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Estimated 1996-97 and Long-Term Average Annual Loads for Suspended Sediment and Selected Trace Metals in Streamflow of the Upper Clark Fork Basin from Warm Springs to Missoula, Montana

Water-Resources Investigations Report 98-4137

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U.S. Department of the Interior

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August 1998

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CONTENTS

ILLUSTRATIONS

TABLES

TABLES--Continued

CONVERSION FACTORS, AND ABBREVIATED UNITS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.028317	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
gallon (gal)	3.785	liter
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer
ounce (oz)	28.35	gram (g)
square mile (mi^2)	2.59	square kilometer
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 equation:

$$°F = 9/5\,(°C) + 32$$

Abbreviated water-quality units and acronyms used in this report:

μg/L micrograms per liter

μm micrometer

mg/L milligrams per liter

Water-year definition:

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

Estimated 1996-97 And Long-Term Average Annual Loads for Suspended Sediment and Selected Trace Metals in Streamflow of the Upper Clark Fork Basin from Warm Springs to Missoula, Montana

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Abstract

The transport of suspended sediment and trace elements has been monitored by the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency and other agencies, at mainstem and tributary sites in the upper Clark Fork basin of western Montana since 1985. Annual loads have been estimated using water-quality data, daily records of streamflow and suspended-sediment discharge, and regression relations. Average annual load estimates previously have been published for the 1985-90 and 1991-95 periods. During 1996-97, high flows occurred that resulted in much larger annual loads than previously had been measured. This report presents the estimated 1996-97 annual loads of suspended sediment, copper, lead, and zinc. These load estimates have been combined with estimates for previous years to provide average annual loads that describe a wider range of hydrologic conditions. In addition, the long-term average annual loads have been used to determine a mass balance of constituent loads in Milltown Reservoir.

INTRODUCTION

The Clark Fork in west-central Montana upstream from Missoula drains an area of about 6,000 square miles (fig. 1). The mainstem Clark Fork begins at the confluence of Silver Bow and Warm Springs Creeks near the town of Warm Springs. Large-scale mining and smelting of metal ores occurred in the basins of these two headwater tributaries near Butte and Anaconda, although small- to moderate-scale mining took place in many tributary drainages. During the century of metal mining from the 1880's to the 1980's, large quantities of mine tailings enriched in heavy metals were dispersed along stream channels and on the Clark Fork flood plain (Andrews, 1987). These tailings and the potential toxicity associated with metal exposure are the subject of numerous investigations directed at characterizing the sources, transport, and fate of metals in the aquatic environment of the Clark Fork.

The U.S. Geological Survey (USGS), in cooperation with multiple State of Montana agencies and the U.S. Environmental Protection Agency (USEPA), has operated a surface-water monitoring network in the upper Clark Fork basin since 1985. The network downstream from the Warm Springs Ponds provides spatial coverage of the Milltown Reservoir Superfund Site, which extends from below the Warm Springs Ponds to Milltown Reservoir (fig. 1). A primary purpose of surface-water monitoring has been to quantify the annual transport of suspended sediment and trace elements throughout the basin. The long-term data collected from mainstem sites and major tributaries enable identification of the primary source areas contributing sediment and metals to the Clark Fork and tracking of changes over time as remedial treatments are implemented to reduce metal inputs.

The original network of 8 stations has expanded over the years and currently (1997) includes 15 sites from Butte to Missoula, Mont. (table 1). Twelve of the sites are located between the Warm Springs Ponds and Missoula at several locations on the Clark Fork mainstem and on major tributaries (fig. 1). This portion of the basin from below the Warm Springs Ponds to the upstream end of Milltown Reservoir also is the focus of a geomorphology study being conducted by a technical committee formed by the USEPA to evaluate geomorphic erosional processes and metal inputs. Consequently, knowledge of sediment and metals transport characteristics is important for geomorphic assessments associated with ongoing Superfund studies in the upper Clark Fork basin.

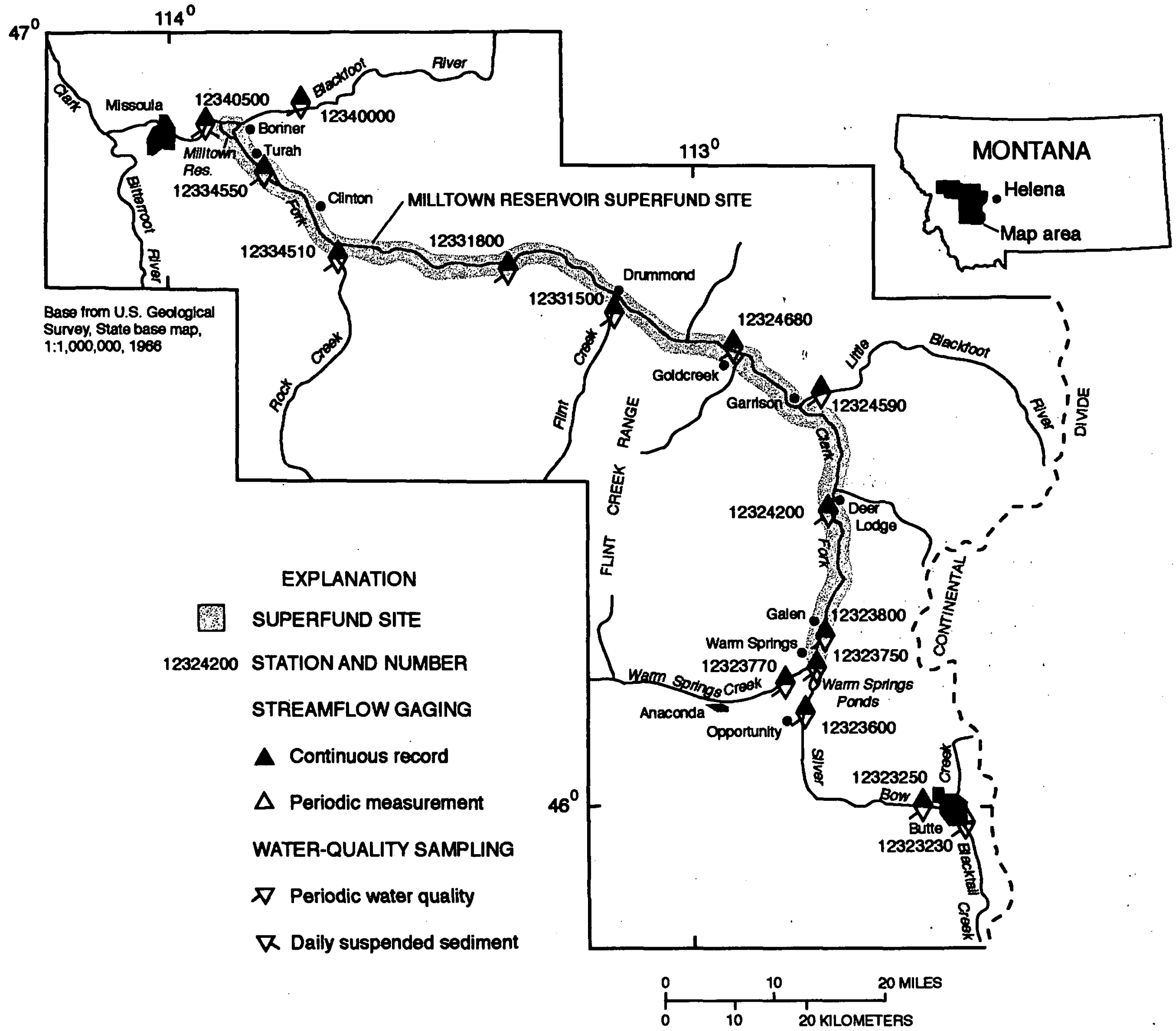

Figure 1. Location of study area.

Average annual loads of suspended sediment and selected trace elements at network sites previously have been published for the 1985-90 and 1991-95 periods (Lambing, 1991; Hornberger and others, 1997). The estimates for 1985-90 were made for the original network of eight sites. The estimates for 1991-95 were made for an expanded network of 12 sites, in which four additional sites on the mainstem and tributaries were established downstream from the Warm Springs Ponds in 1993. The additional sites were established to obtain better resolution of inputs along the Clark Fork mainstem and to document the upstream inputs from the Silver Bow Creek and Warm Springs Creek basins. Load estimates were made for the 1991-95 period at the new and pre-existing sites in order to have a common base period for comparison of loads and to maintain continuity with the previous 1985-90 estimates.

The previous study periods primarily were characterized by lower than normal flows and presumably underestimated long-term metal fluxes. A major ice-breakup in February 1996 and prolonged high flows from spring runoff in 1997 resulted in constituent loads that were substantially higher than those measured in previous years. To enable more accurate characterization of fluvial transport over a wider range of hydrologic conditions, estimates of transport for the two

Table 1. Type and period of data collection at surface-water sampling stations in the upper Clark Fork basin, Montana

[Abbreviation: P, present (1997). Symbol: --, no data]

Station number (fig. 1)	Station name	Continuous-record streamflow	Periodic water quality[1]	Daily suspended-sediment
12323230	Blacktail Creek at Harrison Avenue, at Butte	--	03/93-08/95, 10/96-P	--
12323250	Silver Bow Creek below Blacktail Creek, at Butte	10/83-P	03/93-08/95, 10/96-P	--
12323600	Silver Bow Creek at Opportunity	07/88-P	03/93-08/95, 10/96-P	03/93-09/95
12323750	Silver Bow Creek at Warm Springs	03/72-09/79, 04/93-P	03/93-P	04/93-09/95
12323770	Warm Springs Creek at Warm Springs	10/83-P	03/93-P	--
12323800	Clark Fork near Galen	07/88-P	07/88-P	--
12324200	Clark Fork at Deer Lodge	10/78-P	03/85-P	03/85-08/86, 04/87-P
12324590	Little Blackfoot River near Garrison	10/72-P	03/85-P	--
12324680	Clark Fork at Goldcreek	10/77-P	03/93-P	--
12331500	Flint Creek near Drummond	08/90-P	03/85-P	--
12331800	Clark Fork near Drummond	04/93-P	03/93-P	--
12334510	Rock Creek near Clinton	10/72-P	03/85-P	--
12334550	Clark Fork at Turah Bridge, near Bonner	03/85-P	03/85-P	03/85-P
12340000	Blackfoot River near Bonner	10/39-P	03/85-P	07/86-03/87, 06/88-09/95
12340500	Clark Fork above Missoula	03/29-P	07/86-P[2]	07/86-03/87, 06/88-01/96, 03/96-P

[1]Onsite measurements of physical properties and laboratory analyses of selected major ions, trace elements, and suspended sediment.
[2]Suspended-sediment sampling initiated 07/86; sampling for trace elements not begun until 12/89.

recent years of high flow are presented. The 1996-97 estimates also have been combined with earlier estimates to obtain more representative estimates of long-term average annual loads.

The 1996-97 load estimates also provide better quantification of the long-term mass balance of loads moving through Milltown Reservoir. Earlier load estimates generally indicated that net deposition occurred in most years during 1985-95; however, loads during the recent high flows were presumed to have greatly exceeded the previous inputs and outputs from the reservoir. Determination of loads for a high-flow period would provide a broader perspective on whether the reservoir is acting as a sink for sediment and metals or generally is a flow-through system in long-term equilibrium.

Purpose and Scope

This report presents annual load estimates for suspended sediment and selected trace metals in streamflow at 12 sites in the upper Clark Fork basin from Warm Springs to Missoula during water years 1996-97. Annual constituent loads were calculated using constituent concentrations measured in periodically collected samples, data from daily suspended-sediment and streamflow records, and regression relations. The resulting loads are summarized to provide a spatial characterization of sediment and metals inputs during 1996-97.

Methods used to calculate loads are presented for suspended sediment, total-recoverable copper, lead, and zinc, and dissolved copper. These estimates are an extension of similar work previously published for water years 1985-90 and 1991-95 (Lambing, 1991; Hornberger and others, 1997). The load estimates for 1991-95 were limited to suspended sediment, copper, lead, and zinc owing to budget and time constraints. Consequently, the subsequent load estimates for 1996-97 presented in this report are restricted to the same constituents. The load estimates for the two recent high-flow years are added to the previous record of annual loads to determine average annual loads for the entire period of data collection.

Description of Study Area

The upper Clark Fork basin from Silver Bow Creek below the Warm Springs Ponds to Milltown Dam encompasses about 125 river miles. Within this reach, five major tributaries enter the mainstem—Warm Springs Creek, Little Blackfoot River, Flint Creek, Rock Creek, and the Blackfoot River (fig. 1). Smaller perennial and intermittent tributaries drain the surrounding mountains and terraces on both sides of the Clark Fork valley.

From the Warm Springs Ponds to Garrison, the topography is dominated by a broad valley up to several miles wide bordered by high terraces that rise several hundred feet above the river. The north-trending valley is flanked on the east by the mountains along the Continental Divide and on the west by the Flint Creek Range. Near Garrison, the Clark Fork turns northwesterly and flows through a narrower valley confined by mountain hillslopes and is generally less than 1 mi wide below Drummond. The Clark Fork is a highly meandering river in the upper reach above Garrison, but meanders less downstream where the valley narrows and the river corridor has been further confined by highway and railroad embankments.

Hydrologic Characteristics

Streamflow magnitude is a predominant factor affecting the quantity of suspended sediment and associated materials, such as metals, transported by water. Because streamflow can vary widely from year to year, the mass of transported material (load) can differ substantially between years. Consequently, an adequate long-term estimate of an average annual load passing a stream location is dependent on data from a sufficient number of years to describe a wide range of hydrologic conditions. The representativeness of the hydrology during a particular study period can be evaluated by comparison of streamflow-duration characteristics of the study period to that of a long-term streamflow record. This comparison was made using the streamflow record for the Clark Fork above Missoula, which has the longest record in the upper Clark Fork basin (fig. 2).

Comparisons of streamflow duration for two recent study periods (1991-97 and 1985-97) to streamflow duration for the period of record (1930-97) were used to evaluate whether the periods for which load estimates have been made had streamflow characteristics representative of long-term conditions. All three curves in figure 2 generally are similar; however, the curve for 1985-97 is slightly lower at the upper range of streamflow than that of 1930-97. Consequently, the lower frequency of high flows implies that the loads transported during 1985-97 might have been smaller than long-term loads. In contrast, the streamflow-duration curve for 1991-97 is very similar to that for 1930-97. Load estimates for 1991-97, therefore, may be more representative of long-term average transport conditions than those for 1985-97.

SAMPLE COLLECTION AND ANALYSIS

Surface-water sampling sites were located on the Clark Fork mainstem and several major tributaries between the Warm Springs Ponds and Missoula (fig. 1). The geographic distribution of sites was designed to characterize spatial differences in streamflow and constituent concentrations that would enable quantification of annual loads from various source areas. The original network of surface-water sites that was established in 1985 (Lambing, 1991) was expanded in subsequent years to the current (1997) network of 15 stations (table 1). Twelve of these stations, for which annual loads are described in this report, are located between the Warm Springs Ponds and Missoula.

Suspended-sediment and trace-element samples were collected at the surface-water sites at a frequency of about 5-10 times per year. Mainstem sites were sampled more frequently than tributaries because of the greater variability of transport in the mainstem due to diverse upstream land uses, tributary input, and source areas, including the large source of tailings within the mainstem channel and flood-plain sediments. Tributaries were sampled near their mouths to determine the cumulative contribution from their entire basins. With the exception of Flint Creek, each station for which annual load estimates have been made had a continu-

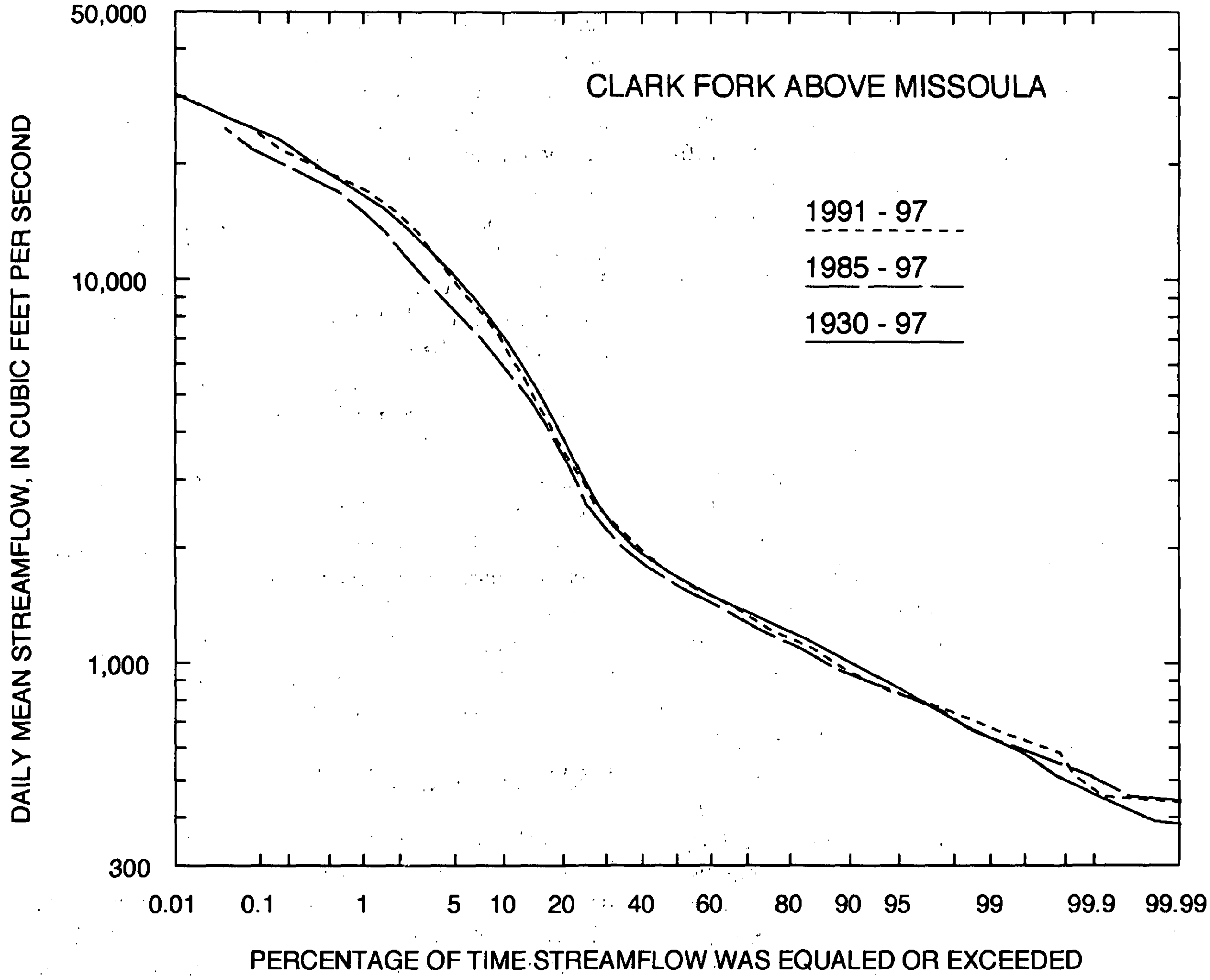

Figure 2. Streamflow-duration curves for the Clark Fork above Missoula for the period of record (water years 1930-97) and for recent study periods (water years 1985-97 and 1991-97).

ous-record streamflow gage during the entire period of water-quality sampling. A streamflow gage was installed at Flint Creek in 1990.

Water samples were depth-integrated from multiple verticals across the stream as described by U.S. Geological Survey (1977), Edwards and Glysson (1988), and Ward and Harr (1990). This sampling method was used during all flow conditions and provides a vertically and laterally discharge-weighted sample (sample volume proportional to the flow). The sampling method provides a water sample that is representative of the distribution of suspended and dissolved material in the water column that passes the stream cross section. Sampling equipment consisted of standard USGS depth-integrating samplers (DH-81 and D-74TM) constructed of plastic or equipped with nylon nozzles and coated with a non-metallic paint. Onsite sample processing, including sample filtration and preservation, was performed according to procedures described by U.S. Geological Survey (1977), Knapton (1985), Ward and Harr (1990), and Horowitz and others (1994). Samples submitted for analysis of dissolved constituents were filtered through a 142 mm-diameter cellulose nitrate flat filter having a pore size of 0.45 μm. Instantaneous streamflow at the time of sampling was determined at all sites by direct measurement or from stage-discharge rating tables (Rantz and others, 1982).

Periodically collected water samples were analyzed for concentration and size distribution (percent finer than 0.062 mm) of suspended sediment by the USGS in Helena, Mont., according to procedures described by Lambing and Dodge (1993). Analysis of trace elements included dissolved and total-recoverable concentrations of arsenic, cadmium, copper, iron, lead, manganese, and zinc. Dissolved calcium and magnesium also were analyzed to determine water hardness. Chemical analyses were performed by the USGS National Water Quality Laboratory in Denver, Colo., according to methods described in Fishman (1993).

Quality-assurance procedures used for the collection and field processing of water-quality samples are described by Knapton (1985), Edwards and Glysson (1988), Ward and Harr (1990), Knapton and Nimick (1991), and Horowitz and others (1994). Standard procedures used by the USGS National Water Quality Laboratory for internal sample handling and quality assurance are described by Friedman and Erdmann (1982), Jones (1987), and Pritt and Raese (1995). Quality-assurance procedures used by the USGS Montana District sediment laboratory are described by Lambing and Dodge (1993).

Analytical results for water samples were evaluated using quality-control samples that were submitted from the field and analyzed concurrently in the laboratory with routine environmental samples (Dodge and others, 1997). Quality-control samples consisted of replicates, blanks, and spikes that provided quantitative information on the precision and bias of the overall field and laboratory process. Each type of quality-control sample was submitted at a proportion equivalent to about 5 percent of the total number of samples, for a collective total of about 15 percent of the samples submitted for analysis.

COMPUTATIONAL METHODS FOR ESTIMATING LOADS

Estimates of annual loads were made utilizing the concentration data from water-quality samples, records of daily streamflow and suspended-sediment discharge, and regression relations between related hydrologic variables. A common base period encompassing at least 5 years of data was utilized in regression analyses to ensure that estimates for all sites were based on an equivalent and broad range of hydrologic conditions. The base period used was the most recent 5-year interval from 1993-97. Because water-quality and daily streamflow data were available for all sites during the 1993-97 interval, the estimates are more direct than in previous study periods when some estimation was required to obtain a complete record of streamflow or sediment discharge (Hornberger and others, 1997). In addition, the hydrology during 1993-97 was characterized by higher flows than the previous study periods (U.S. Geological Survey, issued annually), and streamside tailings in parts of the upper basin have been removed or treated in place. As a result of changing hydrologic and source conditions, a base period that reflects the most recent conditions would be expected to afford the most accurate mathematical estimation of loads for the 1996-97 period.

The computational methods and regression equations used to estimate the 1996-97 annual loads for suspended sediment, total-recoverable copper, lead, and zinc, and dissolved copper are presented in the following sections. Although the equations used for the 1991-95 study period have been updated to represent the most recent transport conditions, the computational methods are the same as those utilized for previous load estimates (Lambing, 1991; Hornberger and others, 1997).

Suspended Sediment

Suspended-sediment concentrations exhibit a strong association with total-recoverable metal concentrations in the Clark Fork (Lambing, 1991). Consequently, suspended-sediment discharge explains more of the variability in metals discharge than streamflow because sediment concentrations can vary seasonally for a given magnitude of flow. This sediment variability, in turn, directly influences the concentration and resultant load of total-recoverable metals. Therefore, to ensure that seasonal differences in metals discharge were accounted for, a daily record of suspended-sediment discharge was developed for each site and used as a basis for estimating a daily record of total-recoverable metal loads.

A daily record of suspended-sediment discharge was available for three mainstem sites (at Deer Lodge, at Turah Bridge, and above Missoula) that were operated as daily sediment stations during 1996-97. At those sites, an observer collected depth-integrated sediment samples from a single vertical near midstream once-daily during the spring runoff months of March through June, then about 2-3 times weekly during lower flows for the remainder of the year. This sampling frequency is sufficient to determine a daily mean suspended-sediment concentration using methods described in Porterfield (1972). The daily mean concentrations were multiplied by the daily mean streamflow and a units-conversion constant to compute a daily suspended-sediment discharge according to the following equation:

$$Qsed = Q \times C \times K \qquad (1)$$

where:

$Qsed$ = 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).

With the exception of about seven unsampled weeks at the Clark Fork above Missoula during January to March 1996, all three daily sediment stations had complete record during 1996-97. The unsampled period for the Clark Fork above Missoula resulted from a loss of program funding that was subsequently reinstated in March 1996. Sediment discharge during the unsampled weeks was estimated based on streamflow records and two water-quality samplings conducted during the period.

At sites other than daily sediment stations, daily suspended-sediment discharge was estimated using regression relations developed from water-quality samples collected periodically during 1993-97. Instantaneous suspended-sediment discharge was computed for each sample by multiplying values of instantaneous streamflow and suspended-sediment concentration according to equation 1. Regression analysis between streamflow and suspended-sediment discharge was then used to develop sediment-transport relations for all 12 sites.

Regression results for various forms of data transformation were examined to assess how well the estimated loads reproduced the measured annual loads and seasonal variability at the three daily sediment sites. Selection of the best data transformation for regression analysis for the three daily sediment sites was based on obtaining equations that were statistically significant at the 95 percent confidence level ($p < 0.05$), produced residuals with constant variance about the regression line, generated a representative seasonal distribution of loads, and had evenly balanced positive and negative errors in annual estimates. For the nine sites without daily sediment record, the best data transformation was selected on the basis of statistical significance of the regression and residual distribution. The equations were then applied to the daily streamflow record at each of the nine sites to generate a daily record of suspended-sediment load.

Regression analysis for estimating 1996-97 suspended-sediment discharge indicated that either logarithmic or square-root transformation of the data produced the best linear relation and residual distribution. Seasonal equations were developed for most sites to better describe the differences in sediment transport between the valley/foothills snowmelt period (January-May) and the mountain snowmelt period (June-December). Figure 3 is an example of the seasonal sediment-transport relations for the Clark Fork at Goldcreek.

Regression equations for estimating suspended-sediment discharge for 1996-97 are presented in table 2. All equations are highly significant ($p < 0.0001$). Standard errors of estimate ranged from 36 to 108 percent. Although daily values of suspended-sediment discharge measured directly at daily sediment stations were used in subsequent metals-transport calculations, equations are given for all stations to provide a mathematical description of sediment transport during the period. Regression equations used for estimating suspended-sediment discharge for water years 1985-90 are presented in Lambing (1991); equations for water years 1991-95 are presented in Hornberger and others (1997).

The accuracy of regression estimates of annual suspended-sediment loads was assessed by comparison of estimated loads to the measured annual loads available for three daily sediment stations on the Clark Fork (at Deer Lodge, at Turah Bridge, and above Missoula). For the 1985-90 period, the mean errors of regression estimates of annual loads were very small and ranged from -1.5 to +3.0 percent (Lambing, 1991). For the 1991-97 period, the mean errors of regression estimates were slightly larger, but still indicated representative estimation of actual loads for a period of higher flows and sediment transport. The mean errors at Deer Lodge and above Missoula were small (+4.0 and -5.4 percent, respectively), whereas the error at Turah Bridge was larger (-12 percent). At Turah Bridge, much of the error in the regression estimate occurred during the large ice-breakup event of 1996 when direct measurement of sediment transport was precluded by unsafe sampling conditions. When the ice-breakup period is excluded, load estimates are within 5 percent of measured loads. On the basis of the close compari-

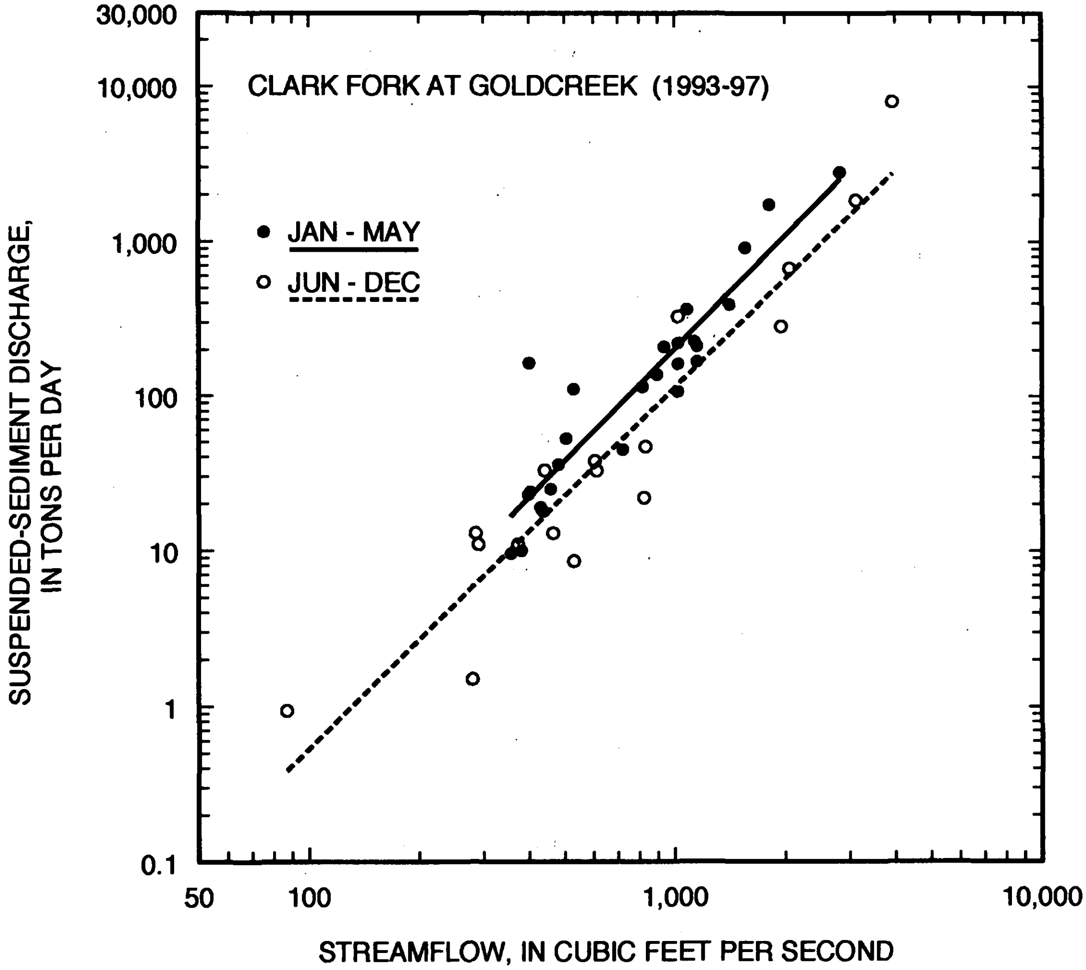

Figure 3. Seasonal relations of suspended-sediment discharge to streamflow for the Clark Fork at Goldcreek, water years 1993-97.

son of estimated loads to measured loads, mathematical adjustment for log-transformation bias (Helsel and Hirsch, 1992) was not warranted.

Total-Recoverable Metals

Annual loads of total-recoverable copper, lead, and zinc were estimated using regression relations between suspended-sediment discharge and metal discharge at each site. The correlations were developed using data from periodic water-quality samples collected during 1993-97. Prior to developing the regression relations, the suspended-sediment and total-recoverable metal concentrations were converted to instantaneous discharge values. Suspended-sediment concentrations were converted to instantaneous suspended-sediment discharge as described in equation 1. Metal concentrations were converted to instantaneous metal discharges by the following equation:

$$Qmetal = Q \times C \times K \qquad (2)$$

where:

$Qmetal$ = metal discharge, in tons per day;
Q = streamflow, in cubic feet per second;
C = metal concentration, in micrograms per liter; and
K = units conversion constant (0.0000027).

After concentrations were converted to discharge, regression relations were developed between instantaneous values of suspended-sediment and total-recoverable metal discharge. Unlike suspended sediment, no

Table 2. Equations for estimating suspended-sediment discharge, water years 1996-97

[R^2, coefficient of determination; p, significance level; SE, standard error of estimate, in percent; LOG, base10 logarithm; SEDQ, suspended-sediment discharge, in tons per day; Q, streamflow, in cubic feet per second; <, less than]

Station	Equation	R^2	p	SE
Silver Bow Creek at Warm Springs:				
January-May	$LOG\ SEDQ = -0.726 + 0.106(Q)^{0.5}$	0.69	<0.0001	80
June-December	$LOG\ SEDQ = -1.16 + .121(Q)^{.5}$	.83	<.0001	93
Warm Springs Creek at Warm Springs:				
January-May	$LOG\ SEDQ = -1.12 + .187(Q)^{.5}$	.88	<.0001	65
June-December	$LOG\ SEDQ = -1.35 + .160(Q)^{.5}$	.95	<.0001	52
Clark Fork near Galen:				
January-May	$SEDQ = .000186(Q)^{2.01}$	.86	<.0001	58
June-December	$SEDQ = .0000603(Q)^{2.10}$	.91	<.0001	85
Clark Fork at Deer Lodge:				
January-May	$SEDQ = .0000631(Q)^{2.31}$	.89	<.0001	36
June-December	$SEDQ = .000145(Q)^{2.04}$	.86	<.0001	96
Little Blackfoot River near Garrison:				
January-May	$SEDQ = .0000275(Q)^{2.37}$	.92	<.0001	67
June-December	$SEDQ = .0000891(Q)^{2.06}$	.94	<.0001	73
Clark Fork at Goldcreek:				
January-May	$SEDQ = .0000110(Q)^{2.42}$	.85	<.0001	65
June-December	$SEDQ = .0000117(Q)^{2.33}$	.90	<.0001	95
Flint Creek near Drummond:				
January-May	$SEDQ = .000389(Q)^{2.09}$	.92	<.0001	46
June-December	$SEDQ = .00135(Q)^{1.80}$	.87	<.0001	80
Clark Fork near Drummond:				
January-May	$SEDQ = .0000123(Q)^{2.38}$	.87	<.0001	59
June-December	$SEDQ = .0000229(Q)^{2.20}$	.84	<.0001	108
Rock Creek near Clinton	$SEDQ = .00000269(Q)^{2.36}$	.95	<.0001	68
Clark Fork at Turah Bridge, near Bonner:				
January-May	$SEDQ = .0000372(Q)^{2.06}$	.89	<.0001	57
June-December	$SEDQ = .00000151(Q)^{2.38}$	.91	<.0001	82
Blackfoot River near Bonner:				
January-May	$SEDQ = .00000389(Q)^{2.23}$	.92	<.0001	79
June-December	$SEDQ = .000000427(Q)^{2.46}$	.97	<.0001	55
Clark Fork above Missoula:				
January-May	$SEDQ = .00000178(Q)^{2.27}$	.88	<.0001	81
June-December	$SEDQ = .000000407(Q)^{2.39}$	.95	<.0001	58

direct measurements of daily metal loads were available to evaluate the accuracy of metals-transport equations. Therefore, the form of the regression equation was selected on the basis of statistical criteria, including correlation significance and uniform distribution of residuals. Examination of regression plots and statistics indicated that logarithmic transformation of suspended-sediment and total-recoverable metal discharges provided the best linear description of metal transport. An example of the copper-transport relation for the Clark Fork at Goldcreek is illustrated in figure 4.

Equations for estimating the discharge of total-recoverable copper, lead, and zinc during 1996-97 are presented in tables 3-5, respectively. All equations are linear using logarithmically transformed data and are significant ($p < 0.001$). The ranges of standard errors are 27-86 percent for copper, 25-68 percent for lead, and 30-92 percent for zinc. Regression equations used for estimating total-recoverable metal discharge for 1985-90 are presented in Lambing (1991). Equations for 1991-95 are presented in Hornberger and others (1997).

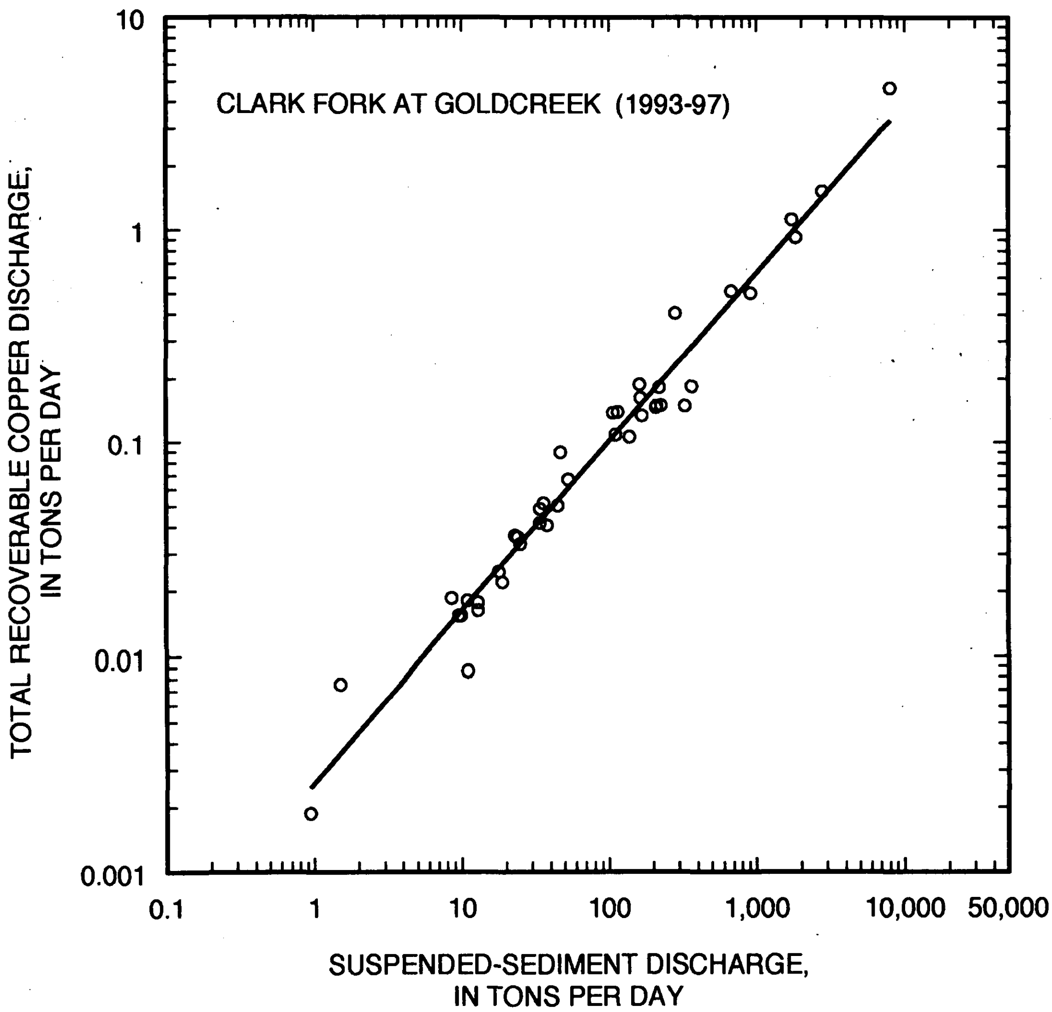

Figure 4. Relation of total-recoverable copper discharge to suspended-sediment discharge for the Clark Fork at Goldcreek, water years 1993-97.

Table 3. Equations for estimating total-recoverable copper discharge, water years 1996-97

[R^2, coefficient of determination; p, significance level; SE, standard error of estimate, in percent; CUQ, total-recoverable copper discharge, in tons per day; SEDQ, suspended-sediment discharge, in tons per day; <, less than]

Station	Equation	R^2	p	SE
Silver Bow Creek at Warm Springs	$CUQ = 0.00457(SEDQ)^{0.608}$	0.76	<0.001	57
Warm Springs Creek at Warm Springs	$CUQ = .00107(SEDQ)^{1.01}$	.94	<.001	54
Clark Fork near Galen	$CUQ = .00380(SEDQ)^{.759}$	.96	<.001	29
Clark Fork at Deer Lodge	$CUQ = .00245(SEDQ)^{.880}$	.97	<.001	27
Little Blackfoot River near Garrison	$CUQ = .000257(SEDQ)^{.722}$	.93	<.001	51
Clark Fork at Goldcreek	$CUQ = .00257(SEDQ)^{.795}$	.97	<.001	28
Flint Creek near Drummond	$CUQ = .000246(SEDQ)^{.815}$	.95	<.001	35
Clark Fork near Drummond	$CUQ = .00158(SEDQ)^{.860}$	.95	<.001	37
Rock Creek near Clinton	$CUQ = .000324(SEDQ)^{.746}$	.91	<.001	72
Clark Fork at Turah Bridge, near Bonner	$CUQ = .00182(SEDQ)^{.835}$	.96	<.001	34
Blackfoot River near Bonner	$CUQ = .000407(SEDQ)^{.802}$	.91	<.001	86
Clark Fork above Missoula	$CUQ = .00240(SEDQ)^{.758}$	.97	<.001	32

Table 4. Equations for estimating total-recoverable lead discharge, water years 1996-97

[R^2, coefficient of determination; p, significance level; SE, standard error of estimate, in percent; PBQ, total-recoverable lead discharge, in tons per day; SEDQ, suspended-sediment discharge, in tons per day; <, less than]

Station	Equation	R^2	p	SE
Silver Bow Creek at Warm Springs	$PBQ = 0.000282(SEDQ)^{0.868}$	0.83	<0.001	68
Warm Springs Creek at Warm Springs	$PBQ = .0000912(SEDQ)^{1.07}$	.95	<.001	50
Clark Fork near Galen	$PBQ = .000257(SEDQ)^{.876}$	.91	<.001	56
Clark Fork at Deer Lodge	$PBQ = .000191(SEDQ)^{.968}$	.98	<.001	27
Little Blackfoot River near Garrison	$PBQ = .000135(SEDQ)^{.771}$	.96	<.001	43
Clark Fork at Goldcreek	$PBQ = .000195(SEDQ)^{.907}$	.98	<.001	27
Flint Creek near Drummond	$PBQ = .000257(SEDQ)^{.952}$	.96	<.001	34
Clark Fork near Drummond	$PBQ = .000151(SEDQ)^{.966}$	.96	<.001	37
Rock Creek near Clinton	$PBQ = .000309(SEDQ)^{.516}$	.97	<.001	25
Clark Fork at Turah Bridge, near Bonner	$PBQ = .000204(SEDQ)^{.894}$	.96	<.001	38
Blackfoot River near Bonner	$PBQ = .000355(SEDQ)^{.611}$	.97	<.001	33
Clark Fork above Missoula	$PBQ = .000240(SEDQ)^{.836}$	.96	<.001	42

Table 5. Equations for estimating total-recoverable zinc discharge, water years 1996-97

[R^2, coefficient of determination; p, significance level; SE, standard error of estimate, in percent; ZNQ, total-recoverable zinc discharge, in tons per day; SEDQ, suspended-sediment discharge, in tons per day; <, less than]

Station	Equation	R^2	p	SE
Silver Bow Creek at Warm Springs	$ZNQ = 0.0100(SEDQ)^{0.522}$	0.51	<0.001	92
Warm Springs Creek at Warm Springs	$ZNQ = .000871(SEDQ)^{.867}$	.91	<.001	57
Clark Fork near Galen	$ZNQ = .00692(SEDQ)^{.669}$	.82	<.001	64
Clark Fork at Deer Lodge	$ZNQ = .00288(SEDQ)^{.855}$	.95	<.001	37
Little Blackfoot River near Garrison	$ZNQ = .00135(SEDQ)^{.553}$	.91	<.001	46
Clark Fork at Goldcreek	$ZNQ = .00389(SEDQ)^{.763}$	.96	<.001	31
Flint Creek near Drummond	$ZNQ = .00115(SEDQ)^{.870}$	.94	<.001	41
Clark Fork near Drummond	$ZNQ = .00245(SEDQ)^{.864}$	.94	<.001	40
Rock Creek near Clinton	$ZNQ = .00417(SEDQ)^{.379}$	.79	<.001	59
Clark Fork at Turah Bridge, near Bonner	$ZNQ = .00331(SEDQ)^{.809}$	.97	<.001	30
Blackfoot River near Bonner	$ZNQ = .00575(SEDQ)^{.412}$	.86	<.001	49
Clark Fork above Missoula	$ZNQ = .00437(SEDQ)^{.747}$	.91	<.001	57

Dissolved Copper

The annual load of dissolved metal during 1996-97 was estimated only for copper because it is the only metal that regularly occurs in detectable concentrations in dissolved form in the Clark Fork mainstem. Thus, copper is the only dissolved metal with sufficient detectability to minimize the uncertainty associated with load calculations made from concentration data that are predominantly or entirely below analytical reporting levels. Dissolved copper concentrations in the tributaries typically are lower than in the mainstem and more often below minimum reporting levels, which may affect the accuracy of computed dissolved loads. Because dissolved copper concentrations vary less than total-recoverable concentrations and are often low enough to be analytically undetectable, estimates of dissolved copper load may be less accurate than those for total-recoverable copper.

Dissolved copper discharge for 1996-97 was estimated in a similar manner as that for total-recoverable metal discharge. Correlations were developed using instantaneous values of streamflow and dissolved copper concentrations measured in periodic stream samples collected during 1993-97. The instantaneous concentrations were converted to dissolved copper discharge according to equation 2. Logarithmically transformed values of dissolved copper discharge and streamflow were then used to develop a linear regression relation. Figure 5 shows an example of the dissolved copper-transport relation for the Clark Fork at Goldcreek.

Regression equations for estimating dissolved copper discharge during 1996-97 are presented in table 6. All equations are linear using logarithmically transformed data and are significant ($p < 0.001$). Standard errors range from 40 to 75 percent. Regression equations used for estimating dissolved copper discharge for water years 1985-90 and 1991-95 are presented in Hornberger and others (1997).

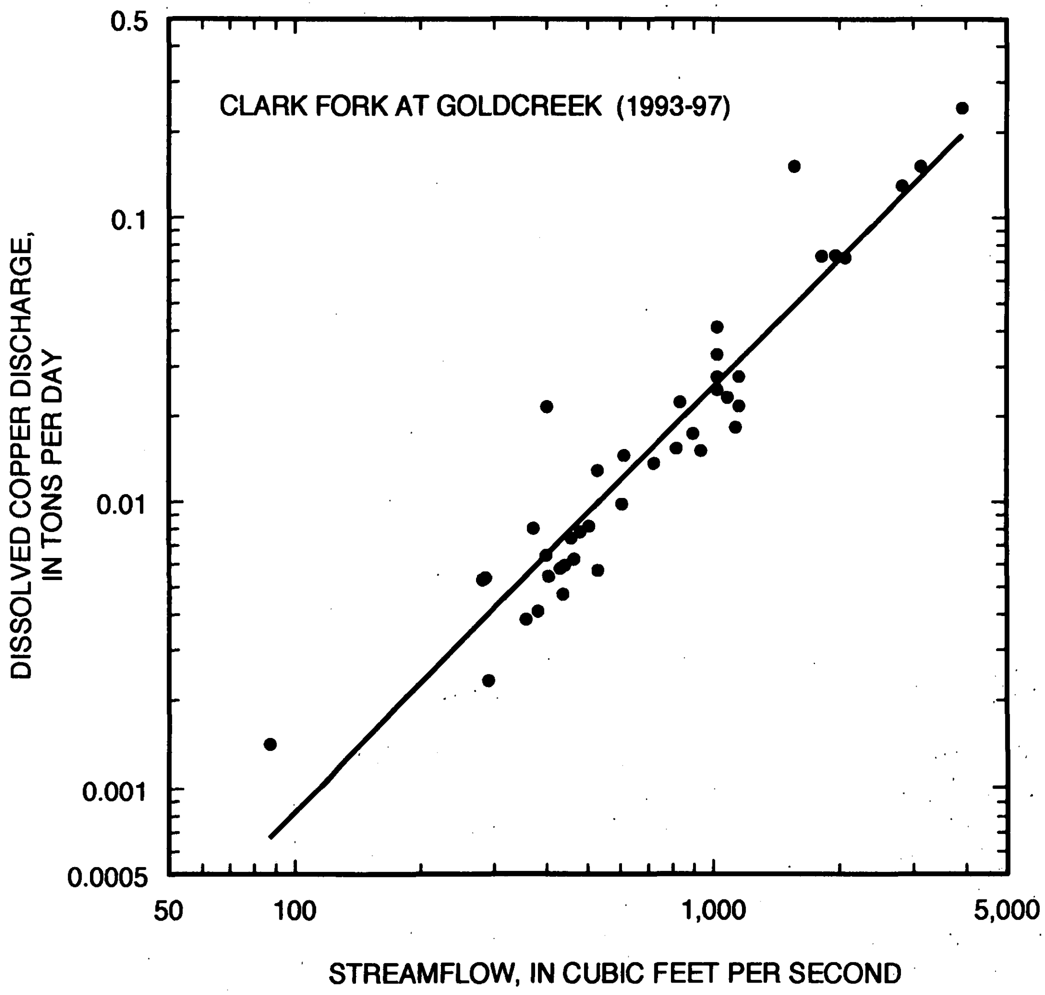

Figure 5. Relation of dissolved copper discharge to streamflow for the Clark Fork at Goldcreek, water years 1993-97.

Table 6. Equations for estimating dissolved copper discharge, water years 1996-97

[R^2, coefficient of determination; p, significance level; SE, standard error of estimate, in percent; CUQ.DIS,dissolved copper discharge, in tons per day; Q, streamflow, in cubic feet per second; <, less than]

Station	Equation	R^2	p	SE
Silver Bow Creek at Warm Springs	$CUQ.DIS = 0.0000151(Q)^{1.17}$	0.82	<0.001	44
Warm Springs Creek at Warm Springs	$CUQ.DIS = .00000209(Q)^{1.34}$	.86	<.001	64
Clark Fork near Galen	$CUQ.DIS = .00000891(Q)^{1.22}$	.86	<.001	43
Clark Fork at Deer Lodge	$CUQ.DIS = .00000118(Q)^{1.56}$	.85	<.001	50
Little Blackfoot River near Garrison	$CUQ.DIS = .000000263(Q)^{1.45}$	.89	<.001	59
Clark Fork at Goldcreek	$CUQ.DIS = .000000871(Q)^{1.49}$	.89	<.001	41
Flint Creek near Drummond	$CUQ.DIS = .000000191(Q)^{1.59}$	.80	<.001	75
Clark Fork near Drummond	$LOG(CUQ.DIS) = -3.10 + .0402(Q)^{.5}$	.87	<.001	48
Rock Creek near Clinton	$CUQ.DIS = .000000200(Q)^{1.34}$	.90	<.001	56
Clark Fork at Turah Bridge, near Bonner	$CUQ.DIS = .000000251(Q)^{1.53}$	.91	<.001	40
Blackfoot River near Bonner	$CUQ.DIS = .0000000447(Q)^{1.51}$	.92	<.001	53
Clark Fork above Missoula	$CUQ.DIS = .000000550(Q)^{1.33}$	.87	<.001	48

ANNUAL LOADS FOR WATER YEARS 1996 AND 1997

Daily loads of suspended sediment, total-recoverable copper, lead, and zinc, and dissolved copper were estimated for 1996 and 1997 for each of the 12 surface-water sites between Warm Springs Ponds and Missoula (table 1) using the transport equations presented in the preceding sections. The daily loads were summed to obtain annual loads for 1996 and 1997. The annual loads for these two years are individually presented to illustrate the transport characteristics during high-flow years, which have a predominant effect on long-term average transport rates. Average annual suspended-sediment and total-recoverable metal loads are presented for 1985-90 in Lambing (1991) and for 1991-95 in Hornberger and others (1997). Average annual dissolved copper loads for both periods are presented in Hornberger and others (1997).

The source area contributing sediment and metal loading to the Clark Fork is the entire watershed upstream from each sampling location. The network of sampling sites divides the upper Clark Fork basin into subareas for determining the amount of material contributed from individual source areas. By documenting the basin-wide spatial distribution of load inputs, the relative importance of each subarea can be determined. Sampling sites near the mouths of tributaries provide a measure of the cumulative load derived from all sources within the tributary basin. Loads measured at mainstem sites provide a measure of the incremental downstream increases in load. The load contributed from the intervening reach between mainstem sites is calculated as the difference in load between mainstem sites, minus the load contributed by a gaged tributary. Various sources within the intervening reach, such as ungaged tributaries, ground-water discharge, and materials in the mainstem channel and flood plain can collectively contribute load. Because these specific inputs are not measured directly, the proportion of load originating from each of the sources within intervening reaches is undetermined.

Estimates of annual suspended-sediment and metal loads also were used to determine the total mass of constituents discharged to and from Milltown Reservoir. The annual load input to Milltown Reservoir was calculated as the sum of the annual loads transported past the Clark Fork at Turah Bridge and the Blackfoot River near Bonner. The annual load output from the reservoir was determined at the Clark Fork above Missoula. The load estimates above and below Milltown Reservoir allow a mass-balance determination of the net quantity of material being deposited in the reservoir and the quantity moving through to downstream reaches.

Suspended Sediment

Sediment-transport equations presented in table 2 were applied to the daily streamflow record for water years 1996-97 to generate daily values of suspended-sediment load, which were summed to provide an annual load. The estimated annual suspended-sediment loads for 1996 and 1997 are presented in tables 7 and 8, respectively.

Table 7. Estimated annual suspended-sediment loads, water year 1996

Location	Annual suspended-sediment load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	1,400		
Warm Springs Creek at Warm Springs		1,830	
Intervening reach (4.2 miles)			640
Clark Fork near Galen	3,870		
Intervening reach (24.8 miles)			16,400
Clark Fork at Deer Lodge	20,300		
Little Blackfoot River near Garrison		9,350	
Intervening reach (25.5 miles)			28,600
Clark Fork at Goldcreek	58,300		
Flint Creek near Drummond		10,300	
Intervening reach (31.3 miles)			38,400
Clark Fork near Drummond	107,000		
Rock Creek near Clinton		20,200	
Intervening reach (33.4 miles)			33,800
Clark Fork at Turah Bridge, near Bonner	161,000		
Blackfoot River near Bonner		104,000	
Total input to Milltown Reservoir	265,000		
Clark Fork above Missoula	317,000		
Net gain (+) or loss (-) in Milltown Reservoir	-52,000		

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

[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Table 8. Estimated annual suspended-sediment loads, water year 1997

Location	Annual suspended-sediment load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	4,450		
Warm Springs Creek at Warm Springs		4,630	
Intervening reach (4.2 miles)			-630
Clark Fork near Galen	8,450		
Intervening reach (24.8 miles)			22,800
Clark Fork at Deer Lodge	31,200		
Little Blackfoot River near Garrison		12,800	
Intervening reach (25.5 miles)			48,100
Clark Fork at Goldcreek	92,100		
Flint Creek near Drummond		15,900	
Intervening reach (31.3 miles)			32,000
Clark Fork near Drummond	140,000		
Rock Creek near Clinton		43,500	
Intervening reach (33.4 miles)			27,500
Clark Fork at Turah Bridge, near Bonner	211,000		
Blackfoot River near Bonner		179,000	
Total input to Milltown Reservoir	390,000		
Clark Fork above Missoula	445,000		
Net gain (+) or loss (-) in Milltown Reservoir	-55,000		

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

[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Total-Recoverable Metals

The equations for estimating total-recoverable copper, lead, and zinc discharges presented in tables 3-5 were applied to the 1996-97 daily suspended-sediment discharge record to generate daily metal loads, which were summed to provide an annual load. Estimated annual loads of total-recoverable copper, lead, and zinc for 1996 and 1997 are presented in tables 9-14.

Table 9. Estimated annual total-recoverable copper loads, water year 1996

Location	Annual total-recoverable copper load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	3.2		
Warm Springs Creek at Warm Springs		2.0	
Intervening reach (4.2 miles)			1.6
Clark Fork near Galen	6.8		
Intervening reach (24.8 miles)			20.3
Clark Fork at Deer Lodge	27.1		
Little Blackfoot River near Garrison		.60	
Intervening reach (25.5 miles)			11.4
Clark Fork at Goldcreek	39.1		
Flint Creek near Drummond		1.2	
Intervening reach (31.3 miles)			21.0
Clark Fork near Drummond	61.3		
Rock Creek near Clinton		1.7	
Intervening reach (33.4 miles)			21.9
Clark Fork at Turah Bridge, near Bonner	84.9		
Blackfoot River near Bonner		11.0	
Total input to Milltown Reservoir	95.9		
Clark Fork above Missoula	105		
Net gain (+) or loss (-) in Milltown Reservoir	-9		

[1]Includes copper contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.

[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Table 10. Estimated annual total-recoverable copper loads, water year 1997

Location	Annual total-recoverable copper load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	5.3		
Warm Springs Creek at Warm Springs		5.2	
Intervening reach (4.2 miles)			1.4
Clark Fork near Galen	11.9		
Intervening reach (24.8 miles)			28.0
Clark Fork at Deer Lodge	39.9		
Little Blackfoot River near Garrison		.79	
Intervening reach (25.5 miles)			19.3
Clark Fork at Goldcreek	60.0		
Flint Creek near Drummond		1.7	
Intervening reach (31.3 miles)			21.6
Clark Fork near Drummond	83.3		
Rock Creek near Clinton		2.8	
Intervening reach (33.4 miles)			22.9
Clark Fork at Turah Bridge, near Bonner	109		
Blackfoot River near Bonner		15.6	
Total input to Milltown Reservoir	124		
Clark Fork above Missoula	129		
Net gain (+) or loss (-) in Milltown Reservoir	-5		

[1]Includes copper contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.
[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Table 11. Estimated annual total-recoverable lead loads, water year 1996

Location	Annual total-recoverable lead load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	0.30		
Warm Springs Creek at Warm Springs		0.21	
Intervening reach (4.2 miles)			0.15
Clark Fork near Galen	.66		
Intervening reach (24.8 miles)			2.6
Clark Fork at Deer Lodge	3.3		
Little Blackfoot River near Garrison		.40	
Intervening reach (25.5 miles)			2.3
Clark Fork at Goldcreek	6.0		
Flint Creek near Drummond		2.2	
Intervening reach (31.3 miles)			4.3
Clark Fork near Drummond	12.5		
Rock Creek near Clinton		.55	
Intervening reach (33.4 miles)			1.6
Clark Fork at Turah Bridge, near Bonner	14.7		
Blackfoot River near Bonner		2.8	
Total input to Milltown Reservoir	17.5		
Clark Fork above Missoula	19.5		
Net gain (+) or loss (-) in Milltown Reservoir	-2.0		

[1]Includes lead contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.
[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Table 12. Estimated annual total-recoverable lead loads, water year 1997

Location	Annual total-recoverable lead load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	0.77		
Warm Springs Creek at Warm Springs		0.57	
Intervening reach (4.2 miles)			-0.04
Clark Fork near Galen	1.3		
Intervening reach (24.8 miles)			3.7
Clark Fork at Deer Lodge	5.0		
Little Blackfoot River near Garrison		.53	
Intervening reach (25.5 miles)			4.0
Clark Fork at Goldcreek	9.5		
Flint Creek near Drummond		3.3	
Intervening reach (31.3 miles)			3.9
Clark Fork near Drummond	16.7		
Rock Creek near Clinton		.70	
Intervening reach (33.4 miles)			1.6
Clark Fork at Turah Bridge, near Bonner	19.0		
Blackfoot River near Bonner		3.3	
Total input to Milltown Reservoir	22.3		
Clark Fork above Missoula	25.1		
Net gain (+) or loss (-) in Milltown Reservoir	-2.8		

[1]Includes lead contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.
[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Table 13. Estimated annual total-recoverable zinc loads, water year 1996

Location	Annual total-recoverable zinc load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	6.1		
Warm Springs Creek at Warm Springs		1.1	
Intervening reach (4.2 miles)			2.4
Clark Fork near Galen	9.6		
Intervening reach (24.8 miles)			18.6
Clark Fork at Deer Lodge	28.2		
Little Blackfoot River near Garrison		1.6	
Intervening reach (25.5 miles)			18.9
Clark Fork at Goldcreek	48.7		
Flint Creek near Drummond		7.0	
Intervening reach (31.3 miles)			42.1
Clark Fork near Drummond	97.8		
Rock Creek near Clinton		4.3	
Intervening reach (33.4 miles)			25.9
Clark Fork at Turah Bridge, near Bonner	128		
Blackfoot River near Bonner		14.1	
Total input to Milltown Reservoir	142		
Clark Fork above Missoula	175		
Net gain (+) or loss (-) in Milltown Reservoir	-33		

[1]Includes zinc contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.
[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Table 14. Estimated annual total-recoverable zinc loads, water year 1997

Location	Annual total-recoverable zinc load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	9.2		
Warm Springs Creek at Warm Springs		2.4	
Intervening reach (4.2 miles)			3.9
Clark Fork near Galen	15.5		
Intervening reach (24.8 miles)			25.6
Clark Fork at Deer Lodge	41.1		
Little Blackfoot River near Garrison		2.0	
Intervening reach (25.5 miles)			30.8
Clark Fork at Goldcreek	73.9		
Flint Creek near Drummond		10.3	
Intervening reach (31.3 miles)			48.8
Clark Fork near Drummond	133		
Rock Creek near Clinton		4.8	
Intervening reach (33.4 miles)			25.2
Clark Fork at Turah Bridge, near Bonner	163		
Blackfoot River near Bonner		14.5	
Total input to Milltown Reservoir	178		
Clark Fork above Missoula	215		
Net gain (+) or loss (-) in Milltown Reservoir	-37		

[1]Includes zinc contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.
[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Dissolved Copper

The dissolved copper-transport equations presented in table 6 were applied to the daily streamflow record for water years 1996-97 to compute daily dissolved copper loads, which were summed to provide an annual load. The estimated annual dissolved copper loads for each site for water years 1996 and 1997 are presented in tables 15 and 16.

Table 15. Estimated annual dissolved copper loads, water year 1996

Location	Annual dissolved copper load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	1.8		
Warm Springs Creek at Warm Springs		0.29	
Intervening reach (4.2 miles)			0.21
Clark Fork near Galen	2.3		
Intervening reach (24.8 miles)			1.9
Clark Fork at Deer Lodge	4.2		
Little Blackfoot River near Garrison		.27	
Intervening reach (25.5 miles)			1.6
Clark Fork at Goldcreek	6.1		
Flint Creek near Drummond		.33	
Intervening reach (31.3 miles)			4.6
Clark Fork near Drummond	11.0		
Rock Creek near Clinton		.64	
Intervening reach (33.4 miles)			1.4
Clark Fork at Turah Bridge, near Bonner	13.0		
Blackfoot River near Bonner		2.7	
Total input to Milltown Reservoir	15.7		
Clark Fork above Missoula	16.4		
Net gain (+) or loss (-) in Milltown Reservoir	-.7		

[1]Includes copper contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.
[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Table 16. Estimated annual dissolved copper loads, water year 1997

Location	Annual dissolved copper load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	2.6		
Warm Springs Creek at Warm Springs		0.47	
Intervening reach (4.2 miles)			0.53
Clark Fork near Galen	3.6		
Intervening reach (24.8 miles)			4.2
Clark Fork at Deer Lodge	7.8		
Little Blackfoot River near Garrison		.35	
Intervening reach (25.5 miles)			1.0
Clark Fork at Goldcreek	9.2		
Flint Creek near Drummond		.51	
Intervening reach (31.3 miles)			4.8
Clark Fork near Drummond	14.5		
Rock Creek near Clinton		.87	
Intervening reach (33.4 miles)			1.0
Clark Fork at Turah Bridge, near Bonner	16.4		
Blackfoot River near Bonner		3.3	
Total input to Milltown Reservoir	19.7		
Clark Fork above Missoula	18.8		
Net gain (+) or loss (-) in Milltown Reservoir	+.9		

[1]Includes copper contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.
[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station

AVERAGE ANNUAL LOADS FOR WATER YEARS 1991-97

The annual loads estimated for 1996 and 1997 were added to the annual loads for 1991-95 (Hornberger and others, 1997) to obtain average annual loads for the 1991-97 period. This extension of the averaging period provides a description of transport conditions during a period that is more representative of long-term streamflow characteristics (fig. 2). In addition to improved hydrologic coverage, greater spatial resolution of load differences along the mainstem is possible because 1991-97 load estimates are available for all of the sites in the expanded monitoring network.

Suspended Sediment

Average annual suspended-sediment loads for water years 1991-97 are presented in table 17. At daily sediment stations, measured daily sediment loads were used to compute averages. At non-daily sites, regression estimates were used as described in preceding sections.

Table 17. Estimated average annual suspended-sediment loads, water years 1991-97

Location	Annual suspended-sediment load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	1,430		
Warm Springs Creek at Warm Springs		1,350	
Intervening reach (4.2 miles)			390
Clark Fork near Galen	3,170		
Intervening reach (24.8 miles)			9,430
Clark Fork at Deer Lodge	12,600		
Little Blackfoot River near Garrison		5,580	
Intervening reach (25.5 miles)			14,100
Clark Fork at Goldcreek	32,300		
Flint Creek near Drummond		5,810	
Intervening reach (31.3 miles)			15,000
Clark Fork near Drummond	53,100		
Rock Creek near Clinton		12,300	
Intervening reach (33.4 miles)			11,300
Clark Fork at Turah Bridge, near Bonner	76,700		
Blackfoot River near Bonner		65,800	
Total input to Milltown Reservoir	142,000		
Clark Fork above Missoula	148,000		
Net gain (+) or loss (-) in Milltown Reservoir	-6,000		

[1]Includes suspended sediment from ungaged tributaries, mainstem channel, and flood plain in the intervening reach between mainstem stations.
[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Total-Recoverable Metals

Average annual loads of total-recoverable copper, lead, and zinc for water years 1991-97 are presented in tables 18-20. Regression estimates of annual loads were used for all sites as described in preceding sections.

Table 18. Estimated average annual total-recoverable copper loads, water years 1991-97

Location	Annual total-recoverable copper load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	2.7		
Warm Springs Creek at Warm Springs		1.5	
Intervening reach (4.2 miles)			1.2
Clark Fork near Galen	5.4		
Intervening reach (24.8 miles)			12.6
Clark Fork at Deer Lodge	18.0		
Little Blackfoot River near Garrison		.38	
Intervening reach (25.5 miles)			5.6
Clark Fork at Goldcreek	24.0		
Flint Creek near Drummond		.74	
Intervening reach (31.3 miles)			8.7
Clark Fork near Drummond	33.4		
Rock Creek near Clinton		1.1	
Intervening reach (33.4 miles)			9.0
Clark Fork at Turah Bridge, near Bonner	43.5		
Blackfoot River near Bonner		6.7	
Total input to Milltown Reservoir	50.2		
Clark Fork above Missoula	54.2		
Net gain (+) or loss (-) in Milltown Reservoir	-4.0		

[1]Includes copper contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.

[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Table 19. Estimated average annual total-recoverable lead loads, water years 1991-97

Location	Annual total-recoverable lead load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	0.26		
Warm Springs Creek at Warm Springs		0.16	
Intervening reach (4.2 miles)			0.11
Clark Fork near Galen	.53		
Intervening reach (24.8 miles)			1.6
Clark Fork at Deer Lodge	2.1		
Little Blackfoot River near Garrison		.25	
Intervening reach (25.5 miles)			1.2
Clark Fork at Goldcreek	3.6		
Flint Creek near Drummond		1.3	
Intervening reach (31.3 miles)			1.6
Clark Fork near Drummond	6.5		
Rock Creek near Clinton		.38	
Intervening reach (33.4 miles)			.92
Clark Fork at Turah Bridge, near Bonner	7.8		
Blackfoot River near Bonner		2.2	
Total input to Milltown Reservoir	10.0		
Clark Fork above Missoula	10.0		
Net gain (+) or loss (-) in Milltown Reservoir	0.0		

[1]Includes lead contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.
[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Table 20. Estimated average annual total-recoverable zinc loads, water years 1991-97

Location	Annual total-recoverable zinc load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	5.6		
Warm Springs Creek at Warm Springs		0.86	
Intervening reach (4.2 miles)			1.5
Clark Fork near Galen	8.0		
Intervening reach (24.8 miles)			12.1
Clark Fork at Deer Lodge	20.1		
Little Blackfoot River near Garrison		1.2	
Intervening reach (25.5 miles)			10.4
Clark Fork at Goldcreek	31.7		
Flint Creek near Drummond		4.3	
Intervening reach (31.3 miles)			19.4
Clark Fork near Drummond	55.4		
Rock Creek near Clinton		2.8	
Intervening reach (33.4 miles)			10.2
Clark Fork at Turah Bridge, near Bonner	68.4		
Blackfoot River near Bonner		10.5	
Total input to Milltown Reservoir	78.9		
Clark Fork above Missoula	84.9		
Net gain (+) or loss (-) in Milltown Reservoir	-6.0		

[1]Includes zinc contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.
[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station

Dissolved Copper

Average annual dissolved copper loads for water years 1991-97 are presented in table 21. Regression estimates of annual loads were used at all sites as described in preceding sections.

Table 21. Estimated average annual dissolved copper loads, water years 1991-97

Location	Annual dissolved copper load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Silver Bow Creek at Warm Springs[2]	1.4		
Warm Springs Creek at Warm Springs		0.22	
Intervening reach (4.2 miles)			0.08
Clark Fork near Galen	1.7		
Intervening reach (24.8 miles)			1.4
Clark Fork at Deer Lodge	3.1		
Little Blackfoot River near Garrison		.19	
Intervening reach (25.5 miles)			.91
Clark Fork at Goldcreek	4.2		
Flint Creek near Drummond		.23	
Intervening reach (31.3 miles)			1.5
Clark Fork near Drummond	5.9		
Rock Creek near Clinton		.44	
Intervening reach (33.4 miles)			1.1
Clark Fork at Turah Bridge, near Bonner	7.4		
Blackfoot River near Bonner		2.0	
Total input to Milltown Reservoir	9.4		
Clark Fork above Missoula	9.2		
Net gain (+) or loss (-) in Milltown Reservoir	+.2		

[1]Includes copper contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.

[2]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

AVERAGE ANNUAL LOADS FOR WATER YEARS 1985-97

The annual loads estimated for 1996 and 1997 were added to the annual loads for 1985-90 (Lambing, 1991) and 1991-95 (Hornberger and others, 1997) to obtain average annual loads for the 1985-97 period. This extension of the averaging period provides a description of transport conditions during the longest available period of record; however, only the eight sites in the original network have data for this extended period. The more limited spatial resolution of loads throughout the upper Clark Fork basin precludes evaluation of inputs from several intervening reaches. Average loads estimated for 1985-97 may be less representative of long-term conditions than the average loads for 1991-97 because streamflow during 1985-97 generally was lower at the upper range (exceedance frequency of about 10 percent or less) than that indicated by long-term streamflow characteristics (fig. 2). Another factor affecting average estimates for this period is that the sampling program was less systematic during the 1985-90 period, and the current rigorous protocols for processing of trace-element samples (Horowitz and others, 1994) were not in effect during that period. In addition, the 1985-97 period spans both pre- and post-remediation conditions that could contribute to variability in annual loads.

Suspended Sediment

Average annual suspended-sediment loads for water years 1985-97 are presented in table 22. At daily sediment stations, measured daily sediment loads were used to compute averages. At non-daily sites, regression estimates were used as described in preceding sections.

Table 22. Estimated average annual suspended-sediment loads, water years 1985-97

Location	Annual suspended-sediment load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Clark Fork near Galen	2,370		
Intervening reach (24.8 miles)			8,330
Clark Fork at Deer Lodge	10,700		
Little Blackfoot River near Garrison		3,920	
Flint Creek near Drummond		5,300	
Rock Creek near Clinton		10,600	
Intervening reach (90.2 miles)			30,700
Clark Fork at Turah Bridge, near Bonner	61,200		
Blackfoot River near Bonner		50,300	
Total input to Milltown Reservoir	111,000		
Clark Fork above Missoula	107,000		
Net gain (+) or loss (-) in Milltown Reservoir	+4,000		

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

Total-Recoverable Metals

Average annual loads of total-recoverable copper, lead, and zinc for water years 1985-97 are presented in tables 23-25. Regression estimates were used to estimate annual loads of total-recoverable metals at all sites as described in the preceding sections. The annual loads of total-recoverable metals for the 1985-90 period were adjusted for analytical bias as described in Hornberger and others (1997) prior to averaging.

Table 23. Estimated average annual total-recoverable copper loads, water years 1985-97

[Annual loads for 1985-90 have been adjusted for an analytical bias of 2 μg/L as described in Hornberger and others, 1997]

Location	Annual total-recoverable copper load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Clark Fork near Galen	4.9		
Intervening reach (24.8 miles)			10.0
Clark Fork at Deer Lodge	14.9		
Little Blackfoot River near Garrison		0.37	
Flint Creek near Drummond		.76	
Rock Creek near Clinton		.90	
Intervening reach (90.2 miles)			22.7
Clark Fork at Turah Bridge, near Bonner	39.6		
Blackfoot River near Bonner		6.2	
Total input to Milltown Reservoir	45.8		
Clark Fork above Missoula	39.6		
Net gain (+) or loss (-) in Milltown Reservoir	+6.2		

[1]Includes copper contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.

Table 24. Estimated average annual total-recoverable lead loads, water years 1985-97

[Annual loads for 1985-90 have been adjusted for an analytical bias of 2 μg/L as described in Hornberger and others, 1997]

Location	Annual total-recoverable lead load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Clark Fork near Galen	0.38		
Intervening reach (24.8 miles)			1.2
Clark Fork at Deer Lodge	1.6		
Little Blackfoot River near Garrison		0.19	
Flint Creek near Drummond		1.2	
Rock Creek near Clinton		.42	
Intervening reach (90.2 miles)			5.5
Clark Fork at Turah Bridge, near Bonner	8.9		
Blackfoot River near Bonner		3.4	
Total input to Milltown Reservoir	12.3		
Clark Fork above Missoula	7.7		
Net gain (+) or loss (-) in Milltown Reservoir	+4.6		

[1]Includes lead contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.

Table 25. Estimated average annual total-recoverable zinc loads, water year 1985-97

[Annual loads for 1985-90 have been adjusted for an analytical bias of 5 µg/L as described in Hornberger and others, 1997]

Location	Annual total-recoverable zinc load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Clark Fork near Galen	7.0		
Intervening reach (24.8 miles)			11.2
Clark Fork at Deer Lodge	18.2		
Little Blackfoot River near Garrison		0.84	
Flint Creek near Drummond		4.1	
Rock Creek near Clinton		2.5	
Intervening reach (90.2 miles)			29.3
Clark Fork at Turah Bridge, near Bonner	54.9		
Blackfoot River near Bonner		8.0	
Total input to Milltown Reservoir	62.9		
Clark Fork above Missoula	66.1		
Net gain (+) or loss (-) in Milltown Reservoir	-3.2		

[1]Includes zinc contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.

Dissolved Copper

Average annual loads of dissolved copper for water years 1985-97 are presented in table 26. Regression estimates were used for annual loads of dissolved copper at all sites as described in the preceding sections. The annual loads of dissolved copper for the 1985-90 period were adjusted for analytical bias as described in Hornberger and others (1997) prior to averaging.

Table 26. Estimated average annual dissolved copper loads, water years 1985-97

[Annual loads for 1985-90 have been adjusted for analytical bias of 1 µg/L as described in Hornberger and others, 1997]

Location	Annual dissolved copper load, in tons		
	Mainstem station	Tributary station	Other sources[1]
Clark Fork near Galen	1.5		
Intervening reach (24.8 miles)			1.3
Clark Fork at Deer Lodge	2.8		
Little Blackfoot River near Garrison		0.17	
Flint Creek near Drummond		.20	
Rock Creek near Clinton		.39	
Intervening reach (90.2 miles)			2.7
Clark Fork at Turah Bridge, near Bonner	6.3		
Blackfoot River near Bonner		2.0	
Total input to Milltown Reservoir	8.3		
Clark Fork above Missoula	7.7		
Net gain (+) or loss (-) in Milltown Reservoir	+.6		

[1]Includes copper contributed from the mainstem channel and flood plain, ungaged tributaries, and ground water in the intervening reach between mainstem stations.

PERCENTAGE OF LOAD CONTRIBUTED FROM VARIOUS SOURCE AREAS

The average annual loads passing each of the sampling sites in the network provides a spatial characterization of the individual tributary basins or mainstem reaches that supply the greatest quantity of metals to the Clark Fork. The load at each site can be expressed as a percentage of the total load entering Milltown Reservoir, thus allowing a basin-wide comparison of the relative proportion contributed from each source area. The ability to compare inputs from different parts of the basin can be useful for tracking changes over time as remedial actions are implemented.

Water Years 1991-97

The percentages of the total load of suspended sediment and total-recoverable trace metals entering Milltown Reservoir from various source areas during 1991-97 are presented in table 27. Load estimates are available for all twelve sampling stations below the Warm Springs Ponds during this period; therefore, the spatial resolution allows a determination of relative inputs from the five major tributaries and five intervening reaches between mainstem sites.

Table 27. Percentage of average annual loads of suspended sediment and trace metals discharged to Milltown Reservoir from various source areas, water years 1991-97

[Source areas represent the entire drainage basin upstream from each site. Intervening reaches represent the combined sources between mainstem sites (channel and flood plain, ungaged tributaries, and ground water), minus the input from gaged tributaries within the reach. Apparent discrepancies in summation of percentages result from rounding effects]

Location	Percentage of average annual load discharged to Milltown Reservoir				
	Suspended sediment	Total recoverable			Dissolved
		Copper	Lead	Zinc	Copper
Silver Bow Creek at Warm Springs[1]	1.0	5.4	2.6	7.1	15
Warm Springs Creek at Warm Springs	1.0	3.0	1.6	1.1	2.3
Intervening reach (4.2 miles)	.3	2.4	1.1	1.9	.9
Clark Fork near Galen	2.2	11	5.3	10	18
Intervening reach (24.8 miles)	6.6	25	16	15	15
Clark Fork at Deer Lodge	8.9	36	21	25	33
Little Blackfoot River near Garrison	3.9	.8	2.5	1.5	2.0
Intervening reach (25.5 miles)	9.9	11	12	13	9.7
Clark Fork at Goldcreek	23	48	36	40	45
Flint Creek near Drummond	4.1	1.5	13	5.4	2.4
Intervening reach (31.3 miles)	11	17	16	25	16
Clark Fork near Drummond	37	67	65	70	63
Rock Creek near Clinton	8.7	2.2	3.8	3.5	4.7
Intervening reach (33.4 miles)	8.0	18	9.2	13	12
Clark Fork at Turah Bridge, near Bonner	54	87	78	87	79
Blackfoot River near Bonner	46	13	22	13	21
Total input to Milltown Reservoir	100	100	100	100	100
Clark Fork above Missoula	104	108	100	108	98
Net percentage gain (+) or loss (-) in Milltown Reservoir	-4	-8	0	-8	+2

[1]For purposes of load routing, Silver Bow Creek is treated as a mainstem station.

Water Years 1985-97

The percentages of the total load of suspended sediment and total-recoverable trace-metals entering Milltown Reservoir from various upstream source areas during 1985-97 are presented in table 28. Load estimates for the 1985-90 portion of the period are only available for the original network of eight sites; therefore, the spatial resolution does not allow determination of relative inputs from as many tributaries and mainstem reaches as that for the 1991-97 period. In addition, the streamflow characteristics during 1985-97 are less representative of long-term conditions than 1991-97 (fig. 2). The annual loads for 1985-90 were adjusted for analytical bias as described in Hornberger and others (1997) prior to calculating percentages.

Table 28. Percentage of average annual loads of suspended sediment and trace metals discharged to Milltown Reservoir from various source areas, water years 1985-97

[Source areas represent the entire drainage basin upstream of each site. Intervening reaches represent the combined sources between mainstem sites (channel and flood plain, ungaged tributaries, and ground water), minus the input from gaged tributaries within the reach. Apparent discrepancies in summation of percentages result from rounding effects]

Location	Percentage of average annual load discharged to Milltown Reservoir				
	Suspended sediment	Total recoverable			Dissolved
		Copper	Lead	Zinc	Copper
Clark Fork near Galen	2.1	11	3.1	11	18
Intervening reach (24.8 miles)	7.5	22	9.8	18	16
Clark Fork at Deer Lodge	9.6	33	13	29	34
Little Blackfoot River near Garrison	3.5	.8	1.5	1.3	2.0
Flint Creek near Drummond	4.8	1.7	9.8	6.5	2.4
Rock Creek near Clinton	9.5	2.0	3.4	4.0	4.7
Intervening reach (90.2 miles)	28	50	45	47	33
Clark Fork at Turah Bridge, near Bonner	55	86	72	87	76
Blackfoot River near Bonner	45	14	28	13	24
Total input to Milltown Reservoir	100	100	100	100	100
Clark Fork above Missoula	96	86	63	105	93
Net percentage gain (+) or loss (-) in Milltown Reservoir	+4	+14	+37	-5	+7

SUSPENDED-SEDIMENT AND METALS LOADS PER RIVER MILE

The average annual loads contributed from the intervening reaches between mainstem sites provide insight to the collective input from multiple sources within each reach, exclusive of the major gaged tributaries. Although the sources can include ungaged tributaries and ground water, it generally is assumed that the primary source of sediment and metals are the mainstem channel and flood plain because of the widely distributed tailings from historic mining activities (Andrews, 1987; Moore and Luoma, 1990; Nimick and Moore, 1994). On the basis of this assumption, the loads contributed from the intervening reaches can be expressed as a unit-length yield, in tons per river mile. Because the intervening reaches differ in length, a comparison of unit-length yields provides a more representative evaluation of longitudinal differences in channel inputs than comparison of total loads per reach. The differences in unit-length inputs are presumably indicative of the varying degree of contamination and channel erosion along the nearly 120-mile length of the Clark Fork from below the Warm Springs Ponds to Turah Bridge.

The average annual loads of suspended sediment and trace metals, per river mile, were calculated as the difference in loads between consecutive mainstem sites, minus the load from gaged tributaries entering within the reach. The resultant load then was divided by the channel length of the intervening reach to determine a load per river mile, or unit-length yield. The expanded network of sites provided sufficient spatial information for five reaches between the Warm Springs Ponds and Turah Bridge during the 1991-97 period. Average annual yields of suspended sediment and trace metals for the 1991-95 period are described in Hornberger and others (1997). The loads estimated for the high-flow years of 1996 and 1997 have been incorporated to provide an updated description of average annual suspended sediment and trace metal yields for the period 1991-97. Average annual loads, per river mile, for 1991-97 are presented in table 29. The limited number of sites operated during 1985-90 provided spatial coverage for only two intervening mainstem reaches; therefore, average annual loads per river mile for the 1985-97 period (table 30) have less spatial resolution for evaluating channel inputs.

Table 29. Estimated average annual loads of suspended sediment and trace metals, per river mile, discharged to the Clark Fork from intervening reaches between mainstem sites, water years 1991-97

[Intervening reaches represent the combined sources between mainstem sites (channel and flood plain, ungaged tributaries, and ground water), minus the input from gaged tributaries within the reach]

Reach	Average annual load, in tons per river mile				
	Suspended sediment	Total recoverable			Dissolved
		Copper	Lead	Zinc	Copper
Silver Bow Creek at Warm Springs to Clark Fork near Galen (4.2 mi)	93	0.29	0.03	0.36	0.02
Clark Fork near Galen to Clark Fork at Deer Lodge (24.8 mi)	380	.51	.06	.49	.06
Clark Fork at Deer Lodge to Clark Fork at Goldcreek (25.5 mi)	553	.22	.05	.41	.04
Clark Fork at Goldcreek to Clark Fork near Drummond (31.3 mi)	479	.28	.05	.62	.05
Clark Fork near Drummond to Clark Fork at Turah Bridge, near Bonner (33.4 mi)	338	.27	.03	.31	.03

Table 30. Estimated average annual loads of suspended sediment and trace metals, per river mile, discharged to the Clark Fork from intervening reaches between mainstem sites, water years 1985-97

[Intervening reaches represent the combined sources between mainstem sites (channel and flood plain, ungaged tributaries, and ground water), minus the input from gaged tributaries within the reach]

Reach	Average annual load, in tons per river mile				
	Suspended sediment	Total recoverable			Dissolved
		Copper	Lead	Zinc	Copper
Clark Fork near Galen to Clark Fork at Deer Lodge (24.8 mi)	336	0.40	0.05	0.45	0.05
Clark Fork at Deer Lodge to Clark Fork at Turah Bridge, near Bonner (90.2 mi)	340	.25	.06	.32	.03

On the basis of the 1991-97 average annual loads per river mile, inputs of suspended sediment were lowest in the most upstream 4.2-mi reach between Warm Springs and Galen. Sediment yields were about 3.5 to 6 times greater in the downstream reaches, with the largest loads per river mile occurring in the two adjoining reaches between Deer Lodge and near Drummond. Sediment yields declined in the most downstream reach from near Drummond to Turah Bridge.

Total-recoverable copper loads per river mile were nearly identical in all reaches, with the exception of the 24.8-mi reach from Galen to Deer Lodge, which was about double that of the other reaches. This pattern is somewhat different than that indicated by the 1991-95 yields (Hornberger and others, 1997), in which both reaches above Deer Lodge yielded similar amounts of copper and the downstream reaches had copper yields only about one-third of those above Deer Lodge. Although the reach from Galen to Deer Lodge is still the area of greatest copper yield, the downstream reaches in 1991-97 had copper yields similar to the most upstream reach from Warm Springs to Galen. In 1991-97, the yields in the reaches below Deer Lodge increased from one-third to about one-half of that between Galen and Deer Lodge. Comparison of the 1991-97 yields, which incorporate high-flow conditions, to the 1991-95 yields (Hornberger and others, 1997) indicates that inputs from the reach above Galen did not change, whereas the yield from the reaches below Deer Lodge increased by 2 to 3 times. The higher copper yields from the downstream reaches probably better represent long-term average yields and illustrate how the increased bank erosion and bed movement that occurs during years of large peak flows or ice breakup can result in different spatial patterns of metal input than those during years having lower peak flows.

Average annual loads per river mile of total-recoverable lead and zinc varied slightly to moderately among reaches, with no distinct spatial pattern or substantially elevated yields relative to other reaches. The maximum yield of total-recoverable lead occurred in the reach between Galen and Deer Lodge, although it was only slightly higher than that of downstream reaches. The maximum yield of total-recoverable zinc occurred in the reach between Goldcreek and near Drummond. The zinc yield from this reach was double that of the next downstream reach from near Drummond to Turah Bridge. Lead yield also declined similarly in this most downstream reach.

Dissolved copper loads per river mile were substantially lower than those of total-recoverable copper, ranging from 7 to 18 percent of the total-recoverable loads. The dissolved copper yield was lowest in the most upstream reach between Warm Springs and Galen. The greatest yield was contributed by the reach from Galen to Deer Lodge, which was triple that of the adjoining upstream reach. Dissolved copper yields from the remaining downstream reaches were intermediate to those of the two upstream reaches.

MASS BALANCE OF AVERAGE ANNUAL LOADS IN MILLTOWN RESERVOIR

The annual loads of suspended sediment and trace metals estimated since 1985 for sites upstream and downstream from Milltown Reservoir provide information on the differences between loads entering and leaving the reservoir. These load differences measured over a period of years enable a mass-balance to be determined that can indicate the degree to which materials discharged to the reservoir are either deposited or transported through the reservoir to downstream reaches. The mass balance is calculated as the combined input to the reservoir from the Blackfoot River near Bonner and the Clark Fork at Turah Bridge, near Bonner, minus the output from the reservoir at the Clark Fork above Missoula. Positive numbers indicate that more load entered than left the reservoir, thus net deposition occurred. Negative numbers indicate that more load left the reservoir than entered, thus material was lost from the reservoir bottom sediments.

The mass balances for the two study periods, 1991-97 and 1985-97, are summarized in table 31. The two study periods represent different hydrologic conditions (fig. 2) which can impact the quantity of material discharged from the two upstream basins (Blackfoot River and upper Clark Fork). Because the reservoir is small and provides only limited retention time for incoming flows, settling of particulate material is presumably minimal compared to larger reservoirs. Also, because the reservoir is shallow, the bottom sediments are subject to scour and removal from the reservoir, thus affecting the long-term net balance. Although individual years may exhibit different patterns of load gains or losses, the average mass balance for the relatively long study periods can indicate whether the reservoir is accumulating material, losing material, or is in long-term equilibrium between input and output.

The balance of average annual loads occurring during the two study periods indicates that hydrologic conditions have a predominant effect on patterns of deposition and scour. Small percentage values may be within estimation error and could represent negligible amounts of deposition or scour. Net losses of suspended sediment and total-recoverable copper and zinc are indicated for the 1991-97 period, which is closely representative of the long-term 1930-97 flow characteristics (fig. 2). The losses, however, represent a small fraction of the total inputs (range of 4 percent for suspended sediment to 8 percent for copper and zinc). Loads of total-recoverable lead showed no difference between input and output. During 1991-97, slightly less dissolved copper was estimated to have left the reservoir than entered, indicating a possible gain in the reservoir. However, because copper may partition between the dissolved and particulate phases under different conditions, the data are inadequate to conclude that there is a net increase in the mass of dissolved copper in the reservoir. In general, during 1991-97, essentially all of the incoming suspended sediment and total-recoverable metals moved through the reservoir to downstream reaches, along with small additional amounts apparently scoured from the bottom sediments or possibly entrained from the short reaches of river just upstream from the reservoir which are downstream from the sampling sites. The bulk of the scouring occurred during the two recent years of 1996 and 1997 (tables 7-14) that experienced a major ice breakup and prolonged high flow.

The 1985-97 period was characterized by a less frequent occurrence of high flows than that of the 1930-97 period (fig. 2). The net balance of loads for 1985-97 indicates an accumulation of suspended sediment and

Table 31. Mass balance of average annual loads in Milltown Reservoir for the 1991-97 and 1985-97 study periods

[Gain (+) or loss (-) of loads in the Milltown Reservoir is the net difference between loads input from upstream sources and loads transported through the reservoir to downstream reaches]

Water years	Net balance of average annual load				
	Suspended sediment	Total recoverable			Dissolved
		Copper	Lead	Zinc	Copper
1991-97					
Tons	-6,000	-4.0	0.0	-6.0	+0.20
Percent of input	-4	-8	0	-8	+2
1985-97					
Tons	+4,000	+6.2	+4.6	-3.2	+.60
Percent of input	+4	+14	+37	-5	+7

total-recoverable copper and lead, in addition to a possible accumulation of dissolved copper. A small amount of total-recoverable zinc (5 percent) was possibly lost from the reservoir. The fraction of incoming load deposited in Milltown Reservoir during 1985-97 ranged from 4 percent for the suspended sediment to 37 percent for the total-recoverable lead.

Based on the predominant pattern of deposition during a period when peak flows were lower than normal, it is likely that constituents accumulate temporarily during low-flow years. Eventually, however, the entire amount of recently deposited material can be removed by the scouring action of larger peak flows or ice breakup. Consequently, the net mass balance of loads in Milltown Reservoir probably is in long-term equilibrium between input and output, with no substantial accumulation or loss of material.

SUMMARY

Annual loads of suspended sediment and selected trace metals during water years 1996-97 have been estimated for 12 sites in the upper Clark Fork basin of western Montana. Estimates of annual loads were made for these two years because a major ice-breakup in 1996 and prolonged high flows in 1997 resulted in much larger loads than previously had been measured in the USGS surface-water monitoring program established in 1985. The annual loads estimated for 1996-97 were added to loads estimated for previous years to determine long-term average loads for two recent study periods—water years 1991-97 and 1985-97.

Streamflow-duration analysis indicates that the streamflow characteristics of the 1991-97 period were very similar to long-term streamflow conditions, as represented by the 1930-97 records for the Clark Fork above Missoula. As a result, load estimates for 1991-97 probably are the most representative of long-term loads. In addition, an expanded monitoring network during this period provided enhanced spatial resolution of load differences along the mainstem.

The 1985-97 period is the longest available period of record, but only for the original network of eight sites. The limited number of sites operated in the original network precludes extensive spatial resolution of load differences along the Clark Fork mainstem. Streamflow during 1985-97 was characterized by a less frequent occurrence of high flows than during 1930-97; consequently, average annual loads for 1985-97 may underestimate long-term loads.

Methods used to calculate 1996 and 1997 annual loads incorporated periodic water-quality data, daily records of streamflow and computed suspended-sediment discharge, and regression relations between related hydrologic variables. Regression equations for estimating loads were developed for each station, which then were applied to either the daily sediment or streamflow record to compute a daily load. These daily loads were summed for each year, then averaged over the 1991-97 and 1985-97 study periods. The load estimates for the recent two years of high flow were incorporated to provide a better estimate of long-term average loads than was previously possible.

The estimates of annual suspended-sediment and metals loads at the network of sampling sites allows a determination of the proportion of the total load entering Milltown Reservoir that is contributed from various subareas of the basin. Comparison of inputs from individual tributaries and mainstem reaches is used to identify the areas within the basin that are supplying the greatest quantities of sediment and metals to the Clark Fork.

The network of sampling sites also can be used to divide the mainstem into individual reaches for determination of loads per river mile or yield. The average annual yield provides an indication of the relative degree of metal contamination and channel erosion in the intervening reach between mainstem sites. The mainstem channel and flood plain are considered to be a primary source of metals to the Clark Fork as a result of historic mining activities; therefore, characterizing yields over a wide range of flow conditions can help to understand long-term fluvial transport processes.

Average annual suspended-sediment loads per river mile during 1991-97 were lowest in the most upstream reach between Warm Springs and Galen, then increased by 3.5 to 6 times in the lower downstream reaches, with the maximum sediment yields occurring between Deer Lodge and near Drummond. In contrast, average-annual total-recoverable copper yields were nearly identical among all reaches, with the exception of the reach from Galen to Deer Lodge, where the yield was about double that of the other reaches. Average annual total-recoverable lead and zinc yields were variable, with no distinct spatial pattern.

Average annual dissolved copper loads per river mile were lowest in the most upstream reach between Warm Springs and Galen. The greatest yield of dissolved copper occurred in the reach from Galen to Deer Lodge, which was about triple that of the adjoining upstream reach. Dissolved copper yields from the downstream reaches were intermediate to those of the two upstream reaches.

Estimates of annual loads at sites immediately upstream and downstream from Milltown Reservoir allow a mass-balance determination for suspended sediment and metals discharged to and from the reservoir. The difference between the combined load inputs from the Clark Fork and Blackfoot River basins and that for the Clark Fork above Missoula represents the net amount of material being deposited or moving through the reservoir to downstream reaches. The average annual loads for the 1991-97 and 1985-97 study periods indicate different patterns of gains and losses, probably as a result of differing hydrologic conditions. On the basis of the 1991-97 period, which is closely representative of long-term streamflow conditions, essentially all of the load entering the reservoir moves through to downstream reaches. Therefore, although net deposition or loss of material may occur in individual years, Milltown Reservoir appears to be in long-term equilibrium and probably is not accumulating or losing substantial amounts of material.

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