	296	240	206	163	121
pH, onsite (standard units)	24	8.4	7.0	7.7	8.3	7.9	7.8	7.6	7.1
Temperature, water (°C)	27	15.5	.0	7.4	14.9	10.5	7.0	5.0	.2
Hardness, total (mg/L as $CaCO_3$)	19	140	51	93	140	130	91	63	51
Alkalinity, onsite (mg/L as $CaCO_3$)	22	129	36	85	128	106	82	65	36
Arsenic, total-recoverable (µg/L as As)	24	17	4	7	16	8	6	5	4
Arsenic, dissolved (µg/L as As)	24	7	4	5	6	5	5	5	4
Cadmium, total-recoverable (µg/L as Cd)	24	2	<1	[2].5	1	<1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	24	1	<1	--	<1	<1	<1	<1	<1
Copper, total-recoverable (µg/L as Cu)	24	45	2	9	41	9	6	4	2
Copper, dissolved (µg/L as Cu)	24	7	1	2	6	3	2	2	1
Iron, total-recoverable (µg/L as Fe)	24	25,000	40	2,700	21,800	2,320	500	137	42
Iron, dissolved (µg/L as Fe)	24	120	<3	40	111	72	33	9	3
Lead, total-recoverable (µg/L as Pb)	24	25	<5	[2]6	21	5	3	<5	<5
Lead, dissolved (µg/L as Pb)	24	6	<1	[2]1	3	1	<5	<1	<1
Manganese, total-recoverable (µg/L as Mn)	24	1,100	10	147	1,060	150	35	20	10
Manganese, dissolved (µg/L as Mn)	24	30	1	8	27	10	7	4	1
Zinc, total-recoverable (µg/L as Zn)	24	140	<10	[2]29	100	30	10	10	<10
Zinc, dissolved (µg/L as Zn)	24	15	<3	[2]5	15	7	4	<3	<3
Sediment[3] concentration (mg/L)	27	1,410	1	119	1,140	66	18	5	1
Sediment[3] discharge (ton/d)	27	7,920	.17	402	5,180	73	15	1	.2
Sediment[3] (percent finer than 0.062 mm)	27	94	49	70	93	86	69	55	49
12331500--Flint Creek near Drummond. Period of record: March 1985-October 1990									
Streamflow, instantaneous (ft^3/s)	29	892	7	212	747	261	151	101	8
Specific conductance, onsite (µS/cm)	27	501	135	298	500	365	275	220	137
pH, onsite (standard units)	27	8.8	7.5	8.1	8.6	8.4	8.1	7.9	7.5
Temperature, water (°C)	29	19.0	.5	10	18.5	13.2	11.5	6.7	1.2
Hardness, total (mg/L as $CaCO_3$)	20	260	60	142	259	195	130	93	60
Alkalinity, onsite (mg/L as $CaCO_3$)	24	238	60	133	236	187	118	88	60
Arsenic, total-recoverable (µg/L as As)	27	50	7	21	49	31	17	12	7
Arsenic, dissolved (µg/L as As)	27	20	5	10	17	12	10	8	5
Cadmium, total-recoverable (µg/L as Cd)	27	3	<1	[2].5	2	<1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	27	<1	<1	--	<1	<1	<1	<1	<1
Copper, total-recoverable (µg/L as Cu)	27	32	3	11	30	13	10	5	3
Copper, dissolved (µg/L as Cu)	27	7	1	3	6	4	3	2	1
Iron, total-recoverable (µg/L as Fe)	27	7,200	170	1,780	6,560	2,200	1,100	480	174
Iron, dissolved (µg/L as Fe)	27	190	4	41	186	47	34	10	4
Lead, total-recoverable (µg/L as Pb)	27	87	<5	[2]19	56	25	13	5	<5
Lead, dissolved (µg/L as Pb)	27	7	<1	[2]2	7	2	<5	<5	<1
Manganese, total-recoverable (µg/L as Mn)	27	1,600	70	354	1,340	560	230	110	70
Manganese, dissolved (µg/L as Mn)	27	120	19	48	111	62	42	33	20
Zinc, total-recoverable (µg/L as Zn)	27	290	10	68	242	110	40	30	10
Zinc, dissolved (µg/L as Zn)	27	27	<3	[2]10	25	15	8	4	<3
Sediment[3] concentration (mg/L)	29	556	7	86	397	109	43	23	7
Sediment[3] discharge (ton/d)	29	904	.21	89	729	58	16	5	.3
Sediment[3] (percent finer than 0.062 mm)	29	98	28	77	97	93	80	63	41

Table 30.--*Statistical summary of streamflow and water-quality data for periodic samples, March 1985 through October 1990*—Continued

12334510--Rock Creek near Clinton. Period of record: March 1985-October 1990

Parameter and unit of measure	Descriptive statistics				Percent of samples in which values were less than or equal to those shown				
	Number of samples	Maximum	Minimum	Mean	95	75	Median 50	25	5
Streamflow, instantaneous (ft^3/s)	26	3,010	114	937	2,800	1,387	802	367	134
Specific conductance, onsite (µS/cm)	25	154	55	100	152	130	90	71	58
pH, onsite (standard units)	25	8.4	6.9	7.7	8.3	7.8	7.6	7.5	6.9
Temperature, water (°C)	26	18.0	.0	8.6	16.4	11.0	9.2	6.3	.1
Hardness, total (mg/L as $CaCO_3$)	18	90	26	49	90	67	39	32	26
Alkalinity, onsite (mg/L as $CaCO_3$)	22	82	22	45	80	56	42	31	23
Arsenic, total-recoverable (µg/L as As)	24	2	<1	[2].9	2	1	<1	<1	<1
Arsenic, dissolved (µg/L as As)	24	1	<1	--	1	<1	<1	<1	<1
Cadmium, total-recoverable (µg/L as Cd)	24	3	<1	[2].8	2	1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	24	1	<1	--	1	<1	<1	<1	<1
Copper, total-recoverable (µg/L as Cu)	24	41	1	8	35	9	4	2	1
Copper, dissolved (µg/L as Cu)	24	5	<1	[2]2	5	2	2	1	<1
Iron, total-recoverable (µg/L as Fe)	24	2,100	40	472	1,980	555	295	97	42
Iron, dissolved (µg/L as Fe)	24	110	7	40	99	57	38	18	7
Lead, total-recoverable (µg/L as Pb)	24	19	<1	[2]5	17	5	2	<5	<1
Lead, dissolved (µg/L as Pb)	24	5	<1	[2]1	5	1	<5	<1	<1
Manganese, total-recoverable (µg/L as Mn)	24	90	<10	[2]24	70	30	20	10	<10
Manganese, dissolved (µg/L as Mn)	24	8	<1	[2]2	5	3	2	<1	<1
Zinc, total-recoverable (µg/L as Zn)	24	60	<10	[2]16	50	20	10	<10	<10
Zinc, dissolved (µg/L as Zn)	24	15	<3	[2]4	13	5	<3	<3	<3
Sediment[3] concentration (mg/L)	26	157	1	25	137	33	12	4	1
Sediment[3] discharge (ton/d)	26	1,280	.31	110	991	106	33	4	.4
Sediment[3] (percent finer than 0.062 mm)	26	95	35	67	95	83	65	55	36

12334550--Clark Fork at Turah Bridge, near Bonner. Period of record: March 1985-October 1990

Parameter and unit of measure	Number of samples	Maximum	Minimum	Mean	95	75	Median 50	25	5
Streamflow, instantaneous (ft^3/s)	76	9,370	296	1,630	4,470	2,000	1,105	789	495
Specific conductance, onsite (µS/cm)	57	483	160	324	445	406	340	247	164
pH, onsite (standard units)	34	8.7	7.4	8.0	8.6	8.2	8.0	7.6	7.4
Temperature, water (°C)	75	22	.0	9.2	17.1	13.0	9.5	4.0	.5
Hardness, total (mg/L as $CaCO_3$)	25	210	67	142	207	185	130	96	69
Alkalinity, onsite (mg/L as $CaCO_3$)	31	147	52	101	146	131	101	71	55
Arsenic, total-recoverable (µg/L as As)	34	110	5	14	75	11	8	7	5
Arsenic, dissolved (µg/L as As)	34	17	4	6	15	7	6	5	4
Cadmium, total-recoverable (µg/L as Cd)	34	4	<1	[2].8	3	1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	34	1	<1	--	<1	<1	<1	<1	<1
Copper, total-recoverable (µg/L as Cu)	34	500	5	78	477	70	35	20	5
Copper, dissolved (µg/L as Cu)	34	25	2	7	23	8	5	4	2
Iron, total-recoverable (µg/L as Fe)	34	19,000	70	2,580	17,500	2,020	775	370	70
Iron, dissolved (µg/L as Fe)	34	170	<3	28	170	31	18	7	3
Lead, total-recoverable (µg/L as Pb)	34	100	<5	[2]19	92	19	10	5	<5
Lead, dissolved (µg/L as Pb)	34	7	<1	[2]1	5	1	<5	<1	<1
Manganese, total-recoverable (µg/L as Mn)	34	2,000	20	273	1,850	192	100	67	20
Manganese, dissolved (µg/L as Mn)	34	31	<1	[2]8	28	10	7	5	<10
Zinc, total-recoverable (µg/L as Zn)	34	1,100	10	149	1,100	92	55	40	10
Zinc, dissolved (µg/L as Zn)	34	39	<3	[2]11	30	15	8	5	<3
Sediment[3] concentration (mg/L)	76	1,370	4	86	354	58	24	11	5
Sediment[3] discharge (ton/d)	76	34,700	4.8	1,000	4,170	309	66	21	8
Sediment[3] (percent finer than 0.062 mm)	65	98	27	67	91	79	69	56	39

Table 30.--*Statistical summary of streamflow and water-quality data for periodic samples, March 1985 through October 1990*--Continued

	Descriptive statistics				Percent of samples in which values were less than or equal to those shown				
Parameter and unit of measure	Number of samples	Maximum	Minimum	Mean	95	75	Median 50	25	5
12340000--Blackfoot River near Bonner. Period of record: March 1985-October 1990									
Streamflow, instantaneous (ft^3/s)	55	10,300	344	2,524	8,400	4,090	1,260	654	405
Specific conductance, onsite (µS/cm)	36	270	131	196	264	239	187	156	138
pH, onsite (standard units)	26	8.5	7.5	8.0	8.4	8.2	8.0	7.8	7.5
Temperature, water (°C)	55	20.5	.0	9.2	19.2	13.0	8.5	5.5	.4
Hardness, total (mg/L as $CaCO_3$)	19	140	55	91	140	130	77	73	55
Alkalinity, onsite (mg/L as $CaCO_3$)	23	141	65	89	140	97	82	72	65
Arsenic, total-recoverable (µg/L as As)	26	2	<1	[2]1	2	1	1	<1	<1
Arsenic, dissolved (µg/L as As)	26	2	<1	[2].8	1	1	<1	<1	<1
Cadmium, total-recoverable (µg/L as Cd)	26	2	<1	[2].7	2	1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	26	1	<1	--	<1	<1	<1	<1	<1
Copper, total-recoverable (µg/L as Cu)	26	34	2	11	32	15	9	6	2
Copper, dissolved (µg/L as Cu)	26	6	1	3	6	4	2	2	1
Iron, total-recoverable (µg/L as Fe)	26	3,600	50	776	3,250	867	405	207	50
Iron, dissolved (µg/L as Fe)	26	100	<3	25	88	34	18	10	3
Lead, total-recoverable (µg/L as Pb)	26	20	<5	[2]8	17	15	7	1	<5
Lead, dissolved (µg/L as Pb)	26	8	<1	[2]2	7	2	<5	<1	<1
Manganese, total-recoverable (µg/L as Mn)	26	180	<10	[2]46	150	60	30	10	<10
Manganese, dissolved (µg/L as Mn)	26	11	<1	[2]3	6	4	2	<1	<1
Zinc, total-recoverable (µg/L as Zn)	26	60	<10	[2]17	50	20	10	<10	<10
Zinc, dissolved (µg/L as Zn)	26	15	<3	[2]5	15	8	3	<3	<3
Sediment[3] concentration (mg/L)	55	271	1	32	150	37	9	4	1
Sediment[3] discharge (ton/d)	55	7,540	1	522	3,150	390	32	6	2
Sediment[3] (percent finer than 0.062 mm)	54	98	42	74	94	82	76	67	47
12340500--Clark Fork above Missoula. Period of record: July 1986-October 1990									
Streamflow, instantaneous (ft^3/s)	42	15,100	720	3,596	14,000	4,380	1,825	1,440	892
Specific conductance, onsite (µS/cm)	25	365	145	269	365	335	280	190	151
pH, onsite (standard units)	11	8.4	7.9	8.1	8.4	8.3	8.1	8.0	7.9
Temperature, water (°C)	39	19.5	.0	9.5	19.5	15.0	8.5	5.0	.5
Hardness, total (mg/L as $CaCO_3$)	11	170	61	118	170	150	120	95	61
Alkalinity, onsite (mg/L as $CaCO_3$)	11	142	69	101	142	121	96	80	69
Arsenic, total-recoverable (µg/L as As)	11	6	2	3	6	4	3	2	2
Arsenic, dissolved (µg/L as As)	11	3	2	2	3	3	3	2	2
Cadmium, total-recoverable (µg/L as Cd)	11	<1	<1	--	<1	<1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	11	<1	<1	--	<1	<1	<1	<1	<1
Copper, total-recoverable (µg/L as Cu)	11	27	5	10	27	12	8	7	5
Copper, dissolved (µg/L as Cu)	11	6	2	3	6	3	3	2	2
Iron, total-recoverable (µg/L as Fe)	11	3,000	70	768	3,000	800	420	170	70
Iron, dissolved (µg/L as Fe)	11	44	<3	[2]22	44	36	23	11	4
Lead, total-recoverable (µg/L as Pb)	11	9	1	3	9	3	2	2	1
Lead, dissolved (µg/L as Pb)	11	1	<1	[2]1	1	1	<1	<1	<1
Manganese, total-recoverable (µg/L as Mn)	11	160	20	60	160	60	40	30	20
Manganese, dissolved (µg/L as Mn)	11	21	7	14	21	19	14	11	7
Zinc, total-recoverable (µg/L as Zn)	11	60	10	22	60	30	20	10	10
Zinc, dissolved (µg/L as Zn)	11	16	<3	[2]7	16	10	7	3	<3
Sediment[3] concentration (mg/L)	42	297	2	34	190	32	8	6	2
Sediment[3] discharge (ton/d)	42	7,670	7	741	6,180	366	48	21	8
Sediment[3] (percent finer than 0.062 mm)	37	98	44	83	97	92	88	77	51

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[1] Multiple minimum reporting levels during the period of record may result in varying values identified with a less-than (<) symbol.

[2] Value is estimated by using a log-probability regression to predict the values of data less than the minimum reporting level (Helsel and Cohn, 1988).

[3] Suspended sediment.