Second Five-Year Review Report
for the
Milltown Reservoir /Clark Fork River
Superfund Site

EPA ID MTD980717565

Milltown
Missoula, Granite, Powell, and Deer Lodge Counties, Montana

September 2016

Prepared By:
United States Environmental Protection Agency
Region 8
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Approved by:

Date:

9/29/16

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Table of Contents

List of Tables

List of Figures

List of Acronyms

ARAR	Applicable or Relevant and Appropriate Requirement
ARCO	Atlantic Richfield Company
AWQC	Ambient Water Quality Criteria
BMP	Best Management Practice
CaCO3	Calcium carbonate
CCC	Criterion Continuous Concentration
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act, as amended
CFR	Code of Federal Regulations
CFROU	Clark Fork River Operable Unit
CMC	Criteria Maximum Concentrations
COC	Contaminant of Concern
CUP	Conditional Use Permit
EPA	United States Environmental Protection Agency
FYR	Five-Year Review
IC	Institutional Control
MCL	Maximum Contaminant Level
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
mg/L	micrograms per liter
MCCHD	Missoula City and County Health Department
MDEQ	Montana Department of Environmental Quality
MDL	Method detection limit
MRSOU	Milltown River Sediments Operable Unit
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPL	National Priorities List
NRDP	Natural Resource Damage Program
OU	Operable Unit
O&M	Operation and Maintenance
PEC	Probable Effects Concentration
POC	Point of compliance
PRP	Potentially Responsible Party
RAMP	Remedial Action Monitoring Plan
RAO	Remedial Action Objective
RI/FS	Remedial Investigation and Feasibility Study
RIPes	Riparian Evaluation System
ROD	Record of Decision
RPM	Remedial Project Manager
SAA	Sediment Accumulation Area
TBC	To-Be-Considered
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

Executive Summary

The Milltown Reservoir /Clark Fork River site includes about 120 miles of the Clark Fork River upstream of the former Milltown Dam and Reservoir. The Milltown Dam and Reservoir were located at the confluence of the Clark Fork and Blackfoot Rivers, a few miles upstream of Missoula. From the 1860s until well into the 20th century, mineral- and arsenic-laden waste from mining activities in the region flowed into the headwaters of the Clark Fork River, contaminating the river and its beds and banks from the Warm Springs Ponds to the Milltown Reservoir. As contaminated sediments and mine-mill wastes moved downstream, about 6.6 million cubic yards of these sediments accumulated behind the Milltown Dam over time. These mining activities and the downstream transport of mining-related wastes contaminated floodplains, sediment, surface water and groundwater with heavy metals.

This FYR report addresses all site operable units (OUs). OU2 is the Milltown Reservoir Sediments (MRSOU), including the area encompassed by the former Milltown dam and reservoir. OU1 (the Milltown Drinking Water Supply OU) is now part of OU2. OU3 is the Clark Fork River (CFROU) area upstream of the MRSOU and downstream of the Silver Bow Creek/Butte Area site and the Anaconda Smelter site.

The MRSOU remedy includes construction of a bypass channel at the reservoir; removal of contaminated reservoir sediment; off-site disposal and use of contaminated sediment as vegetative cap material; removal of the Milltown Dam; continuation of a replacement water supply program in the town of Milltown; implementation of temporary groundwater controls until the Milltown aquifer recovers and other institutional controls; and long-term monitoring of surface water and groundwater. Remedy construction began in 2006 and is substantially complete.

The remedy at MRSOU (OU2) currently protects human health and the environment because potential exposure to contaminated groundwater, surface water and sediment is controlled. For the remedy to be protective over the long term, the following actions need to be taken:

- Implement institutional controls for the MRSOU comprehensive institutional control plan and its components.
- Determine if additional measures are needed to reduce arsenic concentrations in groundwater to levels at or below the cleanup goals.

The CFROU remedy includes soil and sediment removal and disposal outside of the OU, some in-place treatment of soils, revegetation of removed or treated areas, streambank stabilization, weed control, institutional controls and monitoring. MDEQ started the remedial action construction with yard removals in Deer Lodge in 2010-2011, the Trestle Project in 2011-2012, and Eastside Road Pastures, 2012-2013, CFR Reach A, Phase 1 remedial construction on the river began in 2013. Remedial implementation is ongoing.

The remedy at CFROU (OU3) is expected to be protective of human health and the environment upon completion of the remedial action. In the interim, exposure pathways that could result in unacceptable risks are being controlled.

Five-Year Review Summary Form

SITE IDENTIFICATION		
Site Name: Milltown Reservoir /Clark Fork River		
EPA ID: MTD980717565		
Region: 8	**State:** MT	**City/County:** Milltown and Missoula, Granite, Powell and Deer Lodge Counties
SITE STATUS		
NPL Status: Final		
Multiple OUs? Yes	**Has the site achieved construction completion?** No	
REVIEW STATUS		
Lead agency: EPA **If "Other Federal Agency" selected above, enter Agency name:**		
Author name: Sara Sparks (EPA) and Ryan Burdge and Treat Suomi (Skeo)		
Review period: 10/01/2015 – 09/23/2016		
Date of site inspection: 11/02/2015 – 11/04/2015		
Type of review: Statutory		
Review number: 2		
Triggering action date: 09/23/2011		
Due date *(five years after triggering action date)*: 09/23/2016		

Five-Year Review Summary Form (continued)

Issues/Recommendations

OU(s) without Issues/Recommendations Identified in the Five-Year Review:
OU3

Issues and Recommendations Identified in the Five-Year Review:

OU(s): OU2	**Issue Category: Institutional Controls**			
	Issue: Institutional controls for MRSOU are not yet implemented for areas where waste has been left in place and areas where groundwater contamination is above ROD standards.			
	Recommendation: Implement institutional controls for the MRSOU comprehensive institutional control plan and its components.			
Affect Current Protectiveness	**Affect Future Protectiveness**	**Implementing Party**	**Oversight Party**	**Milestone Date**
No	Yes	PRP	EPA/State	09/30/2017

OU(s): OU2	**Issue Category: Remedy Performance**			
	Issue: Groundwater concentrations at MRSOU continue to exceed arsenic cleanup goals and do not appear to be declining			
	Recommendation: Determine if additional measures are needed to reduce arsenic concentrations below the cleanup goals and implement measures determined to be necessary.			
Affect Current Protectiveness	**Affect Future Protectiveness**	**Implementing Party**	**Oversight Party**	**Milestone Date**
No	Yes	PRP	EPA/State	09/30/2017

Protectiveness Statements

Operable Unit: OU2	Protectiveness Determination: Short-term Protective	Addendum Due Date (if applicable):
Protectiveness Statement: The remedy at MRSOU (OU2) currently protects human health and the environment because potential exposure to contaminated groundwater, surface water and sediment is controlled. For the remedy to be protective over the long term, the following actions need to be taken: implement institutional controls for the MRSOU comprehensive institutional control plan and its components and determine if additional measures are needed to reduce arsenic concentrations below the cleanup goals.		

Operable Unit: OU3	Protectiveness Determination: Will be Protective	Addendum Due Date (if applicable):
Protectiveness Statement: The remedy at CFROU (OU3) is expected to be protective of human health and the environment upon completion of the remedial action. In the interim, exposure pathways that could result in unacceptable risks are being controlled.		

Second Five-Year Review Report
for
Milltown Reservoir /Clark Fork River Superfund Site

1.0 Introduction

The purpose of a five-year review (FYR) is to evaluate the implementation and performance of a remedy in order to determine if the remedy is protective of human health and the environment. FYR reports document FYR methods, findings and conclusions. In addition, FYR reports identify issues found during the review, if any, and document recommendations to address them.

The United States Environmental Protection Agency (EPA) prepares FYRs pursuant to the Comprehensive Environmental Response, Compensation and Liability Act as amended (CERCLA) Section 121, 42 U.S.C. § 9621, and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). CERCLA Section 121 states:

> If the President selects a remedial action that results in any hazardous substances, pollutants, or contaminants remaining at the site, the President shall review such remedial action no less often than each 5 years after the initiation of such remedial action to assure that human health and the environment are being protected by the remedial action being implemented. In addition, if upon such review it is the judgment of the President that action is appropriate at such site in accordance with section [104] or [106], the President shall take or require such action. The President shall report to the Congress a list of facilities for which such review is required, the results of all such reviews, and any actions taken as a result of such reviews.

EPA interpreted this requirement further in the NCP, 40 Code of Federal Regulations (CFR) Section 300.430(f)(4)(ii), which states:

> If a remedial action is selected that results in hazardous substances, pollutants, or contaminants remaining at the site above levels that allow for unlimited use and unrestricted exposure, the lead agency shall review such action no less often than every five years after initiation of the selected remedial action.

Skeo, an EPA Region 8 contractor, conducted the FYR and prepared this report regarding the remedy implemented at the Milltown Reservoir /Clark Fork River Superfund site (the Site) in Milltown and Missoula, Granite, Powell, and Deer Lodge Counties, Montana. EPA's contractor conducted this FYR from October 2015 to September 2016.

EPA is the lead agency for developing and implementing the remedy at OU2 through oversight of the potentially responsible party (PRP)-financed cleanup at the Site, and coordination with the State of Montana Natural Resource Damage Program which is performing certain restoration site activities to, in some cases, accomplish remedial goals and objectives. The Montana Department of Environmental Quality (MDEQ), as the support agency representing the State of Montana at OU2, and has reviewed all supporting documentation and provided input to EPA during the FYR process.

MDEQ is the lead agency for implementation of the Remedial Design, the Remedial Action, and the Operation and Maintenance of the Remedy at the Clark Fork Site, through special account funding obtained by EPA and the State through an enforcement settlement at OU3. The State of Montana Natural Resource Damage program is also performing certain natural resource damage restoration activities at OU3 which in cooperation with MDEQ, to date, have been supplemental to the remedial implementation. EPA is the support agency for OU3. EPA has prepared this Site-wide five year review report, in consultation with MDEQ and the State of Montana Natural Resource Damage Program.

This is the second FYR for the Site. The triggering action for this statutory review is the previous FYR. The FYR is required due to the fact that hazardous substances, pollutants or contaminants remain at the Site above levels that allow for unlimited use and unrestricted exposure. The Site consists of two operable units (OUs). This FYR report addresses all OUs for the site.

OU2 is the Milltown Reservoir Sediments (MRSOU), including the area encompassed by the former Milltown dam and reservoir. OU1 (the Milltown Drinking Water Supply OU) is now part of OU2. OU3 is the Clark Fork River (CFROU) area upstream of the MRSOU and downstream of the Silver Bow Creek/Butte Area site and the Anaconda Smelter site.

2.0 Site Chronology

Table 1 lists the dates of important events for the Site.

Table 1: Chronology of Site Events

Event	Date
Local public health authorities discovered arsenic contamination in drinking water wells in Milltown, Montana	1981
EPA added the Site to the Superfund program's National Priorities List (NPL)	September 08, 1983
EPA issued interim Record of Decision (ROD) for OUl, requiring construction of a deep well and water tank to serve as an alternative water supply for Milltown residents. This ROD was amended in 1985.	April 14, 1984
Remedial action construction for OU1 completed	1986
Atlantic Richfield Company prepared major portions of the final CFROU remedial investigation and feasibility study (RI/FS). RI/FS work continued for several years after 1987, including the preparation of a baseline human health and ecological risk assessment.	1987
RI/FS order on consent for MRSOU issued to Atlantic Richfield Company (ARCO)	1991
MRSOU RI and baseline human health, ecological and continued release risk assessments completed	September 16, 1993
PRPs complete Final RI Report for MRSOU	February 15, 1995
Draft FS for MRSOU groundwater released by ARCO. The same year, unforeseen climatic conditions caused ice scour event, which sent high levels of metals contamination down river; EPA expanded FS scope and conducted further risk assessments	1996
EPA issued CFROU ROD	April 2004
MRSOU RI/FS completed; EPA issues MRSOU ROD	December 15, 2004

Event	Date
Consent Decree for PRP performance of MRSOU remedy and O&M entered by federal court; this includes requirements for PRP continued funding of water supply operation and maintenance (O&M) activities. The Consent Decree also provided for the performance of natural resource damage actions by the State of Montana at the MRSOU, some of which are intended to fulfill remedial action requirements.	August 2005
Remedial action at MRSOU begins	February 15, 2006
Initial reservoir drawdown (Stage 1) and start of MRSOU remedial action	June 01, 2006
Consent Decree for PRP cashout of CFROU remedy and O&M entered by federal court. This provides for the performance of the CFROU remedy and O&M by the MDEQ using the cashout money, and funding and performance of natural resource damage actions by the State of Montana Natural Resource Damage program.	August 21, 2008
EPA approves Draft Repository O&M Plan and Changes to the Remedial Action Monitoring Plan (RAMP) for MRSOU	March 2010
MDEQ begins remedial action at CFROU, including irrigated land, Deer Lodge residential, and Trestle area work.	October 5, 2010
Transfer of reservoir property to State of Montana	December 2010
Clark Fork River bypass channel removal begins	December 2010
EPA completes first five-year review for MRSOU	September 2011
MRSOU remedial activities construction activities were significantly completed	June 2012
MDEQ begins remedial action at CFROU Reach A, Phase 1.	March 4, 2013
MDEQ completes remedial action at CFROU Reach A, Phase 1. Work at other Phase areas is ongoing.	April 4, 2014
Remedial action begins at CFROU Phase 5 and 6	July 15, 2014
MDEQ submits construction completion report for Phase 1 to EPA	March 25, 2015
EPA and MDEQ release Explanation of Significant Differences for CFROU	June 12, 2015
Remedial action begins at CFROU Phase 2	June 29, 2015

3.0 Background

3.1 Physical Characteristics

The Clark Fork Basin Superfund complex is made up of four contiguous Superfund sites, each broken into separate NPL sites. The four Superfund sites are the Silver Bow Creek/Butte Area site, the Montana Pole site, the Anaconda Smelter site and Milltown Reservoir /Clark Fork River site. The Anaconda Smelter site, the Silver Bow Creek/Butte Area site and the Milltown Reservoir /Clark Fork River site are each broken into several OUs.

EPA originally designated three OUs for the Site. There are currently two site OUs.

- OU2 is the Milltown Reservoir Sediments (MRSOU). It includes about 540 acres in the Clark Fork River and Blackfoot River floodplain (Figure 1). The MRSOU consists of the area encompassed by the former Milltown dam and reservoir and the associated groundwater contamination. OU1, an interim remedy, is now part of the

MRSOU. It focused on providing a safe water supply to Milltown area residents through the establishment of a public water supply system in Milltown, Montana.

- OU3 is the Clark Fork River (CFROU) area upstream of the MRSOU and downstream of the Silver Bow Creek/Butte Area site and the Anaconda Smelter site (Figure 1). CFROU consists of about 120 river miles of the Clark Fork River, including surface water, groundwater, soils, in-stream sediments, sediment deposition and contaminated property, and air located within and adjacent to the 100-year historic floodplain of the Clark Fork River.

MRSOU is located at the confluence of the Clark Fork and Blackfoot rivers in Missoula County, Montana. The Milltown Reservoir was formed by the Milltown Dam, built from 1905 to 1908. It is located approximately 7 miles upstream of downtown Missoula, Montana.

From its headwaters, the Clark Fork River flows north for approximately 43 river miles past the towns of Galen, Deer Lodge and Garrison (this stretch is known as Reach A of CFROU). The river then runs northwest for approximately 77 river miles to the headwaters of the Milltown Reservoir near Bonner.

To better study and evaluate remedial options, EPA divided the CFROU into three reaches based on physical features of the landscape, proximity to historic mining and intensity of impacts:

- *Reach A – Deer Lodge Valley Reach:* Extends from the southeastern tip of the CFROU near river mile 0 at Warm Springs Creek to just upstream of Garrison at river mile 43. Reach A has the broadest extent of the 100-year floodplain and is nearest to historic mining and milling sites in Butte and Anaconda. There are extensive exposed tailings and unstable streambanks as well as stressed vegetation in this area.

- *Reach B – Drummond Valley Reach*: Extends from immediately upstream of Garrison, where the Little Blackfoot River enters the Clark Fork, to downstream of Drummond at river mile 76, for a total of 31 river miles. At the starting point for this reach, the addition of water from the Little Blackfoot River may, under certain flow conditions, nearly double the Clark Fork's flow. The floodplain is more narrow and the gradient higher than Reach A, and exposed tailings are far less extensive.

- *Reach C – Bearmouth Canyon Reach*: Extends 47 river miles from Drummond to the northwest tip of the OU area. Through this reach, the floodplain is constrained by a narrow valley, roads and railroad grades. Here, the flow is augmented by several tributaries and the reach is farther away from historic mining sites. No exposed tailings are evident.

3.2 Land and Resource Use

The former Milltown Dam was owned and operated as a hydroelectric generating facility by North Western Corporation and its predecessors. The community of Milltown is located a half-mile east of the former dam and powerhouse. The community of Bonner borders Milltown to the northeast. About 1,700 people live in Milltown, according to 2010 U.S. Census data. A new public water supply was developed for Milltown under OU1. Private wells in the area are sampled by the Missoula City and County Health Department (MCCHD).

The MRSOU (OU2) includes the Milltown Reservoir and the adjacent areas of impacted groundwater and contaminated soils and the upland disposal facilities. Land uses along the Clark Fork River riparian zone are primarily recreational and agricultural. The Clark Fork River in the vicinity of MRSOU is used for recreational rafting, kayaking and fishing. The City of Missoula (population 57,000) is located approximately 7 river miles downstream of Milltown, Montana.

Assisted by an EPA Superfund Redevelopment Initiative pilot grant and EPA support, communities near the MRSOU developed a reuse plan. The plan called for the creation of a state park with trails, river access, wildlife habitat and interpretive areas celebrating the region's history and heritage. In 2010, the State of Montana acquired portions of the MRSOU to become a new state park. The state allocated funding for the park's development and land acquisitions. There are several trails in the area and the state has plans to link the new park with the larger community trail network and the newly renovated pedestrian bridge.

About 16,240 people live in the area of CFROU (OU3) according to 2010 U.S. Census data. Approximately 28 percent of the population (4,500 people) lives in or near Reach A. Approximately 89 percent of the land within Reach A is privately owned; the remaining 11 percent of the land is managed by federal and state agencies. Land use in the CFROU consists of residential use, agricultural use and recreational use. The town of Deer Lodge is located within and adjacent to the OU.

3.3 History of Contamination

In the Butte area, mining companies routinely disposed of mining and milling wastes containing various amounts of unrecovered metals and arsenic into local creeks in the headwaters of the Clark Fork River Basin from the late 1860s to well into the 20th century. These streams conveyed the mining and milling wastes downstream to the Clark Fork River. With the introduction of electricity in the early 1900s, milling practices improved and new mining practices significantly increased ore production and metals recovery rates, and substantially increased the volume of annual mine and mill tailings. These wastes subsequently mixed with other stream sediments and were carried down Silver Bow Creek and into the upper Clark Fork.

In 1908, a major flood event mobilized large quantities of metals and arsenic-contaminated sediments from the upper Clark Fork River channel and floodplain, transporting large quantities of waste to the recently constructed Milltown Reservoir. Much of the arsenic and metals contaminated sediment was deposited in the reservoir backwater area created by the dam.

Between 1918 and 1959, a series of settling ponds (known as Warm Springs Ponds, now part of the Silver Bow Creek Superfund site) were built near the end of Silver Bow Creek, to better control the contaminated sediments entering the upper Clark Fork River. As a result, the amount of contaminated sediments from the Butte and Anaconda area reaching the Milltown Dam and reservoir after 1918 significantly lessened. However, substantial quantities of mine waste continued to be washed downstream towards the reservoir from previously deposited areas downstream of Warm Springs Ponds and the Anaconda area as well as output from the ponds.

In addition to fluvial deposition of metals-contaminated sediments in the historic 100-year floodplain, agricultural fields were irrigated with water from the Clark Fork River that at times contained elevated concentrations of metals in dissolved form and as suspended sediment. This caused ongoing contamination, at low levels, of the fields. In some instances, irrigation ditches overflowed or were breached, flooding and contaminating fields downgradient of the ditches with river water. The irrigated fields are located on terraces above the influence of metals and arsenic impacts associated with flood deposition.

3.4 Initial Response

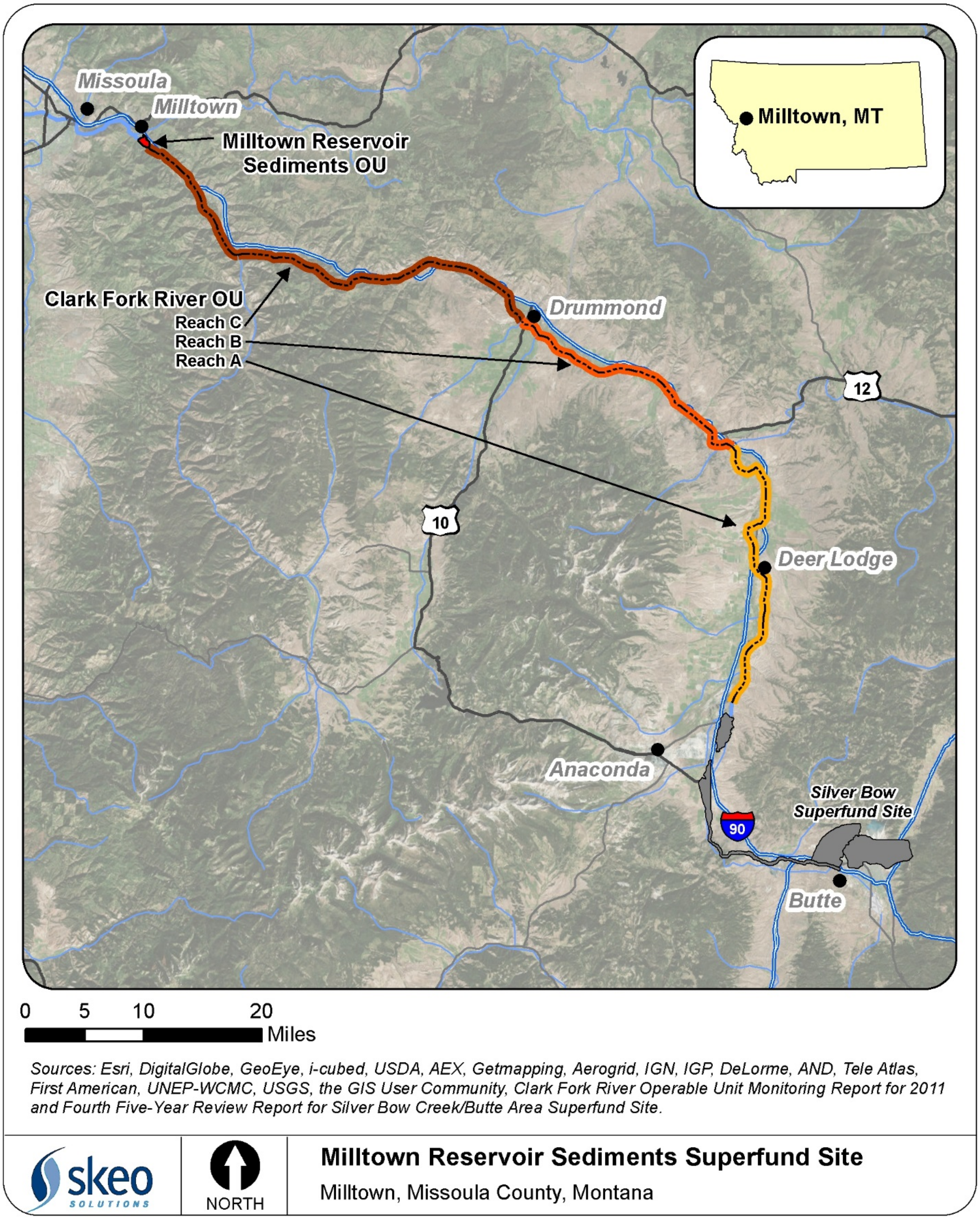
In 1981, local public health authorities found arsenic in drinking water wells in the Milltown area at concentrations exceeding the federal drinking water standard. EPA added the Site to the National Priorities List (NPL) in 1983. Also in 1983, the Atlantic Richfield Company (ARCO) suspended its mining activity in Butte after shutting down the Anaconda smelter.

In 1984, EPA issued an interim record of decision (ROD) for OU1. A resulting fund-lead response action installed a new drinking water system for Milltown (i.e., a water supply well). However, no institutional controls were put in place at that time. The Montana Power Company, a predecessor of the NorthWestern Corporation, implemented rehabilitation and upgrades to the Milltown spillway and dam from 1986 through 1990, and 14,500 cubic yards of reservoir sediments and debris were transported and encapsulated in the Upland Disposal site (near MW 913A, Figure 2). An earlier disposal site had also been constructed on site by the Montana Power Company.

In 1989, the United States sued ARCO for reimbursement of response costs at three of the NPL sites listed above. In 1991, EPA issued an Administrative Order on Consent to ARCO initiating the remedial investigation and feasibility study (RI/FS) process for the MRSOU.

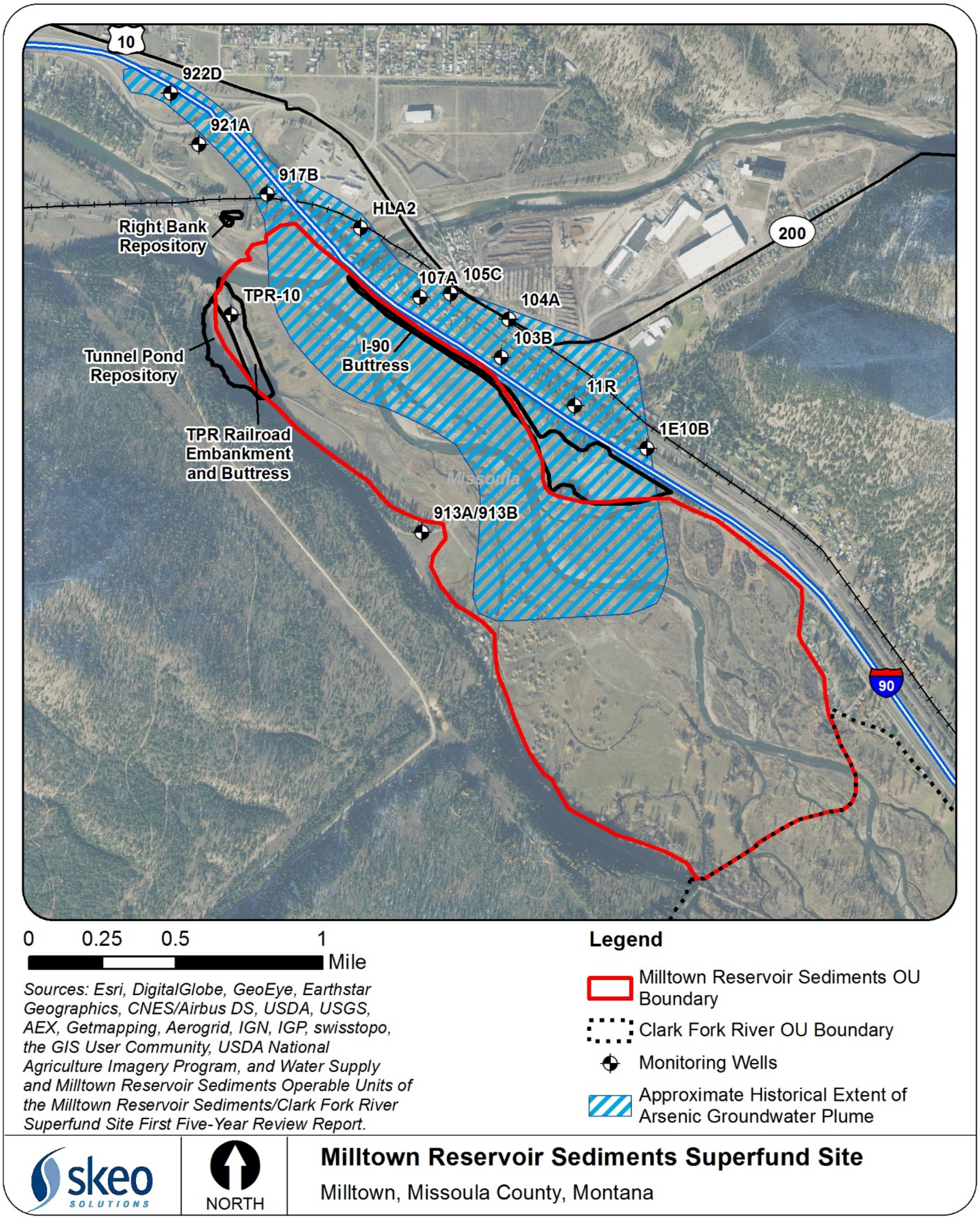
From 1994 to 1995, EPA issued an Administrative Order on Consent to ARCO initiating the RI/FS process for the CFROU. In 2000, EPA issues a time-critical removal action memorandum and a Unilateral Administrative Order to ARCO to address immediate human health risks for residents of Eastside Road in Deer Lodge, in response in part to an Agency for Toxic Substances and Disease Registry health consultation and EPA Human Health Risk Assessment action levels.

Figure 1: Site Map



Disclaimer: This map and any boundary lines within the map are approximate and subject to change. The map is not a survey. The map is for informational purposes only regarding EPA's response actions at the Site.

Figure 2: Detailed Site Map – MRSOU



Disclaimer: This map and any boundary lines within the map are approximate and subject to change. The map is not a survey. The map is for informational purposes only regarding EPA’s response actions at the Site.

3.5 Basis for Taking Action

MRSOU

EPA, in consultation with MDEQ, provided oversight of the MRSOU RI/FS activities conducted by ARCO. The 1993 baseline human health risk assessment for the MRSOU was prepared to assess potential risks at the Site using standard EPA health risk assessment methods for residential and recreational uses. EPA determined that the non-carcinogenic and carcinogenic risks associated with consuming groundwater contaminated with arsenic were unacceptable. Other exposure pathways for humans – including residential use for existing homes near the reservoir and recreational use of land surrounding the reservoir – were considered not significant. If residential use of land immediately surrounding the reservoir occurred, it would be unacceptable. The analysis of a potential detoxification threshold for ingestion of arsenic suggested that long-term exposures at the Site, other than through consumption of impacted groundwater, would not be associated with a greatly increased non-cancer and cancer risk.

The ecological risk assessment determined the water quality downstream exceeded the water quality criteria and that copper caused an unacceptable acute risk to aquatic life. Additionally, the ecological risk assessment determined that normal high-flow events may pose an intermittent low-level chronic risk to fish because of the combined impacts of copper and other metals in the water column and copper in ingested macroinvertebrates.

CFROU

The primary sources of contamination are tailings and tailings mixed with soil in streambanks and the historic floodplain. Contaminants move from tailings and impacted soils through the process of erosion, directly into the river and other surface waters. In addition to erosion of tailings and impacted soils, metals and arsenic can be leached directly from the tailings and contaminated soils into groundwater and surface water.

The CFROU 1998 human health risk assessment identified arsenic as the contaminant of concern (COC) for potential human health risks in Reach A. The RBCs for residential, recreational, and agricultural exposure are listed below. These RBCs are for arsenic concentrations in soils, as averaged over exposure units. EPA considers acceptable exposure levels to be concentration levels that represent an excess upper bound lifetime cancer risk to an individual of between 10^{-4} (1 in 10,000 probability) to 10^{-6} (1 in 1,000,000 probability), with 10^{-6} as the point of departure. EPA proposed the following arsenic concentrations, which represent a 10-4 excess cancer risk:

Residential	150 mg/kg
Recreational	680 mg/kg (children at Arrow Stone Park and other recreational scenarios)
	1,600 mg/kg for fishermen, swimmers and tubers along the river
Rancher/Farmer	620 mg/kg

On historically irrigated lands, however, where residential development has occurred or where it may occur in the future, the risk assessment concluded that risks may be unacceptable.

The CFROU ecological risk assessment found unacceptable risks from the metals contamination to plants and aquatic life within the several reaches of the CFROU. Soils and vegetation areas most clearly show the impacts from these risks. In addition, United States Geological Survey (USGS) studies found excessive rates of erosion along streambanks in the upper reaches of the CFROU. The studies also identified the possibility of severe erosion of the upper river in large floods that would cause large inputs of contaminants and sediment into the river.

4.0 Remedial Actions

In accordance with CERCLA and the NCP, remedial actions are required to protect human health and the environment and to comply with applicable or relevant and appropriate requirements (ARARs). A number of remedial alternatives were considered for each OU at the Site, and final selection was made based on an evaluation of each alternative against nine evaluation criteria that are specified in Section 300.430(e)(9)(iii) of the NCP. The nine criteria are:

1. Overall Protection of Human Health and the Environment
2. Compliance with ARARs
3. Long-Term Effectiveness and Permanence
4. Reduction of Toxicity, Mobility or Volume through Treatment
5. Short-Term Effectiveness
6. Implementability
7. Cost
8. State Acceptance
9. Community Acceptance

4.1 Remedy Selection

<u>Milltown Water Supply OU1</u>

EPA issued an interim ROD in 1984, and amended this action in 1985. A resulting response action installed a new drinking water system for Milltown. This OU1 was combined with OU2.

MRSOU2

In December 2004, EPA signed the final ROD for the MRSOU. Media-specific remedial action objectives (RAOs) include:

Groundwater

- Return contaminated groundwater to its beneficial use within a reasonable timeframe and prevent ingestion until drinking water standards are achieved.
- Comply with state groundwater standards, including non-degradation standards.
- Prevent groundwater discharge containing arsenic and metals that would degrade surface waters.

Surface Water

- Achieve compliance with surface water standards, unless a waiver is justified.
- Prevent ingestion of or direct contact with water posing an unacceptable human health risk.
- Achieve acute and chronic federal Ambient Water Quality Criteria (AWQCs), as well as State water quality standards.

The selected remedy for the MRSOU consists of the following measures:

- Initiating the process of progressively dewatering Milltown Reservoir Sediment Accumulation Area (SAA) I sediments by lowering reservoir surface water levels through use of the existing radial gate and spillway with panels removed (see Appendix H for map of SSAs).
- Isolating SAA I sediments from flowing surface water by excavating a bypass channel through SAA I and armoring the existing embankment along the Blackfoot River boundary of SAA I and converting powerhouse inlets to low level outlets removing the spillway section of the Milltown Dam.
- Removing the radial gate, powerhouse, dividing block, shop and right abutment gravity wall sections of Milltown Dam as part of integration with the Natural Resource Damage Program (NRDP) Trustee Restoration Plan.
- After a period of dewatering and consolidation, remove down to a predetermined contour surface the sediments in SAA I through the use of mechanical excavation techniques, hauling the waste (approximately 90 miles via rail cars), and placing the sediments removed from SAA I in the Opportunity Ponds at the Anaconda Smelter site.
- Reconstructing the Blackfoot River and Clark Fork River channels and banks, including protection of certain infrastructure and regrading/revegetating the Clark Fork River/Blackfoot River floodplain to provide stability.
- Replacement of any drinking water supply that exceeds the drinking water standard for arsenic of 10 micrograms per liter (µg/L) due to remedial action implementation (if appropriate, a temporary controlled groundwater area will be established until the Milltown aquifer recovers using monitored natural attenuation).
- Replacement or retrofitting of domestic wells which are deemed unusable by EPA because of the lowering of the groundwater table.

- Conducting long-term operation, maintenance and monitoring of the areas identified as the dam rehabilitation sediment/debris repositories established by the Montana Power Company, the portions of the new Interstate-90 embankment outside the Montana Department of Transportation's right-of-way, and the area in the lower Clark Fork River channel (SAA III-b) where sediments with elevated concentrations of arsenic and metals will remain after the remedial action and any other on-site repositories established during the remedial action and any other waste repositories established on site.
- Bridge stability mitigation for certain bridges near the MRSOU.
- Monitoring and maintenance of borrow and staging areas revegetated during remedial action.
- Surface water and groundwater monitoring.
- Implementation of additional best management practices or engineering controls as detailed in a contingency plan to be approved by EPA or as otherwise required by EPA, in consultation with MDEQ, if temporary construction-related surface water quality standards are exceeded.
- Implementation of the terms and conditions of the incidental take statement in the United States Fish and Wildlife Service's (USFWS's) Biological Opinion, and wetlands mitigation as necessary to meet the no-net-loss requirement as determined by USFWS.

The OU2 2004 ROD indicates that groundwater standards are expected to be met within four to 10 years following completion of dam and sediment removal. The remedial action construction was significantly completed in June 2012. Cleanup goals are listed in Tables 2 and 3.

Table 2: MRSOU Groundwater COC Cleanup Goals

Groundwater COC	ROD Cleanup Goal (μg/L)[a]
Arsenic	10
Cadmium	5
Copper	1,300
Lead	15
Zinc	2,000
Notes: a. Based on the more stringent of federal or state standards.	

Table 3: MRSOU Surface Water COC Cleanup Goals

COC	Aquatic Life		Human Health
	Acute (µg/L)	Chronic (µg/L)	Standard (µg/L)
Arsenic	340	150	10 – federal 18 – state
Cadmium	2.10	0.27	5
Copper	13	9	1,300[1]
Lead	81	3.2	15
Zinc	119	119	2,000

The ROD also identified the need for groundwater institutional controls for the MRSOU. The institutional controls would include:

- Continued funding for maintaining the existing replacement water supply for Milltown residents (installed under the OU1 remedy).
- Make contingency funds available to reconfigure, expand or update replacement water supplies.
- If needed, establish a controlled groundwater area to ban future wells within or immediately adjacent to the arsenic plume.
- The ROD also identified the need for institutional controls to prevent residential use of the MRSOU and to protect disturbance on-site remedial elements such as disposal units.

<u>CFROU3</u>

In April 2004, EPA signed the final ROD for the CFROU. The 2004 RAOs for floodplain tailings and impacted soils are:

- Prevent or inhibit ingestion of arsenic-contaminated soils/tailings where ingestion or contact would pose an unacceptable health risk.
- Prevent or reduce unacceptable risk to ecological (including agricultural, aquatic, and terrestrial) systems degraded by contaminated soils/tailings.

The groundwater RAOs are:

- Return contaminated shallow groundwater to its beneficial use within a reasonable period.
- Comply with state groundwater standards, including nondegradation standards (Table 4).
- Prevent groundwater discharge containing arsenic and metals that would degrade surface waters.

[1] The MRSOU ROD acknowledges that a waiver of the State standard for copper in the upstream operable unit, and allows for consideration of upstream input into the MRSOU in determining compliance with the copper ARAR.

For surface waters, the RAOs are:

- Reduce or eliminate “pulses” of metals to the river, including those caused by snowmelt and thunderstorm events.
- Achieve compliance with surface water standards, unless a waiver is justified (Table 5).
- Prevent ingestion of, or direct contact with, water posing an unacceptable human health risk.
- Achieve trout toxicity reference values and acute and chronic federal AWQCs.
- Comply with stormwater ARARs.

The selected remedy will be implemented along the erosive streambanks and the historic 100-year floodplain of all of Reach A and small, localized areas of Reach B. The remedy for Reach C is no action.

The remedy is currently under construction (see Section 4.2). The remedial actions will proceed in localized efforts and require about 15 construction seasons to complete. The sequence of properties to be remediated throughout Reach A and localized areas of Reach B will be carefully planned and prepared. While the general approach will be to work from the headwaters down, EPA and MDEQ believes remediation can be done more quickly and effectively and with less threat to river stability by working on discontinuous stretches of the river. Thus, properties will be engaged in a discontinuous manner to prevent jeopardizing the integrity of the floodplain, should a flood event greater than the annual flood occur during the 15-season remedial action period. Affected landowners will be involved in setting these schedules and clearly informed of the sequencing of the work.

Specific components of the remedy, as described in the 2004 ROD, include:

- In most instances, impacted soils and vegetation, also referred to as impacted areas, will be treated in place, using careful lime addition and other amendment as appropriate, soil mixing and revegetation.
- Some impacted areas will be removed, where depth of contamination prevents adequate and effective treatment in place, where saturated conditions make in-situ treatment unimplementable, or where post treatment arsenic levels, after one retreatment attempt, remain above the human health cleanup level for the current or reasonably anticipated land use. Severely impacted soils, also known as slickens, will be removed and revegetated.
- Residential soils above residential action levels will be removed.
- The Riparian Evaluation System (RipES) process will be used in remedial design to identify severely impacted areas and impacted areas, and areas where the exceptions to removal or in-situ treatment will apply.
- Streambanks will be stabilized primarily by “soft” engineering (with limited hard engineering where conditions warrant) for those areas classified and an approximate, flexible 50-foot riparian buffer zone will be established on both sides of the river.
- Opportunity Ponds will be used for disposal of all removed contamination.
- Weed control for in-situ treatment, streambank stabilization, and removal areas is required.

- Best management practices (BMPs) throughout Reach A and in limited areas of Reach B are required to protect the remedy and ensure land use practices are compatible with the long-term protection of the selected remedy.
- Institutional controls and additional sampling, maintenance and possible removal or in-situ treatment of contamination, including the Trestle Area, will be required to protect human health.
- Monitoring during construction, construction BMPs and post-construction environmental monitoring are required.
- The remedy is also modified and expanded for the Grant-Kohrs Ranch National Historic Site, located in Reach A.

Table 4: CFROU Groundwater COC Cleanup Goals

Groundwater COC	ROD Cleanup Goal (µg/L)
Arsenic	10
Cadmium	5
Copper	1,300
Iron	300
Lead	15
Zinc	2,000

Table 5: CFROU Surface Water COC Cleanup Goals

Surface Water COC	Aquatic Life - Acute (µg/L)	Aquatic Life - Chronic (µg/L)	Human Health (µg/L)
Arsenic	340	150	10 – federal 18 – state
Cadmium	2	0.25	5
Copper	13	9	1,300
Lead	81	3.2	15
Zinc	119	119	2,000

The risk-based soils cleanup goals for arsenic at residential, recreational and agricultural areas are listed in Table 6. These goals are for arsenic concentrations in soils, as averaged over exposure units.

Table 6: Arsenic Soil Cleanup Goals

Land Use	ROD Cleanup Goal (mg/kg)
Residential	150
Recreational	680 for children at Arrow Stone Park and other recreational scenarios
	1,600 for fishermen, swimmers and tubers along the river
Rancher/Farmer	620
Notes: mg/kg = milligrams per kilogram	

2015 Explanation of Significant Differences (ESD)

A review of post-ROD sampling of the CFROU and the results of EPA's 2007 RipES mapping for the floodplain tailings and soils component of the remedy led to an ESD for the CFROU in 2015. The ESD provides for the use of the RipES process as a tool in development of the remedial design. However, sampling and field observations relating to vegetation health and other factors (groundwater, riparian vegetation, contaminant sampling, ownership, infrastructure, land use and site specific remedy requirements), showed that use of RipES determination alone would not lead to implementation of ROD requirements or fully meeting RAOs. This ESD changed the scope of the floodplain tailings and soils component of the remedy described in the ROD by adding factors that will be considered during remedial design to determine whether removal, in-situ treatment or other remediation (e.g., best management practices, institutional controls) is appropriate for a given area.

4.2 Remedy Implementation

<u>Milltown Water Supply (OU1)</u>

OU1 is now part of the MRSOU (OU2). The Milltown Water Supply OU focused on providing a safe water supply to area residents through establishment of a public water supply system for the town of Milltown. EPA funded the replacement of one public water supply used by Milltown residents as part of the OU1 remedy and provided funding for maintenance of this water supply well. The PRPs eventually provided permanent maintenance funding to the Milltown Water User's Association for this system. EPA also funded the MCCHD to distribute arsenic test kits to interested residents who wanted to test their private well water. If tests showed exceedance of standards, the Settling Defendants provided for the hookup by these residents to the replacement water supply. The 2004 MRSOU ROD continued funding for maintaining the existing replacement water supply for Milltown residents and made contingency funds available to reconfigure, expand or update replacement water supplies.

MRSOU (OU2)

Reservoir Drawdown and Dam Removal
Remedial design began on July 18, 2005. In August 2005, the PRPs signed a Consent Decree, allowing the project to move out of the planning phase and into remedial action. Remedial action began on February 15, 2006. The initial remedial activity was to lower the water level in the reservoir to dewater the SAA I sediments, facilitate dam removal and ultimately enable the use of mechanical excavation techniques for sediment removal. Removal of the Milltown Dam spillway and ultimate removal of the rest of the dam took place concurrently with reservoir drawdown. PRP contractors completed final dam removal in March 2009.

Dam removal lowered the groundwater table in the Milltown area, which raised the possibility that shallow water supply wells in the Milltown area could go dry. Therefore, EPA managed a well-replacement program as part of the remedial action starting in 2006. Based on the modeling results, EPA replaced 82 private and small public water supply wells in the Milltown area and reconfigured numerous additional wells.

Sediment Dewatering, Removal and Relocation

The RI/FS phase of the project evaluated metals contaminant concentrations in sediments in the Milltown reservoir. Only those sediments shown to be contributing directly to existing groundwater degradation (sediments with the highest pore water contaminant concentrations), and with the potential to contribute to future surface water degradation were removed to meet remedial objectives. Reservoir sediments were divided into two sections: the upper and lower reservoir SAAs. These two reservoir sections were further divided into sub-areas based on sediment accumulation features. The lower reservoir consists of SAAs I, II and III. The upper reservoir encompasses SSAs IV and V. In 2007, sediments in SAA I were removed and isolated from the Clark Fork River channel.

To facilitate reservoir sediment removal, EPA required a bypass channel for the Clark Fork River along the northern boundary of SAA I. Beginning in May 2007, approximately 584,000 cubic yards of reservoir sediment, 40,000 cubic yards of underlying soil material and 57,000 cubic yards of underlying alluvium were excavated to form the bypass channel. Excavated reservoir sediment was relocated by rail transport to Opportunity Ponds. The bypass channel was completed in early 2008. The excavation of SAA I sediments finished in September 2009; a total of 2,331,956 cubic yards of sediment was removed and disposed of at the Opportunity Ponds disposal area at the Anaconda Smelter site. The Clark Fork River was re-diverted to the reconstructed channel in December 2010. EPA funded or performed bridge stability actions for three bridges, and a fourth bridge was addressed by its owner.

The PRPs constructed two repositories to contain debris from the demolition of the dam and SAA III-b and SAA IV sediments. One repository is located just downstream of the removed right abutment of the dam (the Right Bank Repository). The other is the Tunnel Pond Repository. Groundwater monitoring of the Tunnel Pond Repository will entail sampling one well, located downgradient of the repository, at the same frequency and for the same analyte list as the other point of compliance (POC) wells. No groundwater monitoring is required for the Right Bank Repository.

In addition to the two constructed repositories, two other repositories were present prior to remedial action. Disposal Site No. 1 was removed as part of the work to place SAA III-b sediments in the Tunnel Pond Repository. At the second, the Upland Disposal site, the State of Montana built a new repository on top of the Upland Disposal site in which to store a portion of the sediment excavated during implementation of restoration actions from SAA IV and V. Maintenance and monitoring of disposal areas remains the responsibility of the PRPs, according to the 2013 long-term monitoring plan.

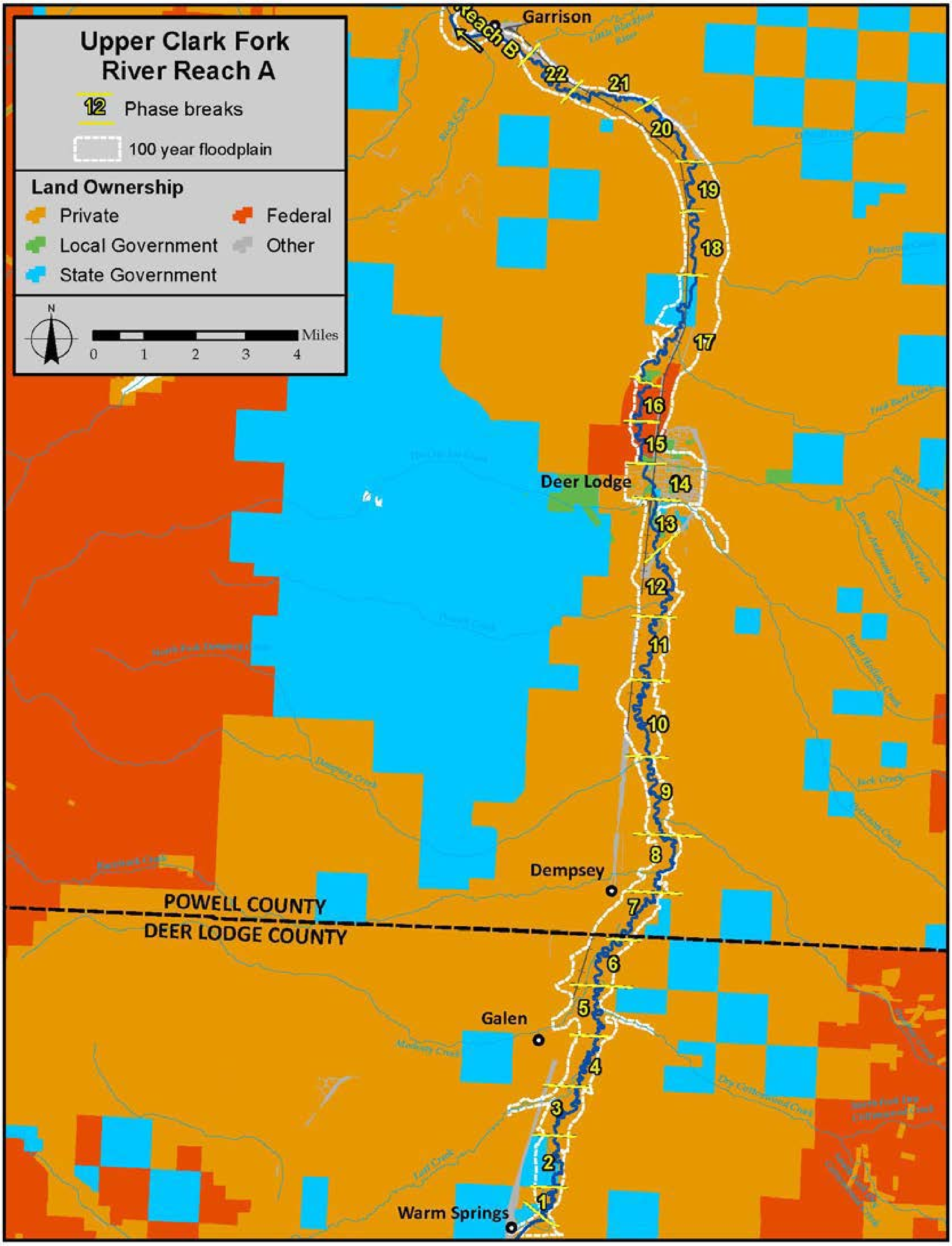
Compliance wells are located within the current arsenic plume and were monitored during the remedial action to track progress in restoring the Milltown alluvial aquifer. A series of early warning wells located around the fringe of the plume and along the Clark Fork River downstream of the MRSOU are also monitored to ensure that groundwater in existing drinking water wells was not unacceptably impacted by construction activities. Finally, MCCHD monitors certain existing public and private water supply wells as public health monitoring wells. Data available for this FYR (2013) consistently indicate no arsenic exceedances in sampled wells.

The State of Montana Natural Resource Damage Program followed PRP construction activities with channel construction, revegetation and reconstruction of the floodplain, revegetation, and development of wetlands. Some of these actions are required to meet certain remedial goals and objectives. Operation and Maintenance of this work is ongoing.

CFROU3

The majority of the CFROU is Reach A, a 43-mile stretch of the river from Warm Springs in Anaconda/Deer Lodge County downstream to Garrison in Powell County. In accordance with the 2004 ROD, in 2006 and 2007, while Consent Decree discussions were in progress, EPA performed RipES mapping for the floodplain tailings and soils component. MDEQ began its remedial design activities in 2008, following entry of the Consent Decree, which designated MDEQ as lead agency for remedy and O&M implementation using cashout funds received from the PRP. MDEQ focused its first remedial actions on immediate human health and irrigated lands concerns and are now proceeding with geographically-defined phases (Figure 3).

Figure 3. CFROU Reach A Phase Breaks



MDEQ, in consultation with EPA, and in accordance with Consent Decree requirements, performed residential yard removals, necessitated by elevated levels of arsenic and lead, in the fall of 2010 through the summer of 2011. Confirmation sampling were collected to ensure all contamination was removed. MDEQ, in consultation with EPA and in accordance with Consent Decree requirements, performed the Trestle Area cleanup within Reach A in the fall and winter of 2011-2012, with planting in the spring of 2012. The trestle cleanup involved removal of residential soils with elevated levels of arsenic and reconstruction and revegetation of 1,000 feet of streambank. In the fall and winter of 2012, MDEQ performed the remedial action for the pasture areas historically irrigated with Clark Fork River water.

The Reach A Phase 1 Remedial Action Project began on March 4, 2013, and finished on April 4, 2014. MDEQ, NRDP and EPA performed a pre-final inspection of the project on May 9, 2014. Additional vegetation was planted in April, May and the fall of 2014. Revegetation activities are ongoing. Monitoring plans for vegetation and streambanks have been developed to ensure that the remedy is successful over the long term. MDEQ has prepared the Construction Completion Reports for Phase 1.

Additional activities underway in Reach A include:

- *Phases 5 and 6 – In Progress*
  MDEQ submitted the final Reach A, Phase 5 & 6 Data Summary Report to EPA on March 14, 2014. Remedial actions began on July 15, 2014, and are ongoing. Phase 5 and 6 involve two private landowners and cleanup on working ranches. The remediation project will consist of tailings removal on 4.5 river miles. The work is scheduled to be completed in the spring of 2016, with revegetation activities in the spring of 2016 and fall of 2016.
- *Phase 2 – In Progress*
  MDEQ submitted the Preliminary Design Plan for Reach A, Phase 2 to EPA on July 1, 2014. Construction began in the summer of 2015. Phase 2 involves two private landowners and State of Montana land. The privately-owned property is actively farmed and ranched. The remediation project will consist of tailings removal on 1.9 river miles and is scheduled to be completed by the fall of 2016 with revegetation activities to follow.
- *Phases 3 and 4 – Preliminary Design*
  Sampling and characterization of the Phases 3 and 4 project areas, located between Perkins Lane and Galen Road, was completed in the winter of 2015. The Preliminary Design Plan has been developed and remedial activities are anticipated to start in fall of 2016.
- *Phases 7, 15 and 16 – Preliminary Design*
  MDEQ is currently working with private landowners, Montana Fish, Wildlife and Parks, and the Grant-Kohrs Ranch on design plans. These plans begin to lay out the details of the design and how and where remedial work will be conducted. MDEQ will continue to provide updates as designs progress.
- *Phase 8 – Sampling and Analysis*
  Phase 8 is currently in the site characterization phase. Crews are digging test pits and sampling material to determine the extent and depth of contamination along the river and

surrounding corridors. Sampling should be completed in early 2016, and the design team will then begin the design process for remedial action.

- *Eastside Road Pastures*
  Remedial Action for the Eastside Road Pastures began on November 5, 2012. The majority of work finished on December 6, 2012; fencing finished in the spring of 2013. MDEQ conducted additional sampling of this area during the spring and summer of 2014. After a year of little growth in the Eastside Road pastures south of Deer Lodge, MDEQ implemented additional revegetation measures in the spring of 2015. Sugar beet lime and top soil was deep tilled into the existing soil. The area was then reseeded and straw was crimped into the ground for erosion control. Monitoring of this area is ongoing.

Reach C was determined to require no further action. Remedial design work on Reach B is expected to occur after work is completed on Reach A. Institutional controls for the CFROU are discussed in Section 6.3.

MDEQ will develop appropriate operation and maintenance plans and best management practice ranch plans on a parcel-specific basis as the cleanup proceeds. An Institutional Control Implementation and Assurance Plan will also be developed.

4.3 Operation and Maintenance (O&M)

<u>MRSOU</u>

The Long-Term Post Remedial Action Construction Monitoring Plan, which is the MRSOU operation and maintenance plan, was finalized in 2013. The plan outlines the groundwater and surface water monitoring requirements as well as the long-term maintenance and monitoring for the constructed repositories and buttress areas. Prior to the 2013 plan, monitoring was performed under the 2007 Remedial Action Monitoring Plan. Groundwater is to be sampled twice each year, during high and low flow.

Surface water sampling occurs at three sites, six-to-eight times per year on a USGS schedule designed to take seasonal and hydrologic variability into account. Suspended-sediment samples are collected by an observer two to 14 times per week, depending on season and flow conditions. Bed sediment data is collected once annually during low, stable flow conditions (typically around August). Biological data is collected once annually, on the same dates as the bed sediment data collection.

The PRPs are responsible for annual maintenance and monitoring of two repositories – Tunnel Pond and Right Bank. Annual monitoring and maintenance of the buttress and railroad berm adjacent to the Tunnel Pond Repository and the Interstate-90 slope and buttress are also the responsibility of the PRPs. Operation and maintenance costs for MRSOU were not available for review during this FYR.

CFROU

The Interim Comprehensive Long-Term Monitoring Plan for the CFROU established monitoring activities for sediment, surface water and groundwater that will determine the environmental effectiveness of remediation and restoration actions within the Site as they are implemented over the next 15 years. The CFROU remedy is intended to remove threats to human health and the environment posed by mining related contaminants within the floodplain of the upper Clark Fork. Monitoring under the Interim Comprehensive Long-Term Plan began in the spring of 2010 at each of six Clark Fork monitoring stations, this was prior to initiation of any remediation and restoration actions within the CFROU. This plan has been updated yearly.

Eventually, a long term operation and maintenance plan will be developed and implemented by MDEQ.

A breakdown of CFROU costs from 2008 to 2014 were provided and reviewed. Since remedial actions are still being designed and implemented at the CFROU, separate O&M costs are not presented. The remedial action at Phase 1 was completed in fiscal year 2014. The next FYR may examine O&M costs for ongoing maintenance at this phase and any others completed at that time.

5.0 Progress Since the Last Five-Year Review

The protectiveness statement from the 2011 FYR for the Site stated:

The remedy at the MRSOU is expected to be protective of human health and the environment upon completion, and in the interim, exposure pathways that could result in unacceptable risks are being controlled. The Water Supply Operable Unit is fully implemented and funded, and is protective of human health and the environment. The long-term protectiveness of the remedial action will be verified through review and approval of remedial action completion documents, a comprehensive O&M Plan, an Institutional Control Plan, and through monitoring of groundwater for all of the ARARs, and periodic evaluation of the O&M results and the institutional controls. Streambank reconstruction and area revegetation efforts should be evaluated in the next FYR Report.

The 2011 FYR included five issues and recommendations for the MRSOU[2]. This report summarizes each recommendation and its current status below.

[2] Because work at the CFROU was in its initial stages, that OU was not evaluated in the 2011 FYR.

Table 7: Progress on Recommendations from the 2011 FYR

Recommendations	Party Responsible	Milestone Date	Action Taken and Outcome	Date of Action
Implement institutional controls for the MRSOU comprehensive institutional control plan and its components.	PRP/State/EPA	September 2014	Ongoing.	Not completed and carried over to the 2016 FYR
Develop and implement O&M requirements through a comprehensive O&M plan. This plan should add a requirement for routine surveying of the Tunnel Pond Repository berm to verify that lateral movement is not occurring over time. Other requirements may also be necessary.	EPA/PRP	September 2013	Completed. Envirocon completed the Long-Term Post-Remedial Action Construction Monitoring Plan for MRSOU.	03/15/2013
Include monitoring for all of the groundwater ARARs, and in a long-term groundwater and surface water monitoring plan.	EPA/PRP	2012	Completed. Monitoring of all of the groundwater ARARs began in 2013 and additional parameters included in the long-term groundwater and surface water monitoring plan.	03/29/2013
Remove and appropriately dispose of contaminated wood timbers left after dam removal (currently scheduled for the fall of 2011).	EPA/PRP	Fall 2011	Completed. Timbers removed.	05/03/2012
Reclaim and revegetate borrow area in accordance with the requirements of the statement of work. The adequacy of vegetation at the other borrow area and the Tunnel Pond Repository should also be reviewed.	EPA/PRP	September 2012	Completed. Areas reseeded in the spring of 2012.	07/20/2012

6.0 Five-Year Review Process

6.1 Administrative Components

EPA Region 8 initiated the FYR in October 2015 and scheduled its completion for September 2016. EPA remedial project manager (RPM) Sara Sparks led the EPA site review team, and contractor support was provided to EPA by Skeo. In August 2015, EPA held a scoping call with the review team to discuss the Site and items of interest as they related to the protectiveness of the remedy currently in place. The review schedule established consisted of the following activities:

- Community notification.
- Document review.
- Data collection and review.
- Site inspection.
- Local interviews.
- FYR Report development and review.

6.2 Community Involvement

On November 1, 2015, EPA participated in a radio interview that was broadcast on KQRV in Deer Lodge, Montana. This interview announced the commencement of the FYR process for the Site and invited community participation in the FYR process. In June 2016, EPA published a public notice in the *Missoulian* and the *Missoula Independent* newspapers providing contact information for EPA RPM Sara Sparks and inviting community participation in the FYR process for the Site. The press notice is available in Appendix B. No one contacted EPA as a result of the advertisement.

EPA will make the final FYR Report available to the public. EPA will place copies of the document in the designated site repositories: Grant-Kohrs Ranch National Historic Site, 266 Warren Lane, Deer Lodge, Montana 59722 and Missoula City/County Library, 301 East Main Street, Missoula, Montana 59802. Upon completion of the FYR, EPA will place a public notice in the *Silver State Post*, *Missoulian* and *Missoula Independent* newspapers to announce the availability of the final FYR Report in the Site's document repositories.

6.3 Document Review

This FYR included a review of relevant site-related documents. Appendix A provides a complete list of the documents reviewed.

<u>ARARs Review</u>

Section 121 (d)(2)(A) of CERCLA specifies that Superfund remedial actions must meet any federal standards, requirements, criteria or limitations that are determined to be ARARs. ARARs are those standards, criteria or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site. To-Be-Considered criteria (TBCs) are non-promulgated advisories and guidance that are not legally binding, but should be considered in determining the necessary level of cleanup for protection of human health or the environment. While TBCs do not have the status of ARARs, EPA's approach to determining if a remedial action is protective of human health and the environment involves consideration of TBCs along with ARARs.

Chemical-specific ARARs are specific numerical quantity restrictions on individually listed contaminants in specific media. Examples of chemical-specific ARARs include the maximum contaminant levels specified under the Safe Drinking Water Act as well as the ambient water quality criteria enumerated under the Clean Water Act. The remedy selected for the Site was designed to meet or exceed all chemical-specific ARARs and meet location- and action-specific ARARs.

Groundwater ARARs

The decision documents established federal Maximum Contaminant Levels (MCLs) and Montana Water Quality Standards as ARARs for groundwater at the Site. Numerical values listed in decision documents were compared to current federal and state standards to identify any changes that could affect protectiveness of the remedy (Table 8). The state standard for arsenic is now the same as the federal standard, which was selected in the 2004 ROD.

Table 8: Previous and Current ARARs for Groundwater COCs

	Standards Identified in 2004 ROD		**2016 Standards**	
Compound	**State (µg/L)**	**Federal (µg/L)**	**State (µg/L)[a]**	**Federal (µg/L)[b]**
Arsenic	20	10	10	10
Cadmium	5	5	5	5
Copper	1,300	1,300	1,300	1,300
Lead	15	15	15	15
Zinc	2,000	N/A	2,000	N/A

Notes:

a. Montana Numeric Water Quality Standards – Circular DEQ-7. February 2012.

b. Safe Drinking Water Act contaminants and federal MCLs.

Surface Water ARARs

The decision documents established federal AWQCs and Montana Water Quality Standards as ARARs for surface water at the Site. Numerical values listed in decision documents were compared to current federal and state standards to identify any changes that could affect protectiveness of the remedy (Table 9). At the time of the ROD, the State of Montana's surface water quality standard for arsenic was 18 µg/L, based on human health, and 20 µg/L for groundwater as a drinking water supply. The state standard for arsenic for surface water and groundwater is now 10 µg/L, matching the federal standards. No other changes were identified in this review.

Table 9: Previous and Current ARARs for Surface Water COCs

	2016 Surface Water Standards					2004 ROD Standards				
	State (1)			Federal (2)		State (1)			Federal (2)	
	Aquatic Life		Human Health (µg/L)	CMC (Acute) (3)	CCC (Chronic) (4)	Aquatic Life		Human Health	CMC (Acute) (3)	CCC (Chronic) (4)
Compound	Acute (µg/L)	Chronic (µg/L)		(µg/L)	(µg/L)	Acute (µg/L)	Chronic (µg/L)	Standard (µg/L)	(µg/L)	(µg/L)
Arsenic	340	150	10	340	150	340	150	18	340	150
Cadmium	0.52*	0.097*	5	2***	0.25***	0.52*	0.097*	5	2***	0.25***
Copper	3.79*	2.85*	1,300	N/A	N/A	3.79*	2.85*	1,300	2.337#	1.45#
Iron	N/A	1,000	N/A	N/A	N/A	N/A	1000	300a	N/A	N/A
Lead	13.98*	0.545*	15	65***	2.5***	13.98*	0.545*	15	65***	2.5***
Zinc	37*	37*	2,000	120***	120***	37*	37*	2,000	120***	120***

Notes:
* = value indicated is for a hardness of 25 milligrams per liter (mg/L) as calcium carbonate (CaCO3).
** = value indicated is for a hardness of 50 mg/L as CaCO3.
*** = value indicated is for a hardness of 100 mg/L as CaCO3.
**** = value indicated is for a hardness of 150 mg/L as CaCO3.
# = standards are hardness dependent. Value indicated is for a hardness of 84.6 mg/L as CaCO3. Source: http://www.epa.gov/waterscience/criteria/copper/2007/criteria-full.pdf.
a = indicates value is a secondary MCL based on aesthetics (taste, odor, staining).
1. Montana Numeric Water Quality Standards – Circular DEQ-7. February 2012.
2. Current National Recommended Water Quality Criteria, EPA, http://www.epa.gov/waterscience/criteria/wqctable/#mm.
3. CMC = Criteria Maximum Concentration is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect.
4. CCC = Criterion Continuous Concentration is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.

Institutional Control Review

MRSOU

The ROD identified that institutional controls, dealing primarily with groundwater but also addressing residential use and protection of waste repositories, were required at the Site. To date, a controlled groundwater area or similar institutional control has not been implemented. Site regulatory agencies are continuing to discuss the need for this institutional control. A Missoula County ordinance currently in place appears to preclude installation of new public water wells in the vicinity of the MRSOU arsenic plume. However, these ordinances do not preclude private well installation in the plume area (Figure 2). Additional institutional controls may be needed to control private well installation in the arsenic plume, prevent residential use and protect the waste repositories and the sediments left in place.

An institutional control preventing river access during certain time periods has been necessary in the past, and may be needed in the future. The majority of the MRSOU has been designated as a future Montana State Park. Institutional controls dealing with water consumption, residential use and the waste repositories will need to be incorporated into the future park design and planning documents.

CFROU

Institutional controls for the CFROU may include county zoning regulations, deed restrictions, permanent funding for Arrow Stone Park, and groundwater sampling and use controls. Environmental monitoring is required during all activities.

The Powell County Overlay District covers the area contaminated by mining and smelting wastes from operations further upstream in the Butte and Anaconda areas (Figure 4).[3] The Overlay District is intended to ensure that future land use in the Superfund Overlay District is compatible with the presence of potential contaminants and the various remedial actions required to remove or isolate those potential contaminants from the environment. Requirements include:

- *Property Development:* All use changes and development in the Superfund Overlay Zone are subject to the securing of a Conditional Use Permit (CUP). All applications for a CUP or variance in the Superfund Overlay Zone shall include the following additional information beyond that which is required for any CUP or variance. Where no remedial structures exist on a site, the application materials shall include arsenic tests, as required by Powell County, and detailed plans (if necessary) for achieving compliance with the maximum arsenic level allowed for the proposed use.

- *Groundwater Wells:* A development certificate shall be required to drill or dig a well in the Superfund Overlay Zone. Prior to the issuance of a completion certificate of any well in this overlay district, the well is required to be tested for coliform bacteria, arsenic, barium, cadmium, chromium, copper, lead, mercury and nitrate, and the results of the tests submitted to Powell County. No certificate of compliance shall be

[3] http://powellcountymt.gov/ez/inner.php?PageID=1501.

issued for any well in which the water exceeds state water quality standards for the proposed use.

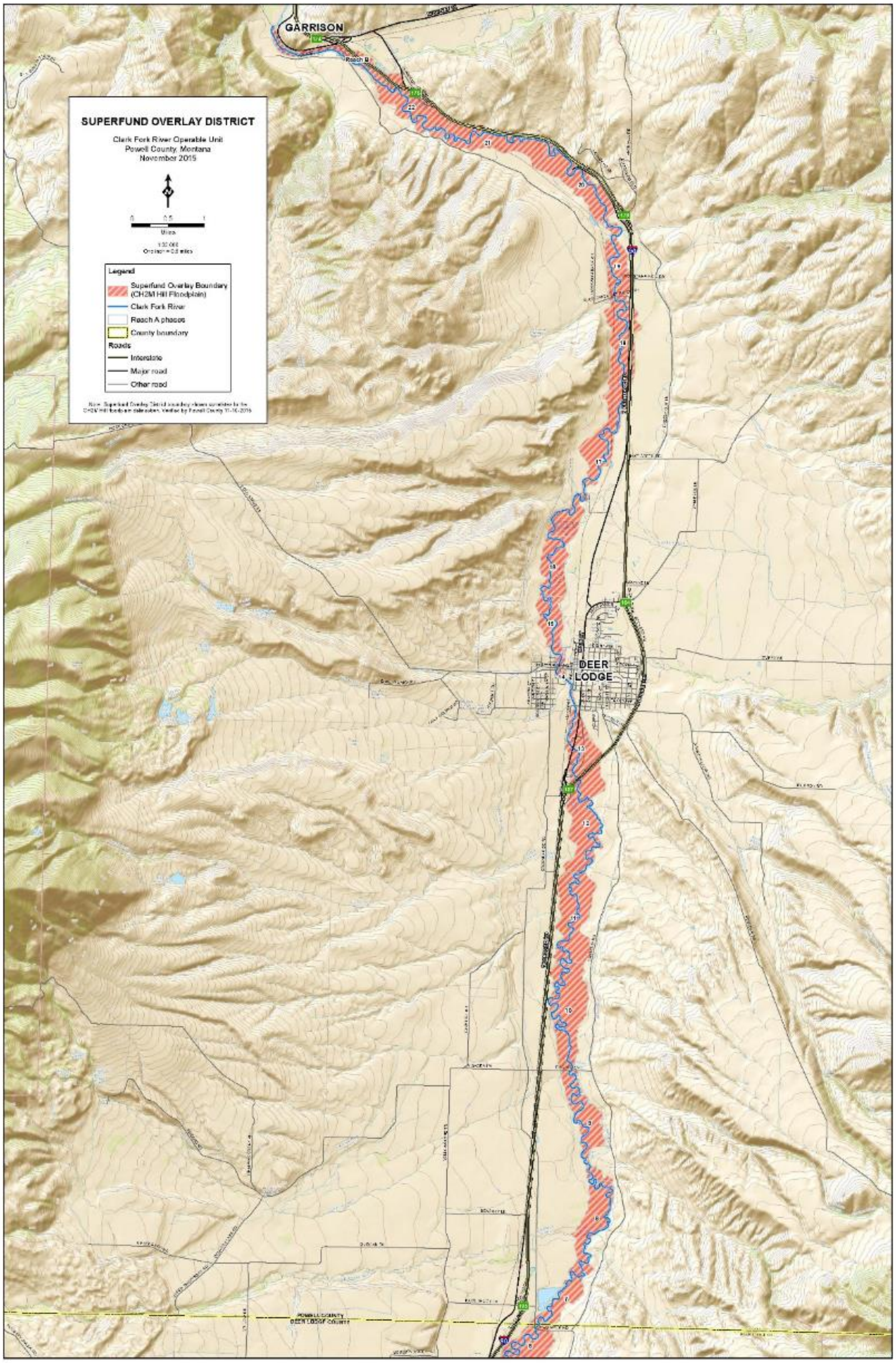
- *Notice to Purchasers:* Before any parcel or any interest in any parcel in the Superfund Overlay Zone is conveyed, the following statement shall be placed on the deed, contract for sale or other instrument of conveyance: "This parcel is within a Superfund site. A permit must be obtained before any development or construction covered by these regulations is initiated."

Table 10 lists the institutional controls associated with areas of interest at the Site.

Table 10: Institutional Control (IC) Summary Table

Media	ICs Needed	ICs Called for in the Decision Documents	Impacted Area (s)	IC Objective	Instrument in Place	Notes
MRSOU Groundwater	Yes	Yes	area of delineated arsenic plume	Prevent consumption of contaminated groundwater.	Missoula County zoning ordinances in place preclude installation of new public water wells in the vicinity of the arsenic plume.	Additional controls may be needed to prohibit private well installation.
MRSOU Soil	Yes	No	repository and sediment areas	Prevent activities that could affect the integrity of the remedy. Prevent residential use.	None	None
CFROU Groundwater	Yes	Yes	to be determined during each Phase	Prevent consumption of contaminated groundwater, if necessary.	Powell County Overlay District	ICs could include county zoning regulations, deed restrictions, permanent funding for Arrow Stone Park, and groundwater sampling and use controls.
CFROU Soil	Yes	Yes	To be determined during each Phase	Prevent activities that could affect the integrity of the remedy or cause unacceptable human health exposures.	Powell County Overlay District	ICs could include county zoning regulations, deed restrictions, permanent funding for Arrow Stone Park.

Figure 4: Powell County Overlay District (CFROU)



Disclaimer: This map and any boundary lines within the map are approximate and subject to change. The map is not a survey. The map is for informational purposes only regarding EPA's response actions at the Site.

6.4 Data Review

<u>MRSOU</u>

Groundwater Monitoring
Groundwater monitoring at the MRSOU is designed to meet three objectives: 1) ensure that the remedy is performing as designed; 2) ensure that the remedy complies with applicable performance standards; and 3) evaluate the need for additional remedial or O&M activities. In 2013, MRSOU long-term post-remedial action monitoring began, replacing the prior remedial action monitoring plan. The 2013 monitoring plan revised the number of wells to be monitored to 12 wells and revised the list of dissolved metals requiring analysis.

Data available for the 10 compliance wells (104A, 921A, 917B, 922D, 105C, 107A, 110B, HLA2, 11R and 103B), the Upland Disposal Site monitoring well 913A, and the Tunnel Pond Repository monitoring well (TPR10) were sampled during high-flow conditions in June 2015 and low-flow conditions in January 2016. The 2015 and 2016 well samples were only analyzed for dissolved arsenic in accordance with EPA's April 20, 2015 correspondence, which approved dropping analysis for the other COCs due to two years of data showing no exceedances of state standards.

Arsenic concentrations in the compliance wells ranged from 0.867 µg/L to 67.4 µg/L in the most recent annual monitoring, with nine (during the June monitoring 2015) and eight (during the December 2015 monitoring event) of the 12 compliance wells continued to exceed the 10 µg/L groundwater standard. Overall, arsenic concentrations in all wells are lower than historic levels years (Figures 5-7). The ROD indicates that groundwater standards are expected to be met within approximately four to 10 years following completion of dam and sediment removal. A waiver of groundwater standards is not currently proposed. However, the PRPs may seek a waiver of groundwater cleanup standards if compliance is not achieved and is technically impracticable.

Groundwater monitoring of the Tunnel Pond Repository will entail sampling one well, located downgradient of the repository, on the same frequency and for the same analyte list as the other POC wells. No groundwater monitoring is required for the right bank repository. The 2013 monitoring plan identifies that the POC well for the Repository was left as "to be determined" because some of the past sampling results in the existing monitoring well, TPR10, were above the pertinent ARAR and the state's 10 ug/L groundwater arsenic performance standard. In a September 16, 2013 letter, the PRPs proposed using well TPR10 as the Tunnel Pond Repository POC and evaluating its data using a two-part statistical test to assess potential impacts to groundwater quality from repository construction and use. The statistics were proposed to determine if:

1. The rolling average concentration in the last four samples exceeds the state groundwater standard.
2. The Mann-Kendall analysis shows a statistically significant increasing trend in concentrations in the last eight samples.

The results show the rolling average concentration in the last four samples does exceed the arsenic groundwater standard; the Mann-Kendall analysis does not show a significant increasing trend in concentrations in the last eight samples. The PRPs continue to recommend statistical analysis of TPR10 as the Tunnel Pond Repository POC with assessment of potential impacts to groundwater from repository construction and use.

Figure 5: Arsenic Concentrations in Wells 905, 103B, 917B and 107C

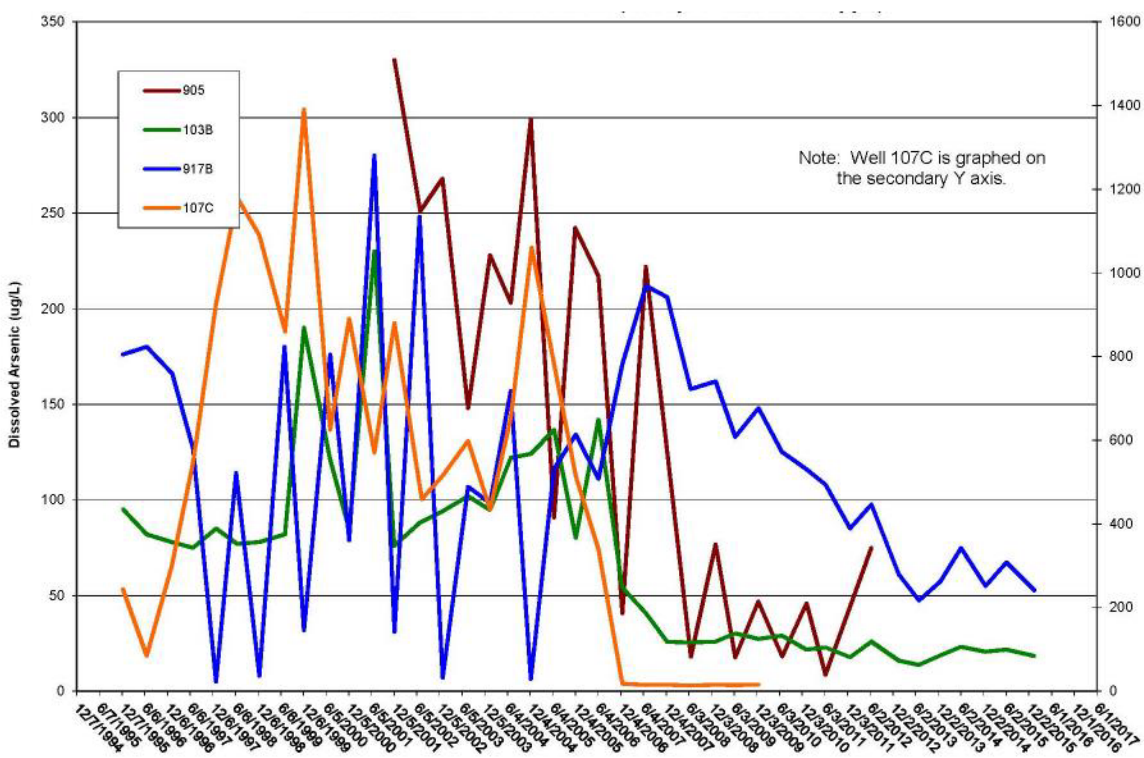


Figure 6: Arsenic Concentrations in Wells 105C, 11, HLA2, 107A and 11R

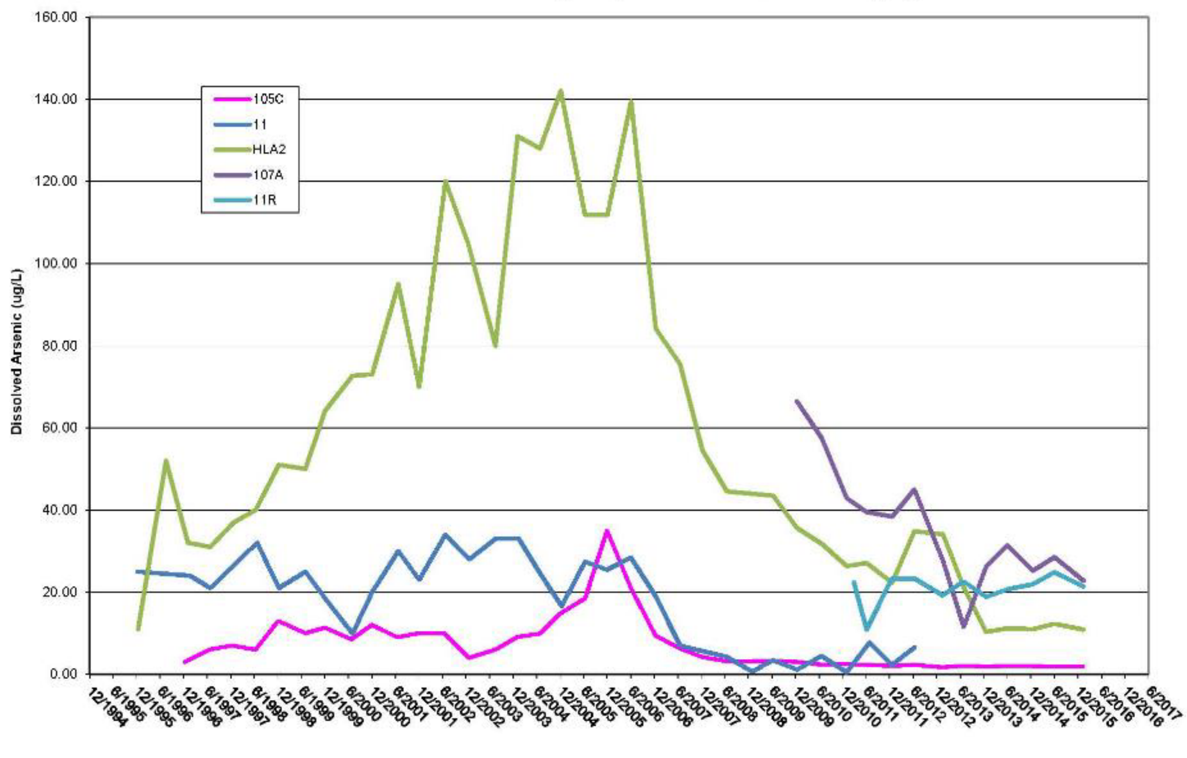
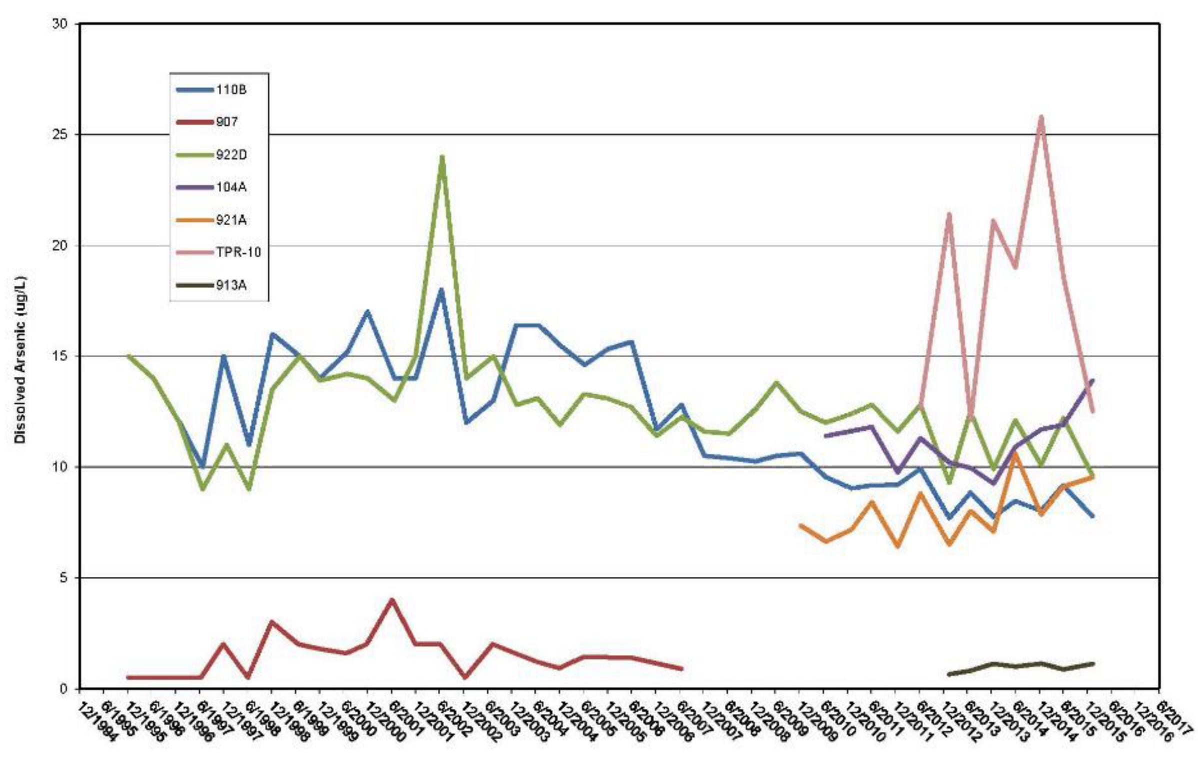


Figure 7: Arsenic Concentrations in Wells 110B, 907, 922D, 104A, 921A, TPR-10 and 913A



Surface Water Monitoring

In 2015, surface water quality samples were collected at all three stations six to eight times on a USGS schedule designed to describe seasonal and hydrologic variability. Flow was monitored continuously. An observer collected suspended-sediment samples two to 14 times per week, depending on season and flow conditions. Bed sediment and biota samples were collected once in August 2015.

The 2015 surface water quality sample results at the three stations for the five COCs are summarized on Appendix F. At the downstream Clark Fork River near Missoula station, there were no exceedances of federal standards and the only exceedances of state standards were for total recoverable copper in the June 10 sample. Total recoverable copper concentration on this date was significantly higher at the Clark Fork River at Turah station sample, showing the Site was not causing the downstream exceedance of state standards. The Consent Decree provides for the consideration of upstream contamination entering the MRSOU to determine compliance with surface water standards.

To assist with surface water data evaluation, EPA asked the U.S. Geological Survey (USGS) to conduct a trends analysis for the Site, using the ongoing data collected by USGS at the Site. The analysis, title "Water-Quality Trends and Constituent-Transport Analysis for Selected Sampling Sites in the Milltown Reservoir/Clark Fork River Superfund Site in the Upper Clark Fork Basin, Montana, Water Years 1996 – 2015" is included as Appendix I.

The primary purposes of this report are to characterize temporal trends in flow-adjusted concentrations (filtered and unfiltered) of mining-related contaminants and assess those trends in the context of source areas and transport of those contaminants through the Milltown/Clark Fork River Superfund Site in the upper Clark Fork Basin. Trend analysis was done on specific conductance, selected trace elements (arsenic, copper and zinc), and suspended sediment for seven sampling sites for water years 1996-2015. This report provides an update and supersedes the trend results reported by Sando and others (2014) for seven sampling sites in the Milltown/Clark Fork River Superfund Site. This report presents the results and information on trend-analysis methods, streamflow conditions, and various data-related factors that affect trend results. This information is presented to assist in evaluation trend results; however, it is beyond the scope of this report to provide detailed explanations of all observed temporal changes.

Vegetation Inspection and Maintenance

The performance standard for vegetation is to establish on the reclaimed areas a "diverse, effective and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area except that introduced species may be used in the revegetation process where desirable and necessary to achieve the approved post-mining land use plan. Vegetative cover must be capable of:

- Regenerating under the natural conditions prevailing at the site, including occasional drought, heavy snowfalls and strong winds.

- Preventing soil erosion to the extent achieved prior to the operation."

Another performance standard for vegetation is to control noxious weeds consistent with weed management criteria developed under MCA 7-22-2109 (2)(b) and to meet the <10 percent guideline for the amount of cover by noxious weeds.

On June 18, 2015, vegetation performance was assessed on the reclaimed areas for which the PRPs retain O&M responsibility. The inspection covered over 17 acres and included estimation of percent vegetative cover, determination of species present (including weed species) and recommendations for maintenance.

In their approval of the 2014 Annual Report, EPA agreed that vegetation performance standards had been met for two consecutive years at the Right Bank Repository, the Tunnel Pond Repository and the Interstate-90 buttress. Observations during the 2015 inspection suggest that vegetation performance standards for remaining areas (the Bonner Development Group Parcel and the Sheriff Posse Grounds Parcel) have now also been met for two consecutive years. Based on this data, the PRPs requested that EPA approve completion of the vegetation performance monitoring responsibilities, and EPA, in consultation with MDEQ and the State NRD Program approved of this request.

Repository Inspection and Maintenance

The PRPs visually inspected both repositories, the buttress and railroad berm adjacent to the Tunnel Pond Repository and the Interstate-90 buttress on June 18, 2015. The PRPs also visually inspected the Tunnel Pond Repository stormwater conveyance system on May 13, 2015. Overall, the inspections found the stormwater conveyance systems were clean and functioning and the repository caps and the Tunnel Pond and Interstate-90 buttresses were in good condition and, with the exception of a few small subsidence holes observed in the Tunnel Pond railroad embankment and Right Bank Repository cover, did not show visible impacts from settlement, subsidence or erosion. Pioneer Technical Services did a geotechnical review of the Tunnel Pond subsidence holes which determined "these features are not anticipated to impact the geotechnical stability of the tunnel pond embankment" but they should continue to be observed as part of annual monitoring.

In addition to the inspections described above, the PRPs also installed settlement monuments in the crest and toe of the Tunnel Pond Repository embankment in April 2014 as required by the Monitoring Plan. To support this FYR, the monuments were surveyed on October 28, 2015, to identify any lateral movement in the embankment. Comparison between the 2014 and 2015 survey results were below the 1-inch trigger for initiating additional review assessment.

Community Well Monitoring

MCCHD monitors certain existing public and private water supply wells as public health monitoring wells. Data available for this FYR (2013) consistently indicate the groundwater in these areas remained below the arsenic standard of 10 µg/L.

CFROU

Remediation performance standards were established for the CFROU ROD for surface water, groundwater and vegetation. No performance standards were established in the CFROU ROD for aquatic biota (e.g., macroinvertebrates and periphyton), instream sediments or geomorphology. However, the Sampling and Analysis Plan identifies benchmarks for those environmental media which may serve to evaluate biological conditions and instream sediment toxicity (Appendix G). The CFROU monitoring network in 2014 included 14 sites; six mainstem sites and eight tributary sites. Not all sites were sampled for each environmental medium or for each analyte of each environmental medium. All of the environmental media monitored in 2014 was to be monitored in 2015, with the addition of monitoring for birds. Data from 2015 sampling were not available for this FYR.

Arsenic and copper are the COCs in surface water with regular exceedances. Of 30 samples collected in the mainstem Clark Fork River in 2014, no samples had zinc concentrations exceeding the performance goal. One sample had cadmium concentrations exceeding the performance goal. Four samples had lead concentrations exceeding the performance goal. However, arsenic commonly exceeded performance goals, particularly in Reach A. Of 24 samples collected in the CFROU in Reach A, 96 percent of them exceeded the dissolved arsenic performance goal and 46 percent of them exceeded the total recoverable arsenic performance goal. Mill-Willow Creek and Silver Bow Creek through the Warm Springs Ponds are sources of arsenic to the Clark Fork River.

Total recoverable copper concentration exceeded the state of Montana chronic aquatic life standard in the mainstem Clark Fork River sites in 95 percent of the samples collected in the first and second quarters, but only at Deer Lodge in the third and fourth quarters. The Clark Fork River reach upstream from Deer Lodge is a major source of copper loading and copper concentrations throughout the river are strongly related to streamflows.

The highest instream sediment COC concentrations in the mainstem of the Clark Fork River were typically observed in the uppermost sample sites in Reach A. The lowest concentrations were typically observed at the downstream-most site at Turah. Concentrations of arsenic, copper, and zinc exceeded the probable effect concentration (PEC) at all Clark Fork River mainstem monitoring stations during both sample periods in 2014. Among all sites in the CFROU, arsenic most commonly exceeded the PEC (88 percent) followed by copper (83 percent), lead (79 percent), zinc (75 percent) and cadmium (50 percent).

6.5 Site Inspection

MRSOU

Site inspection participants included Keith Large from MDEQ, Sara Sparks from EPA, and Treat Suomi and Claire Marcussen from Skeo. The inspection took place on November 2, 2015. See Appendix D-1 and E-1 for the site inspection checklist and photographs.

The inspection began at the Milltown Bluff, providing an overall view of the MRSOU remedial components, including the Tunnel Repository and associated embankment and buttress, Railroad Grade and Main Repository, the Right Bank Repository, the Interstate-90 slope and buttress, the Bonner Development Group Parcel and the Sheriff Posse Grounds Parcel. From the bluff, participants observed areas of sparse vegetation along the gravel road near the Buttress slope; the area has recently been regraded and seeded to promote growth of vegetation and is flagged for ongoing monitoring of vegetative growth. The stormwater diversion ditch along the Tunnel Repository was well maintained. Participants saw that most timber debris from the Milltown Dam demolition has been removed. However, there were still some timbers near the former dam area on the north side of the Clark Fork River. EPA later determined that these timbers were brought in by the Montana Fish, Wildlife and Parks Department for use in park construction.

Participants visited the Right Bank Repository where a relative small area of subsidence was observed (about 2 square feet) and flagged for ongoing monitoring to ensure the subsidence does not expand. Participants walked along the Blackfoot River to observe the riprap stabilizing the banks of the river, and used inclinometers to measure the Interstate-90 bridge settlement. The riprap was intact. However, a number of timbers were observed below the Interstate-90 bridge along the banks of the Blackfoot River. These salvaged timbers belong to the Montana Fish, Wildlife and Parks and will be used for the construction of a State Park near this area. Participants also viewed monitoring wells 917B and 921A; both wells were secured with locks.

The participants visited the Bonner Development Group Parcel and the Sheriff Posse Grounds Parcel. Both parcels appear to have established vegetation. Vegetation was also beginning to become established along the Clark Fork River southwest of the two parcels. The Sheriff Posse Grounds Parcel consists of about 3 acres of reclaimed areas. It includes a community park with picnic tables and trails, a rodeo ground, and a cultural slope area. Apart from the rodeo ground, all were covered with vegetation. The rodeo ground is currently used for rodeo activities.

<u>CFROU</u>

Site inspection participants included Brian Bartkowiak from MDEQ, Sara Sparks from EPA, and Treat Suomi and Claire Marcussen from Skeo. The inspection took place on November 3, 2015. See Appendix D-2 and E-2 for the site inspection checklist and photographs.

The inspection began immediately north of the town of Warm Springs below the Warm Springs Ponds, the beginning of the Clark Fork River Phase 1 remediation area. The riverbanks have been remediated and are vegetated. An 8-foot fence was observed; it is intended to keep wildlife away from the new growth along the riverbank until the vegetation is well established. The inspection proceeded by car. MDEQ staff noted the location of the Phase 2 remediation area where remedy construction started on June 2015. Participants observed the Beck Borrow area where clean fill material is obtained and then mixed with compost for use in filling the excavated floodplain areas (located west of the Phase 10 area).

Participants proceeded to the town of Deer Lodge to view Arrow Stone Park, which is owned by the City of Deer Lodge and leased to Powell County. Two removal actions there addressed arsenic-contaminated soils during installation of utility poles and an outhouse. The park is located in the Phase 13 and Phase 14 remediation areas. Parts of the riverbank were eroded where the Clark Fork River meanders. The park includes picnic areas and a walking trail system.

The site inspection continued in Deer Lodge where residential and streambank remediation of arsenic-contaminated areas were observed in the Trestle Area. Participants then visited the large area of pastureland east of the Phase 13 and 14 areas historically irrigated by a ditch that brought water from the Clark Fork River to the area. The pastures visited included the Eastside Pastures/Road area and the Windy Mountain Ranch (also known as the Broken Circle Ranch) area where large areas of contaminated pasture land were remediated in 2011. The pastures were vegetated with grass. The inspection proceeded to the Phase 7 remediation area, where Race Track Pond was observed. Participants then visited the Phase 5 and 6 active remediation area. Trucks and earthmoving equipment were observed removing contaminated floodplain soils and filling in excavated areas with soil and compost from the Beck borrow area. The tour ended with a visit to the Opportunity Pond repository where contaminated soils and sediment are placed.

6.6 Interviews

The FYR process included interviews with parties affected by the Site, including the current landowners and regulatory agencies involved in site activities or aware of the Site. The purpose was to document the perceived status of the Site and any perceived problems or successes with the phases of the remedy implemented to date. EPA reached out to multiple stakeholders to invite them to participate in the interview process. The interviews with those that were interested took place in person, over the phone and in writing. All interviews are summarized below. Appendix C provides the complete interviews.

MRSOU

Jeffrey Johnson: Jeffrey Johnson represents the National Park Service at the Grant-Kohrs Ranch National Historic Site in Phase 15. Overall, he believes that the remedial activities at the Milltown Reservoir were completed efficiently and that maintenance activities are sufficient. He mentioned the current performance of the remedy is performing as expected. He is not aware of any complaints from residents, new state laws that might affect the protectiveness of the remedy or any changes in projected land uses at the Site. He is comfortable with the status of institutional controls at the Site.

Chris Brick: Chris Brick is the director of a local community organization, Clark Fork Coalition Sciences. Overall, she believes site cleanup has been successful. Vegetation at the former bypass channel is not coming in very well, leading her to believe the cleanup might not be complete. Another area of concern is an on-site repository adjacent to the bluff where a waste monitoring well has had arsenic exceedances. As far as maintenance, the repository has reasonably good grass but Ms. Brick mentioned that there should be more native shrubs. Ms. Brick is satisfied with the reuse plans for a park on site. However, there are access issues and these need to be resolved in order to move forward with redevelopment. Ms. Brick mentioned she has seen mostly positive effects on the community. There were positive effects from the construction work and the people like that they can continue to float and fish on the river. Lastly, Ms. Brick commented that EPA did a great job keeping involved parties informed of site activities while cleanup was ongoing. However, now most of the information comes from Powell County and applies to the CFROU. She is interested in using the former email list to update the community.

Michael Kustudia: Michael Kustudia is the manager of the Milltown State Park located on the MRSOU. He has been involved with the MRSOU in various capacities over the last 15 years. Overall he feels well informed and works closely with other involved agencies. He did not provide any information regarding issues that might affect the protectiveness of the Site. He had a few suggestions to keep community members informed on a continual basis, including creating a fact sheet for area residents and users of the park updating people on the status of the arsenic in groundwater at the Site and the results of the FYR. He also would like to see growth media brought in for the top of the buttress near the tunnel pond repository. In addition, Mr. Kustudia identified a small area of slickens at the site that he will show to EPA on their next field visit. He indicated this is in a remote, hard to find area of the park.

CFROU

Resident 1: Resident 1 is a nearby resident of the CFROU and represents the local community. He is aware of the former issues at the Site and believes that cleanup, maintenance and reuse activities are coming along well. He mentioned the Site has had a positive economic effect on the community by bringing in outside businesses. He commented that EPA has done a very good job at keeping involved parties informed of site activities. EPA, MDEQ and the Clark Fork River Technical Assistance Committee work well together in order to do this. He mentioned they should keep informing local media of site activities. EPA is also putting him on an email list. Resident 1 owns a private well south of town near Phases five and 6, which he tests regularly and has never contained site-related contaminants. Resident 1 wants to be sure communication between parties stays open.

Jeffrey Johnson: Jeffrey Johnson represents the National Park Service at the Grant-Kohrs Ranch National Historic Site in Phase 15. Overall, he believes the remedial activities and maintenance are being conducted efficiently and commented that the remedy is performing as expected. He is aware that some nearby private landowners have submitted comments to MDEQ. He mentioned that the National Park Service has provided support for MDEQ in site investigations, the preliminary design plan and the remedial design. He is not aware of any changes in state laws or any changes in projected land use at the Site. He is comfortable with the status of institutional controls at the Site.

Brian Bartkowiak: Brian Bartkowiak represents MDEQ. Overall, he believes MDEQ is completing the cleanup in an efficient, cost-effective and protective manner, while also ensuring protection of human health and the environment. As far as the remedy, MDEQ has designed plans consistent with the requirements of the ROD and Consent Decree and is currently monitoring completed projects. He commented that some residents are concerned regarding the scale of cleanup activities and the large-scale disturbances of the floodplain. As lead agency, MDEQ oversees, manages, coordinates, designs and implements the remedial action for the Site in collaboration with EPA. The agency also coordinates with Montana's NRDP and the National Park Service for restoration components of the remedy. He commented that MDEQ also provides public outreach for the Site, providing newsletter updates, weekly ads in the local newspaper, radio segments providing the public with information on current activities, outreach at various local events, and providing documents to information repositories. He is not aware of any changes to state laws or projected land uses at the Site. Institutional controls will be developed as phases of the cleanup are completed.

Brian Bender: Brian Bender is the Powell County Planning Director. Overall he states that he is well-informed about the activities at the CFROU by the MDEQ staff. He is not aware of any land use changes or changes in local regulations that would affect the protectiveness of the remedy. Mr. Bender indicated that the overlay district works well, even if occasionally it catches something after work in the area is completed. At that point they involve MDEQ and the situation is quickly resolved. He thinks information about the overlay district could be better communicated with the community so they understand they need to get things investigated before the start a project. Mr. Bender would like both EPA and MDEQ administrators to have more of a presence in Powell County. He suggested they visit with County officials on a quarterly, or more regular basis.

7.0 Technical Assessment

7.1 Question A: Is the remedy functioning as intended by the decision documents?

MRSOU

Yes. Review of the data collected during the FYR period and supporting documentation indicates that the MRSOU remedial action continues to be operating and functioning as designed. The primary objectives of the remedial action are to reduce or eliminate the groundwater arsenic plume, and reduce a threat to aquatic life below the dam from the release of contaminated sediments. The Milltown Dam has been completely removed, contaminated sediments have been excavated or capped, and the Clark Fork River is flowing in the new channel with no sedimentation or erosion issues identified. Floodplain vegetation is expected to achieve performance standards. The SAA III-b sediments have been excavated and placed in the Tunnel Pond Repository, which has been filled and the cover completed. The on-site repositories, Interstate-90 bank improvements, removal and re-grading of the Bypass Channel, bridge replacements and strengthening of the Interstate-90 Bridge abutments on the Blackfoot River are completed and functioning as designed.

Vegetation performance standards have now been met for all areas where the PRPs retained responsibility for revegetation. The PRPs expect to submit a Construction Completion Report in 2016. EPA and the State NRD program will continue to work cooperatively regarding other vegetation areas and performance standards. Monitoring of the repositories and groundwater will continue.

The ROD anticipated the dam removal would restore the aquifer by complying with ARARs for groundwater approximately four to 10 years after dam removal and construction completion. However, at the time this report was being drafted, it had only been four years since substantial construction was completed. Groundwater monitoring indicates arsenic concentrations continue to exceed the arsenic groundwater standard. However, the statistical analysis does not show a significant increasing trend in concentrations in the last eight samples. This issue requires further investigation at a minimum until the 10-year period has passed.

The PRPs continue to recommend using statistical analysis of TPR10 as the Tunnel Pond Repository POC with assessment of potential impacts to groundwater from repository construction and use.

At the time of this FYR, permanent institutional controls have not been put in place for the groundwater plume, for the waste repositories, for contaminated sediments left in place or for site access control/residential use. Site regulatory agencies are continuing to discuss the need for additional institutional controls. A Missoula County ordinance currently in place appears to preclude installation of new public water wells in the vicinity of the MRSOU arsenic plume. However, these ordinances do not preclude private well installation in the plume area. Additional institutional controls may be needed to control private well installation in the arsenic plume and with respect to the management of the waste repositories and the sediments left in place. Wells monitored by MCCHD are consistently below the arsenic standard of 10 µg/L.

An institutional control preventing river access during certain time periods has been necessary in the past, and may be needed in the future. The majority of the MRSOU has been designated as a future Montana State Park. Institutional controls dealing with water consumption, residential use and the waste repositories will need to be incorporated into the future park design and planning documents.

<u>CFROU</u>

Yes. Remedy implementation is ongoing. Remediation of Phase 1 of Reach A finished in April 2014. Revegetation activities are still ongoing. Long-term monitoring is underway to assess groundwater, surface water and vegetation during and after remediation. Additional monitoring efforts include streambed sediments, macroinvertebrates, periphyton, nutrients and fish populations.

Institutional controls for CFROU to be implemented may include additional county zoning regulations, deed restrictions, permanent funding for Arrow Stone Park, and groundwater sampling and use controls. Environmental monitoring is required during all activities. Institutional controls currently in place include the Powell Creek Overlay District. The Overlay District, an existing institutional control, is intended to ensure that future land uses in affected areas are compatible with the presence of potential contaminants and the remedial actions required to isolate those potential contaminants from the environment.

7.2 Question B: Are the exposure assumptions, toxicity data, cleanup levels and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. The exposure assumptions, toxicity data, cleanup levels and RAOs used at the time of remedy selection remain valid for both the MRSOU and the CFROU.

The MRSOU ROD indicates that groundwater standards are expected to be met within approximately four to 10 years following completion of dam and sediment removal. A waiver of groundwater standards is not currently proposed. However, the PRPs may seek a waiver of groundwater cleanup standards if compliance is not achieved and is technically impracticable.

At the time of the ROD, the State of Montana's surface water quality standard for arsenic was 18 µg/L, based on human health, and 20 µg/L for groundwater as a drinking water supply. As reflected in the August 2010 version of DEQ-7 (MDEQ2010), the state standard for arsenic for surface water and groundwater is now 10 µg/L, matching the federal standards. This revision to the state standards does not impact the performance standards for the MRSOU, as the more stringent federal standards were established in the 2004 ROD. Other groundwater and surface water cleanup goals are based on federal and state standards that have not changed.

The MRSOU remedy is not expected to achieve compliance at all times with the State's WQB-7 standard for copper because of continued contaminant loading originating upstream of the reservoir primarily from the CFROU. The ROD confirmed that a waiver of the copper standard, based on technical impracticability, for the upstream CFROU will carry over into and be applied to the MRSOU ambient surface water. The Consent Decree provides for the consideration of upstream contamination in determining surface water ARAR compliance.

The risk-based soil cleanup goals for arsenic in the CFROU remain valid, as the toxicity characteristics of arsenic have not changed since EPA issued the ROD. Land use in affected areas has not changed in such a way as to affect the exposure assumptions applied in the development of these site-specific cleanup goals.

7.3 Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. No other information has come to light that could call into question the protectiveness of the remedy.

7.4 Technical Assessment Summary

<u>MRSOU</u>

Yes. Review of the data collected during the FYR period and supporting documentation indicates that the MRSOU remedial action continues to be operating and functioning as designed. The Milltown Dam has been completely removed, contaminant sediments have been excavated or capped, and the Clark Fork River is flowing in the new channel with no sedimentation or erosion issues identified. Vegetation performance standards have now been met at area for which the PRPs are responsible, and are being monitored and improved in areas where the State NRD program is responsible. Groundwater monitoring indicates arsenic concentrations continue to exceed the arsenic groundwater standard. However, compliance may still be possible and monitoring and further analysis should continue.

Permanent institutional controls have not been put in place for the groundwater plume, for the waste repositories, for contaminated sediments left in place or for site access control. Site regulatory agencies are continuing to discuss the need for additional institutional controls. Missoula County zoning ordinances are in place that preclude installation of new public water wells in the vicinity of the arsenic plume. Additional institutional controls may be needed to control private well installation in the arsenic plume and with respect to the management of the waste repositories and the sediments left in place.

CFROU

Yes. Remedy implementation is ongoing. Remediation of Phase 1 of Reach A finished in April 2014. Long-term monitoring is underway to assess groundwater, surface water and vegetation during remediation.

Institutional controls currently in place include the Powell County Overlay District. The Overlay District is intended to ensure that future land use in affected areas are compatible with the presence of potential contaminants and the various remedial actions required to isolate those potential contaminants from the environment. Additional institutional controls for CFROU areas may include county zoning regulations, deed restrictions, permanent funding for Arrow Stone Park, and groundwater sampling and use controls.

8.0 Issues

Table 11 summarizes the current site issues.

Table 11: Current Site Issues

Issue	Affects Current Protectiveness?	Affects Future Protectiveness?
Institutional controls for MRSOU are not yet implemented for areas where waste has been left in place and areas where groundwater contamination is above ROD standards.	No	Yes
Groundwater concentrations at MRSOU continue to exceed arsenic cleanup goals and do not appear to be declining.	No	Yes

9.0 Recommendations and Follow-up Actions

Table 12 provides recommendations to address the current site issues.

Table 12: Recommendations to Address Current Site Issues

Issue	Recommendation / Follow-Up Action	Party Responsible	Oversight Agency	Milestone Date	Affects Protectiveness?	
					Current	Future
Institutional controls for MRSOU are not yet implemented for areas where waste has been left in place and areas where groundwater contamination is above ROD standards.	Implement institutional controls for the MRSOU comprehensive institutional control plan and its components.	PRP/ State/EPA	EPA/MDEQ	09/30/2017	No	Yes
Groundwater concentrations at MRSOU continue to exceed arsenic cleanup goals and do not appear to be declining.	Determine if additional measures are needed to reduce arsenic concentrations below the cleanup goals.	PRP	EPA/MDEQ	09/30/2017	No	Yes

The following additional item, though not expected to affect protectiveness, warrants additional follow up:

MRSOU

- Two areas of the Tunnel Pond Repository showed subsidence of the cover. There was also some minor erosion of the cover material in spots. Inspection of the one downgradient monitoring well indicated that a locking well cap had not been put in place. Envirocon indicated that these areas would be re-graded after the spring runoff was over.

10.0 Protectiveness Statements

The remedy at MRSOU (OU2) currently protects human health and the environment because potential exposure to contaminated groundwater, surface water and sediment is controlled. For the remedy to be protective over the long term, the following actions need to be taken:

- Implement institutional controls for the MRSOU comprehensive institutional control plan and its components.
- Determine if additional measures are needed to reduce arsenic concentrations below the cleanup goals.

- Continue monitoring GW for at least six more years and tracking the arsenic trends to see if concentrations are going down per the discussion in the ROD.

The remedy at CFROU (OU3) is expected to be protective of human health and the environment upon completion of the remedial action. In the interim, exposure pathways that could result in unacceptable risks are being controlled.

11.0 Next Review

The next FYR will be due within five years of the signature/approval date of this FYR.

Appendix A: List of Documents Reviewed

2010 Milltown Transformation Retrospective, Diane Hammer, U.S. EPA. December 2010.

2011 Milltown Vegetation Monitoring Report. Geum Environmental Consulting, Inc. July 2012.

2011 Trestle Area Remedial Action Project Remedial Action Monitoring Plan. TerraGraphics Environmental Engineering, Inc. October 2011.

2012 Milltown Vegetation Monitoring Report. University of Montana & Geum Environmental Consulting, Inc. April 2013.

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Appendix B: Press Notice

EPA Five-Year Review Planned for the Milltown Reservoir/ Clark Fork River Superfund Site

The U.S. Environmental Protection Agency (EPA) is conducting the second Five-Year Review of remedial actions performed under the Superfund program at the Milltown Reservoir/ Clark Fork River Superfund site in Butte, Montana. The purpose of the Five-Year Review is to make sure the selected cleanup actions remain protective of human health and the environment. The Five-Year Review is scheduled for completion by September 2016.

The Site consists of three operable units. Operable unit 1 was focused on providing a safe water supply to Milltown area residents through establishment of a public water supply system for the town of Milltown. The Milltown Reservoir Sediments operable unit (MRSOU) is operable unit 2 and includes approximately 540 acres in the Clark Fork River and Blackfoot River floodplain. MRSOU consists of the area encompassed by the former Milltown Dam and Reservoir and the area where arsenic contamination exists in groundwater. The Clark Fork River Operable Unit consists of approximately 120 river miles of the Clark Fork River and extends from the confluence of the old Silver Bow Creek channel with the reconstructed lower Mill-Willow bypass, near Anaconda, to the maximum former Milltown Reservoir pool elevation east of Missoula. The Milltown Reservoir/ Clark Fork River site is one of four contamination areas, jointly known as the Clark Fork Basin Sites.

More information is available at the site's information repository and on EPA's website:

EPA Superfund Records Center
Montana Office
10 West 15th Street, Suite 3200
Helena, MT 59626
(406) 457-5046
(866) 457-2690 (toll free)

http://www2.epa.gov/region8/milltown-reservoir-sediments-clark-fork-river

EPA invites community participation in the Five-Year Review process: Community members are encouraged to contact EPA staff with any information that may help the Agency make its determination regarding the protectiveness and effectiveness of the remedies at the site.

EPA Region 8
Sara Sparks
Remedial Project Manager
Phone: (406) 782-7415
Email: sparks.sara@epa.gov

Appendix C: Interview Forms

Milltown Reservoir/ Clark Fork River Superfund Site			**Five-Year Review Interview Form**
Site Name:	**Milltown Reservoir Sediments OU**	**EPA ID No.:**	**MTD980717565**
Interviewer Name:	**Self**	**Affiliation:**	**Skeo**
Subject Name:	**Jeffrey Johnson**	**Affiliation:**	**National Park Service**
Subject Contact Information:	**jeffrey_g_johnson@nps.gov**		
Time:	**Not Applicable**	**Date:**	**01/28/2016**
Interview Location:	**Grant-Kohrs Ranch NHS 266 Warren Lane Deer lodge, MT 59722**		
Interview Format (circle one):	**In Person** **Phone** **Mail**	**Other: Email**	

Interview Category: **Federal Agency**

1. What is your overall impression of the project, including cleanup, maintenance and reuse activities (as appropriate)?

The remedial activities at the Milltown Reservoir were done efficiently. The maintenance is good.

2. What is your assessment of the current performance of the remedy in place at the Site?

The remedy in place is performing within expectations.

3. Are you aware of any complaints or inquiries regarding site-related environmental issues or remedial activities from residents in the past five years?

No.

4. Has your office conducted any site-related activities or communications in the past five years? If so, please describe the purpose and results of these activities.

Not for the Milltown Reservoir OU.

5. Are you aware of any changes to state laws that might affect the protectiveness of the Site's remedy?

No.

6. Are you comfortable with the status of the institutional controls at the Site? If not, what are the associated outstanding issues?

Yes.

7. Are you aware of any changes in projected land use(s) at the Site?

No.

8. Do you have any comments, suggestions or recommendations regarding the management or operation of the Site's remedy?

No.

Site Name:	**Milltown Reservoir Sediments OU**	**EPA ID No.:**	**MTD980717565**
Interviewer Name:	**Treat Suomi**	**Affiliation:**	**Skeo**
Subject Name:	**Chris Brick**	**Affiliation:**	**Clark Fork Coalition Sciences**
Subject Contact Information:	**Director: (406) 542-0539**		
Time: **2:00 p.m.**		**Date:**	**11/02/2015**
Interview Location:	**140 South 4th Street West, Suite 1 Missoula, MT**		
Interview Format (circle one):	**In Person**	**Phone** **Mail**	**Other:**

Interview Category: **Local Community Organization**

1. Are you aware of the former environmental issues at the Site and the cleanup activities that have taken place to date?

   Yes.

2. What is your overall impression of the project, including cleanup, maintenance and reuse activities (as appropriate)?

   Overall, I think it has been successful. I would rate the cleanup an eight out of 10. The vegetation at the former bypass channel is not coming in very well. The NRDP has done testing and my understanding is that the area still has some high metals so the substandard vegetation leads to a belief that the cleanup might not be complete. So, I think it is 80 to 90 percent effective.

   The other area is an on-site repository adjacent to the bluff where 3B waste monitoring well downstream has had arsenic exceedances. At the AR repository, there are questions about what to do. I think that this is a red flag and that is one area of concern.

   Maintenance: that same repository is getting reasonably good grass but I argued for a long time that there should be more native shrubs. The Interstate-90 bridge piers are the same concerns that have been previously voiced.

   Reuse: there are great plans for a park. There are access problems for the FWP and International Paper, though. Last I heard, they might be working on that. The state has money and plans to do park construction and it has been blocked by the access issue. This needs to be resolved. This has prevented complete redevelopment.

   Great job on the bluff, mainly the side and the former reservoir and the area below.

3. What have been the effects of the Site on the surrounding community, if any?

There have been a lot of A's in the community. There were positive effects from the construction work. It is also beneficial that people have been able to continue to float and fish. And I understand fish move up the Black Foot and Upper Clark Rivers to spawn. But any beneficial effects to the community have been stalled due to access issues and slowed redevelopment. It is beneficial that people have been able to float and fish. I understand fish move up Black Foot and the Upper Clark Fork in order to spawn.

4. Have there been any problems with unusual or unexpected activities at the Site, such as emergency response, vandalism or trespassing?

   Not that I am aware of.

5. Has EPA kept involved parties and surrounding neighbors informed of activities at the Site? How can EPA best provide site-related information in the future?

   EPA did a great job while project was ongoing, but now there is not much to report. Most of the information comes from Powell County now. I am interested in the vegetation of the bypass channel and water quality. I am also interested in the using the former email list and allowing people to opt in for future updates.

6. Do you own a private well in addition to or instead of accessing city/municipal water supplies? If so, for what purpose(s) is your private well used?

   There are not any near the Site.

7. Are you aware of any changes in projected land use(s) at the Site?

   No, I am not aware of any.

8. Do you have any comments, suggestions or recommendations regarding any aspects of the project?

   No, other than making sure the issues at the former bypass channel with the revegetation are solved and the water quality issues resulting from issues with the repository. There may be other issues I am currently unaware of.

Milltown Reservoir/ Clark Fork River Superfund Site **Five-Year Review Interview Form**

Site Name:	**Milltown Reservoir Sediments OU**	**EPA ID No.:**	**MTD980717565**
Interviewer Name:	**Treat Suomi**	**Affiliation:**	**Skeo**
Subject Name:	**Resident 1**	**Affiliation:**	**Nearby Resident**
Time:	**10:00 a.m.**	**Date:**	**11/04/2015**
Interview Location:	**7956 East Side Road**		

Interview Format (circle one): **In Person** **Phone** **Mail** **Other:**

Interview Category: **Residents**

1. Are you aware of the former environmental issues at the Site and the cleanup activities that have taken place to date?

   Yes.

2. What is your overall impression of the project, including cleanup, maintenance and reuse activities (as appropriate)?

   I think it is coming along well.

3. What have been the effects of the Site on the surrounding community, if any?

   Economically, it has helped. It has brought some outside businesses here.

4. Have there been any problems with unusual or unexpected activities at the Site, such as emergency response, vandalism or trespassing?

   Not to my knowledge.

5. Has EPA kept involved parties and surrounding neighbors informed of activities at the Site? How can EPA best provide site-related information in the future?

   I think they have done a very good job at this. I serve on CFRTAC and together, EPA, DEQ and CFRTAC have done a good job; the three organizations work well together. They should continue to keep it coming to the local media. They have done a good job. EPA is putting me on an email list, too.

6. Do you own a private well in addition to or instead of accessing city/municipal water supplies? If so, for what purpose(s) is your private well used?

I own a private well south of town, near Phases five and six. I test regularly and have never seen site-related contaminants.

7. Do you have any comments, suggestions or recommendations regarding any aspects of the project?

    Keep the lines of communication open.

Milltown River/ Clark Fork River Superfund Site **Five-Year Review Interview Form**

Site Name:	**Clark Fork River OU**	**EPA ID No.:**	**MTD980717565**
Interviewer Name:	**Self**	**Affiliation:**	**Skeo**
Subject Name:	**Jeffrey Johnson**	**Affiliation:**	**National Park Service**
Subject Contact Information:	**jeffrey_g_johnson@nps.gov**		
Time:	**Not Applicable**	**Date:**	**01/28/2016**
Interview Location:	**Grant-Kohrs Ranch NHS 266 Warren Lane Deer lodge, MT 59722**		

Interview Format (circle one): In Person Phone Mail Other: Email

Interview Category: Federal Agency

1. What is your overall impression of the project, including cleanup, maintenance and reuse activities (as appropriate)?

The remedial activities at the Clark Fork River are being conducted efficiently. The maintenance is good.

2. What is your assessment of the current performance of the remedy in place at the Site?

The remedy in place is performing within expectations.

3. Are you aware of any complaints or inquiries regarding site-related environmental issues or remedial activities from residents in the past five years?

I am aware that some private landowners have commented to MDEQ.

4. Has your office conducted any site-related activities or communications in the past five years? If so, please describe the purpose and results of these activities.

MDEQ has completed investigations and prepared the Preliminary Design Plan. They are currently completing the remedial design. Grant-Kohrs Ranch has supported these activities.

5. Are you aware of any changes to state laws that might affect the protectiveness of the Site's remedy?

No.

6. Are you comfortable with the status of the institutional controls at the Site? If not, what are the associated outstanding issues?

Yes.

7. Are you aware of any changes in projected land use(s) at the Site?

No.

8. Do you have any comments, suggestions or recommendations regarding the management or operation of the Site's remedy?

No.

Milltown River/ Clark Fork River Superfund Site **Five-Year Review Interview Form**

Site Name: **<u>Clark Fork River OU</u>** **EPA ID No.:** **<u>MTD980717565</u>**
Interviewer Name: **<u>Treat Suomi</u>** **Affiliation:** **<u>Skeo</u>**
Subject Name: **<u>Brian Bartkowiak</u>** **Affiliation:** **<u>MDEQ</u>**
Subject Contact Information: **<u>1225 Cedar Street</u>**
<u>P.O. Box 200901</u>
<u>Helena, MT 59620-0901</u>
<u>(406) 444-0214</u>
Time: **<u>Not Applicable</u>** **<u>Date:</u>** **<u>12/16/2015</u>**

Interview Format (circle one): **In Person** **Phone** **Mail** **Other: Email**

Interview Category: **State Agency**

1. What is your overall impression of the project, including cleanup, maintenance and reuse activities (as appropriate)?

MDEQ is implementing the project in an efficient, cost-effective and protective manner while ensuring the protection of human health and the environment and emphasizing worker and public safety.

2. What is your assessment of the current performance of the remedy in place at the Site?

MDEQ design teams have developed designs consistent with the requirements of the ROD and Consent Decree. MDEQ is currently monitoring performance of completed project to ensure performance metrics, performance targets and performance standards are being met.

3. Are you aware of any complaints or inquiries regarding site-related environmental issues or remedial activities from residents in the past five years?

Some residences have concerns regarding the scale of the cleanup activities. Residents have expressed concerns over the large-scale disturbances of the floodplain.

4. Has your office conducted any site-related activities or communications in the past five years? If so, please describe the purpose and results of these activities.

MDEQ, as lead agency, oversees, manages, coordinates, designs and implements the remedial action for the Site in consultation with EPA. MDEQ coordinates with the State of Montana's NRDP and the U.S. National Park Service for the implementation and integration of restoration components into the work. Four primary functions of consultation and coordination among the agencies for the Site are to: 1) understand and receive the information to be collected; 2) understand how that information is to be analyzed; 3) provide review and comment; and 4) *maximize the use of the resources available for and the environmental benefits to the Site in the successful and cost-effective completion of the work.*

MDEQ also conducts significant public outreach, including, but not limited to: monthly stakeholder and landowner tours during construction, periodic newsletter updates, weekly ads in the local newspaper and radio providing the public with information on current activities, design review meetings, outreach at local events, and providing key documents at site information repositories.

5. Are you aware of any changes to state laws that might affect the protectiveness of the Site's remedy?

No.

6. Are you comfortable with the status of the institutional controls at the Site? If not, what are the associated outstanding issues?

Yes. The cleanup is underway and individual institutional control plans will be developed as project phases are completed.

7. Are you aware of any changes in projected land use(s) at the Site?

No.

8. Do you have any comments, suggestions or recommendations regarding the management or operation of the Site's remedy?

No.

Milltown River/ Clark Fork River Superfund Site **Five-Year Review Interview Form**

Site Name:	**Clark Fork River OU**	**EPA ID No.:**	**MTD980717565**
Interviewer Name:	**Treat Suomi**	**Affiliation:**	**Skeo**
Subject Name:	**Brian Bender**	**Affiliation:**	**Powell County Planning Director**
Subject Contact Information:	**bbender@powellcountymt.com | 406-846-9795**		
Time: **2:30 p.m.**		**Date:**	**06/14/2016**
Interview Location:	**Phone**		

Interview Format (circle one): **In Person** **Phone** **Mail** **Other:**

Interview Category: **Local Government**

1. Are you aware of the former environmental issues at the Site and the cleanup activities that have taken place to date?

   Yes.

2. Do you feel well-informed regarding the Site's activities and remedial progress? If not, how might EPA convey site-related information in the future?

   Yes, I feel well informed. We get quarterly reports anything site-specific from MDEQ staff. However, EPA has not communicated with us in over three years. County staff would appreciate regular communications form EPA on the status of the project.

3. Have there been any problems with unusual or unexpected activities at the Site, such as emergency response, vandalism or trespassing?

   Nothing that was critical. MDEQ staff have indicated that there is an occasional incident of trespassing but they have not indicated that it has been a serious situation.

4. Are you aware of any changes to state laws or local regulations that might affect the protectiveness of the Site's remedy?

   No.

5. Are you aware of any changes in projected land use(s) at the Site?

   No. I am not aware of any and I do not believe any are being proposed. Through the Powell County Planning Department, we have a Superfund Overlay District. Someone would have to initiate any changes they wanted. Occasionally, the Overlay District catches something after the fact, so maybe information about the Overlay District could be better communicated with the community so they know they need to have things investigated earlier. However, MDEQ has been good to communicate with and they come in and haul away waste if needed.

6. Has EPA kept involved parties and surrounding neighbors informed of activities at the Site? How can EPA best provide site-related information in the future?

   MDEQ puts weekly notices in the paper and on the radio. EPA does not really have much of a local presence. EPA is supposed to help residents and now that work in Powell County has started, we have not really heard from EPA. We used to have a funding mechanism in place to help fund the Powell County Planning Department and that was abruptly taken away.

7. Do you have any comments, suggestions or recommendations regarding the project?

   EPA needs more presence with property owners and county officials, both formally and informally. It would also be good if MDEQ could meet quarterly or every six weeks with county officials. Now that work is in Deer Lodge, the same regular, in-person updates could be given to City Council. Specifically, it would be good to have MDEQ administrators or senior officials visit on a regular, maybe quarterly, basis.

Site Name: **Milltown Reservoir OU** **EPA ID No.:** **MTD980717565**
Interviewer Name: **Treat Suomi** **Affiliation:** **Skeo**
Subject Name: **Michael Kustudia** **Affiliation:** **Milltown State Park, Montana Fish, Wildlife & Parks, Region Two**
Subject Contact Information: **MKustudia@mt.gov**
Time: **11:00 a.m.** **Date:** **07/26/2016**
Interview Format (circle one): **In Person** **Phone** **Mail** **Other:**

Interview Category: **Local Government**

1. Are you aware of the former environmental issues at the Site and the cleanup activities that have taken place to date?

   Yes. I am the manager of Milltown State Park. And before that I was involved it the TAG. So I have been involved for the last 15 years.

2. Do you feel well-informed regarding the Site's activities and remedial progress? If not, how might EPA convey site-related information in the future?

   I feel like I am well informed. Through EPA, NRD and other sister agencies I feel well informed.

3. Have there been any problems with unusual or unexpected activities at the Site, such as emergency response, vandalism or trespassing?

   The site has become part of a state park now. WE are working on transferring it from the NRD program. Tunnel that gets vandalized but nothing that would affect the protectiveness of the remedy.

4. Are you aware of any changes to state laws or local regulations that might affect the protectiveness of the Site's remedy?

   I am not.

5. Are you aware of any changes in projected land use(s) at the Site?

   Aside from developing the state park as planned.

6. Has EPA kept involved parties and surrounding neighbors informed of activities at the Site? How can EPA best provide site-related information in the future?

EPA (Sara has kept me informed reasonably well. This interview is an example of that. As far as the community goes, the remedy is largely complete and there really isn't a need for the public meetings we used to have.

7. Do you have any comments, suggestions or recommendations regarding the project?

   I have a couple of suggestions. In the spring we went out for an annual visit. This has been one of my continuing messages. The buttress to the buttress for the tunnel pond repository – it never got any growth media put down on the top. Getting some growth media on the top would be my wish. We are pretty good at mobilizing volunteers for plantings and such so if we could get some topsoil there we could get it planted but it is beyond our budget to bring in the growth media. I am relatively pleased with the vegetation in the area. The surrounding areas look great but there are too many weeds for my liking. We are likely to have a Mullen weed pulling event soon.

   There is a small area of slickens upstream from the confluence, approximately 5 – 10 feet across and 3-4 feet wide (15 – 30 square feet). It is an isolated spot. It is hard to find. Right below the confluence there is a red spot/stain with a trickle of water. I did a ph test on it and it was practically neutral. It does seem seasonal. I noticed the trickle before peak runoff and by the time the runoff came it was gone and I haven't seen it since.

   Now that the work is largely done. In terms of the monitoring that goes on in the wells, where do we stand? Are we on the right trajectory in terms of the arsenic in groundwater? I think the public would like to hear an update about that as well. Even a one-page fact sheet after the Five Year Review would be good. There might not be enough for an actual meeting but some sort of outreach might be helpful as progress is made.

Appendix D-1: MRSOU Site Inspection Checklist

FIVE-YEAR REVIEW SITE INSPECTION CHECKLIST

I. SITE INFORMATION

Site name: Milltown Sediments OU	**Date of inspection:** 11/02/2015
Location and Region: Milltown, Missoula County, Montana, EPA Region 8	**EPA ID:** MTD980717565
Agency, office, or company leading the five-year review: EPA	**Weather/temperature:** mostly cloudy, low 40s

Remedy Includes: (Check all that apply)

- ☒ Landfill cover/containment
- ☒ Access controls
- ☒ Institutional controls
- ☐ Groundwater pump and treatment
- ☐ Surface water collection and treatment
- ☐ Other ______
- ☐ Monitored natural attenuation
- ☐ Groundwater containment
- ☐ Vertical barrier walls

Attachments: ☒ Inspection team roster attached ☒ Site map attached (See Figure 2)

II. INTERVIEWS (Check all that apply)

1. **O&M staff** Name Title Date
   Title Date
   Name
   Interviewed ☐ at site ☐ at office ☐ by phone Phone no. ______
   Problems, suggestions; ☐ Report attached ______

2. **Local regulatory authorities and response agencies** (i.e., State and Tribal offices, emergency response office, police department, office of public health or environmental health, zoning office, recorder of deeds, or other city and county offices, etc.). Fill in all that apply.

   Agency:
   Contact
   Name Title Date Phone No.
   Problems; suggestions; ☐ Report attached

4. **Other interviews** (optional) ☐ Report attached

Jeffrey Johnson, National Park Service; Chris Brick, Clark Fork Coalition Sciences

III. ON-SITE DOCUMENTS & RECORDS VERIFIED (Check all that apply)

1. **O&M Documents**

☒ O&M manual	☒ Readily available	☒ Up to date	☐ N/A
☐ As-built drawings	☐ Readily available	☐ Up to date	☒ N/A
☒ Maintenance logs	☒ Readily available	☒ Up to date	☐ N/A

Remarks:

2.	**Site-Specific Health and Safety Plan**	☐ Readily available	☐ Up to date	☒ N/A
	☐ Contingency plan/emergency response plan	☐ Readily available	☐ Up to date	☒ N/A
	Remarks: _____			
3.	**O&M and OSHA Training Records**	☒ Readily available	☐ Up to date	☒ N/A
	Remarks: _____			
4.	**Permits and Service Agreements**			
	☐ Air discharge permit	☐ Readily available	☐ Up to date	☒ N/A
	☐ Effluent discharge	☐ Readily available	☐ Up to date	☒ N/A
	☐ Waste disposal, POTW	☐ Readily available	☐ Up to date	☒ N/A
	☐ Other permits _____	☐ Readily available	☐ Up to date	☒ N/A
	Remarks: _____			
5.	**Gas Generation Records**	☐ Readily available	☐ Up to date	☒ N/A
	Remarks: _____			
6.	**Settlement Monument Records**	☒ Readily available	☒ Up to date	☐ N/A
	Remarks: _____			
7.	**Groundwater Monitoring Records**	☒ Readily available	☒ Up to date	☐ N/A
	Remarks:			
8.	**Leachate Extraction Records**	☐ Readily available	☐ Up to date	☒ N/A
	Remarks: _____			
9.	**Discharge Compliance Records**			
	☐ Air	☐ Readily available	☐ Up to date	☒ N/A
	☐ Water (effluent)	☐ Readily available	☐ Up to date	☒ N/A
	Remarks: _____			
10.	**Daily Access/Security Logs**	☐ Readily available	☐ Up to date	☒ N/A
	Remarks: _____			

IV. O&M COSTS

1.	**O&M Organization**	
	☒ State in-house	☐ Contractor for State
	☐ PRP in-house	☒ Contractor for PRP
	☐ Federal Facility in-house	☐ Contractor for Federal Facility
	☐ _____	

2. **O&M Cost Records**

☐ Readily available ☐ Up to date

☐ Funding mechanism/agreement in place ☒ Unavailable

3. **Unanticipated or Unusually High O&M Costs During Review Period**

Describe costs and reasons: None

V. ACCESS AND INSTITUTIONAL CONTROLS ☒ Applicable ☐ N/A

A. Fencing

1. **Fencing damaged** ☐ Location shown on site map ☐ Gates secured ☒ N/A

Remarks: Fencing is present in areas where public can get to river only. There are also locked gates on roads that lead to the remedial action construction areas.

B. Other Access Restrictions

1. **Signs and other security measures** ☐ Location shown on site map ☐ N/A

Remarks: Signage is currently present near the river across from the Site. Primarily concerned with protecting revegetation areas.

C. Institutional Controls (ICs)

1. **Implementation and enforcement**

Site conditions imply ICs not properly implemented ☐ Yes ☐ No ☒ N/A

Site conditions imply ICs not being fully enforced ☐ Yes ☐ No ☒ N/A

Type of monitoring (e.g., self-reporting, drive by) _____

Frequency _____

Responsible party/agency

Contact	_____	mm/dd/yyyy	_____
Name	Title	Date	Phone no.

Reporting is up-to-date ☐ Yes ☐ No ☒ N/A

Reports are verified by the lead agency ☐ Yes ☐ No ☒ N/A

Specific requirements in deed or decision documents have been met ☐ Yes ☒ No ☐ N/A

Violations have been reported ☐ Yes ☐ No ☒ N/A

Other problems or suggestions: ☐ Report attached

IC Plan is still in development.

2. **Adequacy** ☐ ICs are adequate ☒ ICs are inadequate ☐ N/A

Remarks: A Missoula County ordinance currently in place appears to preclude installation of new public water wells in the vicinity of the MRSOU arsenic plume. However, these ordinances do not preclude private well installation in the plume area. Additional institutional controls may be needed to control private well installation in the arsenic plume, prevent residential use and protect the waste repositories and the sediments left in place. An institutional control preventing river access during certain time periods has been necessary in the past, and may be needed in the future. The majority of the MRSOU has been designated as a future Montana State Park. Institutional controls dealing with water consumption, residential use and the waste repositories will need to be incorporated into the future park design and planning documents.

D. General

1. **Vandalism/trespassing** ☐ Location shown on site map ☒ No vandalism evident

Remarks: River rafters are not obeying signage and floating down the river in prohibited areas.

2. **Land use changes on site** ☒ N/A

Remarks: Land formerly owned by NorthWestern Corp. (dam operator) was acquired by the State of Montana for future use as a state park.

3. **Land use changes off site** ☒ N/A

Remarks: _____

VI. GENERAL SITE CONDITIONS

A. Roads ☐ Applicable ☒ N/A

VII. LANDFILL COVERS ☒ Applicable ☐ N/A

A. Landfill Surface

1. **Settlement** (Low spots) ☐ Location shown on site map ☐ Settlement not evident

Arial extent _____ Depth _____

Remarks: Settlement is evident in the Tunnel Pond Repository. Subsidence is evident at the Right Bank Repository. PRPs are monitoring and have worked on revegetation efforts at the Tunnel Pond Repository area of settlement. Area appears to have grown in size since the last FYR.

2. **Cracks** ☐ Location shown on site map ☐ Cracking not evident

Lengths _____ Widths _____ Depths _____

Remarks: Cracks are associated with slumping of the ground during settlement. The 2015 Draft Annual Report noted cracks from settlement in the appendix.

3. **Erosion** ☐ Location shown on site map ☒ Erosion not evident

Arial extent _____ Depth _____

Remarks:

4. **Holes** ☐ Location shown on site map ☐ Holes not evident

Arial extent _____ Depth _____

Remarks: Right Bank Repository had evidence of holes. They were flagged for continued PRP monitoring.

5. **Vegetative Cover**	☒ Grass		☐ Cover properly established
☒ No signs of stress	☐ Trees/Shrubs (indicate size and locations on a diagram)		
Remarks: Several minor ruts were observed in the cover where grass has not yet come in.			
6. **Alternative Cover** (armored rock, concrete, etc.)			☒ N/A
Remarks:			
7. **Bulges**	☐ Location shown on site map		☒ Bulges not evident
Arial extent _____			Height _____
Remarks: _____			
8. **Wet Areas/Water Damage**	☒ Wet areas/water damage not evident		
☐ Wet areas	☐ Location shown on site map		Arial extent _____
☐ Ponding	☐ Location shown on site map		Arial extent _____
☐ Seeps	☐ Location shown on site map		Arial extent _____
☐ Soft subgrade	☐ Location shown on site map		Arial extent _____
Remarks: _____			
9. **Slope Instability**	☐ Slides		☐ Location shown on site map
☒ No evidence of slope instability			
Arial extent _____			
Remarks: None noted.			
B. Benches	☐ Applicable	☒ N/A	
(Horizontally constructed mounds of earth placed across a steep landfill side slope to interrupt the slope in order to slow down the velocity of surface runoff and intercept and convey the runoff to a lined channel.)			
C. Letdown Channels	☒ Applicable	☐ N/A	
(Channel lined with erosion control mats, riprap, grout bags, or gabions that descend down the steep side slope of the cover and will allow the runoff water collected by the benches to move off of the landfill cover without creating erosion gullies.)			
1. **Settlement** (Low spots)	☐ Location shown on site map		☒ No evidence of settlement
Arial extent _____			Depth _____
Remarks: _____			
2. **Material Degradation**	☐ Location shown on site map		☒ No evidence of degradation
Material type_____			Arial extent _____
Remarks: _____			
3. **Erosion**	☐ Location shown on site map		☒ No evidence of erosion
Arial extent _____			Depth _____
Remarks: _____			

4.	**Undercutting**	☐ Location shown on site map	☒ No evidence of undercutting
	Arial extent _____		Depth _____
	Remarks: _____		
5.	**Obstructions**	Type _____	☒ No obstructions
	☐ Location shown on site map	Arial extent _____	
	Size _____		
	Remarks: _____		
6.	**Excessive Vegetative Growth**	Type _____	
	☒ No evidence of excessive growth		
	☐ Vegetation in channels does not obstruct flow		
	☐ Location shown on site map	Arial extent _____	
	Remarks: _____		
D. Cover Penetrations		☐ Applicable	☒ N/A
E. Gas Collection and Treatment		☐ Applicable	☒ N/A
F. Cover Drainage Layer		☐ Applicable	☒ N/A
G. Detention/Sedimentation Ponds		☐ Applicable	☒ N/A
H. Retaining Walls		☒ Applicable	☐ N/A
1.	**Deformations**	☐ Location shown on site map	☐ Deformation not evident
	Horizontal displacement _____	Vertical displacement _____	
	Rotational displacement _____		
	Remarks: Using a historic railroad grade as a retaining wall or berm for SAA IIIb contaminated sediments. PRPs have bolstered the toe of the grade to prevent movement. In addition, the PRPs also installed settlement monuments in the crest and toe of the Tunnel Pond Repository embankment in April 2014 as required by the Monitoring Plan. .		
2.	**Degradation**	☐ Location shown on site map	☒ Degradation not evident
	Remarks: _____		
I. Perimeter Ditches/Off-Site Discharge		☒ Applicable	☐ N/A
1.	**Siltation**	☐ Location shown on site map	☒ Siltation not evident
	Area extent _____		Depth _____
	Remarks: _____		
2.	**Vegetative Growth**	☐ Location shown on site map	☐ N/A
	☒ Vegetation does not impede flow		
	Area extent _____		Type _____
	Remarks: There is some vegetative growth in ditch. It does not appear to impede flow.		

3. **Erosion**	☐ Location shown on site map	☒ Erosion not evident	
Area extent _____		Depth _____	
Remarks: _____			
4. **Discharge Structure**	☒ Functioning	☒ N/A	
Remarks: _____			

VIII. VERTICAL BARRIER WALLS ☐ Applicable ☒ N/A

IX. GROUNDWATER/SURFACE WATER REMEDIES ☒ Applicable ☐ N/A

A. Groundwater Extraction Wells, Pumps, and Pipelines ☐ Applicable ☒ N/A

B. Surface Water Collection Structures, Pumps, and Pipelines ☐ Applicable ☒ N/A

C. Treatment System ☐ Applicable ☒ N/A

D. Monitoring Data

1. **Monitoring Data**

☒ Is routinely submitted on time ☒ Is of acceptable quality

2. **Monitoring data suggests:**

☒ Groundwater plume is effectively contained ☐ Contaminant concentrations are declining

E. Monitored Natural Attenuation

1. **Monitoring Wells** (natural attenuation remedy)

☒ Properly secured/locked	☒ Functioning	☒ Routinely sampled	☒ Good condition
☐ All required wells located	☐ Needs Maintenance		☐ N/A

Remarks: Did not visit all of the compliance wells on site. Those observed were in good condition.

X. OTHER REMEDIES

If there are remedies applied at the site and not covered above, attach an inspection sheet describing the physical nature and condition of any facility associated with the remedy. An example would be soil vapor extraction. Not applicable.

XI. OVERALL OBSERVATIONS

A. Implementation of the Remedy

Review of the data collected during the FYR period and supporting documentation indicates that the MRSOU remedial action continues to be operating and functioning as designed. The Milltown Dam has been completely removed, contaminant sediments have been excavated or capped, and the Clark Fork River is flowing in the new channel with no sedimentation or erosion issues identified. Vegetation performance standards have now been met at areas for which the PRPs are responsible and are progressing at other areas. Groundwater monitoring indicates arsenic concentrations continue to exceed the arsenic groundwater standard.

B. Adequacy of O&M

The Long-Term Post Remedial Action Construction Monitoring Plan for MRSOU was finalized in 2013. The plan outlines the groundwater and surface water monitoring requirements as well as the long-term maintenance and monitoring requirements for the constructed repositories and buttress areas. Prior to the 2013 plan, monitoring was performed under the 2007 Remedial Action Monitoring Plan.

C. Early Indicators of Potential Remedy Problems

	Describe issues and observations such as unexpected changes in the cost or scope of O&M or a high frequency of unscheduled repairs that suggest that the protectiveness of the remedy may be compromised in the future. None identified.
D.	**Opportunities for Optimization**
	Describe possible opportunities for optimization in monitoring tasks or the operation of the remedy. None identified.

Site Inspection Team:

- Sara Sparks, EPA
- Brian Bartkowiak, MDEQ
- Claire Marcussen, Skeo
- Treat Suomi, Skeo

Appendix D-2: CFROU Site Inspection Checklist

FIVE-YEAR REVIEW SITE INSPECTION CHECKLIST	
I. SITE INFORMATION	
Site name: Clark Fork River OU	**Date of inspection: 11/03/2015**
Location and Region: Milltown, Missoula County, Montana, EPA Region 8	**EPA ID: MTD980717565**
Agency, office, or company leading the five-year review: EPA	**Weather/temperature: 30°s Fahrenheit, cloudy, occasional snow**
Remedy Includes: (Check all that apply) ☒ Landfill cover/containment ☐ Access controls ☒ Institutional controls ☐ Groundwater pump and treatment ☐ Surface water collection and treatment ☒ Other In-situ treatment of soils and sediments.	☐ Monitored natural attenuation ☐ Groundwater containment ☐ Vertical barrier walls
Attachments: ☒ Inspection team roster attached	☒ Site map attached (See Figure 1)
II. INTERVIEWS (Check all that apply)	
1. **O&M site manager/ Local Regulatory Authorities and Response Agencies** _____ Name _____ Title mm/dd/yyyy Date Interviewed ☐ at site ☐ at office ☐ by phone Phone no. _____ Problems, suggestions; ☐ Report attached _____	
2. **O&M staff** _____ Name _____ Title mm/dd/yyyy Date Interviewed ☐ at site ☐ at office ☐ by phone Phone no. _____ Problems, suggestions; ☐ Report attached _____	
3. **Other interviews** (optional) ☐ Report attached	

Jeffrey Johnson, National Park Service; nearby resident

III. ON-SITE DOCUMENTS & RECORDS VERIFIED (Check all that apply)

1. **O&M Documents**

☐ O&M manual	☒ Readily available	☒ Up to date	☒ N/A
☐ As-built drawings	☒ Readily available	☒ Up to date	☒ N/A
☐ Maintenance logs	☒ Readily available	☒ Up to date	☒ N/A

Remarks: A breakdown of costs for the CFROU from 2008 to 2014 were provided and reviewed. Since remedial actions are still being designed and implemented at the CFROU, separate O&M costs are not presented.

2. **Site-Specific Health and Safety Plan**	☒ Readily available	☒ Up to date	☒ N/A
☒ Contingency plan/emergency response plan	☒ Readily available	☒ Up to date	☒ N/A

Remarks: Safety requirements are in bid packages. Contractors have site-specific health and safety plans.

3. **O&M and OSHA Training Records**	☒ Readily available	☒ Up to date	☒ N/A

Remarks: _____

4. **Permits and Service Agreements**

☐ Air discharge permit	☐ Readily available	☐ Up to date	☒ N/A
☐ Effluent discharge	☐ Readily available	☐ Up to date	☒ N/A
☐ Waste disposal, POTW	☐ Readily available	☐ Up to date	☒ N/A
☐ Other permits _____	☐ Readily available	☐ Up to date	☒ N/A

Remarks: _____

5. **Gas Generation Records**	☐ Readily available	☐ Up to date	☒ N/A

Remarks: _____

6. **Settlement Monument Records**	☐ Readily available	☐ Up to date	☒ N/A

Remarks: _____

7. **Groundwater Monitoring Records**	☐ Readily available	☐ Up to date	☒ N/A

Remarks:

8. **Leachate Extraction Records**	☐ Readily available	☐ Up to date	☒ N/A

Remarks: _____

9. **Discharge Compliance Records**

☐ Air	☐ Readily available	☐ Up to date	☒ N/A
☐ Water (effluent)	☐ Readily available	☐ Up to date	☒ N/A

Remarks: _____

10. **Daily Access/Security Logs**	☐ Readily available	☐ Up to date	☒ N/A
Remarks: ______			

IV. O&M COSTS

1. **O&M Organization**

☒ State in-house	☒ Contractor for State
☐ PRP in-house	☐ Contractor for PRP
☐ Federal Facility in-house	☐ Contractor for Federal Facility
☐ ______	

2. **O&M Cost Records**

☒ Readily available	☐ Up to date
☐ Funding mechanism/agreement in place	☐ Unavailable

3. **Unanticipated or Unusually High O&M Costs During Review Period**

Describe costs and reasons: None.

V. ACCESS AND INSTITUTIONAL CONTROLS ☒ Applicable ☐ N/A

A. Fencing

1. **Fencing damaged** ☐ Location shown on site map ☐ Gates secured ☐ N/A

Remarks: Fencing is located throughout Reach A to protect revegetation efforts from humans and wildlife.

B. Other Access Restrictions

1. **Signs and other security measures** ☐ Location shown on site map ☐ N/A

Remarks: Signs in Reach A notify people of access restrictions. However, there are no warning signs anywhere else (including Reaches B and C).

C. Institutional Controls (ICs)

1.	**Implementation and enforcement** Site conditions imply ICs not properly implemented ☐ Yes ☒ No ☐ N/A Site conditions imply ICs not being fully enforced ☐ Yes ☒ No ☐ N/A Type of monitoring (e.g., self-reporting, drive by) ______ Frequency ______ Responsible party/agency Contact ______ ______ mm/dd/yyyy ______ Name Title Date Phone no. Reporting is up-to-date ☐ Yes ☐ No ☒ N/A Reports are verified by the lead agency ☐ Yes ☐ No ☒ N/A Specific requirements in deed or decision documents have been met ☒ Yes ☐ No ☐ N/A Violations have been reported ☐ Yes ☐ No ☒ N/A Other problems or suggestions: ☐ Report attached The Powell Creek Overlay District covers the area contaminated by mining and smelting wastes from operations further upstream in the Butte and Anaconda areas. The Overlay District is intended to ensure that future land use in the Superfund Overlay District is compatible with the presence of potential contaminants and the remedial actions required to isolate those potential contaminants from the environment.
2.	**Adequacy** ☒ ICs are adequate ☐ ICs are inadequate ☐ N/A Remarks: As additional remedial actions are completed, additional institutional controls may be needed in other areas of the Site.
D. General	
1.	**Vandalism/trespassing** ☐ Location shown on site map ☒ No vandalism evident Remarks: ______
2.	**Land use changes on site** ☒ N/A Remarks:
3.	**Land use changes off site** ☒ N/A Remarks: ______
VI. GENERAL SITE CONDITIONS	
A. Roads ☒ Applicable ☐ N/A	
1.	Roads damaged ☐ Location shown on site map ☒ Roads adequate ☐ N/A Remarks: Roads are kept graded and wet to limit dust.
B. Other Site Conditions	
	Remarks:
VII. LANDFILL COVERS ☒ Applicable ☐ N/A	
A. Landfill Surface	

1.	**Settlement** (Low spots)	☐ Location shown on site map	☒ Settlement not evident
	Arial extent _____		Depth _____
	Remarks: _____		
2.	**Cracks**	☐ Location shown on site map	☒ Cracking not evident
	Lengths _____	Widths _____	Depths _____
	Remarks: _____		
3.	**Erosion**	☐ Location shown on site map	☒ Erosion not evident
	Arial extent _____		Depth _____
	Remarks:		
4.	**Holes**	☐ Location shown on site map	☒ Holes not evident
	Arial extent _____		Depth _____
	Remarks: _____		
5.	**Vegetative Cover**	☐ Grass	☒ Cover properly established
	☐ No signs of stress	☐ Trees/Shrubs (indicate size and locations on a diagram)	
	Remarks: East Side Road pasture was recently revegetated and lined.		
6.	**Alternative Cover** (armored rock, concrete, etc.)		☒ N/A
	Remarks:		
7.	**Bulges**	☐ Location shown on site map	☒ Bulges not evident
	Arial extent _____		Height _____
	Remarks: _____		
8.	**Wet Areas/Water Damage**	☒ Wet areas/water damage not evident	
	☐ Wet areas	☐ Location shown on site map	Arial extent _____
	☐ Ponding	☐ Location shown on site map	Arial extent _____
	☐ Seeps	☐ Location shown on site map	Arial extent _____
	☐ Soft subgrade	☐ Location shown on site map	Arial extent _____
	Remarks: _____		
9.	**Slope Instability**	☐ Slides	☐ Location shown on site map
	☒ No evidence of slope instability		
	Arial extent _____		
	Remarks: _____		

B. Benches ☐ Applicable ☒ N/A

(Horizontally constructed mounds of earth placed across a steep landfill side slope to interrupt the slope in order to slow down the velocity of surface runoff and intercept and convey the runoff to a lined channel.)

C. Letdown Channels	☐ Applicable	☒ N/A
(Channel lined with erosion control mats, riprap, grout bags, or gabions that descend down the steep side slope of the cover and will allow the runoff water collected by the benches to move off of the landfill cover without creating erosion gullies.)		
D. Cover Penetrations	☐ Applicable	☒ N/A
E. Gas Collection and Treatment	☐ Applicable	☒ N/A
F. Cover Drainage Layer	☐ Applicable	☒ N/A
G. Detention/Sedimentation Ponds	☐ Applicable	☒ N/A
H. Retaining Walls	☐ Applicable	☒ N/A
I. Perimeter Ditches/Off-Site Discharge	☐ Applicable	☒ N/A
VIII. VERTICAL BARRIER WALLS	☐ Applicable	☒ N/A
IX. GROUNDWATER/SURFACE WATER REMEDIES	☐ Applicable	☒ N/A
A. Groundwater Extraction Wells, Pumps, and Pipelines	☐ Applicable	☒ N/A
B. Surface Water Collection Structures, Pumps, and Pipelines	☐ Applicable	☒ N/A
C. Treatment System	☐ Applicable	☒ N/A

X. OTHER REMEDIES

If there are remedies applied at the site and not covered above, attach an inspection sheet describing the physical nature and condition of any facility associated with the remedy. An example would be soil vapor extraction.

XI. OVERALL OBSERVATIONS

A. Implementation of the Remedy

Describe issues and observations relating to whether the remedy is effective and functioning as designed. Begin with a brief statement of what the remedy is to accomplish (i.e., to contain contaminant plume, minimize infiltration and gas emission, etc.).

Remedy implementation is ongoing. Remediation of Phase 1 of Reach A finished in April 2014. Long-term monitoring is underway to assess groundwater, surface water and vegetation during remediation.

B. Adequacy of O&M

Describe issues and observations related to the implementation and scope of O&M procedures. In particular, discuss their relationship to the current and long-term protectiveness of the remedy.

Not applicable.

C. Early Indicators of Potential Remedy Problems

Describe issues and observations such as unexpected changes in the cost or scope of O&M or a high frequency of unscheduled repairs that suggest that the protectiveness of the remedy may be compromised in the future.

None identified.

D. Opportunities for Optimization

Describe possible opportunities for optimization in monitoring tasks or the operation of the remedy.

None identified.

Site Inspection Team:

- Sara Sparks, EPA

- Brian Bartkowiak, MDEQ
- Claire Marcussen, Skeo
- Treat Suomi, Skeo

Appendix E-1: Photographs from MRSOU Site Inspection

Information sign overlooking Milltown Reservoir at the Milltown Bluff


Clark Fork river from bluff at Milltown State Park. Includes views of several site repositories, including the Right Bank Repository and the Interstate-90 slope.


View of the Sheriff Posse Grounds Parcel from Milltown Bluff.


The Tunnel Pond Repository.


View of the Interstate-90 slope.


Orange cone marking hole in the Right Bank Repository.


View of the Clark Fork River.


Flagging marking area of subsidence at the Right Bank Repository.

View of the Bonner Development Group Parcel.

Timbers for use in park construction.

”Keep Out” sign at the Milltown Reservoir revegetation area.


Riprap along the banks of the Blackfoot River under the Interstate-90 bridge.

Rodeo grounds at the Sheriff Posse Grounds Parcel.


Milltown Bluff and the Tunnel Pond Repository.


Sundial at Bonner Learning Park.

Appendix E-2: Photographs from the CFROU Site Inspection


CFROU Phase 1 remediation area.


CFROU Phase 1 remediation area.

Sign for river closure at the CFROU.

Phase 2 remediation in progress.

View of Arrow Stone Park.

Riverbank at Arrow Stone State Park


Residential area in Deer Lodge.


Trestle area in Deer Lodge.


KOA property, Clark Fork River and residential trailers.


East Side Road and pasture remediation revegetation.

Downstream of Phase 7.


Racetrack Pond.

Signage along road due to remedial work.


Revegetation crew.


Revegetation area.

Grant-Kohrs Ranch National Historic Site.

Grant-Kohrs Ranch National Historic Site.

USGS gauge station along the Clark Fork River.


View of Clark Fork River along Reach C.

Appendix F: MRSOU Monitoring Data

Table F-1. Historic Dissolved Arsenic Concentration Data Summary, 2008 to 2015

Compliance Well Number	**Dissolved Arsenic** (µg/L)															
Month/Year	Jun-08	Jan-09	Jun-09	Dec-09	Jun-10	Jan-11	Jun-11	Dec-11	Jun-12	Jan-13	Jun-13	Dec-13	Jun-14	Dec-14	Jun-15	Jan-16
105C	3.24	3.16	3.24	2.98	2.33	2.46	2.29	2.03	2.29	1.71	2.08	1.87	2.03	1.99	1.87	1.85
11R						**22.4** [2]	**10.9**	**23.3**	**23.3**	**19.2**	**22.6**	**18.8**	**20.7**	**21.9**	**24.8**	**21.4**
110B	**10.40**	**10.25**	**10.5**	**10.6**	9.5	9.0	9.17	9.19	9.92	7.70	8.84	7.75	8.47	8.02	9.17	7.79
922D	**11.50**	**12.60**	**13.8**	**12.5**	**12.0**	**12.4**	**12.8**	**11.6**	**12.8**	9.29	**12.50**	9.91	**12.1**	**10.1**	**12.2**	9.60
107A				**66.50**	**57.6**	**42.9**	**39.5**	**38.4**	**45.0**	**27.7**	**11.5**	**26.2**	**31.4**	**25.2**	**28.5**	**22.9**
104A					**11.4**		**11.8**	9.8	**11.3**	**10.2**	9.96	9.25	**10.9**	**11.70**	**11.9**	**13.9**
103B	**25.40**	**25.90**	**30.2**	**27.3**	**29.0**	**21.8**	**22.9**	**17.7**	**25.9**	**16.0**	**13.7**	**18.7**	**23.2**	**20.6**	**21.8**	**18.4**
HLA-2	**45.50**		**43.50**	**35.6**	**31.8**	**26.3**	**27.1**	**22.3**	**34.8**	**34.1**	**21.2**	**10.3**	**11.2**	**11.0**	**12.3**	**10.9**
917B	**158**	**162**	**133**	**148**	**125**	**116**	**108**	**85**	**97.6**	**61.1**	**47.4**	**57.5**	**74.9**	**55.0**	**67.4**	**52.8**
921A				7.35	6.63	7.19	8.42	6.41	8.80	6.50	8.02	7.09	10.6	7.85	9.12	9.53
TPR-10					2.33	8.22	7.78	**16.6**	**12.7**	**21.4**	**12.1**	**21.1**	**19.0**	**25.8**	**18.8**	**12.5**
913A										0.649 J	0.814J	1.12J	0.994J	1.13J	0.867J	1.12J
11 [1]	4.23	0.68	3.420	1.13	4.43	0.449 J	7.70 [3]	2.30	6.51	well has been replaced by "11R"						
104B [1]				0.18		1.85 [2]				well has been replaced by "104A"						
905 [1]	**18.10**	**76.80**	**17.60**	**46.8**	**18.1**	**45.9**	8.61	DRY	**74.9**	well is damaged, no longer on compliance list						
107C [1]	**13.40**	**15.30**	**14.50**	**15.8**						well has been replaced by "107A"						

Notes:
J = analyte detected below the reporting limit
1 = former compliance well
2 = sampled on March 1, 2011
3 = sampled on July 1, 2011
ND = not detected above the method detection limit (MDL)
Bold denotes exceedance of MCL

Table 2. Surface Water Data Summary, 2015

	Arsenic DISS	Arsenic TOT	Cadmium DISS	Cadmium TOT	Copper DISS	Copper REC	Lead DISS	Lead REC	Zinc DISS	Zinc REC	Hardness NA
Units	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**mg/L**
12340500 - Clark Fork River near Missoula											
3/25/2015	1.9	2.5	< 0.030	0.03	1.3	4.7	0.07	0.77	< 2.0	7.7	96.5
4/22/2015	2.2	2.6	< 0.030	< 0.030	1.7	4.2	0.04	0.59	< 2.0	6.5	99.8
5/13/2015	2	1.9	< 0.030	< 0.030	1.6	2.4	0.14	0.30	< 2.0	3.1	89.6
5/28/2015	3.3	5.8	< 0.030	0.06	3	8.6	0.19	1.11	2.1	3.9	95.2
6/10/2015	3.7	4.8	< 0.030	0.10	2.2	**10.8**	0.07	1.51	< 2.0	13.1	105
7/15/2015	3.1	3.3	< 0.030	< 0.030	1.9	2.8	< 0.040	0.17	< 2.0	3.5	129
8/12/2015	3.3	3.6	< 0.030	< 0.030	1.6	2.8	< 0.040	0.30	< 2.0	4.3	143
10/21/2015	4	4.6	< 0.030	< 0.030	1.3	3.7	< 0.040	0.51	< 2.0	5.8	158
12340000 - Blackfoot River near Bonner											
4/22/2015	0.8	0.89	< 0.030	< 0.030	< 0.80	0.9	< 0.040	0.15	< 2.0	< 2.0	93.2
5/13/2015	0.79	0.82	< 0.030	< 0.030	< 0.80	< 0.80	< 0.040	0.11	< 2.0	< 2.0	89.9
5/28/2015	0.96	1.1	< 0.030	< 0.030	0.96	1.3	0.167	0.39	< 2.0	< 2.0	95.9
7/15/2015	1.2	1.3	< 0.030	< 0.030	< 0.80	< 0.80	< 0.040	0.05	< 2.0	< 2.0	132
8/12/2015	1.2	1.4	< 0.030	< 0.030	< 0.80	< 0.80	< 0.040	0.06	< 2.0	< 2.0	133
10/21/2015	1.1	1.4	< 0.030	< 0.030	< 0.80	< 0.80	< 0.040	< 0.04	< 2.0	< 2.0	142
12334550 - Clark Fork River at Turah Bridge											
3/25/2015	3.6	5.2	0.03	0.077	2.6	**12**	0.11	1.85	3.3	16.8	110
4/22/2015	4.1	5.4	< 0.030	0.054	3	9.3	0.09	1.26	2.3	12.7	111
5/13/2015	3.5	3.9	< 0.030	< 0.030	2	4.1	0.06	0.45	< 2.0	4.9	85.1
5/28/2015	7.3	9.9	0.08	0.2	17.9	**37.8**	2.79	**6.16**	17.4	44.6	100
6/10/2015	7.4	9.6	< 0.030	0.15	4.3	**27.9**	0.17	**3.94**	5.1	30.7	110
7/15/2015	4.8	5.5	< 0.030	< 0.030	2.7	5	< 0.040	0.39	< 2.0	4.9	133
8/12/2015	5.2	6	< 0.030	0.041	2	5.2	0.042	0.56	< 2.0	8.2	155
10/21/2015	5.9	6.7	< 0.030	0.037	1.8	7.2	< 0.040	1.05	2.4	10.5	179

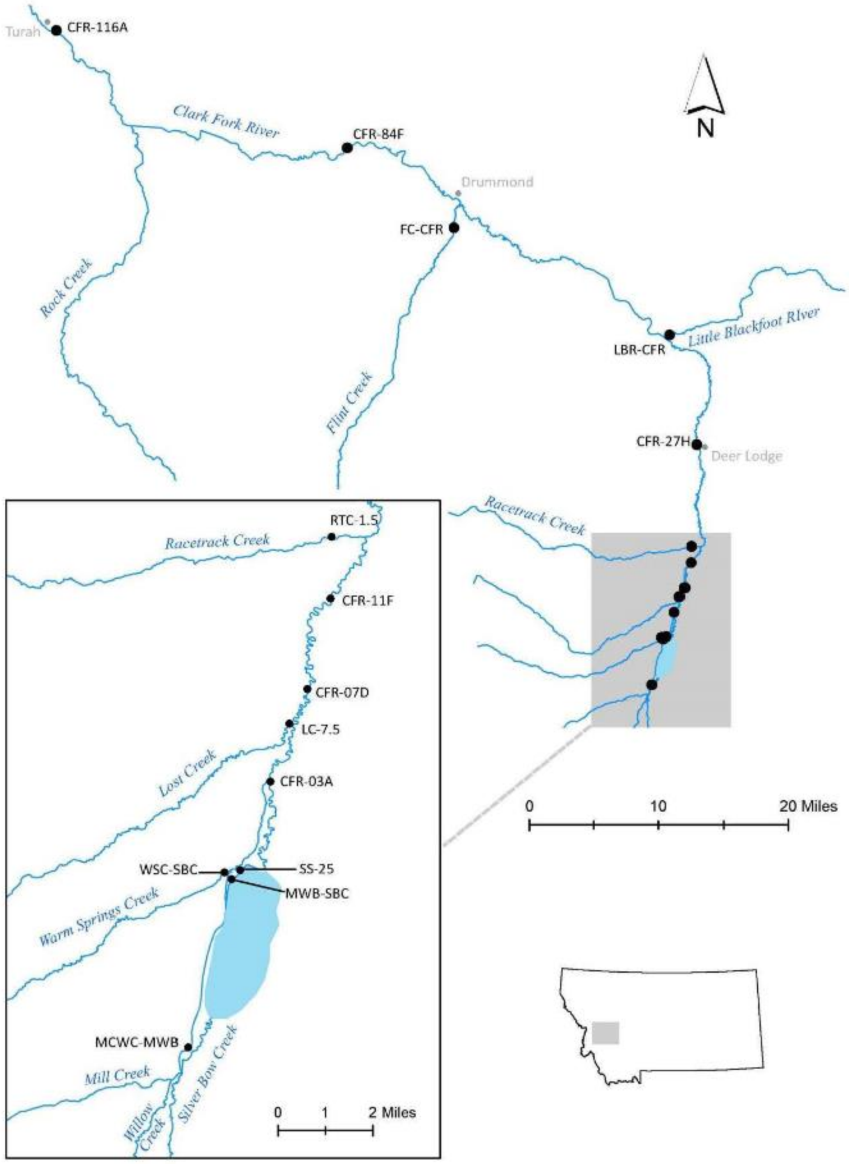
Notes:
Bold values denote exceedance of Montana DEQ-7 surface water standard which are measured as total recoverable concentrations.
Bold italic values denote exceedance of federal standards which are measured as dissolved.
The performance standard for copper is derived from the federal water quality criteria measured as dissolved.

Appendix G: CFROU Monitoring Data Summary

Surface Water

Arsenic and copper are the site COCs in surface water with regular exceedances. Of 30 samples collected in the mainstem Clark Fork River in 2014, no samples had zinc concentrations exceeding the performance goal. One sample had cadmium concentrations exceeding the performance goal. Four samples had lead concentrations exceeding the performance goal. However, arsenic commonly exceeded performance goals, particularly in Reach A. Of 24 samples collected in the Clark Fork River in Reach A, 96 percent exceeded the dissolved arsenic and 46 percent exceeded the total recoverable arsenic performance goals.

Silver Bow Creek and the Mill-Willow Creek appear to be sources of arsenic to the Clark Fork River; 17 of 18 of the samples from those sites exceeded the dissolved arsenic and 14 of 18 samples from those sites exceeded the total recoverable performance goals. Total recoverable copper concentration exceeded State of Montana chronic aquatic life standard in the mainstem Clark Fork River sites in 95 percent of the samples collected in the first and second quarters, but only at Deer Lodge in the third and fourth quarters. These results support the conclusion that copper contamination in the upper Clark Fork River is strongly related to streamflow and contaminant loading occurs primarily in Reach A.



Sediment

The highest instream sediment COC concentrations in the mainstem of the Clark Fork River were typically observed in the uppermost sample sites in Reach A and the lowest concentrations were typically observed at the downstream-most site at Turah in 2014. Concentrations of arsenic, copper, and zinc exceeded the probable effect concentration (PEC) at all of the Clark Fork River mainstem monitoring stations during both sample periods in 2014. Among all sites in the CFROU, arsenic most commonly exceeded the PEC (88 percent) followed by copper (83 percent), lead (79 percent), zinc (75 percent) and cadmium (50 percent).

Geomorphology

Geomorphology data were collected during the third quarter of 2014 in Phase 1 of Reach A in the CFROU. All monitoring metrics for channel dimension (i.e., cross-sectional area, bankfull width, mean bankfull depth and width-to-depth ratio), pool density and residual pool depth were within specified target ranges. The secondary channel stability performance target was also met because the secondary channel did not carry more than 10 percent of the streamflow of the main channel when streamflows reached the design bankfull level. Performance targets that were not met included floodplain connectivity and floodplain stability. Failure to meet the performance targets for channel connectivity and floodplain stability was the result of an over-connected river channel and floodplain, which results in increased avulsion risk, rather than the disconnected pre-project channel and floodplain. Performance targets for channel slope, sinuosity, bank erosion rate and channel migration rate were not scheduled for monitoring in Year 1 (2014). They will be evaluated in Year 5 (2018).

Vegetation Monitoring Data

Vegetation monitoring data were collected during the third quarter of 2014 in Phase 1 of Reach A in the CFROU. The only vegetation monitoring metric applicable to Year 1 monitoring was for overall floodplain plant survival which was 87.7 percent, exceeding the performance target for Year 1 (80 percent). However, survival was 17.2 percent lower in in the floodplain riparian shrub cover type (primarily consisting of swales) compared to the other floodplain cover types and survival of planted birch trees (*Betula occidentalis*) was particularly low. Low survival in swales may have been caused by the relatively deep swale excavation in combination with prolonged flood inundation which resulted in drowning. Other monitoring metrics with Year 1 performance targets (floodplain total native cover and noxious weed cover) will be monitored in 2015. Some floodplain plant survival monitoring plots will be monitored for plant survival in 2015 in planting units that had not yet been planted at the time of monitoring in 2014.

Macroinvertebrate

Overall biotic integrity of the macroinvertebrate community was either “none” or “slight” at all Clark Fork River tributary and mainstem sites; overall biointegrity scores throughout the CFROU ranged from 84.1 to 90.9. For metals sensitivity, index classifications in the mainstem were “none” at all sites except at Gemback Road which was “slight”; metals sensitivity scores in the mainstem ranged from 75.0 to 87.5. Metals sensitivity index classifications in the tributary sites was “moderate” at Racetrack Creek and Warm Springs Creek, “slight” in Silver Bow Creek and the Little Blackfoot River, and “none” in Mill-Willow Creek and Lost Creek; metals sensitivity scores in the tributaries ranged from 56.9 to 88.9. Nutrient sensitivity index classifications were “none” at all CFROU sites, with scores ranging from 81.9 to 100.0.

Periphyton

Periphyton monitoring results revealed that many of the non-diatom algae observed in the CFROU were tolerant to elevated nutrients, acidity, metals, or combinations of those conditions. However, diatom algae dominated the periphyton assemblage at all CFROU sites monitored in

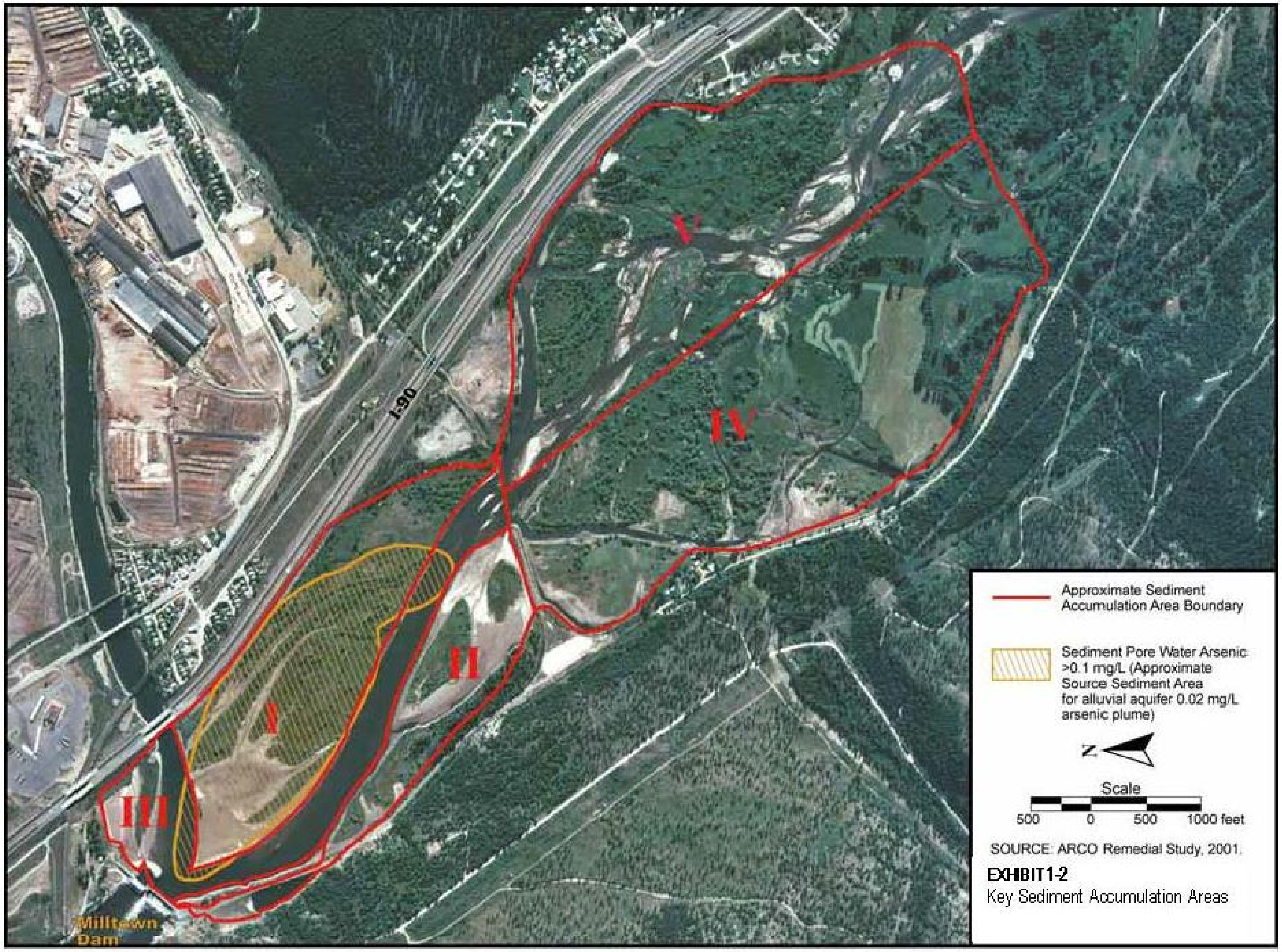
2014 and periphyton samples were scored according to several bioassessment indices. Impairment from sediment was more likely than not (i.e., ≥ 51 percent) in three tributary sites (Mill-Willow Creek, 93 percent; the Mill-Willow Bypass, 77 percent; and Silver Bow Creek, 81%) and four mainstem sites (near Galen, 88 percent; at Galen Road, 57 percent; at Gemback Road, 79 percent; and at Deer Lodge, 93 percent). Impairment from metals was more likely than not (i.e., ≥ 51 percent) in one tributary site (Silver Bow Creek, 74 percent) and four mainstem sites (near Galen, 74 percent; at Galen Road, 88 percent; at Gemback Road, 76 percent; and at Turah, 94 percent).

Fish

Fish Population
Based on fish population monitoring in the Clark Fork River, brown trout continue to dominate the trout species assemblage in the upper Clark Fork River. This is presumably due, at least in part, to their relatively high tolerance to metals compared to other salmonids. Brown trout populations appear to be moderately increasing since 2011 at monitoring sites in the mid- and upper-reaches of the Clark Fork River. Trout abundance in the Bearmouth reach remained low in 2014, as in prior years, relative to other reaches of the upper Clark Fork River. It is possible that above average discharge in 2011 increased the quality and quantity of brown trout spawning and rearing habitat in the upper Clark Fork River and tributaries, resulting in the modest increase in trout abundance in 2014.

Caged Fish
Results of survival monitoring of caged juvenile brown trout indicated that, as in previous survival studies in the upper Clark Fork River, mortality rates varied among sites and among months. Most of the mortality in 2014 in the caged fish occurred in April, July and August. This bimodal pattern was consistent with results from caged fish studies in 2012 and 2013. Mortality tended to be highest during spring runoff and on the descending limb of the hydrograph as water temperatures increased. Brown trout confined in the cages accumulated both copper and zinc in their tissues at both mainstem Clark Fork River and tributary sites. Tissue burdens of fish immediately after release from the hatchery were low compared to fish sampled from cages in the CFROU. Fish from cages in the mainstem had significantly higher metals burdens compared to fish from tributaries, but the difference was less pronounced for zinc.

Appendix H: MRSOU Sediment Accumulation Areas



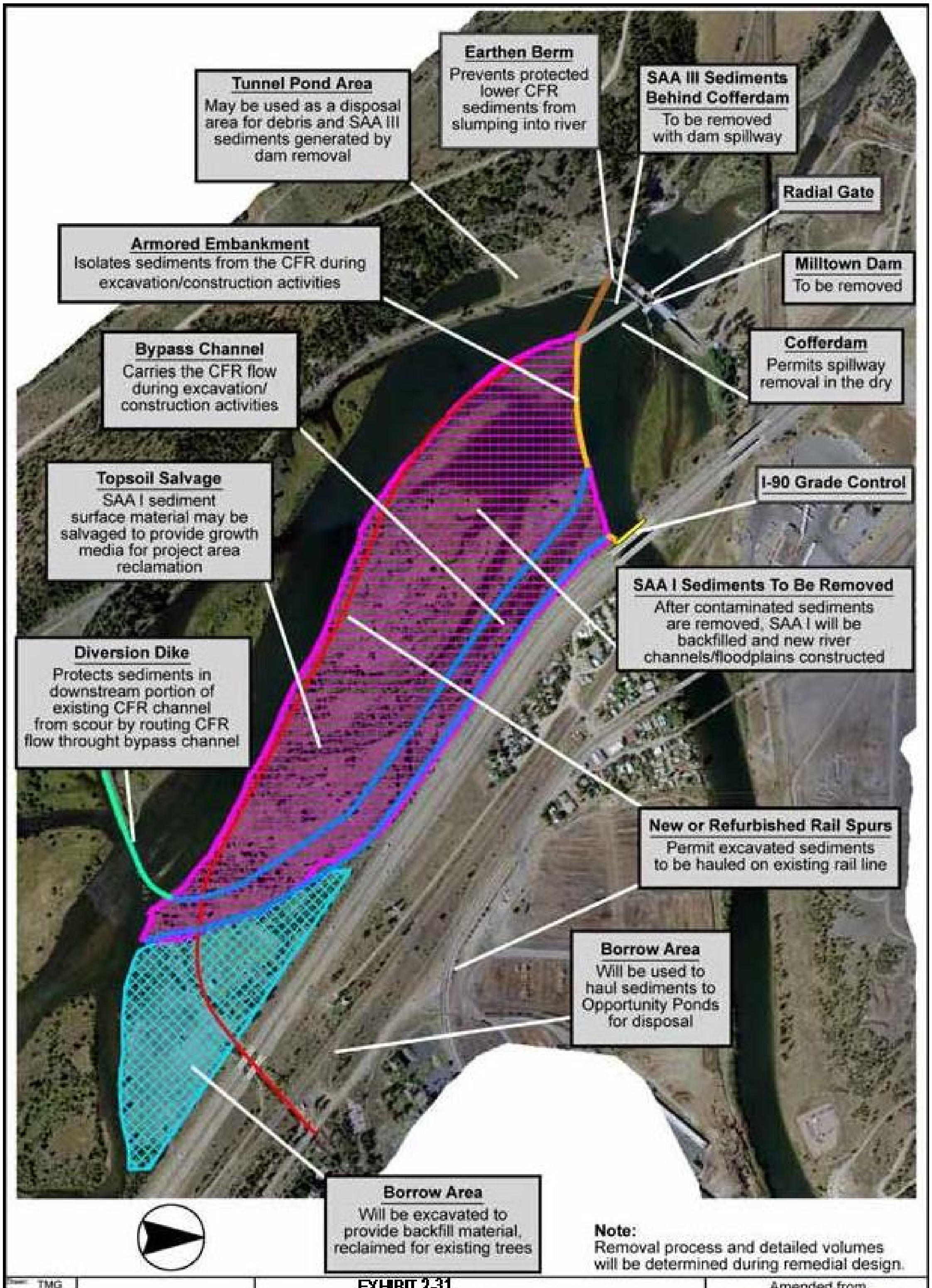


EXHIBIT 2-31
Conceptual Model of Remedial Cleanup Plan

Appendix I: Surface Water Data Evaluation

USGS
science for a changing world

Prepared in cooperation with the U.S. Environmental Protection Agency

Water-Quality Trends and Constituent-Transport Analysis for Selected Sampling Sites in the Milltown Reservoir/Clark Fork River Superfund Site in the Upper Clark Fork Basin, Montana, Water Years 1996–2015

Scientific Investigations Report 2016–5100

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U.S. Department of the Interior
U.S. Geological Survey

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SALLY JEWELL, Secretary

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Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

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Suggested citation:
Sando, S.K., and Vecchia, A.V., 2016, Water-quality trends and constituent-transport analysis for selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 1996–2015: U.S. Geological Survey Scientific Investigations Report 2016–5100, 82 p., http://dx.doi.org/10.3133/sir20165100.

ISSN 2328-0328 (online)

Contents

Figures

Appendix Figures

Tables

Appendix Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Concentrations of chemical constituents in water are given either in micrograms per liter (µg/L) or milligrams per liter (mg/L).

Load estimates are given in kilograms per day (kg/d).

Water year is defined as the 12-month period from October 1 through September 30 of the following calendar year. The water year is designated by the calendar year in which it ends. For example, water year 2010 is the period from October 1, 2009, through September 30, 2010.

Abbreviations

AMC	Anaconda Mining Company
FAC	flow-adjusted concentration
LRL	laboratory reporting level
LOWESS	locally weighted scatter plot smooth
NWQL	National Water Quality Laboratory
NWIS	National Water Information System
SEE	standard error of estimate
SRL	study reporting level
TSM	time-series model
USGS	U.S. Geological Survey

Water-Quality Trends and Constituent-Transport Analysis for Selected Sampling Sites in the Milltown Reservoir/Clark Fork River Superfund Site in the Upper Clark Fork Basin, Montana, Water Years 1996–2015

By Steven K. Sando and Aldo V. Vecchia

Abstract

During the extended history of mining in the upper Clark Fork Basin in Montana, large amounts of waste materials enriched with metallic contaminants (cadmium, copper, lead, and zinc) and the metalloid trace element arsenic were generated from mining operations near Butte and milling and smelting operations near Anaconda. Extensive deposition of mining wastes in the Silver Bow Creek and Clark Fork channels and flood plains had substantial effects on water quality. Federal Superfund remediation activities in the upper Clark Fork Basin began in 1983 and have included substantial remediation near Butte and removal of the former Milltown Dam near Missoula. To aid in evaluating the effects of remediation activities on water quality, the U.S. Geological Survey began collecting streamflow and water-quality data in the upper Clark Fork Basin in the 1980s.

Trend analysis was done on specific conductance, selected trace elements (arsenic, copper, and zinc), and suspended sediment for seven sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site for water years 1996–2015. The most upstream site included in trend analysis is Silver Bow Creek at Warm Springs, Montana (sampling site 8), and the most downstream site is Clark Fork above Missoula, Montana (sampling site 22), which is just downstream from the former Milltown Dam. Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Trend analysis was done by using a joint time-series model for concentration and streamflow. To provide temporal resolution of changes in water quality, trend analysis was conducted for four sequential 5-year periods: period 1 (water years 1996–2000), period 2 (water years 2001–5), period 3 (water years 2006–10), and period 4 (water years 2011–15). Because of the substantial effect of the intentional breach of Milltown Dam on March 28, 2008, period 3 was subdivided into period 3A (October 1, 2005–March 27, 2008) and period 3B (March 28, 2008–September 30, 2010) for the Clark Fork above Missoula (sampling site 22). Trend results were considered statistically significant when the statistical probability level was less than 0.01.

In conjunction with the trend analysis, estimated normalized constituent loads (hereinafter referred to as "loads") were calculated and presented within the framework of a constituent-transport analysis to assess the temporal trends in flow-adjusted concentrations (FACs) in the context of sources and transport. The transport analysis allows assessment of temporal changes in relative contributions from upstream source areas to loads transported past each reach outflow.

Trend results indicate that FACs of unfiltered-recoverable copper decreased at the sampling sites from the start of period 1 through the end of period 4; the decreases ranged from large for one sampling site (Silver Bow Creek at Warm Springs [sampling site 8]) to moderate for two sampling sites (Clark Fork near Galen, Montana [sampling site 11] and Clark Fork above Missoula [sampling site 22]) to small for four sampling sites (Clark Fork at Deer Lodge, Montana [sampling site 14], Clark Fork at Goldcreek, Montana [sampling site 16], Clark Fork near Drummond, Montana [sampling site 18], and Clark Fork at Turah Bridge near Bonner, Montana [sampling site 20]). For period 4 (water years 2011–15), the most notable changes indicated for the Milltown Reservoir/Clark Fork River Superfund Site were statistically significant decreases in FACs and loads of unfiltered-recoverable copper for sampling sites 8 and 22. The period 4 changes in FACs of unfiltered-recoverable copper for all other sampling sites were not statistically significant.

Trend results indicate that FACs of unfiltered-recoverable arsenic decreased at the sampling sites from period 1 through period 4 (water years 1996–2015); the decreases ranged from minor (sampling sites 8–20) to small (sampling site 22). For period 4 (water years 2011–15), the most notable changes indicated for the Milltown Reservoir/Clark Fork River Superfund Site were statistically significant decreases in FACs and loads of unfiltered-recoverable arsenic for sampling site 8 and near statistically significant decreases for sampling site 22. The period 4 changes in FACs of unfiltered-recoverable arsenic for all other sampling sites were not statistically significant.

Trend results indicate that FACs of suspended sediment decreased at the sampling sites from period 1 through period 4 (water years 1996–2015); the decreases ranged from moderate (sampling site 8) to small (sampling sites 11–22). For period 4 (water years 2011–15), the changes in FACs of suspended sediment were not statistically significant for any sampling sites.

The reach of the Clark Fork from Galen to Deer Lodge is a large source of metallic contaminants and suspended sediment, which strongly affects downstream transport of those constituents. Mobilization of copper and suspended sediment from flood-plain tailings and the streambed of the Clark Fork and its tributaries within the reach results in a contribution of those constituents that is proportionally much larger than the contribution of streamflow from within the reach. Within the reach from Galen to Deer Lodge, unfiltered-recoverable copper loads increased by a factor of about 4 and suspended-sediment loads increased by a factor of about 5, whereas streamflow increased by a factor of slightly less than 2. For period 4 (water years 2011–15), unfiltered-recoverable copper and suspended-sediment loads sourced from within the reach accounted for about 41 and 14 percent, respectively, of the loads at Clark Fork above Missoula (sampling site 22), whereas streamflow sourced from within the reach accounted for about 4 percent of the streamflow at sampling site 22. During water years 1996–2015, decreases in FACs and loads of unfiltered-recoverable copper and suspended sediment for the reach generally were proportionally smaller than for most other reaches.

Unfiltered-recoverable copper loads sourced within the reaches of the Clark Fork between Deer Lodge and Turah Bridge near Bonner (just upstream from the former Milltown Dam) were proportionally smaller than contributions of streamflow sourced from within the reaches; these reaches contributed proportionally much less to copper loading in the Clark Fork than the reach between Galen and Deer Lodge. Although substantial decreases in FACs and loads of unfiltered-recoverable copper and suspended sediment were indicated for Silver Bow Creek at Warm Springs (sampling site 8), those substantial decreases were not translated to downstream reaches between Deer Lodge and Turah Bridge near Bonner. The effect of the reach of the Clark Fork from Galen to Deer Lodge as a large source of copper and suspended sediment, in combination with little temporal change in those constituents for the reach, contributes to this pattern.

With the removal of the former Milltown Dam in 2008, substantial amounts of contaminated sediments that remained in the Clark Fork channel and flood plain in reach 9 (downstream from Turah Bridge near Bonner) became more available for mobilization and transport than before the dam removal. After the removal of the former Milltown Dam, the Clark Fork above Missoula (sampling site 22) had statistically significant decreases in FACs of unfiltered-recoverable copper in period 3B (March 28, 2008, through water year 2010) that continued in period 4 (water years 2011–15). Also, decreases in FACs of unfiltered-recoverable arsenic and suspended sediment were indicated for period 4 at this site. The decrease in FACs of unfiltered-recoverable copper for sampling site 22 during period 4 was proportionally much larger than the decrease for the Clark Fork at Turah Bridge near Bonner (sampling site 20). Net mobilization of unfiltered-recoverable copper and arsenic from sources within reach 9 are smaller for period 4 than for period 1 when the former Milltown Dam was in place, providing evidence that contaminant source materials have been substantially reduced in reach 9.

Introduction

Mining in the upper Clark Fork Basin in Montana began in 1864 when small-scale placer mining operations extracted gold from Silver Bow Creek and its tributaries in and near Butte (Freeman, 1900; U.S. Environmental Protection Agency, 2005; fig. 1). By the early 1900s, the small gold mining operations had transitioned to larger scale underground silver and copper mining owned by the former Anaconda Mining Company (AMC), with most of the ore being processed at AMC milling and smelting facilities near Anaconda (U.S. Environmental Protection Agency, 2005, 2010; Gammons and others, 2006). In 1955, the AMC mining operations began to transition from underground to open-pit mining, with the opening of the Berkeley Pit north of Butte. The Berkeley Pit mining operations and AMC milling and smelting operations continued until closure in the early 1980s.

During the extended history of mining in the upper Clark Fork Basin, large amounts of waste materials enriched with metallic contaminants (cadmium, copper, lead, and zinc) and the metalloid trace element arsenic were generated from mining operations near Butte and the milling and smelting operations near Anaconda (Andrews, 1987; Gammons and others, 2006). Extensive deposition of mining wastes in the Silver Bow Creek and Clark Fork channels and flood plains had substantial effects on water quality. Federal Superfund remediation activities in the upper Clark Fork Basin began in 1983 and have included substantial remediation near Butte and removal of the former Milltown Dam near Missoula in 2008 (U.S. Environmental Protection Agency, 2004, 2010; CDM, 2005; Sando and Lambing, 2011). The various Superfund activities are distributed among three National Priorities List sites: the Silver Bow Creek/Butte Area Site, the Anaconda Smelter Site, and the Milltown Reservoir/Clark Fork River Superfund Site, which are described in the "Description of Study Area" section of this report.

Water-quality data collection by the U.S. Geological Survey (USGS) in the upper Clark Fork Basin began during 1985–88 with the establishment of a small long-term monitoring program that has expanded through time and continued through present (2016). Sando and others (2014) analyzed the monitoring data and characterized flow-adjusted trends in mining-related contaminants for 22 sampling sites in the Silver Bow Creek/Butte Area Site, the Anaconda Smelter Site, and the Milltown Reservoir/Clark Fork River Superfund Site in the

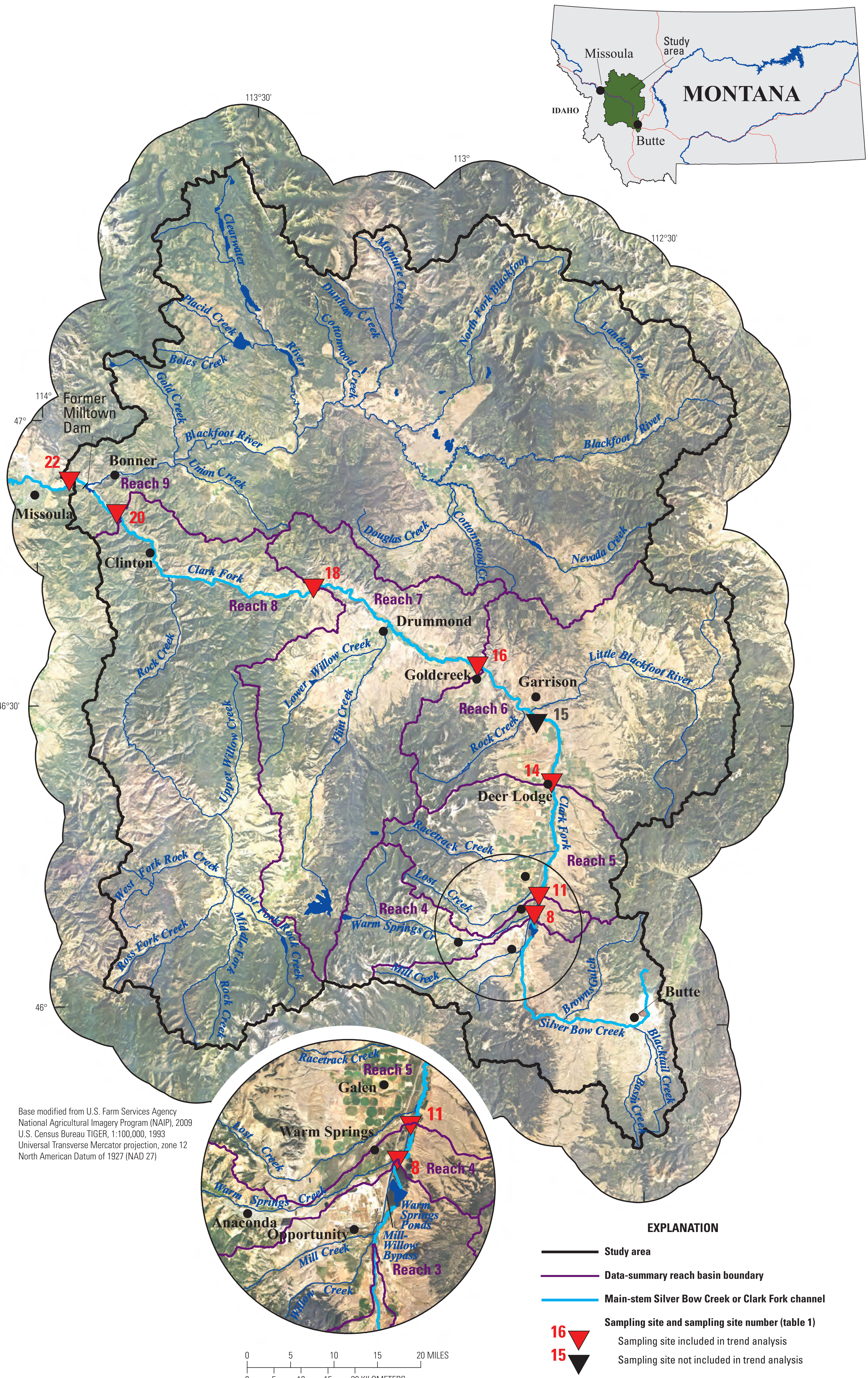

Figure 1. Location of study area, selected sampling sites, and data-summary reaches in the upper Clark Fork Basin, Montana; the Milltown Reservoir/Clark Fork River Superfund Site includes the reaches from sampling site 8 to sampling site 22.

upper Clark Fork Basin for water years 1996–2010 (water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends). An update of flow-adjusted water-quality trends for the monitoring data was needed for seven sampling sites to provide timely information for the 2016 5-year review for the Milltown Reservoir/Clark Fork River Superfund Site. The USGS, in cooperation with the U.S. Environmental Protection Agency, conducted this study to test for flow-adjusted trends (water years 1996–2015) in water quality at seven sampling sites (fig. 1, table 1) in the Milltown Reservoir/Clark Fork River Superfund Site by using a joint time-series model (TSM; Vecchia, 2005) for concentration and streamflow; an eighth site (Clark Fork above Little Blackfoot River near Garrison, Montana [sampling site 15; fig. 1, table 1]) was included in the study for the purpose of statistically summarizing water-quality data collected during water years 2011–15, but the period of water-quality data collection was insufficient for trend analysis.

Purpose and Scope

The primary purposes of this report are to (1) characterize temporal trends in flow-adjusted concentrations (filtered and unfiltered) of mining-related contaminants and (2) assess those trends in the context of source areas and transport of those contaminants through the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin. Trend analysis was done on specific conductance, selected trace elements (arsenic, copper, and zinc), and suspended sediment for seven sampling sites for water years 1996–2015. This report provides an update of and supersedes the trend results reported by Sando and others (2014) for seven sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site. This report presents the trend results and information on trend-analysis methods, streamflow conditions, and various data-related factors that affect trend results. This information is presented to assist in evaluating trend results; however, it is beyond the scope of this report to provide detailed explanations for all observed temporal changes.

Description of Study Area

The Clark Fork drains an extensive region in western Montana and northern Idaho in the Columbia River Basin (not shown on fig. 1). The main-stem Clark Fork begins at the confluence of Silver Bow and Warm Springs Creeks near Warm Springs, Montana, and flows about 485 miles (mi) through Montana and Idaho. The study area (fig. 1) encompasses the upper Clark Fork Basin in west-central Montana upstream from Clark Fork above Missoula, Montana (sampling site 22, table 1), with a drainage area of 5,999 square miles (mi^2). Sando and others (2014) presented somewhat detailed information describing the hydrographic, physiographic, climatic, and geologic characteristics of the upper Clark Fork Basin and an overview of mining and remediation activities.

Early Federal Superfund activities in the upper Clark Fork Basin involved designation of three areas as National Priorities List sites in 1983: the Silver Bow Creek Site, the Anaconda Smelter Site, and the Milltown Reservoir Site. The Silver Bow Creek Site was redesignated as the Silver Bow Creek/Butte Area Site in 1987 and includes remnants from mining operations near Butte and about 26 river miles of Silver Bow Creek extending from near Butte to the outlet of Warm Springs Ponds (U.S. Environmental Protection Agency, 2000; CDM, 2005). The Anaconda Smelter Site includes about 300 mi^2, primarily in the Mill, Willow, Warm Springs, and Lost Creek drainage basins near Anaconda (U.S. Environmental Protection Agency, 2010). Many remediation activities within the Anaconda Smelter Site are administered within the Regional Water, Waste, and Soils Operable Unit (Henry Elsen, U.S. Environmental Protection Agency, written commun., January 2016). The Milltown Reservoir Site was redesignated as the Milltown Reservoir/Clark Fork River Superfund Site in 1992. The Milltown Reservoir/Clark Fork River Superfund Site includes two primary operable units: the Milltown Reservoir Operable Unit and the Clark Fork Operable Unit. The Milltown Reservoir Operable Unit includes about 0.84 mi^2 defined by the area inundated by maximum pool elevation of the former Milltown Reservoir (U.S. Environmental Protection Agency, 2004). The Clark Fork Operable Unit includes streamside areas of the 115-mi reach of the Clark Fork extending from the Warm Springs Ponds outlet to the start of Milltown Reservoir Operable Unit (Montana Department of Environmental Quality, 2016).

The specific focus of this study is the Milltown Reservoir/Clark Fork River Superfund Site, which includes the Clark Fork Operable Unit and the Milltown Reservoir Operable Unit, and extends about 123 river miles from the outlet of Warm Springs Ponds on Silver Bow Creek (represented by sampling site 8) to the outlet of the former Milltown Reservoir (represented by sampling site 22, which is about 3 river miles downstream from the former Milltown Dam). Sampling sites included in this study are located on the main-stem channels of Silver Bow Creek and the Clark Fork. Sando and others (2014) included trend analyses for several sampling sites on tributaries to Silver Bow Creek or the Clark Fork in the Milltown Reservoir/Clark Fork River Superfund Site; however, data collection for most of the tributary sampling sites was discontinued in water year 2004. No tributary sampling sites were included in this study. The sampling site numbers and reach designations assigned by Sando and others (2014) generally have been retained to facilitate comparisons. An exception is Clark Fork above Little Blackfoot River near Garrison (USGS streamgage 12324400), for which data collection began in water year 2009. Streamgage 12324400 was not included in Sando and others (2014). A discontinued tributary sampling site (Little Blackfoot River near Garrison, Montana; USGS streamgage 12324590) was designated as sampling site 15 in Sando and others (2014), but in this study Clark Fork above Little Blackfoot River near Garrison (USGS streamgage 12324400) is designated as sampling site 15. The period of

Table 1. Information for selected sampling sites and data-summary reaches in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. USGS, U.S. Geological Survey; NA, not applicable]

Sampling site number[1] (fig. 1)	USGS site identification number	USGS site name	Abbreviated sampling site name	Data-summary reach[1,2]	Drainage area, in square miles	Period of water-quality data collection	Median annual sampling frequency, in samples per year (range)	Trend analysis periods[3]
8	12323750	Silver Bow Creek at Warm Springs, Montana	Silver Bow Creek at Warm Springs	3 and 4	473	3/1993–8/2015	8 (6–11)	1, 2, 3, 4
11	12323800	Clark Fork near Galen, Montana	Clark Fork near Galen	4 and 5	651	7/1988–8/2015	8 (1–13)	1, 2, 3, 4
14	12324200	Clark Fork at Deer Lodge, Montana	Clark Fork at Deer Lodge	5 and 6	995	3/1985–8/2015	8 (4–20)	1, 2, 3, 4
15	12324400	Clark Fork above Little Blackfoot River near Garrison, Montana	Clark Fork near Garrison	6	1,139	3/2009–8/2015	8 (7-8)	NA[4]
16	12324680	Clark Fork at Goldcreek, Montana	Clark Fork at Goldcreek	6 and 7	1,704	3/1993–8/2015	8 (6–10)	1, 2, 3, 4
18	12331800	Clark Fork near Drummond, Montana	Clark Fork near Drummond	7 and 8	2,501	3/1993–8/2015	8 (6–10)	1, 2, 3, 4
20	12334550	Clark Fork at Turah Bridge near Bonner, Montana	Clark Fork at Turah Bridge	8 and 9	3,641	3/1985–8/2015	8 (6–23)	1, 2, 3, 4
22	12340500	Clark Fork above Missoula, Montana	Clark Fork above Missoula	9	5,999	7/1986–8/2015	8 (2–18)	1, 2, 3A, 3B, 4

[1]For this study, the sampling site numbers and reach designations assigned by Sando and others (2014) generally have been retained to facilitate comparisons.

[2]Where two reach numbers are shown, the site is both an outflow from the upstream reach and an inflow to the downstream reach.

[3]The numerical designations of the trend analysis periods are defined as
water years 1996–2000;
1: water years 2001–5;
2: water years 2006–10;
3: water years 2011–15.
4: Because of the substantial effect of the breach and removal of Milltown Dam in 2008, for Clark Fork above Missoula (station 12340500), period 3 was subdivided into period 3A (October 1, 2005–March 27, 2008) and period 3B (March 28, 2008–September 30, 2010).

[4]Period of water-quality data collection is insufficient for trend analysis. Site was included in the study for the purpose of statistically summarizing water-quality data collected during water years 2011–15.

water-quality data collection is insufficient for trend analysis for sampling site 15, but this site was included in the study for the purpose of statistically summarizing water-quality data collected during water years 2011–15.

Data-Collection and Analytical Methods

Sando and others (2014) present information concerning historical aspects of data-collection and analytical methods used in the monitoring program. Data collected in the monitoring program are published (typically on an annual basis) in data reports that present the methods of data collection, water-quality data, quality-assurance data, and statistical summaries of the data (for example, Dodge and others, 2015). A brief overview of field and laboratory data-collection and analytical methods is presented in the following paragraphs.

The sampling design of the monitoring program provides information relevant to several objectives, including evaluating constituent transport, regulatory compliance, and long-term trends. Since 1993, the sampling frequency of the main-stem sampling sites in the monitoring program generally has been consistent, with the sites sampled eight times per year in most years. In the monitoring program, the seasonal timing of sample collection placed greater emphasis on the snowmelt runoff period (typically April–July), when streamflow conditions are high and variable and constituent transport is large. About 75 percent of samples were collected during April–July. In general, the frequency and timing of sample collection throughout the period of data collection among the sites are reasonably consistent to provide reasonable consistency in trend-analysis results.

In the monitoring program, water samples were collected from vertical transits throughout the entire stream depth at multiple locations across the stream by using standard USGS depth- and width-integration methods (U.S. Geological Survey, variously dated). Those methods provide a vertically and laterally discharge-weighted composite sample that is intended to be representative of the entire flow passing through the cross section of a stream (Dodge and others, 2015). Specific conductance was measured onsite in subsamples from the composite water samples. Subsamples of the composite water samples were analyzed at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, for filtered (0.45-micrometer pore size) and unfiltered-recoverable concentrations of the trace-element constituents (table 2) by using methods described by Garbarino and Struzeski (1998) and Garbarino and others (2006). Water samples also were analyzed for suspended-sediment concentrations by the USGS sediment laboratory in Helena, Montana. All water-quality data are available in the USGS National Water Information System (NWIS; U.S. Geological Survey, 2015).

Quality Assurance

Sando and others (2014) present information concerning historical aspects of quality-assurance procedures used in the monitoring program. Quality-assurance data collected in the monitoring program are reported and statistically summarized in annual data reports (for example, Dodge and others, 2015). Selected quality-assurance information relevant to this study is presented in the following paragraphs.

Analytical results for field quality-assurance samples (including field blank and replicate samples) that were collected in the monitoring program during water years 1993–2015 were compiled and statistically summarized (table 1–1 in appendix 1 at the back of the report). Those data provide information on the consistency and environmental representativeness of data collection. Representative sampling for trace elements in streams is particularly difficult because of low concentrations in stream waters and ubiquitous presence in the sampling environment that produce an associated large potential for contamination.

Summary of analytical results for field blank samples (table 1–1 in appendix 1 at the back of the report) provides information on potential effects of contamination during the sampling process on trend-analysis results. For the trace-element constituents included in the trend analysis (table 2), the frequency of detection in field blank samples at concentrations greater than the laboratory reporting level (LRL) at the time of analysis ranged from 0.5 percent (filtered arsenic) to 10.7 percent (unfiltered-recoverable zinc). Precise statistical analysis of the analytical results of field blank samples is difficult because of the multiple LRLs used by NWQL during the study period (table 2). Also, it is difficult to precisely quantify the field blank sample results with respect to the study datasets because contamination indicated by field blank samples was routinely monitored in the Clark Fork monitoring program, and stream-sample data judged to be affected by persistent contamination issues were identified during periodic reviews of the data and excluded from data analysis. However, it is important that trend-analysis procedures are structured to minimize potential effects of sampling contamination on low-concentration data included in the trend analysis. Specific procedures used in application of the trend-analysis method with respect to handling of low-concentration and censored data (that is, analytical results reported as less than the LRL; Helsel, 2005) are described in the section of this report "General Description of the Time-Series Model."

Summary of analytical results for field replicate samples (table 1–1 in appendix 1 at the back of the report) provides information on data precision. For the entire study period, the relative standard deviations (a measure of overall precision) for field replicate sample pairs were within 20 percent for all constituents, indicating reasonable precision (Taylor, 1987; Dodge and others, 2015).

Table 2. Properties, constituents, and associated information relating to laboratory and study reporting levels.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. NWQL, U.S. Geological Survey National Water Quality Laboratory; µS/cm, microsiemen per centimeter at 25 degrees Celsius; NA, not applicable; mg/L, milligram per liter; µg/L, microgram per liter]

Property or constituent	Units of measurement	Number of NWQL laboratory reporting levels during water years 1993–2015	Range in NWQL laboratory reporting levels	Study reporting level used in application of the time-series model[1]
Specific conductance[2]	µS/cm	NA	NA	NA
pH, standard units	standard units	NA	NA	NA
Calcium, filtered	mg/L	5	0.005–0.022	NA
Magnesium, filtered	mg/L	7	0.002–0.011	NA
Cadmium, filtered	µg/L	7	0.01–1.0	NA
Cadmium, unfiltered-recoverable	µg/L	10	0.007–1.0	NA
Copper, filtered[2]	µg/L	4	0.2–1	1.0
Copper, unfiltered-recoverable[2]	µg/L	6	0.3–2	1.0
Lead, filtered	µg/L	10	0.015–5	NA
Lead, unfiltered-recoverable	µg/L	6	0.03–5	NA
Zinc, filtered	µg/L	7	0.9–20	NA
Zinc, unfiltered-recoverable[2]	µg/L	4	2–31	2.0
Arsenic, filtered[2]	µg/L	7	0.022–1	1.0
Arsenic, unfiltered-recoverable[2]	µg/L	7	0.06–1	1.0
Suspended sediment[2]	mg/L	NA	NA	1

[1]Procedures for determining and applying the study reporting level used in the application of the time-series model are discussed in the section of this report "General Description of the Time-Series Model."

[2]Property or constituent was analyzed for temporal trends.

Analytical results for laboratory-spiked deionized-water blank samples and stream-water samples that were collected in the monitoring program during water years 1993–2015 are presented in tables 1–2 and 1–3, respectively, in appendix 1 at the back of the report. Annual mean recoveries for laboratory-spiked deionized-water blank samples for all constituents combined have ranged from 82.3 to 118 percent (mean of 104 percent). Annual mean recoveries for laboratory-spiked stream-water samples for all constituents combined have ranged from 84.3 to 114 percent (mean of 105 percent). Potential effects of temporal variability in spike recoveries on trend results are described in appendix 1 and also the section "Specific Aspects of the Application of the Time-Series Model in this Study" in appendix 2. Based on analysis of all quality-assurance data, the quality of the study datasets were determined to be suitable for trend analysis.

Overview of Streamflow and Water-Quality Characteristics for Water Years 2011–15

Statistically summarizing recent streamflow and water-quality characteristics of the study sampling sites (fig. 1, table 1) is useful for generally describing water quality and in providing comparative information relevant for interpreting trend results. Data are summarized for water years 2011–15, a summary period that represents recent water-quality conditions and the increment of data collected after the study period 1996–2010 reported by Sando and others (2014).

General Streamflow Characteristics for Water Years 2011–15

To aid in interpreting water-quality characteristics of the sampling sites, statistical summaries of continuous streamflow data are presented in table 3. The continuous streamflow data are available in NWIS (U.S. Geological Survey, 2015). In general, streamflow conditions during water years 2011–15 were somewhat high. Mean annual streamflows for water years 2011–15 generally were about 10–20 percent higher than period-of-record mean annual streamflows.

Water-Quality Characteristics for Water Years 2011–15

Statistical summaries of water-quality data (water years 2011–15) for sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin are presented in table 4. The statistical summaries in table 4 are based on unadjusted trace-element concentrations (the observed concentrations before flow adjustment). Flow adjustment, described in the sections of this report “General Description of the Time-Series Model” and “Factors that Affect Trend Results and Interpretation,” is relevant when interpreting trends in concentrations of water-quality constituents that are strongly dependent on streamflow conditions. However, flow adjustment is not relevant for statistically summarizing the observed water-quality data during water years 2011–15.

In addition to statistical summaries of unadjusted concentrations, ratios of median filtered to unfiltered-recoverable trace-element concentrations are reported in table 4 to provide general information on the predominant phase (that is, dissolved or particulate) of transport. Values of aquatic-life standards (Montana Department of Environmental Quality, 2012; based on median hardness for each site for water years 2011–15) for cadmium, copper, lead, and zinc are presented in table 1–4 in appendix 1 at the back of the report; those values were used for plotting the standards in relation to statistical distributions of selected trace elements. The arsenic human-health standard is 10 micrograms per liter (µg/L; Montana Department of Environmental Quality, 2012). Percentages of samples (water years 2011–15) with unadjusted unfiltered-recoverable concentrations exceeding water-quality standards for each site are presented in table 5. The exceedance percentages for the hardness-based aquatic-life standards for cadmium, copper, lead, and zinc in table 5 were based on comparison of trace-element concentrations of each individual sample with the aquatic-life standards that were calculated by using the hardness for each individual sample.

Statistical distributions of water-quality characteristics of the sampling sites are illustrated in figure 2 by using boxplots of selected example constituents (unadjusted specific conductance and unadjusted concentrations of copper, arsenic, and suspended sediment); the boxplots provide an overview of important water-quality characteristics in the upper Clark Fork Basin. Also shown in figure 2 are applicable water-quality standards. Specific conductance is presented as an example because it is an index of ionic strength, is strongly correlated with hardness (which is used in calculations of aquatic-life standards), and provides information on the extent of water contact with geologic materials, types of geologic materials present in the sampling-site basins, and potential effects of remediation activities on ionic strength. Copper and arsenic are presented as examples of trace elements because they are constituents of concern with respect to potential toxicity issues, but they have much different geochemical characteristics. Spatial and temporal variability in copper concentrations in the upper Clark Fork Basin generally is similar to variability in other metallic contaminants that tend to adsorb to particulates in water (Sando and others, 2014) and is considered generally representative of those constituents. In contrast, arsenic in the upper Clark Fork Basin tends to largely exist in the dissolved phase and does not exhibit the same variability as metallic contaminants (Sando and others, 2014). Suspended sediment is presented because it provides information on transport of particulate materials, which is a factor that can strongly affect transport of metallic contaminants.

To assist in the presentation of results, Sando and others (2014) divided Silver Bow Creek and the Clark Fork into nine data-summary reaches based on the location of sampling sites along the main-stems of those streams. The sampling site numbers and reach designations assigned by Sando and others (2014) generally have been retained to facilitate comparisons, and water-quality characteristics for sampling sites in six reaches (reaches 4–9) are presented. Water-quality characteristics within the six reaches are affected by environmental characteristics within the delineated reach basin boundaries (fig. 1). Water-quality characteristics of the sampling sites are described for each of the data-summary reaches. Emphasis is placed on describing spatial differences in observed water quality in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin during water years 2011–15.

Table 3. Statistical summaries of continuous streamflow data for selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft^3/s, cubic foot per second; POR, period of record]

Sampling site number (fig. 1, table 1)	Abbreviated sampling site name (table 1)	Drainage area, in square miles	Analysis period, in water years (number of years)	Statistical summaries of daily mean streamflow, in ft^3/s					
				Minimum	25th percentile	Median	Mean (also referred to as “mean annual streamflow”)	75th percentile	Maximum
8	Silver Bow Creek at Warm Springs	473	2011–15 (5)	22	51	65	96	97	1,060
			POR: 1994–2015 (22)	15	41	59	88	88	1,060
11	Clark Fork near Galen	651	2011–15 (5)	35	92	130	172	174	1,390
			POR: 1989–2015 (27)	13	70	100	143	152	1,390
14	Clark Fork at Deer Lodge	995	2011–15 (5)	55	187	237	283	302	1,960
			POR: 1979–2015 (37)	22	159	219	257	298	2,390
15	Clark Fork near Garrison	1,139	2011–15 (5)	61	198	263	315	331	2,560
			POR: 2010–15 (6)	61	209	267	323	334	2,560
16	Clark Fork at Goldcreek	1,704	2011–15 (5)	112	320	409	570	583	6,100
			POR: 1978–2015 (38)	55	280	380	519	556	9,100
18	Clark Fork near Drummond	2,501	2011–15 (5)	185	461	595	771	813	7,740
			POR: 1994–2015 (22)	77	419	563	718	758	8,430
20	Clark Fork at Turah Bridge	3,641	2011–15 (5)	250	790	990	1,490	1,560	12,700
			POR: 1985–2015 (31)	177	678	870	1,260	1,260	12,700
22	Clark Fork above Missoula	5,999	2011–15 (5)	500	1,400	1,730	3,330	3,760	28,100
			POR: 1930–2015 (86)	340	1,270	1,650	2,930	2,960	30,800

Table 4. Statistical summaries of water-quality data collected at selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 2011–15.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft³/s, cubic foot per second; NA, not applicable; µS/cm, microsiemen per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, unadjusted (not flow adjusted) units of measurement	Statistical summaries of water-quality data[1]							Ratios of median filtered to median unfiltered-recoverable concentrations for trace elements, in percent[3]
	Number of samples (values in parentheses indicate number of censored values)	Minimum uncensored value[2]	25th percentile	Median	Mean	75th percentile	Maximum	
Silver Bow Creek at Warm Springs, Montana (sampling site 8, fig. 1, table 1)								
Streamflow, instantaneous, ft³/s	40	20	66	89	146	161	1,030	NA
Specific conductance, µS/cm	40	182	342	394	407	489	577	NA
pH, standard units	40	8.1	8.5	8.8	NA	9.1	9.4	NA
Hardness, filtered, mg/L as $CaCO_3$	40	74.9	136	170	169	203	253	NA
Calcium, filtered, mg/L	40	22.5	39.7	48.4	48.7	58.6	73.3	NA
Magnesium, filtered, mg/L	40	4.52	9.10	11.8	11.5	14.4	16.9	NA
Cadmium, filtered, µg/L	40 (4)	0.023	0.031	0.038	0.044	0.054	0.096	45
Cadmium, unfiltered-recoverable, µg/L	40	0.027	0.065	0.085	0.119	0.125	0.567	
Copper, filtered, µg/L	40	1.6	2.6	3.5	4.3	4.7	21.4	51
Copper, unfiltered-recoverable, µg/L	40	2.8	5.0	6.8	9.5	11.2	35.2	
Iron, filtered, µg/L	40	7.0	16.2	30.0	30.0	38.7	63.0	13
Iron, unfiltered-recoverable, µg/L	40	61.1	159	225	256	313	839	
Lead, filtered, µg/L	40	0.044	0.103	0.158	0.162	0.186	0.566	14
Lead, unfiltered-recoverable, µg/L	40	0.37	0.81	1.16	1.80	2.07	6.39	
Manganese, filtered, µg/L	40	27.1	42.7	61.2	72.6	84.7	208	64
Manganese, unfiltered-recoverable, µg/L	40	60.1	77.5	95.2	116	130	332	
Zinc, filtered, µg/L	40 (11)	1.5	1.7	2.8	2.8	3.3	6.1	33
Zinc, unfiltered-recoverable, µg/L	40 (2)	2.3	5.5	8.6	13.3	14.1	69.8	
Arsenic, filtered, µg/L	40	8.4	13.4	19.2	20.9	28.0	38.1	86
Arsenic, unfiltered-recoverable, µg/L	40	10.4	16.9	22.4	22.8	28.8	37.9	
Suspended sediment, mg/L	40	1	3	6	6	7	21	NA
Suspended sediment, percent fines[4]	40	60	84	88	87	92	98	NA

Table 4. Statistical summaries of water-quality data collected at selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 2011–15.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft^3/s, cubic foot per second; NA, not applicable; µS/cm, microsiemen per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, unadjusted (not flow adjusted) units of measurement	Statistical summaries of water-quality data[1]							Ratios of median filtered to median unfiltered-recoverable concentrations for trace elements, in percent[3]
	Number of samples (values in parentheses indicate number of censored values)	Minimum uncensored value[2]	25th percentile	Median	Mean	75th percentile	Maximum	
Clark Fork near Galen, Montana (sampling site 11, fig. 1, table 1)								
Streamflow, instantaneous, ft^3/s	40	38	110	175	249	284	1,380	NA
Specific conductance, µS/cm	40	182	292	367	360	434	498	NA
pH, standard units	40	8.2	8.4	8.6	NA	8.7	9.1	NA
Hardness, filtered, mg/L as $CaCO_3$	40	76.4	125	164	158	191	225	NA
Calcium, filtered, mg/L	40	23.2	37.1	47.9	46.4	55.4	65.1	NA
Magnesium, filtered, mg/L	40	4.44	7.75	10.6	10.2	12.7	15.1	NA
Cadmium, filtered, µg/L	40 (2)	0.020	0.037	0.041	0.044	0.049	0.111	42
Cadmium, unfiltered-recoverable, µg/L	40	0.034	0.076	0.098	0.115	0.160	0.287	
Copper, filtered, µg/L	40	1.4	3.1	3.7	4.3	4.7	19.8	31
Copper, unfiltered-recoverable, µg/L	39	4.8	9.2	11.9	15.4	17.5	51.6	
Iron, filtered, µg/L	40	7.5	11.7	20.0	20.2	27.1	43.0	8
Iron, unfiltered-recoverable, µg/L	40	67.5	167	248	297	370	860	
Lead, filtered, µg/L	40	0.037	0.074	0.112	0.116	0.132	0.387	7
Lead, unfiltered-recoverable, µg/L	40	0.40	1.10	1.51	2.06	2.82	6.33	
Manganese, filtered, µg/L	40	13.1	37.8	41.8	54.7	63.8	130	48
Manganese, unfiltered-recoverable, µg/L	40	40.9	73.0	87.5	102	122	220	
Zinc, filtered, µg/L	40 (7)	1.4	1.8	2.6	2.8	3.3	9.4	24
Zinc, unfiltered-recoverable, µg/L	40	2.8	7.1	10.7	13.5	18.0	45.1	
Arsenic, filtered, µg/L	40	7.0	10.4	12.7	13.8	18.0	27.5	82
Arsenic, unfiltered-recoverable, µg/L	40	8.9	12.4	15.4	16.0	19.0	31.5	
Suspended sediment, mg/L	40	2	5	8	12	12	59	NA
Suspended sediment, percent fines[4]	40	32	68	76	75	87	96	NA

Table 4. Statistical summaries of water-quality data collected at selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 2011–15.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft^3/s, cubic foot per second; NA, not applicable; µS/cm, microsiemen per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, unadjusted (not flow adjusted) units of measurement	Statistical summaries of water-quality data[1]							Ratios of median filtered to median unfiltered-recoverable concentrations for trace elements, in percent[3]
	Number of samples (values in parentheses indicate number of censored values)	Minimum uncensored value[2]	25th percentile	Median	Mean	75th percentile	Maximum	
Clark Fork at Deer Lodge, Montana (sampling site 14, fig. 1, table 1)								
Streamflow, instantaneous, ft^3/s	40	44	197	265	353	357	2,000	NA
Specific conductance, µS/cm	40	228	346	436	412	481	525	NA
pH, standard units	40	7.9	8.2	8.3	NA	8.4	8.9	NA
Hardness, filtered, mg/L as $CaCO_3$	40	97.1	154	200	183	214	231	NA
Calcium, filtered, mg/L	40	29.1	46.0	58.8	54.0	62.8	68.8	NA
Magnesium, filtered, mg/L	40	5.92	9.56	13.1	11.8	13.7	15.5	NA
Cadmium, filtered, µg/L	40	0.035	0.049	0.065	0.069	0.072	0.280	43
Cadmium, unfiltered-recoverable, µg/L	40	0.046	0.094	0.152	0.203	0.221	0.784	
Copper, filtered, µg/L	40	3.4	5.6	7.0	8.3	7.7	45.9	25
Copper, unfiltered-recoverable, µg/L	40	9.4	15.2	27.6	46.3	49.3	220	
Iron, filtered, µg/L	40	5.5	11.7	18.5	18.7	24.9	45.8	4
Iron, unfiltered-recoverable, µg/L	40	63.0	224	436	708	788	4,290	
Lead, filtered, µg/L	40 (1)	0.041	0.082	0.142	0.152	0.189	0.372	4
Lead, unfiltered-recoverable, µg/L	40	0.55	1.61	3.28	5.70	6.63	32.8	
Manganese, filtered, µg/L	40	11.7	22.6	30.0	32.6	38.7	70.8	36
Manganese, unfiltered-recoverable, µg/L	40	22.9	57.4	82.9	97.5	115	364	
Zinc, filtered, µg/L	40	1.6	3.6	5.5	6.5	6.6	50.6	23
Zinc, unfiltered-recoverable, µg/L	40	5.0	15.3	23.2	34.9	37.6	164	
Arsenic, filtered, µg/L	40	7.7	10.3	13.3	14.0	16.2	36.6	81
Arsenic, unfiltered-recoverable, µg/L	40	9.7	13.8	16.4	19.2	20.3	46.6	
Suspended sediment, mg/L	40	2	8	17	33	31	218	NA
Suspended sediment, percent fines[4]	40	39	72	81	77	86	96	NA

Table 4. Statistical summaries of water-quality data collected at selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 2011–15.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft^3/s, cubic foot per second; NA, not applicable; µS/cm, microsiemen per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, unadjusted (not flow adjusted) units of measurement	Statistical summaries of water-quality data[1]							Ratios of median filtered to median unfiltered-recoverable concentrations for trace elements, in percent[3]
	Number of samples (values in parentheses indicate number of censored values)	Minimum uncensored value[2]	25th percentile	Median	Mean	75th percentile	Maximum	
Clark Fork above Little Blackfoot River near Garrison, Montana (sampling site 15, fig. 1, table 1)								
Streamflow, instantaneous, ft^3/s	39	71	227	289	410	418	2,310	NA
Specific conductance, µS/cm	39	249	363	449	421	479	527	NA
pH, standard units	39	7.9	8.2	8.4	NA	8.6	8.9	NA
Hardness, filtered, mg/L as $CaCO_3$	39	107	162	202	186	213	228	NA
Calcium, filtered, mg/L	39	31.9	47.4	58.8	54.1	61.7	66.5	NA
Magnesium, filtered, mg/L	39	6.65	10.4	13.4	12.3	14.4	15.5	NA
Cadmium, filtered, µg/L	39 (1)	0.024	0.050	0.065	0.067	0.072	0.227	42
Cadmium, unfiltered-recoverable, µg/L	39	0.027	0.117	0.155	0.227	0.272	0.835	
Copper, filtered, µg/L	39	2.8	6.2	7.9	9.2	9.7	40.6	25
Copper, unfiltered-recoverable, µg/L	39	10.0	19.1	31.9	51.3	54.0	222	
Iron, filtered, µg/L	38	5.2	9.2	15.7	19.0	25.2	64.4	3
Iron, unfiltered-recoverable, µg/L	38	40.7	256	505	806	823	3,860	
Lead, filtered, µg/L	39 (1)	0.048	0.086	0.135	0.181	0.247	0.715	4
Lead, unfiltered-recoverable, µg/L	39	0.33	2.08	3.74	6.40	6.63	32.3	
Manganese, filtered, µg/L	39	8.6	20.7	27.2	29.4	35.7	65.1	32
Manganese, unfiltered-recoverable, µg/L	39	13.4	63.4	84.5	105	129	344	
Zinc, filtered, µg/L	39 (2)	1.9	3.1	4.9	5.6	6.9	37.1	18
Zinc, unfiltered-recoverable, µg/L	39 (1)	3.2	15.9	26.7	43.9	44.5	181	
Arsenic, filtered, µg/L	39	7.8	10.9	15.2	15.0	17.3	36.7	87
Arsenic, unfiltered-recoverable, µg/L	39	10.5	15.2	17.4	20.3	21.2	46.0	
Suspended sediment, mg/L	39	1	11	21	37	37	205	NA
Suspended sediment, percent fines[4]	39	46	72	79	77	83	92	NA

Table 4. Statistical summaries of water-quality data collected at selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 2011–15.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft^3/s, cubic foot per second; NA, not applicable; µS/cm, microsiemen per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, unadjusted (not flow adjusted) units of measurement	Statistical summaries of water-quality data[1]							Ratios of median filtered to median unfiltered-recoverable concentrations for trace elements, in percent[3]
	Number of samples (values in parentheses indicate number of censored values)	Minimum uncensored value[2]	25th percentile	Median	Mean	75th percentile	Maximum	
Clark Fork at Goldcreek, Montana (sampling site 16, fig. 1, table 1)								
Streamflow, instantaneous, ft^3/s	40	137	393	522	820	902	4,450	NA
Specific conductance, µS/cm	40	216	297	364	353	411	456	NA
pH, standard units	40	7.9	8.1	8.3	NA	8.6	9.1	NA
Hardness, filtered, mg/L as $CaCO_3$	40	98.5	131	165	158	186	211	NA
Calcium, filtered, mg/L	40	29.6	38.7	48.2	46.5	55.0	62.1	NA
Magnesium, filtered, mg/L	40	5.96	8.21	10.6	10.2	12.2	13.6	NA
Cadmium, filtered, µg/L	40 (3)	0.020	0.031	0.041	0.044	0.050	0.124	40
Cadmium, unfiltered-recoverable, µg/L	40	0.021	0.072	0.102	0.158	0.209	0.530	
Copper, filtered, µg/L	40	2.1	4.3	5.1	6.1	6.4	23.3	27
Copper, unfiltered-recoverable, µg/L	40	5.6	11.4	18.6	32.1	41.3	133	
Iron, filtered, µg/L	40 (1)	3.8	8.8	18.6	25.9	36.0	93.7	5
Iron, unfiltered-recoverable, µg/L	40	31.8	182	360	699	922	2,940	
Lead, filtered, µg/L	40 (2)	0.035	0.056	0.111	0.141	0.170	0.677	5
Lead, unfiltered-recoverable, µg/L	40	0.14	1.31	2.24	4.33	5.99	19.9	
Manganese, filtered, µg/L	40	5.5	12.8	16.1	18.3	20.0	45.1	24
Manganese, unfiltered-recoverable, µg/L	40	9.3	46.9	67.4	84.4	107	253	
Zinc, filtered, µg/L	40 (5)	1.8	2.3	3.5	4.1	5.7	17.7	20
Zinc, unfiltered-recoverable, µg/L	40 (1)	2.9	11.0	17.3	29.9	41.7	113	
Arsenic, filtered, µg/L	40	5.6	7.9	9.0	9.9	11.5	22.5	79
Arsenic, unfiltered-recoverable, µg/L	40	7.5	9.7	11.4	13.3	14.4	28.4	
Suspended sediment, mg/L	40	2	8	16	35	40	176	NA
Suspended sediment, percent fines[4]	40	56	71	82	78	87	94	NA

Table 4. Statistical summaries of water-quality data collected at selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 2011–15.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft^3/s, cubic foot per second; NA, not applicable; µS/cm, microsiemen per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, unadjusted (not flow adjusted) units of measurement	Statistical summaries of water-quality data[1]							Ratios of median filtered to median unfiltered-recoverable concentrations for trace elements, in percent[3]
	Number of samples (values in parentheses indicate number of censored values)	Minimum uncensored value[2]	25th percentile	Median	Mean	75th percentile	Maximum	
Clark Fork near Drummond, Montana (sampling site 18, fig. 1, table 1)								
Streamflow, instantaneous, ft^3/s	40	248	563	781	1,040	1,090	5,540	NA
Specific conductance, µS/cm	40	243	346	417	403	458	560	NA
pH, standard units	40	7.9	8.1	8.1	NA	8.2	8.5	NA
Hardness, filtered, mg/L as $CaCO_3$	40	109	158	190	184	211	265	NA
Calcium, filtered, mg/L	40	32.6	45.1	54.3	52.7	59.7	74.9	NA
Magnesium, filtered, mg/L	40	6.75	10.7	13.2	12.9	15.0	19.0	NA
Cadmium, filtered, µg/L	40 (2)	0.021	0.032	0.043	0.045	0.053	0.101	35
Cadmium, unfiltered-recoverable, µg/L	40 (1)	0.026	0.072	0.124	0.168	0.241	0.536	
Copper, filtered, µg/L	40	1.9	3.9	4.8	5.6	6.2	19.8	24
Copper, unfiltered-recoverable, µg/L	40	5.4	9.8	19.4	29.9	36.7	107	
Iron, filtered, µg/L	40 (2)	3.6	9.0	15.0	20.7	26.9	88.7	3
Iron, unfiltered-recoverable, µg/L	40	24.8	180	440	710	979	3,170	
Lead, filtered, µg/L	40 (2)	0.039	0.059	0.115	0.142	0.152	0.592	4
Lead, unfiltered-recoverable, µg/L	40	0.17	1.27	3.02	4.61	6.29	19.8	
Manganese, filtered, µg/L	40	4.2	12.4	15.5	17.4	22.0	37.7	20
Manganese, unfiltered-recoverable, µg/L	40	9.9	49.7	76.6	96.0	121	294	
Zinc, filtered, µg/L	40 (1)	2.2	3.5	4.3	4.7	5.3	13.2	19
Zinc, unfiltered-recoverable, µg/L	40 (1)	4.6	12.0	22.7	35.0	48.3	134	
Arsenic, filtered, µg/L	40	6.3	8.0	9.7	10.1	11.3	23.9	86
Arsenic, unfiltered-recoverable, µg/L	40	7.7	10.6	11.3	13.3	13.9	30.7	
Suspended sediment, mg/L	40	2	9	22	40	57	216	NA
Suspended sediment, percent fines[4]	40	42	68	79	76	86	93	NA

Table 4. Statistical summaries of water-quality data collected at selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 2011–15.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft^3/s, cubic foot per second; NA, not applicable; µS/cm, microsiemen per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, unadjusted (not flow adjusted) units of measurement	Statistical summaries of water-quality data[1]							Ratios of median filtered to median unfiltered-recoverable concentrations for trace elements, in percent[3]
	Number of samples (values in parentheses indicate number of censored values)	Minimum uncensored value[2]	25th percentile	Median	Mean	75th percentile	Maximum	
Clark Fork at Turah Bridge near Bonner, Montana (sampling site 20, fig. 1, table 1)								
Streamflow, instantaneous, ft^3/s	40	462	1,050	1,500	2,230	2,640	10,600	NA
Specific conductance, µS/cm	40	140	214	285	277	340	385	NA
pH, standard units	40	7.8	8.0	8.1	NA	8.2	8.4	NA
Hardness, filtered, mg/L as $CaCO_3$	40	60.1	97.6	132	127	156	186	NA
Calcium, filtered, mg/L	40	17.3	27.8	35.9	35.6	43.5	52.8	NA
Magnesium, filtered, mg/L	40	4.11	6.76	9.57	9.27	11.6	13.1	NA
Cadmium, filtered, µg/L	40 (12)	0.017	0.019	0.027	0.031	0.037	0.083	37
Cadmium, unfiltered-recoverable, µg/L	40 (3)	0.025	0.048	0.073	0.104	0.132	0.404	
Copper, filtered, µg/L	40	1.3	2.2	2.9	3.8	3.9	17.9	27
Copper, unfiltered-recoverable, µg/L	40	3.8	5.9	10.5	16.8	20.1	61.9	
Iron, filtered, µg/L	40 (3)	3.3	7.1	20.4	29.7	34.0	359	6
Iron, unfiltered-recoverable, µg/L	40	47.7	132	316	507	527	2,450	
Lead, filtered, µg/L	40 (6)	0.030	0.039	0.069	0.134	0.137	2.79	4
Lead, unfiltered-recoverable, µg/L	40	0.20	0.58	1.67	2.67	3.33	11.9	
Manganese, filtered, µg/L	40	3.0	5.4	6.9	9.6	9.8	48.6	16
Manganese, unfiltered-recoverable, µg/L	40	9.5	26.9	43.5	57.7	66.7	212	
Zinc, filtered, µg/L	40 (4)	1.5	2.3	3.3	3.9	4.7	17.4	23
Zinc, unfiltered-recoverable, µg/L	40	3.8	8.4	14.2	22.9	27.3	109	
Arsenic, filtered, µg/L	40	2.7	4.5	5.6	5.6	6.0	14.2	90
Arsenic, unfiltered-recoverable, µg/L	40	3.0	5.6	6.2	7.3	8.2	21.0	
Suspended sediment, mg/L	40	3	7	16	32	30	186	NA
Suspended sediment, percent fines[4]	40	44	66	78	74	85	91	NA

Table 4. Statistical summaries of water-quality data collected at selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 2011–15.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft^3/s, cubic foot per second; NA, not applicable; µS/cm, microsiemen per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, unadjusted (not flow adjusted) units of measurement	Statistical summaries of water-quality data[1]							Ratios of median filtered to median unfiltered-recoverable concentrations for trace elements, in percent[3]
	Number of samples (values in parentheses indicate number of censored values)	Minimum uncensored value[2]	25th percentile	Median	Mean	75th percentile	Maximum	
Clark Fork above Missoula, Montana (sampling site 22, fig. 1, table 1)								
Streamflow, instantaneous, ft^3/s	40	910	1,710	4,100	5,530	7,240	22,900	NA
Specific conductance, µS/cm	40	148	189	230	239	288	341	NA
pH, standard units	40	8.0	8.2	8.3	NA	8.4	8.7	NA
Hardness, filtered, mg/L as $CaCO_3$	40	70.7	88.5	109	113	141	163	NA
Calcium, filtered, mg/L	40	19.3	23.8	29.5	30.3	36.9	44.9	NA
Magnesium, filtered, mg/L	40	5.30	6.98	8.48	9.06	11.3	12.9	NA
Cadmium, filtered, µg/L	40 (25)	0.017	0.014	0.018	0.019	0.023	0.046	47
Cadmium, unfiltered-recoverable, µg/L	40 (12)	0.020	0.021	0.038	0.056	0.067	0.345	
Copper, filtered, µg/L	40	1.0	1.5	1.7	2.1	2.1	7.0	35
Copper, unfiltered-recoverable, µg/L	40	1.9	3.2	4.8	9.0	9.4	53.1	
Iron, filtered, µg/L	40 (1)	3.7	6.6	17.3	22.6	34.2	60.5	7
Iron, unfiltered-recoverable, µg/L	40	40.9	96.3	255	370	344	2,030	
Lead, filtered, µg/L	40 (10)	0.026	0.031	0.054	0.068	0.089	0.212	7
Lead, unfiltered-recoverable, µg/L	40	0.13	0.41	0.80	1.40	1.57	8.04	
Manganese, filtered, µg/L	40	3.5	5.5	6.5	7.7	8.5	20.0	24
Manganese, unfiltered-recoverable, µg/L	40	8.8	19.7	27.5	36.5	41.4	155	
Zinc, filtered, µg/L	40 (16)	1.4	1.4	1.9	2.0	2.4	5.5	26
Zinc, unfiltered-recoverable, µg/L	40 (4)	2.3	4.9	7.2	12.2	12.2	84.4	
Arsenic, filtered, µg/L	40	1.2	2.5	3.1	3.1	3.6	7.1	85
Arsenic, unfiltered-recoverable, µg/L	40	1.4	2.9	3.7	4.1	4.8	13.2	
Suspended sediment, mg/L	40	2	5	13	26	20	176	NA
Suspended sediment, percent fines[4]	40	61	73	82	79	85	95	NA

[1]Distributional parameters affected by censored observations (that is, concentrations reported as less than the laboratory reporting level) were estimated by using adjusted maximum likelihood estimation (Cohn, 1988).

[2]Minimum uncensored value refers to the smallest concentration reported as detected above any of the various laboratory reporting levels applicable for a given constituent.

[3]Ratio of median filtered to unfiltered-recoverable concentration greater than 100 percent affected by low median concentrations near minimum laboratory reporting levels (table 2) and small bias in filtered concentrations.

[4]Percent fines refers to the percentage of suspended sediment smaller than 0.062-millimeter diameter.

Table 5. Percentages of samples with unadjusted unfiltered-recoverable concentrations exceeding water-quality standards for selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, water years 2011–15.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. $CaCO_3$, calcium carbonate]

Sampling site number (fig. 1, table 1)	Abbreviated sampling site name (table 1)	Percentage of samples exceeding indicated standard								
		Arsenic human-health standard	Aquatic-life standards							
			Cadmium		Copper		Lead		Zinc	
			Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic
8	Silver Bow Creek at Warm Springs	100	0	3	8	18	0	3	0	0
11	Clark Fork near Galen	98	0	0	26	41	0	8	0	0
14	Clark Fork at Deer Lodge	95	0	15	58	75	0	23	3	3
15	Clark Fork near Garrison	100	0	18	59	79	0	23	3	3
16	Clark Fork at Goldcreek	68	0	18	48	60	0	28	0	0
18	Clark Fork near Drummond	80	0	15	38	58	0	25	3	3
20	Clark Fork at Turah Bridge	13	0	13	28	48	0	25	0	0
22	Clark Fork above Missoula	3	0	5	15	23	0	13	0	0

Reach 4

Reach 4 extends about 2 river miles from Silver Bow Creek at Warm Springs, Montana (sampling site 8), to Clark Fork near Galen, Montana (sampling site 11). Within the reach, water from Warm Springs Ponds mixes and geochemically reacts with water contributed from the Mill-Willow Bypass and Warm Springs Creek; thus, complex water-quality processes are possible in the short reach.

The Warm Springs Ponds system was originally constructed during 1908–17 (and expanded during the 1950s) to trap sediment enriched in trace elements (CDM, 2005). In about 1967, the AMC started introducing a lime and water suspension into Silver Bow Creek upstream from Warm Springs Ponds to raise pH and promote precipitation and deposition of metals in Warm Springs Ponds (U.S. Environmental Protection Agency, 2000). The Mill-Willow Bypass was constructed in about 1969 to capture streamflows of Mill and Willow Creeks near their mouths and divert the combined streamflows (believed to be relatively clean water; U.S. Environmental Protection Agency, 2000) around Warm Springs Ponds and into Silver Bow Creek between the outlet from the Warm Springs Ponds and sampling site 8 (CDM, 2005). Warm Springs Creek originates in the mountains west of the AMC Smelter, flows generally east through areas adjacent to the AMC Smelter and various tailings piles and ponds, and joins Silver Bow Creek to form the Clark Fork near Warm Springs. The Warm Springs Creek Basin is affected by pollution from milling and smelting operations of the AMC Smelter. Thick tailings deposits are extensive in the Silver Bow Creek and Clark Fork flood plain near Warm Springs (Smith and others, 1998) and provide a source of sediment enriched with metallic contaminants within reach 4.

In reach 4, the mean annual streamflow for water years 2011–15 increased by about 79 percent from 96 cubic feet per second (ft^3/s) at sampling site 8 to 172 ft^3/s at sampling site 11 (table 3) primarily because of contributions from Warm Springs Creek and also ephemeral gulches and groundwater inflow. Near the end of reach 4, Warm Springs Creek and Silver Bow Creek join to form the Clark Fork.

Silver Bow Creek at Warm Springs (sampling site 8) is about 0.2 river mile downstream from Warm Springs Ponds, which were designed to trap suspended sediment and metallic contaminants by physical deposition and treatment (liming; U.S. Environmental Protection Agency, 2000). Median concentrations of unfiltered-recoverable copper and zinc (6.8 and 8.6 μg/L, respectively) and suspended sediment (6 milligrams per liter [mg/L]) are lower than median concentrations of most downstream main-stem Clark Fork sampling sites (fig. 2, table 4). The median concentration of unfiltered-recoverable arsenic (22.4 μg/L) at sampling site 8 is higher than median concentrations at the downstream main-stem Clark Fork sampling sites. The high median arsenic concentration at sampling site 8 is affected by contributions of water with high arsenic concentrations from the Mill-Willow Bypass and by complex hydrologic and limnologic factors that affect arsenic biogeochemical processing in Warm Springs Ponds (Chatham, 2012). The median pH for sampling site 8 is 8.8 standard units, which is higher than the median pH of the downstream main-stem Clark Fork sampling sites (table 4). High pH in Warm Springs Ponds (a result of a combination factors, including liming and nutrient processing by aquatic vegetation; Chatham, 2012) promotes arsenic solubility and mobilization (Stumm and Morgan, 1970). Exceedances of most water-quality standards were infrequent (that is, less than or equal to 20 percent of samples) for sampling site 8; however, the

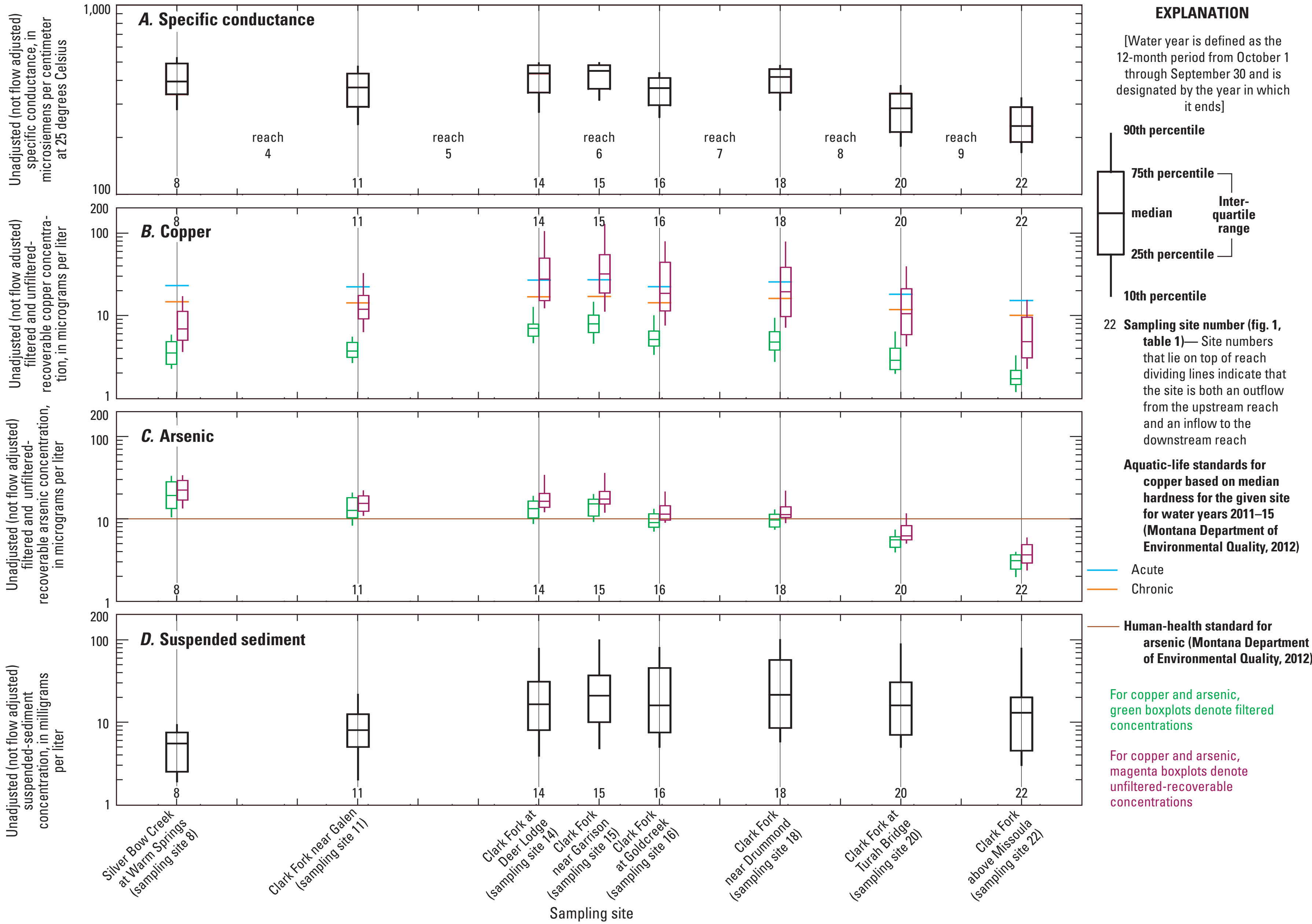

Figure 2. Statistical distributions of selected constituents for selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 2011–15. *A*, specific conductance; *B*, copper; *C*, arsenic; and *D*, suspended sediment.

arsenic human-health standard was exceeded in 100 percent of samples (table 5).

Clark Fork near Galen (sampling site 11) is about 2 river miles downstream from sampling site 8 and about 1 river mile downstream from the start of the Clark Fork at the confluence of Silver Bow Creek and Warm Springs Creek. Spatial changes in water quality between sampling sites 8 and 11 in water years 2011–15 include increases in median concentrations of unfiltered-recoverable metallic trace elements and suspended sediment, as well as decreases in median concentrations of unfiltered-recoverable arsenic (fig. 2, table 4). Factors that might contribute to the patterns include mobilization of materials from flood-plain tailings deposits near Warm Springs and complex processes as water from Warm Springs Ponds mixes and geochemically reacts with water contributed from the Mill-Willow Bypass and Warm Springs Creek. Exceedances of most water-quality standards were somewhat infrequent for sampling site 11, but the acute aquatic-life standard for copper was exceeded in 26 percent of samples, the chronic aquatic-life standard for copper was exceeded in 41 percent of samples, and the arsenic human-health standard was exceeded in 98 percent of samples (table 5).

Reach 5

Reach 5 extends about 21 river miles from Clark Fork near Galen (sampling site 11) to Clark Fork at Deer Lodge, Montana (sampling site 14), and meanders through a broad valley with extensive flood-plain tailings deposits. Lost Creek (a tributary to the Clark Fork in reach 5) originates in the mountains northwest of the AMC Smelter and flows generally east to its confluence with the Clark Fork near Galen. The Lost Creek Basin is affected by pollution from milling and smelting operations of the AMC Smelter (U.S. Environmental Protection Agency, 2010). In reach 5, the mean annual streamflow for water years 2011–15 increased by about 65 percent from 172 ft^3/s at sampling site 11 to 283 ft^3/s at sampling site 14 (table 3) partly because of contributions from Lost Creek and also numerous other tributaries, ephemeral gulches, and groundwater inflow.

Spatial changes in water quality between sampling sites 11 and 14 in water years 2011–15 include substantial increases in median concentrations of unfiltered-recoverable metallic trace elements and suspended sediment (fig. 2, table 4). Mobilization of mining wastes from extensive flood-plain tailings deposits and stream banks contribute to the pattern. Exceedances of water-quality standards were frequent for sampling site 14: the acute aquatic-life standard for copper was exceeded in 58 percent of samples, the chronic aquatic-life standard for copper was exceeded in 75 percent of samples, the chronic aquatic-life standard for lead was exceeded in 23 percent of samples, and the arsenic human-health standard was exceeded in 95 percent of samples (table 5).

Reach 6

Reach 6 extends about 26 river miles from Clark Fork at Deer Lodge (sampling site 14) to Clark Fork at Goldcreek, Montana (sampling site 16). Clark Fork above Little Blackfoot River near Garrison (sampling site 15), is in reach 6 and is located about 14 river miles downstream from sampling site 14 and about 12 river miles upstream from sampling site 16. Water-quality data collection for sampling site 15 began in water year 2009 (table 1); thus, water-quality data for sampling site 15 are suitable for summarizing water years 2011–15 water-quality characteristics but are not adequate for trend analysis.

The Clark Fork meanders through a broad valley from Deer Lodge to Garrison, in which flood-plain tailings along the Clark Fork are present to a similar extent as in the valley upstream from Deer Lodge (Smith and others, 1998). The Little Blackfoot River (a tributary to the Clark Fork in reach 6) drains a basin with moderate density of agricultural and historical mining activity (in comparison with other tributaries downstream from Deer Lodge) and discharges into reach 6 near Garrison (about 1 river mile downstream from sampling site 15) where the Clark Fork Valley begins to narrow. Downstream from Garrison, flood-plain tailings are less extensive than in the valley upstream. In reach 6, the mean annual streamflow for water years 2011–15 increased by about 11 percent from 283 ft^3/s at sampling site 14 to 315 ft^3/s at sampling site 15 and then by about 81 percent to 570 ft^3/s at sampling site 16 (table 3). The overall increase in streamflow from sampling site 14 to sampling site 16 was about 101 percent, mostly because of contributions from the Little Blackfoot River and also numerous other tributaries, ephemeral gulches, and groundwater inflow.

Spatial changes in water quality between sampling sites 14 and 16 in water years 2011–15 include decreases in median concentrations of unfiltered-recoverable metallic trace elements, unfiltered-recoverable arsenic, and suspended sediment, despite small increases in most of these values between sampling sites 14 and 15. Water-quality changes in reach 6 primarily were affected by transport of mining wastes from upstream source areas in combination with streamflow inputs from areas with less mining effects (including the Little Blackfoot River). Dispersion and dilution of mining wastes generally result in decreasing water-quality effects with distance downstream from primary source areas. Exceedances of water-quality standards were frequent for sampling site 15: the acute aquatic-life standard for copper was exceeded in 59 percent of samples, the chronic aquatic-life standard for copper was exceeded in 79 percent of samples, the chronic aquatic-life standard for lead was exceeded in 23 percent of samples, and the arsenic human-health standard was exceeded in 100 percent of samples (table 5). Exceedances of water-quality standards were somewhat frequent for sampling site 16: the acute aquatic-life standard for copper was exceeded in 48 percent of samples, the chronic aquatic-life standard for copper was exceeded in 60 percent of samples, the chronic aquatic-life standard for lead was exceeded in 28 percent of samples, and the arsenic human-health standard was exceeded in 68 percent of samples (table 5).

Reach 7

Reach 7 extends about 31 river miles from Clark Fork at Goldcreek (sampling site 16) to Clark Fork near Drummond, Montana (sampling site 18). In reach 7, channel meandering and exposed flood-plain tailings are less extensive than in upstream reaches (Lambing, 1998; Smith and others, 1998). Flint Creek (a tributary that discharges to the Clark Fork in reach 7 near Drummond) drains a basin with high density of agricultural and historical mining activity (in comparison with other tributaries downstream from Deer Lodge). Downstream from Drummond, the Clark Fork Valley narrows further, and meandering of the Clark Fork decreases further in association with the narrow valley and presence of highway and railroad embankments (Lambing, 1998; Smith and others, 1998). In reach 7, the mean annual streamflow for water years 2011–15 increased by about 35 percent from 570 ft^3/s at sampling site 16 to 771 ft^3/s at sampling site 18 (table 3) mostly because of contributions from Flint Creek and also numerous other tributaries, ephemeral gulches, and groundwater inflow.

Spatial changes in water quality between sampling sites 16 and 18 in water years 2011–15 include generally small increases in median concentrations of unfiltered-recoverable metallic trace elements and suspended sediment. Although the increases were not large, they contrast with the pattern of decreasing water-quality effects with distance downstream from primary mining-waste source areas in the upper Clark Fork Basin. The spatial changes in water quality between sites 16 and 18 probably were affected by streamflow contributions from the Flint Creek Basin, which has high density of agricultural and historical mining activity (in comparison with other tributaries downstream from Deer Lodge). The Clark Fork flood plain and stream banks downstream from Flint Creek probably also contain mining-waste deposits sourced from the Flint Creek Basin. Exceedances of water-quality standards were somewhat frequent for sampling site 18: the acute aquatic-life standard for copper was exceeded in 38 percent of samples, the chronic aquatic-life standard for copper was exceeded in 58 percent of samples, the chronic aquatic-life standard for lead was exceeded in 25 percent of samples, and the arsenic human-health standard was exceeded in 80 percent of samples (table 5).

Reach 8

Reach 8 extends about 34 river miles from Clark Fork near Drummond (sampling site 18) to Clark Fork at Turah Bridge near Bonner, Montana (sampling site 20). In reach 8, the Clark Fork flows through a narrow flood plain (generally less than 1 mi wide) with little or no visible mining tailings. Rock Creek (a tributary to the Clark Fork in reach 8) drains a heavily forested basin with low density of agricultural and historical mining activity (in comparison with other tributaries downstream from Deer Lodge) and discharges into reach 8 near Clinton, Montana. In reach 8, the mean annual streamflow for water years 2011–15 increased by about 93 percent from 771 ft^3/s at sampling site 18 to 1,490 ft^3/s at sampling site 20 (table 3) primarily because of contributions from Rock Creek, as well as numerous other tributaries, ephemeral gulches, and groundwater inflow.

Spatial changes in water quality between sampling sites 18 and 20 in water years 2011–15 include generally substantial decreases in median concentrations of unfiltered-recoverable metallic trace elements, unfiltered-recoverable arsenic, and suspended sediment. Water-quality changes in reach 8 were affected by dilution from Rock Creek. Exceedances of most water-quality standards were somewhat infrequent for sampling site 20, but the acute aquatic-life standard for copper was exceeded in 28 percent of samples, the chronic aquatic-life standard for copper was exceeded in 48 percent of samples, and the chronic aquatic-life standard for lead was exceeded in 25 percent of samples (table 5).

Reach 9

Reach 9 extends about 9 river miles from Clark Fork at Turah Bridge (sampling site 20) to Clark Fork above Missoula, Montana (sampling site 22). Reach 9 includes the former Milltown Reservoir where large amounts of mining wastes had been deposited. The former Milltown Dam was removed in 2008. The Blackfoot River (a tributary that discharges to the Clark Fork in reach 9 near Bonner) drains a largely forested basin with low density of agricultural and historical mining activity (in comparison with other tributaries downstream from Deer Lodge). In reach 9, mean annual streamflow increased by about 123 percent from 1,490 ft^3/s at sampling site 20 to 3,330 ft^3/s at sampling site 22 (table 3) primarily because of contributions from the Blackfoot River.

Spatial changes in water quality between sampling sites 20 and 22 in water years 2011–15 include generally substantial decreases in median concentrations of unfiltered-recoverable metallic trace elements, unfiltered-recoverable arsenic, and suspended sediment. Water-quality changes in reach 9 were affected by dilution from the Blackfoot River. Exceedances of most water-quality standards were infrequent for sampling site 22, but the chronic aquatic-life standard for copper was exceeded in 23 percent of samples (table 5).

Water-Quality Trend- and Constituent-Transport Analysis Methods

This section of the report describes methods used to analyze trends in flow-adjusted concentrations of water-quality constituents. Normalized loads (as defined in the section of this report "Estimation of Normalized Constituent Loads") were estimated to evaluate temporal changes in relative contributions of selected trace elements and suspended sediment from upstream source areas to the outflows of each data-summary reach. Methods used for estimation of normalized constituent loads also are described.

General Description of the Time-Series Model

The TSM for streamflow and constituent concentration (Vecchia, 2005) was used to detect water-quality trends. Details on theory and parameter estimation for the model are presented in Vecchia (2005), and the model is summarized in appendix 2 of this report. Specific information concerning suitability of application of the TSM to the study datasets and procedures for determination of statistical significance and magnitude of trends also are presented in appendix 2.

The TSM analyzes trends in flow-adjusted concentrations (FACs); that is, the TSM computes FACs, estimates unbiased best-fit trend lines that represent temporal changes in FACs, and determines statistical significance of changes. Flow adjustment is necessary because concentrations of many water-quality constituents are strongly dependent on streamflow conditions, which are primarily affected by climatic variability in the study area. The intent of flow adjustment is to identify and remove streamflow-related variability in concentrations and thereby enhance the capability to detect trends independent from effects of climatic variability. Flow-adjustment procedures produce FACs that are estimates of constituent concentrations after removing effects of streamflow variability.

The TSM uses multiple flow-related variables computed from concurrent (same day as the concentration sample) and antecedent (days before the concentration sample) daily mean streamflow in the flow-adjustment process. The TSM FACs provide detailed accounting by incorporating interannual, seasonal, and short-term streamflow variability (Vecchia, 2005), which compensates for interannual, seasonal, and short-term hysteresis processes that affect concentration and streamflow relations (Colby, 1956; Chanat and others, 2002; Vecchia, 2005). Detailed analysis of continuous streamflow data provides definition of the context of streamflow conditions associated with a given water sample, handling of temporal variability in sampling frequency, and interpolation of trend patterns to periods when water-quality data are sparse or absent. The TSM inherently accounts for effects of serial correlation.

The TSM incorporates base-10 logarithm (hereinafter referred to as "log") transformation of the concentration and streamflow data. As such, the fitted trends in FACs quantify temporal changes in central tendency represented by the geometric mean of concentration in reference to log-transformed streamflow. The geometric mean is the mean of the logs transformed back into their original units.

All of the study datasets (except for Clark Fork near Garrison [sampling site 15], which was not analyzed for trends) met the data criteria for applying the TSM, which include at least 15 years of continuous streamflow data and at least 15 years of water-quality data with at least 60 total water-quality samples and at least 10 samples total in each 3-month season (Vecchia, 2005). A limitation of the TSM is that it does not handle censored data in a rigorous manner. In the TSM, a single value is substituted for all censored data for a given constituent; thus, criteria must be set to specify the allowable amount of censored data and a consistent substitution value for each constituent. Based on analysis of trial datasets with artificially imposed variable levels of censoring, the TSM generally can be applied to datasets with about 10 percent or less censored data without substantial effects on trend results (Vecchia, 2003). Multiple LRLs (table 2) in the datasets of the Clark Fork monitoring program complicate the task of setting consistent substitution values. In applying the TSM to the study datasets, study reporting levels (SRLs; table 2) were established to set consistent substitution values for each trace-element constituent based on investigation of the time frame during which various NWQL LRLs were used, the frequency of censoring that resulted from each LRL, and field blank sample data that provided information on potential contamination bias of low concentrations. The SRLs were applied to the study datasets by (1) substituting one-half the SRL for all censored observations with LRLs equal or close to the SRL, (2) substituting one-half the SRL for all reported uncensored concentrations (analyzed during times when the LRL was less than the SRL) that were less than the SRL, and (3) excluding censored data with LRLs substantially larger than the SRL. Any analytical result that was revised by either substitution or exclusion was considered to be affected by the recensoring procedures used in applying the SRL. The study datasets largely were unaffected by recensoring for the trace-element constituents included in the trend analysis (table 2); unfiltered-recoverable zinc was the only affected constituent, and no sampling site had more than 8.5 percent of values affected by the recensoring procedures. Further, for individual constituents, the maximum frequency of detection in field blank samples at concentrations greater than the SRL was 2.7 percent (for unfiltered-recoverable zinc; table 1–1).

The TSM accounts for many hydrologic factors that contribute to complexity in concentration and streamflow relations. In this study, the TSM was applied as consistently as possible among sampling-site and constituent combinations and is considered to be a useful tool for simplifying the environmental complexity in the upper Clark Fork Basin to provide a large-scale evaluation of general temporal changes in FACs and constituent transport independent from streamflow variability. As such, the TSM provides a consistent relational framework for evaluating temporal water-quality changes among the sampling sites. The TSM best-fit trend lines were considered to provide important information beyond the strict statistical characteristics of the trend results (in terms of statistical probability levels [*p*-values] and levels of significance) because they aid in comparing and summarizing large-scale patterns among sampling sites.

Selection of Trend-Analysis Time Periods

Appropriate selection of trend-analysis time periods is important because the results of trend analyses are dependent on how the time periods are structured. Factors considered in selection of trend-analysis time periods included providing capability to (1) compare trend results among sampling sites with different periods of data collection, (2) distinguish somewhat short-term timing of changes in concentration and streamflow relations during the long study period, and (3) allow periodic future updates of trend analyses for evaluation of effects of remediation activities. Based primarily on those factors, trend-analysis periods were defined as sequential 5-year periods that extended from near the start of long-term data-collection activities for most sampling sites in the upper Clark Fork Basin to the end of water year 2015. Thus, four trend-analysis time periods were defined: period 1 (water years 1996–2000), period 2 (water years 2001–5), period 3 (water years 2006–10), and period 4 (water years 2011–15).

The TSM-fitted trends for a given trend-analysis period are monotonic trends that are smoothed to produce generally consistent slopes across the middle section of the trend-analysis period that become flatter near the ends of the trend-analysis period. The flatter slopes near the ends provide gradual transition between adjacent trend-analysis periods. In some cases, the fitted trends in a given trend-analysis period do not precisely follow the patterns in FACs, and there are short-term (about 1–2 years) trend patterns in FACs that are unresolved in the fitted trends. In those cases, better temporal resolution might have been attained by defining two or more trend-analysis periods in a given 5-year trend-analysis period. This approach generally was avoided because it would have required detailed trend analysis for potentially inconsistent time periods among the various sampling-site and constituent combinations. An important consideration in the design of the trend-analysis structure of this study was making general comparisons among the sampling-site and constituent combinations to evaluate large-scale effects of mining and remediation activities for consistent time periods. In general, when unresolved trending was apparent, more complicated trend models (with additional trend-analysis periods) were tested, and the more complicated models did not change the general findings and conclusions of this report; that is, the overall fitted trends in the affected trend-analysis periods were consistent with overall patterns in FACs in the period. However, because of the substantial effect of the intentional breach of the former Milltown Dam on March 28, 2008, an exception to consistent trend-analysis periods was made. For Clark Fork above Missoula (sampling site 22), period 3 was subdivided into period 3A (October 1, 2005–March 27, 2008) and period 3B (March 28, 2008–September 30, 2010). The intentional breach of the former Milltown Dam was part of an extensive remediation effort from about 2006–8 that resulted in the removal of the former Milltown Dam (Sando and Lambing, 2011).

Estimation of Normalized Constituent Loads

Normalized constituent loads were estimated to assess the temporal trends in FACs of mining-related contaminants in the context of sources and transport. The fitted trends are unbiased best-fit lines through the FACs, which are independent of streamflow variability. The FAC trends at individual sampling sites are important descriptors of water-quality changes in the upper Clark Fork Basin, but without consideration of differences in streamflow magnitudes among different sampling sites, the trends do not provide direct information on resultant changes in contaminant source-area contributions and transport characteristics. Combining the FAC trends with a stationary streamflow index (that maintains relative differences in streamflow magnitudes among sampling sites but normalizes streamflow for a given sampling site to a constant value through time) allows assessment of how the temporal changes in FACs translate into relative temporal changes in source and transport of mining-related contaminants in the upper Clark Fork Basin. Thus, normalized loads were estimated to conduct a transport analysis.

Normalized loads were estimated for each of the four 5-year trend-analysis periods. The stationary streamflow index used in estimating normalized loads was the geometric mean streamflow for each sampling site for water years 1996–2015. The geometric mean was selected as a measure of central tendency in streamflow to maintain consistency with the TSM analysis, which is conducted on log-transformed data.

For each sampling-site and constituent combination and each of the 5-year periods, the normalized load was estimated by multiplying the mean annual fitted trend FAC during the 5-year analysis period times the geometric mean streamflow for water years 1996–2015 and a units conversion factor, according to the following equation:

$$LOAD = MAC * GMQ * K \tag{1}$$

where

LOAD is the estimated normalized constituent load (in kilograms per day) for the indicated 5-year period;

MAC is the mean annual fitted trend FAC (in micrograms per liter for trace elements or milligrams per liter for suspended sediment) for the indicated 5-year period;

GMQ is the geometric mean of daily mean streamflow for water years 1996–2015, in cubic feet per second; and

K is a units conversion constant (0.00245 for concentrations in micrograms per liter or 2.45 for concentrations in milligrams per liter) to convert instantaneous constituent discharge (in mass units per second) to an equivalent daily constituent load (in kilograms per day).

The *MAC* is calculated by temporally averaging (in each of the four 5-year periods) the fitted trend FACs that quantify temporal changes in central tendency based on the geometric mean. It is notable that the *MAC* is referred to as a "mean annual value"; this terminology indicates temporal averaging of geometric mean concentrations. The temporal averaging of geometric mean concentrations in each 5-year period effectively results in the *MAC* representing the center of the 5-year period, which introduces a conservative approach to the transport analysis. The geometric mean generally is closely associated with the median of the original untransformed units for data that are approximately log-normally distributed. Thus, because of effects of analysis of log-transformed data, the estimated normalized loads generally represent quantification with respect to near-median conditions. As such, the estimated normalized loads do not represent actual magnitudes of total mass transport, but rather provide information on relative temporal changes in constituent transport characteristics of the study sampling sites quantified with respect to near-median conditions.

Factors that Affect Trend Analysis and Interpretation

Several factors affect temporal trends in water quality. Climatic variability (interannual and seasonal) is indicated in variability in streamflow conditions, which strongly affect concentration and streamflow relations. Investigating streamflow conditions during the study period is relevant to interpreting trend results. Other factors relating to data assessment or treatment that also are relevant to understanding trend-analysis procedures and interpreting trend results include relations between unadjusted concentrations and FACs, and data transformation.

Streamflow Conditions

Daily mean streamflows for water years 1993–2015 for selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin are presented in figure 3. Locally weighted scatter plot smooth (LOWESS; Cleveland and McGill, 1984; Cleveland, 1985) lines through the daily mean streamflows also are presented in figure 3 to represent temporal variability in the moving central tendency of streamflow. The geometric mean streamflows for water years 1996–2015 are presented to represent overall central tendency of streamflow during the period of trend analysis. Silver Bow Creek at Warm Springs (sampling site 8), Clark Fork at Deer Lodge (sampling site 14), and Clark Fork at Turah Bridge (sampling site 20) were selected as examples for showing hydrologic patterns (fig. 3) that generally apply to the other sampling sites.

Temporal variability in streamflow conditions during the study period generally is similar among sampling sites. In about water year 1993, streamflow conditions generally increased to above the geometric mean streamflows during a period of several years. Streamflows were high during water years 1996–97, near the start of period 1 (water years 1996–2000). During period 1, streamflows above the geometric mean streamflows generally persisted through water year 1999 and then decreased substantially to below the geometric mean streamflows during water year 2000. High streamflows were prevalent during most of period 1 and are evident in annual maximum streamflows being higher than maximums of most other years and also in annual minimum streamflows being higher than minimums of most other years (fig. 3). Streamflow during water year 1997 was particularly unusual in that the receding limb of snowmelt runoff was less abrupt and less variable than in most years, and post-runoff base streamflows generally were above or near the geometric mean streamflow. Further, the post-runoff base streamflows in water year 1997 at sampling site 14 (fig. 3*B*) sometimes exceeded annual maximum streamflows during the low streamflow years 2000–2002. During period 2 (water years 2001–5), streamflows generally were below the geometric mean streamflows. During period 3 (water years 2006–10), streamflows gradually increased from below the geometric mean streamflows in water year 2006 to above the geometric mean streamflows in water year 2010. During period 4 (water years 2011–15), streamflows generally were above the geometric mean streamflows in water years 2011–12 and then decreased to near the geometric mean streamflows in water year 2013. Streamflows in water year 2011 were especially high and generally similar to streamflows in water year 1997.

Other Factors

Factors relating to data requirements, treatments, and assessment that affect trend analysis and interpretation of results include relations between unadjusted concentrations and FACs, and data transformation. Unadjusted concentrations are the observed concentrations before flow adjustment.

The FACs are estimates of constituent concentrations after removing effects of streamflow variability; thus, FACs typically have less variability than unadjusted concentrations, although the strength of this pattern is variable among sampling-site and constituent combinations, and also can be variable through time for a given sampling-site and constituent combination. Time-series streamflow, unfiltered-recoverable copper, unfiltered-recoverable arsenic, and

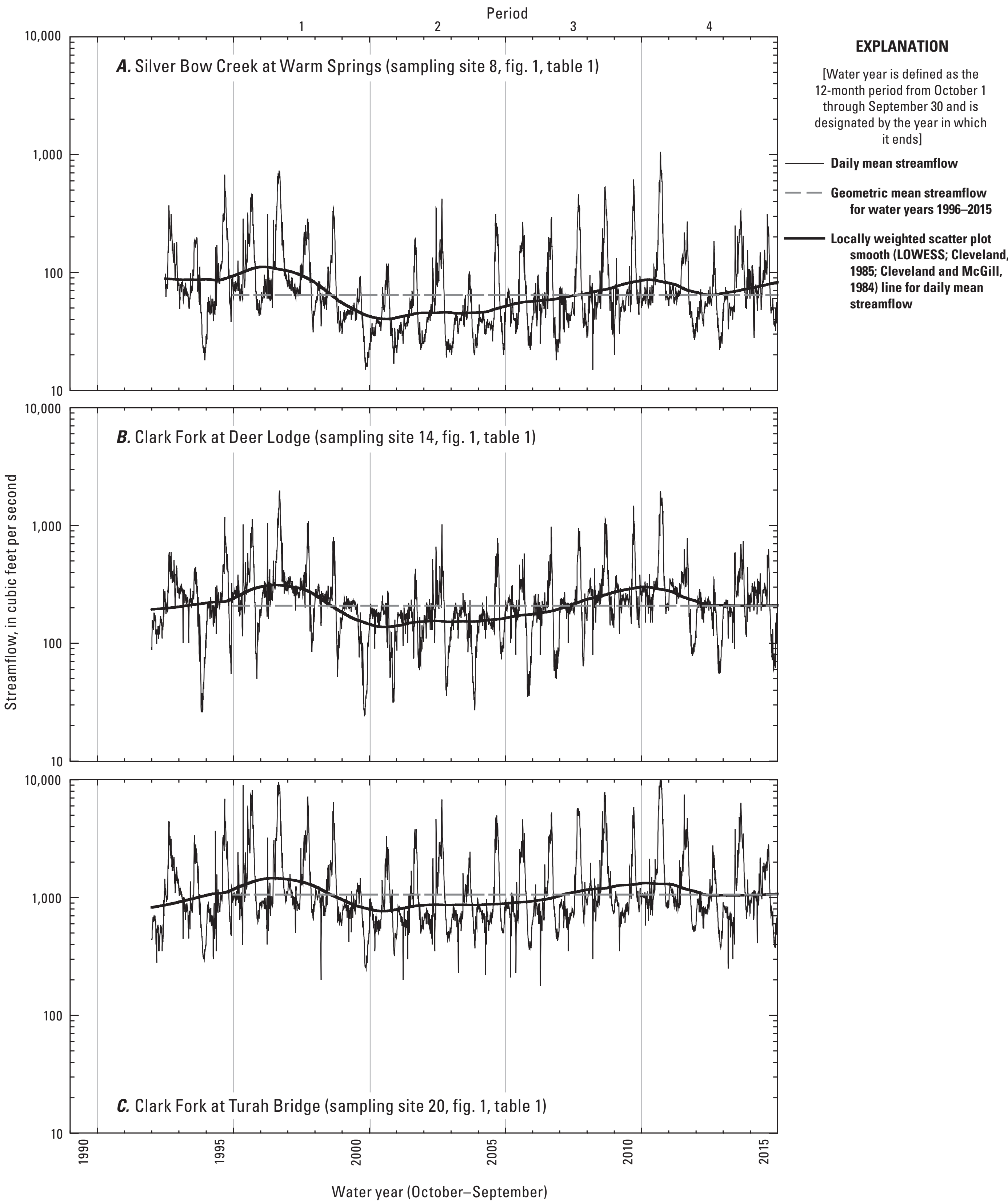

Figure 3. Daily mean streamflow for selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 1993–2015. *A*, Silver Bow Creek at Warm Springs, Montana; *B*, Clark Fork at Deer Lodge, Montana; and *C*, Clark Fork at Turah Bridge near Bonner, Montana.

suspended-sediment data for Clark Fork near Galen (sampling site 11) are presented in figure 4 to provide examples for discussion of relations between unadjusted and flow-adjusted concentrations.

Similarities among the LOWESS lines for streamflow (fig. 4*A*) and unadjusted suspended-sediment concentrations (fig. 4*D*) illustrate the direct relations between streamflow and unadjusted suspended-sediment concentrations. Unadjusted suspended-sediment concentrations tend to be higher during high streamflow conditions than during low streamflow conditions. During high streamflow conditions, with associated high hydraulic energy, particulate material is mobilized and transported in the stream. During low streamflow conditions, streams have less capacity for transporting particulate materials. Flow-adjustment procedures account for the response of suspended-sediment concentrations to variations in streamflow and produce FACs that represent temporal variability in consistent streamflow conditions. In the Clark Fork, suspended-sediment FACs in high streamflow conditions are less variable and lower than unadjusted concentrations (for example, fig. 4*D*, water years 1996–99). Suspended-sediment FACs in low streamflow conditions are less variable and generally centered within unadjusted concentrations (for example, fig. 4*D*, water years 2000–2001).

Unfiltered-recoverable copper has concentration and streamflow relations that are similar to suspended sediment because of adsorption on inorganic and organic particulate materials; these same relations generally apply to other metallic elements. As a result, patterns in unadjusted concentrations and FACs for unfiltered-recoverable copper (fig. 4*B*) are similar to those of suspended sediment (fig. 4*D*).

Arsenic in streams in the upper Clark Fork Basin typically is mostly in dissolved phase and has less variability and a weaker direct relation with streamflow than is the case for metallic elements. Arsenic has been widely dispersed in the upper Clark Fork Basin as a result of deposition of flue dust and smelter emissions with resultant large-scale soil and groundwater contamination (U.S. Environmental Protection Agency, 2010). Further, arsenic generally is more soluble than metallic elements in the geochemical conditions that are prevalent in the upper Clark Fork Basin. These factors result in high arsenic concentrations in groundwater in some areas and also mobilization of arsenic to stream channels for a large range of streamflow conditions. Thus, patterns in unadjusted concentrations and FACs for unfiltered-recoverable arsenic (fig. 4*C*) generally are less variable than for unfiltered-recoverable copper (fig. 4*B*) and suspended sediment (fig. 4*D*). Also, unadjusted concentrations of unfiltered-recoverable arsenic have less correspondence with streamflow than unfiltered-recoverable copper and suspended sediment.

Similarities among the LOWESS lines for streamflow (fig. 4*A*), unfiltered-recoverable copper (fig. 4*B*), and suspended sediment (fig. 4*D*) indicate that temporal variability in streamflow might confound interpretation of temporal variability in unadjusted constituent concentrations. Examination of temporal variability during water years 1993–2015 indicates that, in all cases, the LOWESS lines for streamflow (fig 4*A*), unfiltered-recoverable copper (fig. 4*B*), and suspended sediment (fig. 4*D*) are highest about 1996–97 and lowest about 2000–2001, then variably increase during 2002–11 and generally decrease during 2012–15. Because of the strong association between constituent concentrations and streamflow, interpreting temporal changes in unadjusted constituent concentrations during specific time periods is difficult. For example, in water years 2000–2002, mean annual streamflow was low (about 60 percent of the long-term mean annual streamflow). Annual mean streamflow in water year 2003 somewhat increased to near-normal conditions (about 90 percent of the long-term mean annual streamflow). Associated with the increase in streamflow in 2003 were somewhat abrupt increases in unadjusted concentrations of unfiltered-recoverable copper and suspended sediment that are reflected by somewhat abrupt increases in the LOWESS lines for those constituents. The somewhat abrupt increases in unadjusted concentrations of unfiltered-recoverable copper and suspended sediment in water year 2003 probably were affected by the near-normal streamflow conditions of water year 2003 immediately following the low streamflow conditions of water years 2000–2002. During water years 2000–2002, low streamflow conditions might have promoted storage of particulate materials in the basin; the stored particulate materials might have been readily mobilized during water year 2003. Beginning in water year 2005, streamflow conditions gradually transitioned from generally low streamflow conditions to high streamflow conditions in water year 2011. The gradual transition might have affected the response in unadjusted concentrations of unfiltered-recoverable copper and suspended sediment to the high streamflow conditions of water year 2011, particularly in comparison with the more abrupt increase in streamflow in water year 2003. Thus, various complexities in concentration and streamflow relations contribute to difficulties in interpreting temporal patterns in unadjusted constituent concentrations. Temporal variability in streamflow strongly confounds the ability to interpret temporal variability in unadjusted constituent concentrations.

The TSM flow-adjustment procedure analyzes concentration and streamflow relations on multiple timescales (interannual, seasonal, and short-term) and accounts for streamflow variability. In contrast to the LOWESS lines through the unadjusted constituent concentrations, the TSM-fitted trends in figure 4 indicate consistent decreases in FACs of unfiltered-recoverable copper and suspended sediment. The dissimilar patterns between unadjusted concentrations and FACs indicate the importance of flow-adjusted trend analysis for identifying actual patterns in constituent concentrations independent from variability in streamflow conditions.

An important consideration in interpreting trend results relates to the trend-analysis methods incorporating log transformation of constituent concentrations. Log transformation results in datasets that are approximately normally distributed and allows analysis using rigorous parametric procedures; however, log transformation decreases variability in the data

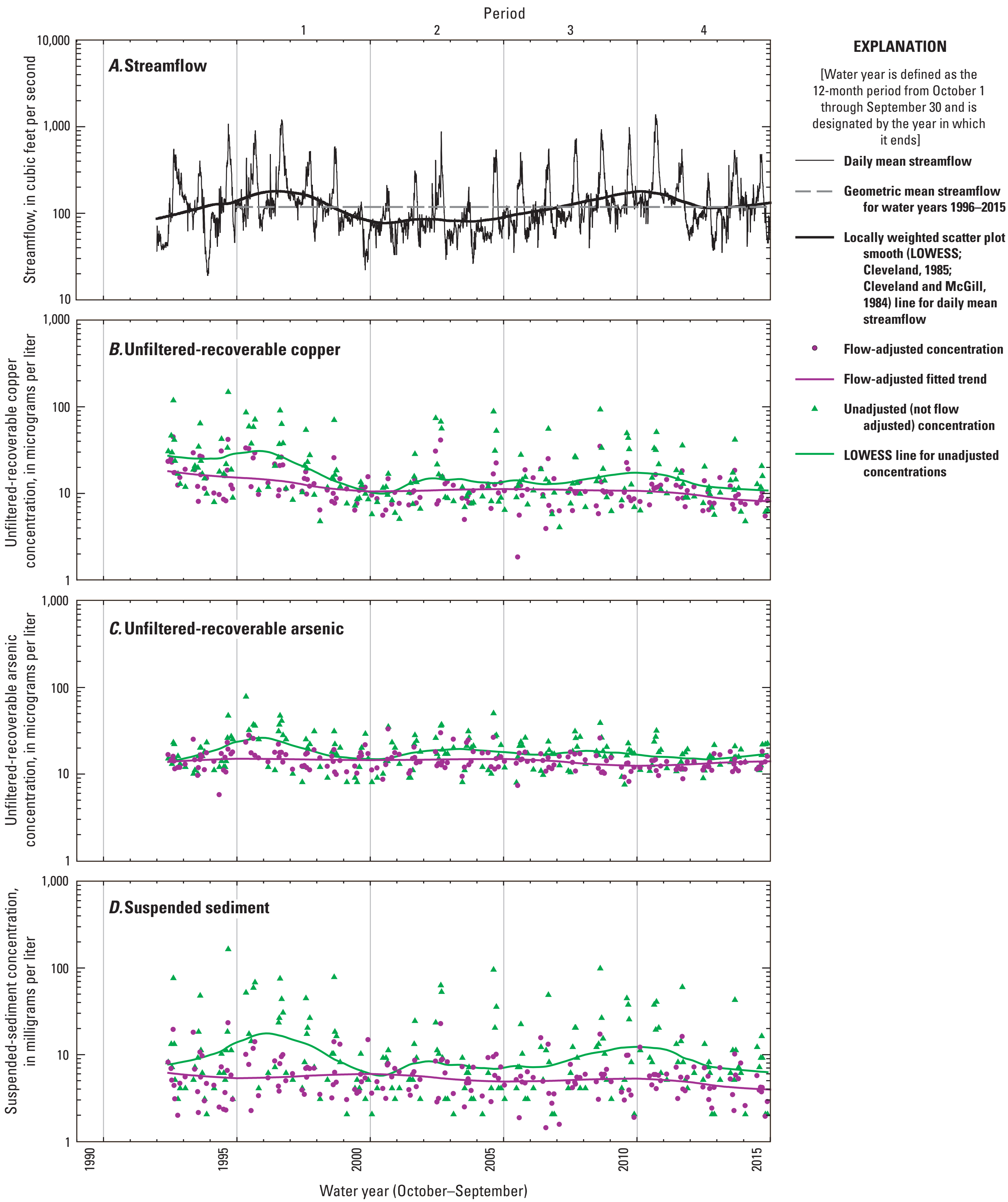

Figure 4. Selected streamflow and constituent concentration information for Clark Fork near Galen, Montana (sampling site 11), water years 1993–2015. *A*, streamflow; *B*, unfiltered-recoverable copper; *C*, unfiltered-recoverable arsenic; and *D*, suspended sediment.

relative to the original untransformed units representative of actual environmental variability. In general, the statistical distributions of constituent concentrations and streamflow (in original untransformed units) for sampling sites in the upper Clark Fork Basin are right skewed, indicating that the extent of data higher than the median is greater than the extent of data lower than the median. Log transformation results in expansion of the lower end of the distribution and compression of the higher end of the distribution. Compression of the higher end of the distribution has a relatively larger effect than expansion of the lower end of the distribution. This factor is important in interpreting trend results with respect to various regulatory issues, including compliance with human-health or aquatic-life standards. Trends in FACs represent changes in central tendency quantified as changes in the geometric mean in reference to log-transformed streamflow. Thus, the trends in FACs provide general information on overall temporal changes (in terms of directions and relative magnitudes) in concentrations but lack the specificity to indicate compliance or noncompliance with various regulatory standards. Effects of data transformation, however, do not negatively affect the primary purpose of this study in determining temporal water-quality trends through time and using the trend results to evaluate relative changes in constituent transport characteristics among sampling sites. In the trend analyses, all data (high as well as low values) affect changes in FAC geometric means; thus, the fitted trends appropriately represent unbiased estimates of overall changes in central tendency.

Water-Quality Trends and Constituent-Transport Analysis Results

This section of the report presents water-quality trend and transport-analysis results for selected sampling sites in the data-summary reaches in the Milltown Reservoir/Clark Fork River Superfund Site for water years 1996–2015. Results are presented for all constituents investigated, but emphasis is placed on copper, arsenic, and suspended sediment in the following subsections.

Water-Quality Trends in Flow-Adjusted Concentrations

For all constituents investigated, detailed results for trend magnitudes, computed as the total percent changes in FAC geometric means from the beginning to the end of each 5-year period, are presented in appendix 3 in tables 3–1 (for most sampling sites) and 3–2 (for Clark Fork above Missoula [sampling site 22]). Detailed trend results are graphically presented in figures 3–1 through 3–7 in appendix 3. The detailed graphical presentations in appendix 3 present fitted trends for all constituents and allow evaluation of the fitted trends for a given sampling site in conjunction with FACs.

Fitted trend values (that quantify the temporal changes in FAC geometric means in terms of concentration units) are summarized in tables 6 (for most sampling sites) and 7 (for Clark Fork above Missoula [sampling site 22]) and graphically summarized in figures 5–10. The summary graphical presentations in figures 5–10 show side-by-side fitted trends for the adjacent sampling sites in a given reach and allow comparisons in temporal patterns between the reach inflow and outflow; these comparisons facilitate interpretation of the constituent-transport analysis results.

In this report, qualitative observations are described for the overall trend magnitude (percent change) from the start of period 1 to the end of period 4. Overall trend magnitude was considered to be (1) large, if the absolute value was greater than about 60 percent; (2) moderate, if the absolute value was in the range of about 40–60 percent; (3) small, if the absolute value was in the range of about 20–40 percent; and (4) minor, if the absolute value was less than about 20 percent.

Trend-magnitude and fitted trend values are considered semiquantitative estimates determined by complex statistical analysis. Throughout this report, trend-magnitude and fitted trend values frequently are mentioned in figures, tables, and discussion of temporal and spatial changes in water quality (reported to two significant figures for all constituents except specific conductance, which is reported to three significant figures). Reference to specific trend-magnitude and fitted trend values is intended to facilitate presentation and discussion of relative spatial and temporal differences between values but is not intended to represent absolute accuracy at two significant figures. The *p*-values and levels of significance (a *p*-value less than 0.01 is considered statistically significant in this report) associated with the trend results are indicated in the tables and figures that present trend results. Significance levels were not the only factor in evaluating the substance of the trends, but rather were considered in conjunction with trend directions and relative magnitudes, and patterns among sites and constituents. In this study, the TSM is considered to be a useful tool for simplifying the environmental complexity in the upper Clark Fork Basin to provide a large-scale evaluation of general temporal changes in FACs and constituent transport independent from streamflow variability. Thus, the TSM best-fit trend lines are considered to provide important information beyond the strict statistical characteristics of the trend results (in terms of *p*-values and levels of significance) because they aid in comparing and summarizing large-scale patterns among the sampling sites. Factors affecting temporal variability in water quality in the upper Clark Fork Basin are complex. Much information on changes in water quality is presented herein, but it is beyond the scope of this report to provide detailed explanations for all of the changes or to link specific trends with specific remediation activities.

Table 6. Summary of flow-adjusted trend results for selected sampling sites and constituents, water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates a statistically significant (*p*-value less than 0.01) trend for the trend period before the shaded value. *p*-value, statistical probability level; µS/cm, microsiemen per centimeter at 25 degrees Celsius; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, flow-adjusted units of measurement	Fitted trend values					Percent change from start of period 1 through end of period 4[1]
	Start of water year 1996 (start of period 1)	Start of water year 2001 (start of period 2)	Start of water year 2006 (start of period 3)	Start of water year 2011 (start of period 4)	End of water year 2015 (end of period 4)	
Silver Bow Creek at Warm Springs, Montana (sampling site 8, fig. 1, table 1)						
Specific conductance, µS/cm	521	514	501	513	446	-14
Copper, filtered, µg/L	8.9	4.6	4.1	3.8	2.9	-67
Copper, unfiltered-recoverable, µg/L	15	9.3	7.9	7.0	5.0	-67
Zinc, unfiltered-recoverable, µg/L	35	16	8.4	9.8	6.1	-83
Arsenic, filtered, µg/L	19	19	20	21	17	-11
Arsenic, unfiltered-recoverable, µg/L	22	22	23	23	19	-14
Suspended sediment, mg/L	5.3	6.3	4.6	2.7	3.1	-42
Clark Fork near Galen, Montana (sampling site 11, fig. 1, table 1)						
Specific conductance, µS/cm	447	454	415	443	388	-13
Copper, filtered, µg/L	7.6	4.2	4.0	3.3	3.4	-55
Copper, unfiltered-recoverable, µg/L	15	11	11	11	8.1	-46
Zinc, unfiltered-recoverable, µg/L	30	13	9.0	12	7.1	-76
Arsenic, filtered, µg/L	12	11	13	10	11	-8
Arsenic, unfiltered-recoverable, µg/L	15	14	15	12	14	-7
Suspended sediment, mg/L	5.2	5.8	4.7	5.1	3.8	-27
Clark Fork at Deer Lodge, Montana (sampling site 14, fig. 1, table 1)						
Specific conductance, µS/cm	479	482	463	454	456	-5
Copper, filtered, µg/L	6.9	5.8	6.1	5.4	5.8	-16
Copper, unfiltered-recoverable, µg/L	30	23	24	25	23	-23
Zinc, unfiltered-recoverable, µg/L	39	24	24	22	19	-51
Arsenic, filtered, µg/L	11	11	13	11	11	0
Arsenic, unfiltered-recoverable, µg/L	16	14	15	14	14	-13
Suspended sediment, mg/L	18	15	14	15	12	-33
Clark Fork at Goldcreek, Montana (sampling site 16, fig. 1, table 1)						
Specific conductance, µS/cm	425	418	406	398	398	-6
Copper, filtered, µg/L	4.8	3.8	4.3	3.8	3.9	-19
Copper, unfiltered-recoverable, µg/L	19	19	15	14	15	-21
Zinc, unfiltered-recoverable, µg/L	27	20	13	15	13	-52
Arsenic, filtered, µg/L	9.4	8.2	8.8	8.6	8.2	-13
Arsenic, unfiltered-recoverable, µg/L	12	10	10	10	9.7	-19
Suspended sediment, mg/L	15	17	8.3	13	11	-27

Table 6. Summary of flow-adjusted trend results for selected sampling sites and constituents, water years 1996–2015.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates a statistically significant (*p*-value less than 0.01) trend for the trend period before the shaded value. *p*-value, statistical probability level; µS/cm, microsiemen per centimeter at 25 degrees Celsius; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, flow-adjusted units of measurement	Fitted trend values					Percent change from start of period 1 through end of period 4[1]
	Start of water year 1996 (start of period 1)	Start of water year 2001 (start of period 2)	Start of water year 2006 (start of period 3)	Start of water year 2011 (start of period 4)	End of water year 2015 (end of period 4)	
Clark Fork near Drummond, Montana (sampling site 18, fig. 1, table 1)						
Specific conductance, µS/cm	461	459	449	434	461	0
Copper, filtered, µg/L	3.9	3.9	4.3	3.3	3.7	-5
Copper, unfiltered-recoverable, µg/L	17	15	14	13	12	-29
Zinc, unfiltered-recoverable, µg/L	36	19	15	17	13	-64
Arsenic, filtered, µg/L	9.6	9.0	9.4	8.4	8.6	-10
Arsenic, unfiltered-recoverable, µg/L	12	10	11	10	10	-17
Suspended sediment, mg/L	21	16	13	16	13	-38
Clark Fork at Turah Bridge near Bonner, Montana (sampling site 20, fig. 1, table 1)						
Specific conductance, µS/cm	347		324	334	327	-6
Copper, filtered, µg/L	3.3	2.5	2.8	2.6	2.1	-36
Copper, unfiltered-recoverable, µg/L	10	9.0	8.3	8.2	7.9	-21
Zinc, unfiltered-recoverable, µg/L	21	13	9.2	14	9.7	-54
Arsenic, filtered, µg/L	5.4	5.1	5.4	5.5	4.7	-13
Arsenic, unfiltered-recoverable, µg/L	6.8	6.1	6.1	6.6	5.6	-18
Suspended sediment, mg/L	13	12	8.8	12	9.5	

[1]Shading represents qualitative observations on overall trend magnitudes (percent change from start of water year 1996 to end of water year 2015) as follows: no shading—minor (the absolute value was less than about 20 percent); green shading—small (the absolute value was in the range of about 20–40 percent; tan shading—moderate (the absolute value was in the range of about 40–60 percent; and purple shading—large (the absolute value was greater than about 60 percent).

Table 7. Summary of flow-adjusted trend results for Clark Fork above Missoula, Montana (sampling site 22), for selected constituents, water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates a statistically significant (*p*-value less than 0.01) trend for the trend period before the shaded value. *p*-value, statistical probability level; µS/cm, microsiemen per centimeter at 25 degrees Celsius; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, flow-adjusted units of measurement	Fitted trend values						Percent change from start of period 1 through end of period 4[1]
	Start of water year 1996 (start of period 1)	Start of water year 2001 (start of period 2)	Start of water year 2006 (start of period 3A)	March 28, 2008 (start of period 3B)	Start of water year 2011 (start of period 4)	End of water year 2015 (end of period 4)	
Clark Fork above Missoula, Montana (sampling site 22, fig. 1, table 1)							
Specific conductance, µS/cm	277	275	270	273	283	265	-4
Copper, filtered, µg/L	2.3	1.7	2.1	2.4	1.9	1.4	-39
Copper, unfiltered-recoverable, µg/L	6.4	4.9	6.9	15	6.3	3.0	-53
Zinc, unfiltered-recoverable, µg/L	14	7.2	10	30	10	5.0	-64
Arsenic, filtered, µg/L	3.3	2.8	3.2	3.6	3.4	2.6	-21
Arsenic, unfiltered-recoverable, µg/L	4.2	3.3	3.9	4.8	4.0	3.0	-29
Suspended sediment, mg/L	7.7	7.4	9.2	25	9.9	6.0	-22

[1]Shading represents qualitative observations on overall trend magnitudes (percent change from start of water year 1996 to end of water year 2015) as follows: no shading—minor (the absolute value was less than about 20 percent); green shading—small (the absolute value was in the range of about 20–40 percent; tan shading—moderate (the absolute value was in the range of about 40–60 percent; and purple shading—large (the absolute value was greater than about 60 percent).

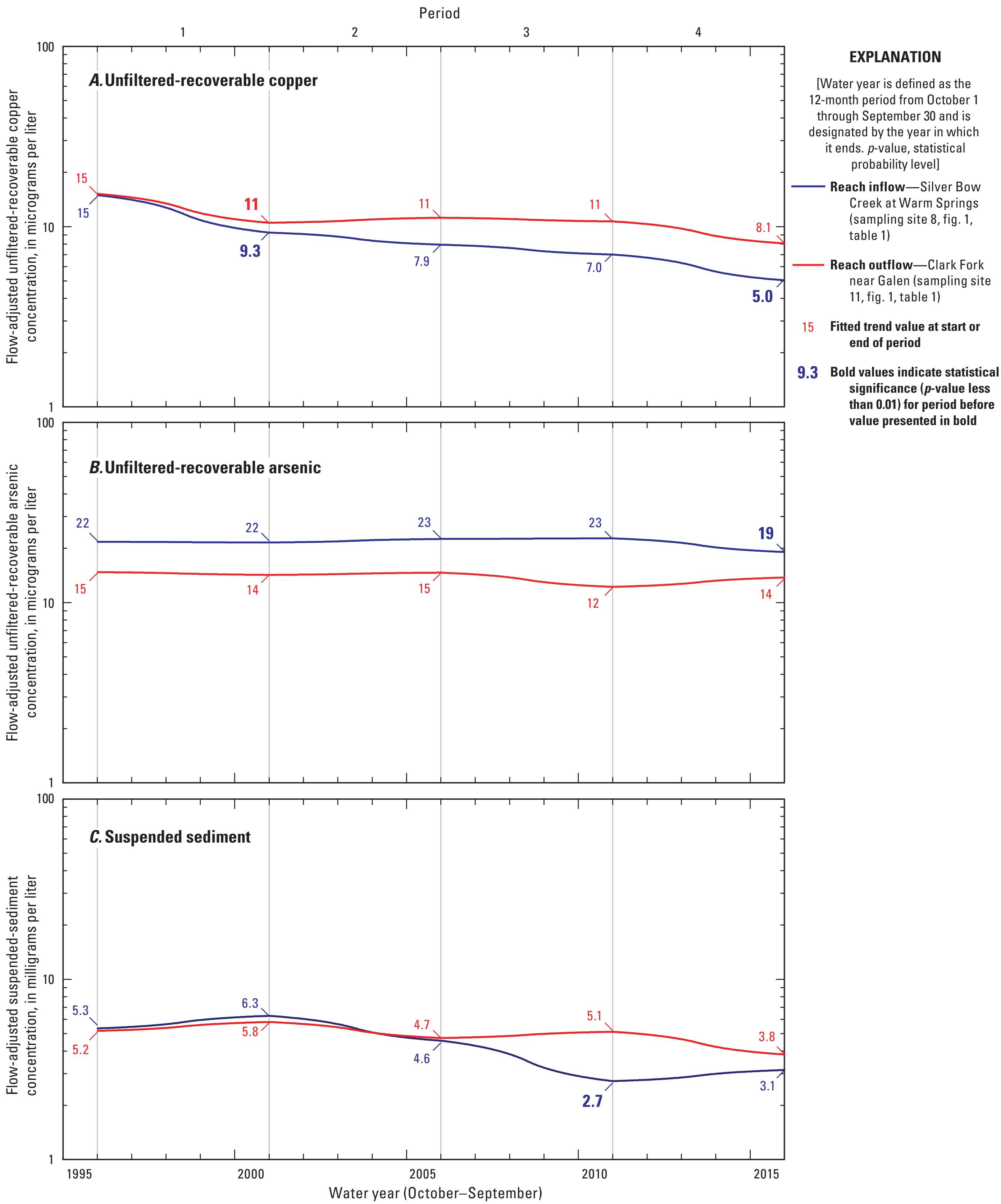

Figure 5. Flow-adjusted fitted trends for selected constituents for sampling sites in reach 4, extending from Silver Bow Creek at Warm Springs, Montana (sampling site 8), to Clark Fork near Galen, Montana (sampling site 11), water years 1996–2015.

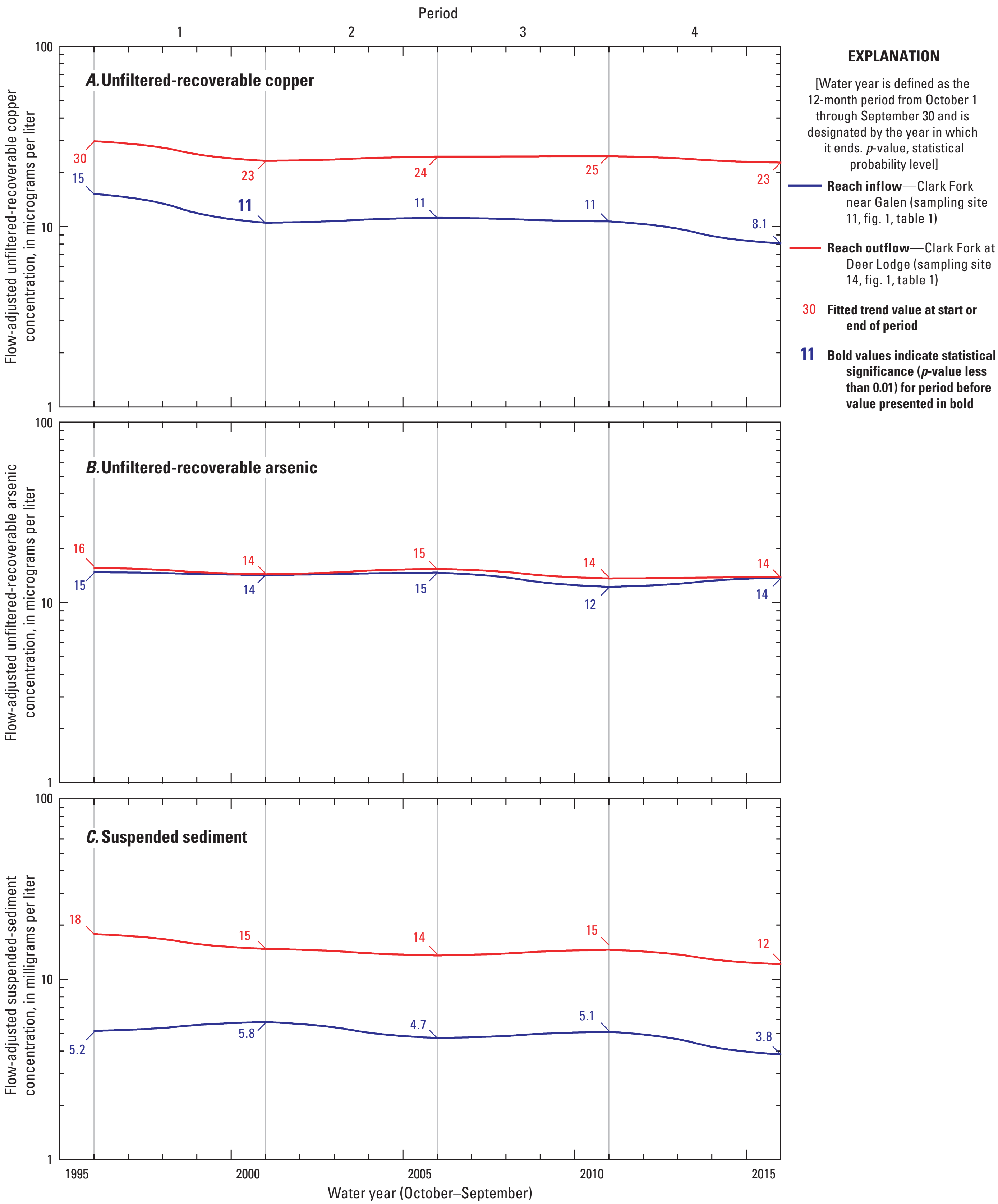

Figure 6. Flow-adjusted fitted trends for selected constituents for sampling sites in reach 5, extending from Clark Fork near Galen, Montana (sampling site 11), to Clark Fork at Deer Lodge, Montana (sampling site 14), water years 1996–2015.

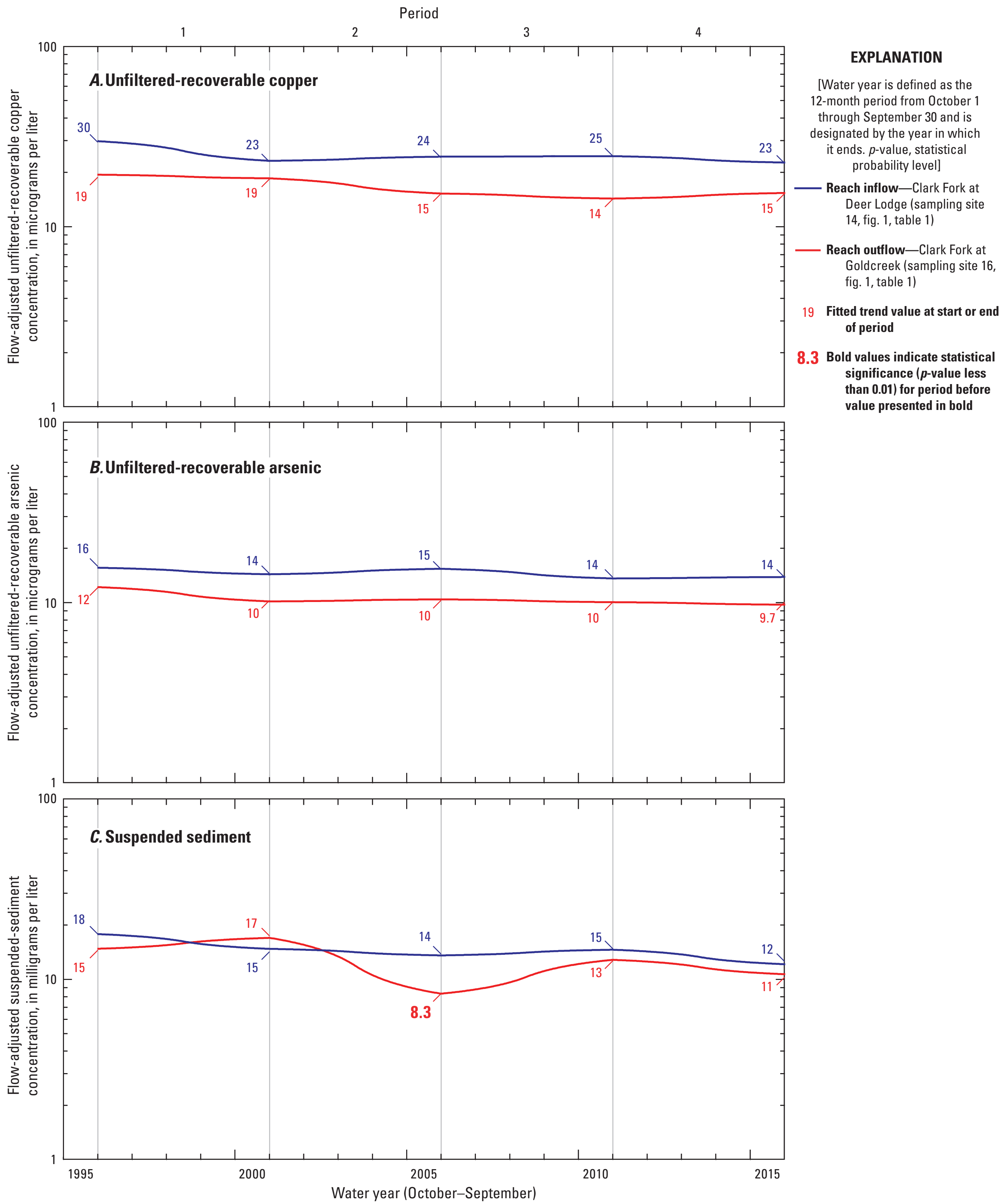

Figure 7. Flow-adjusted fitted trends for selected constituents for sampling sites in reach 6, extending from Clark Fork at Deer Lodge, Montana (sampling site 14), to Clark Fork at Goldcreek, Montana (sampling site 16), water years 1996–2015.

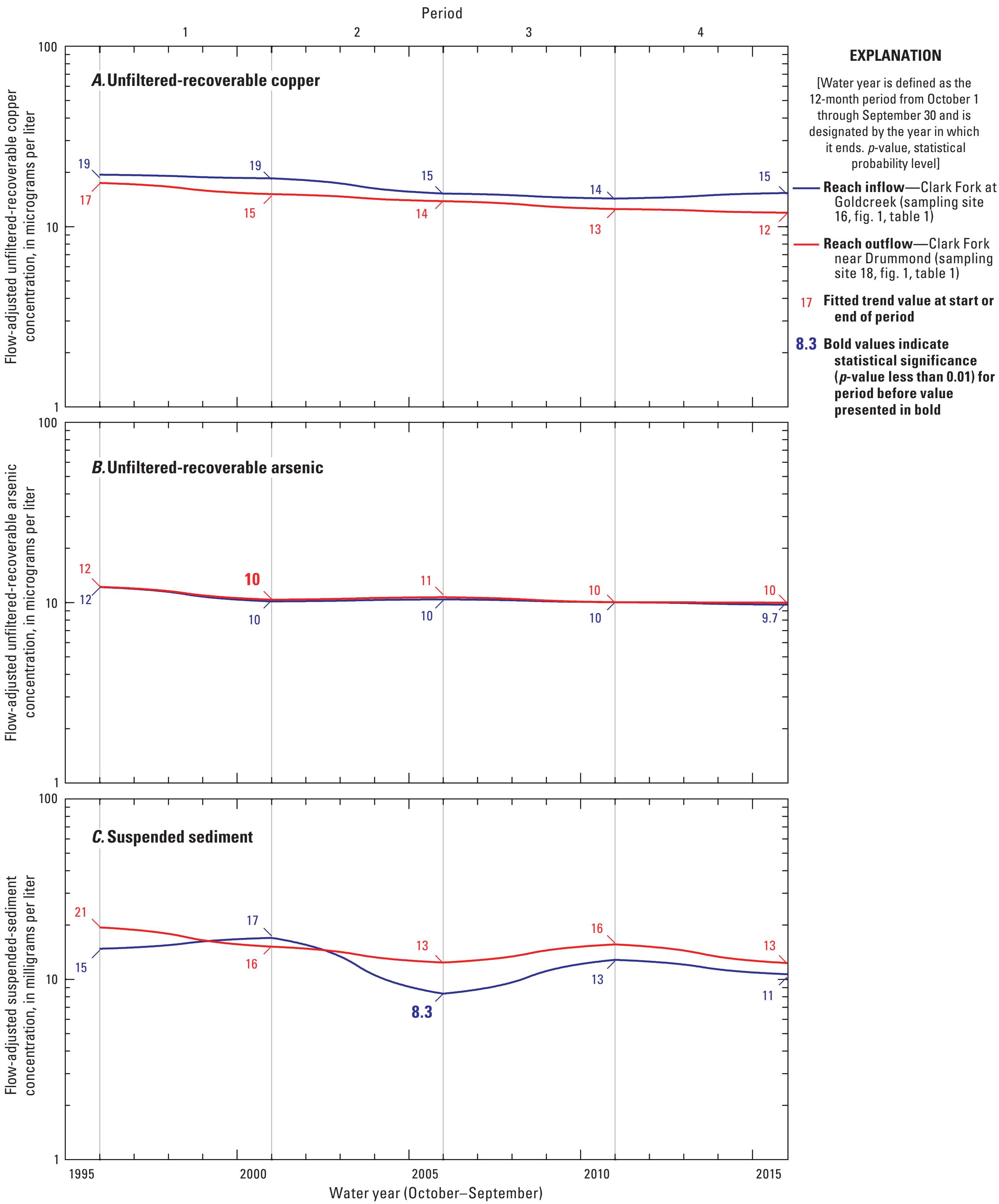

Figure 8. Flow-adjusted fitted trends for selected constituents for sampling sites in reach 7, extending from Clark Fork at Goldcreek, Montana (sampling site 16), to Clark Fork near Drummond, Montana (sampling site 18), water years 1996–2015.

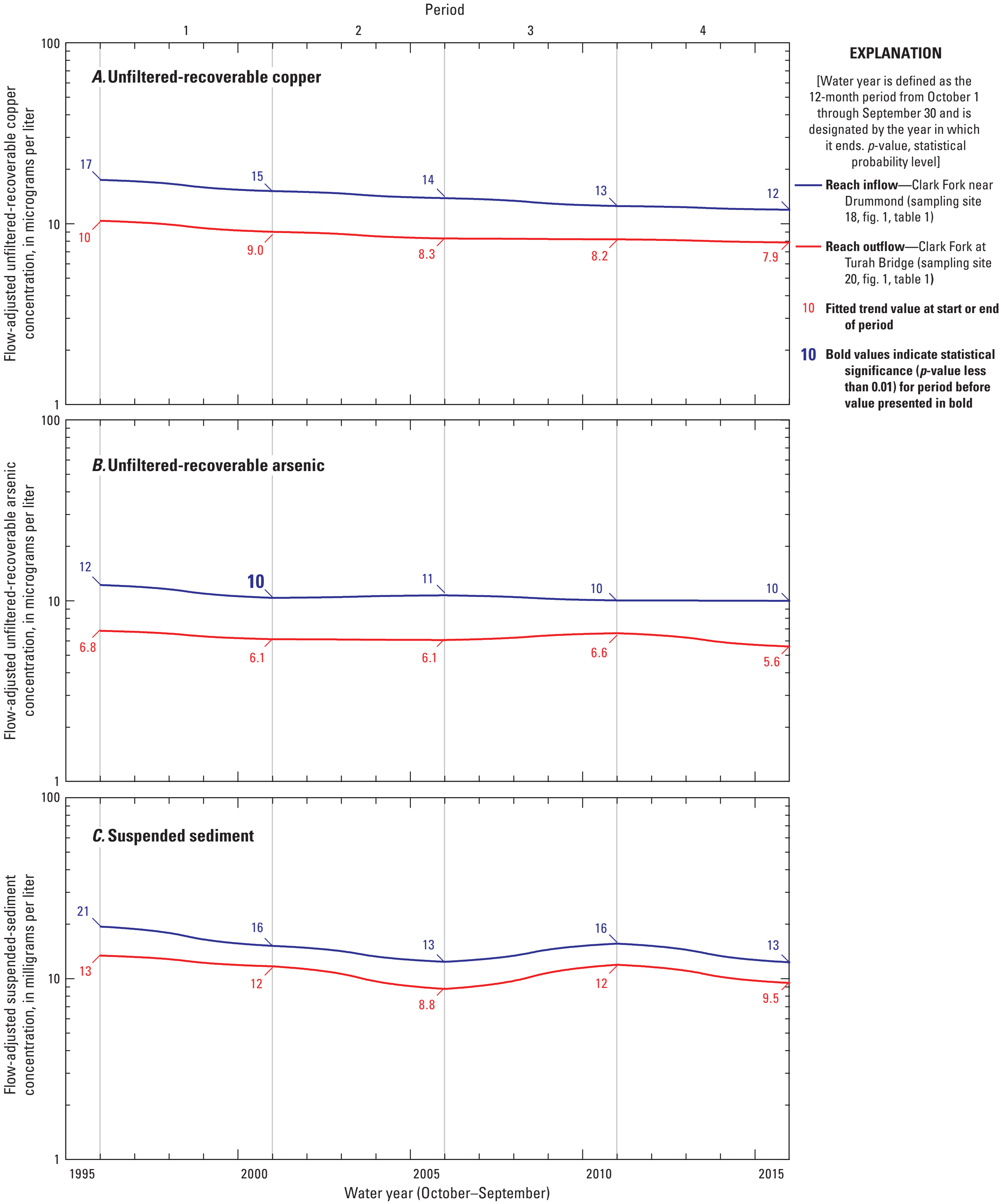

Figure 9. Flow-adjusted fitted trends for selected constituents for sampling sites in reach 8, extending from Clark Fork near Drummond, Montana (sampling site 18), to Clark Fork at Turah Bridge near Bonner, Montana (sampling site 20), water years 1996–2015.

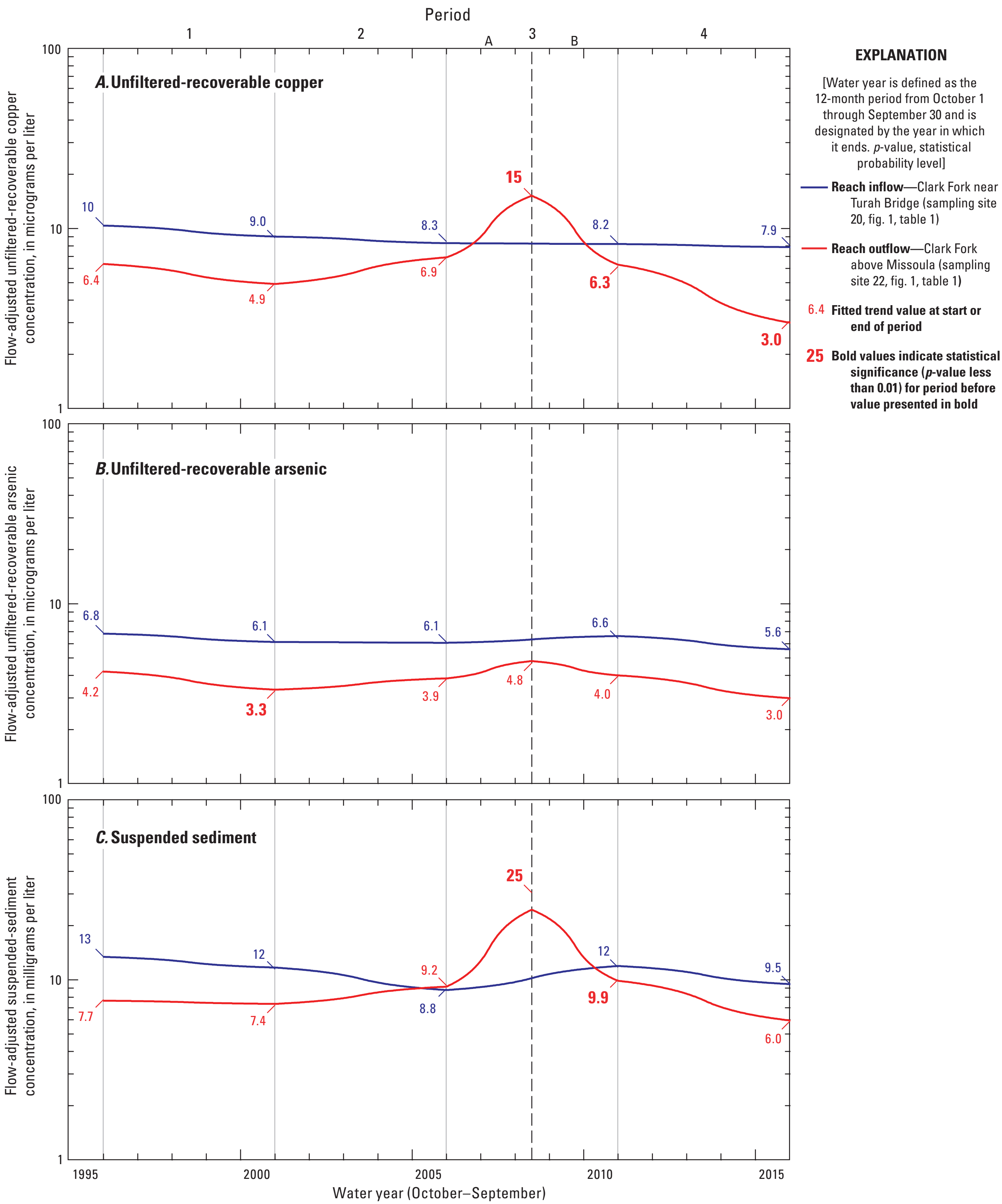

Figure 10. Flow-adjusted fitted trends for selected constituents for sampling sites in reach 9, extending from Clark Fork at Turah Bridge near Bonner, Montana (sampling site 20), to Clark Fork above Missoula, Montana (sampling site 22), water years 1996–2015.

Copper

Trend results indicate that FACs of unfiltered-recoverable copper decreased at the sampling sites from the start of period 1 through the end of period 4 (tables 6 and 7); the decreases ranged from large for one sampling site (Silver Bow Creek at Warm Springs [sampling site 8]) to moderate for two sampling sites (Clark Fork near Galen [sampling site 11] and Clark Fork above Missoula [sampling site 22]) to small for four sampling sites (Clark Fork at Deer Lodge [sampling site 14], Clark Fork at Goldcreek [sampling site 16], Clark Fork near Drummond [sampling site 18], and Clark Fork at Turah Bridge [sampling site 20]). For period 4 (water years 2011–15), the most notable changes indicated for the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin were statistically significant decreases in FACs of unfiltered-recoverable copper for sampling sites 8 and 22. For all other sampling sites, the period 4 changes in FACs of unfiltered-recoverable copper were not statistically significant.

Arsenic

Trend results indicate that FACs of unfiltered-recoverable arsenic decreased at the sampling sites from the start of period 1 through the end of period 4 (tables 6 and 7); the decreases ranged from minor for six sampling sites (sampling sites 8–20) to small for one sampling site (sampling site 22). For period 4 (water years 2011–15), the most notable changes indicated for the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin were statistically significant decreases in FACs of unfiltered-recoverable arsenic for sampling site 8 and near statistically significant decreases for sampling site 22; the *p*-value (0.012) for the period 4 decrease for sampling site 22 is not statistically significant but is only slightly larger than the selected alpha level (0.01 in this report). For all other sampling sites, the period 4 changes in FACs of unfiltered-recoverable arsenic were not statistically significant.

Suspended Sediment

Trend results indicate that FACs of suspended sediment decreased at the sampling sites from the start of period 1 through the end of period 4 (tables 6 and 7); the decreases ranged from moderate for one sampling site (sampling site 8) to small for six sampling sites (sampling sites 11–22). For period 4 (water years 2011–15), the changes in FACs of suspended sediment were not statistically significant for any sampling sites.

Overview of Water-Quality Trend Results

The most notable changes in water quality in period 4 were indicated for Silver Bow Creek at Warm Springs (sampling site 8; reach 4 inflow) and Clark Fork above Missoula (sampling 22; reach 9 outflow). Trend results for sampling site 8 indicated more substantial changes than most other sampling sites; the decreases in specific conductance, unfiltered-recoverable copper, unfiltered-recoverable zinc, and unfiltered-recoverable arsenic were statistically significant (fig. 5 and 3–1; tables 6 and 3–1). The most extensive remediation activities in the upper Clark Fork Basin have been conducted in the Silver Bow Creek Basin upstream from the reach 4 inflow (sampling site 8). Sando and others (2014) noted that among the most notable changes indicated in the upper Clark Fork Basin during water years 1996–2010 were moderate to large decreases in FACs and loads of copper and suspended sediment in Silver Bow Creek upstream from Warm Springs. The period 4 (water years 2011–15) statistically significant decreases in FACs of unfiltered-recoverable copper and zinc provide indication that FACs of metallic contaminants continued to substantially decline at sampling site 8.

The removal of the former Milltown Dam, which was located between Clark Fork at Turah Bridge (sampling site 20; reach 9 inflow) and Clark Fork above Missoula (sampling site 22; reach 9 outflow), in 2008 was an important remediation activity in the upper Clark Fork Basin and strongly affected water-quality trends and transport characteristics within reach 9. As such, detailed discussion of trends is presented for reach 9. During periods 1 and 2, the former Milltown Dam was in place, and large amounts of contaminated sediments were retained in the former Milltown Reservoir in reach 9; however, the contaminated sediments largely were unavailable for mobilization and transport because of backwater effects of the former Milltown Dam (Sando and Lambing, 2011). Remediation activities preparing for the removal of the former Milltown Dam started in period 2 but were focused early in period 3 and included physical removal of large amounts of contaminated sediments; however, substantial amounts of contaminated sediments still remained in the Clark Fork channel and flood plain in reach 9. With the removal of the former Milltown Dam in 2008, the remaining contaminated sediments in reach 9 became more available for mobilization and transport than before the dam removal. Because of the substantial effect of the intentional breach of Milltown Dam on March 28, 2008, for sampling site 22, period 3 was subdivided into period 3A (October 1, 2005–March 27, 2008) and period 3B (March 28, 2008–September 30, 2010).

A statistically significant increase in FACs of unfiltered-recoverable copper is indicated for period 3A for sampling site 22 (117 percent, from 6.9 to 15 µg/L; table 7). The temporary increase in FACs is associated with activities that prepared for the removal of the Milltown Dam, including construction of roads and facilities, reservoir level drawdowns, and physical removal of large amounts of contaminated sediments, which likely increased mobilization of sediments enriched in trace elements (Sando and Lambing, 2011). After the intentional breach, statistically significant decreases were indicated for unfiltered-recoverable copper for period 3B (-58 percent, from 15 to 6.3 µg/L) and period 4 (-52 percent, from 6.3 to 3.0 µg/L). For unfiltered-recoverable arsenic, an increase in FACs is indicated for period 3A (23 percent, from 3.9 to 4.8 µg/L). After the intentional breach, a decrease is indicated for unfiltered-recoverable arsenic for period 3B (-17 percent, from 4.8 to 4.0 µg/L) and a near statistically significant decrease is indicated for period 4 (-25 percent, from 4.0 to 3.0 µg/L; *p*-value of 0.012). For suspended sediment, a statistically significant increase is indicated for period 3A (172 percent, from 9.2 to 25 mg/L). After the intentional breach, a statistically significant decrease for suspended sediment is indicated for period 3B (-60 percent, from 25 to 9.9 mg/L), and a decrease is indicated for period 4 (-39 percent, from 9.9 to 6.0 mg/L). For period 4 (water years 2011–15), trend results for the reach 9 outflow (sampling site 22) indicate more substantial changes than most other sampling sites; decreases in unfiltered-recoverable copper, unfiltered-recoverable zinc, and filtered arsenic were statistically significant. The *p*-value (0.012) for the period 4 decrease in FACs of unfiltered-recoverable arsenic for sampling site 22 is not statistically significant but is only slightly larger than the selected alpha level (0.01 in this report).

The somewhat high streamflow conditions of period 4 promoted mobilization of trace-element contaminants from the former Milltown Reservoir, thus decreasing within-reach source materials and resulting in lower FACs. The substantial decreases in FACs of unfiltered-recoverable copper for period 3B continued in period 4. Comparison of the period 4 fitted trends for unfiltered-recoverable copper between the reach 9 inflow (sampling site 20) and the reach 9 outflow (sampling site 22) indicates large deviation from the start of to the end of period 4 (fig. 10*A*) and provides evidence of continued effects of the removal of the former Milltown Dam. Deviations in fitted trends between the period 4 reach inflow and reach outflow also are apparent for unfiltered-recoverable arsenic (fig. 10*B*) and suspended sediment (fig. 10*C*); however, the deviations are not as strong for those constituents as for unfiltered-recoverable copper.

Constituent-Transport Analysis Results

Estimated normalized loads are presented in the framework of a transport analysis to assess the temporal trends in FACs in the context of sources and transport. Drainage area and streamflow information relevant to the transport analysis are presented in table 8. Balance calculations for the transport analysis (that is, differences between reach inflows and reach outflows) are presented in tables 4–1 through 4–6 for reaches 4–9, respectively, in appendix 4. The transport balance calculations indicate within-reach changes in estimated normalized loads and allow assessment of temporal changes in relative contributions from upstream source areas to loads transported past each reach outflow.

Hydrologic characteristics of the source areas (geometric mean streamflow; table 8) and balance results for the transport analysis are illustrated by using pie charts that show source-area information and load contributions to reach outflow. Pie charts illustrating temporal patterns in estimated normalized loads for all data-summary reaches are presented in figures 11–13 for unfiltered-recoverable copper, unfiltered-recoverable arsenic, and suspended sediment, respectively. The pie charts provide a side-by-side graphical summary for evaluating spatial and temporal variability in constituent transport relative to streamflow contributions in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin. The estimated normalized loads (hereinafter referred to as “loads”) do not represent actual magnitudes of total mass transport, but rather provide information on relative temporal changes in constituent transport characteristics in the upper Clark Fork Basin quantified with respect to near-median conditions.

In figures 11–13, geometric mean streamflows (water years 1996–2015) for each reach are shown across the top of each figure, with the size (area) of each pie chart being proportional to the geometric mean streamflow for Clark Fork above Missoula (sampling site 22; reach 9 outflow). Pie charts that illustrate the constituent-transport analysis results for each reach for periods 1–4 are shown below the pie charts representing geometric mean streamflows. Pie charts illustrating loads are sized proportionally to the period 1 reach 9 outflow load. The period 1 reach 9 outflow load was selected as an index for sizing the pie charts because it represents the total load transported from the Milltown Reservoir/Clark Fork River Superfund Site somewhat near the start of remediation activities. As such, the period 1 reach 9 outflow load is a useful index in evaluating effects of remediation in the upper Clark Fork Basin.

Figure 11 presents pie charts representing loads for unfiltered-recoverable copper and serves as an example for explaining the presentation of the constituent-transport analysis results. The size (area) of each loads pie chart represents the total outflow from the reach, with colored areas indicating relative contributions from each of the two source areas; that is, (1) the reach inflow and (2) the intervening drainage between the reach inflow and outflow (or within-reach sources). The left-hand column of the load pie charts presents results for reach 4 for periods 1–4. The period 1 load transported past the reach 4 outflow (sampling site 11) is 3.7 kilograms per day (kg/d), which is 13 percent of the period 1 load transported past the reach 9 outflow (29 kg/d at sampling site 22 shown in right-hand column); thus, the size of the period 1 reach 4 pie chart is 13 percent of the size of the period 1 reach 9 pie chart. The blue-colored part of the period 1 reach 4 pie chart represents the load (1.9 kg/d) transported past the reach 4 inflow (sampling site 8). The orange-colored part of the period 1 reach 4 pie chart represents the total within-reach change in load (that is, net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain). The total within-reach change in load (1.8 kg/d) was calculated by subtracting the reach inflow (1.9 kg/d) from the reach outflow (3.7 kg/d). In figure 11, results for reach 9 are not shown for period 3 because of effects of the removal of the former

Table 8. Drainage area and streamflow information relevant to the transport analysis for data-summary reaches in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft^3/s, cubic foot per second]

Abbreviated sampling site name (table 1) and number or summation category	Drainage area, in square miles	Geometric mean streamflow, water years 1996–2015, in ft^3/s
Reach 4 [extending about 2 river miles from Silver Bow Creek at Warm Springs (sampling site 8, fig. 1, table 1) to Clark Fork near Galen (sampling site 11, fig. 1, table 1)]		
Inflow		
Silver Bow Creek at Warm Springs (sampling site 8)	473	64
Outflow		
Clark Fork near Galen (sampling site 11)	651	118
Within-reach change—outflow (sampling site 11) minus inflow (sampling site 8) (contributions from all within-reach sources, including groundwater inflow and tributaries)	178	54
Reach 5 [extending about 21 river miles from Clark Fork near Galen (sampling site 11, fig. 1, table 1) to Clark Fork at Deer Lodge (sampling site 14, fig. 1, table 1)]		
Inflow		
Clark Fork near Galen (sampling site 11)	651	118
Outflow		
Clark Fork at Deer Lodge (sampling site 14)	995	208
Within-reach change—outflow (sampling site 14) minus inflow (sampling site 11) (contributions from all within-reach sources, including groundwater inflow and tributaries)	344	90
Reach 6 [extending about 26 river miles from Clark Fork at Deer Lodge (sampling site 14, fig. 1, table 1) to Clark Fork at Goldcreek (sampling site 16, fig. 1, table 1)]		
Inflow		
Clark Fork at Deer Lodge (sampling site 14)	995	208
Outflow		
Clark Fork at Goldcreek (sampling site 16)	1,704	406
Within-reach change—outflow (sampling site 16) minus inflow (sampling site 14) (contributions from all within-reach sources, including groundwater inflow and tributaries)	709	198

Milltown Dam and difficulties in presenting those results in conjunction with results for other reaches.

Constituent-transport analysis results are described for copper, arsenic, and suspended sediment in the following subsections. Observations are made comparing the relative proportions of within-reach contributions of constituent loads and within-reach contributions of streamflow. Those proportional comparisons indicate the importance of a given reach as a source of constituent loading to Silver Bow Creek or the Clark Fork. If the contribution of a constituent from within a reach is proportionally much larger than the contribution of streamflow from within a reach, the given reach is indicated to be an important disproportionate source of constituent loading. Conversely, if the contribution of a constituent from within a reach is proportionally smaller than or similar to the contribution of streamflow from within a reach, the given reach is not indicated to be an important disproportionate source of constituent loading and generally acts as a flow-through reach.

Table 8. Drainage area and streamflow information relevant to the transport analysis for data-summary reaches in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 1996–2015.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. ft^3/s, cubic foot per second]

Abbreviated sampling site name (table 1) and number or summation category	Drainage area, in square miles	Geometric mean streamflow, water years 1996–2015, in ft^3/s
Reach 7 [extending about 31 river miles from Clark Fork at Goldcreek (sampling site 16, fig. 1, table 1) to Clark Fork near Drummond (sampling site 18, fig. 1, table 1)]		
Inflow		
Clark Fork at Goldcreek (sampling site 16)	1,704	406
Outflow		
Clark Fork near Drummond (sampling site 18)	2,501	589
Within-reach change—outflow (sampling site 18) minus inflow (sampling site 16) (contributions from all within-reach sources, including groundwater inflow and tributaries)	797	183
Reach 8 [extending about 34 river miles from Clark Fork near Drummond (sampling site 18, fig. 1, table 1) to Clark Fork at Turah Bridge (sampling site 20, fig. 1, table 1)]		
Inflow		
Clark Fork near Drummond (sampling site 18)	2,501	589
Outflow		
Clark Fork at Turah Bridge (sampling site 20)	3,641	1,060
Within-reach change—outflow (sampling site 20) minus inflow (sampling site 18) (contributions from all within-reach sources, including groundwater inflow and tributaries)	1,140	470
Reach 9 [extending about 9 river miles from Clark Fork at Turah Bridge (sampling site 20, fig. 1, table 1) to Clark Fork above Missoula (sampling site 22, fig. 1, table 1)]		
Inflow		
Clark Fork at Turah Bridge (sampling site 20)	3,641	1,060
Outflow		
Clark Fork above Missoula (sampling site 22)	5,999	2,100
Within-reach change—outflow (sampling site 22) minus inflow (sampling site 20) (contributions from all within-reach sources, including groundwater inflow and tributaries)	2,358	1,040

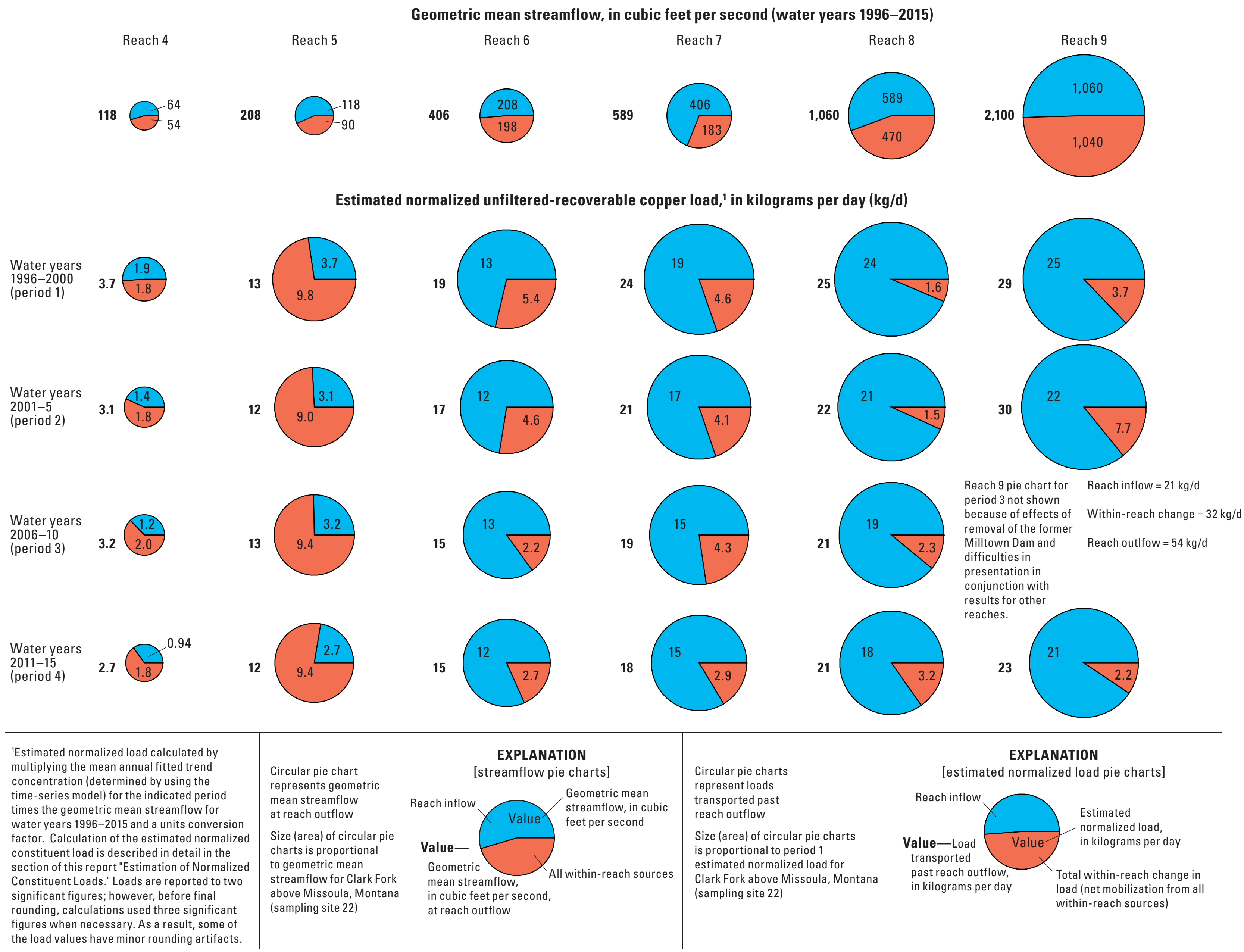

Figure 11. Pie charts representing geometric mean streamflow and estimated normalized unfiltered-recoverable copper loads contributed from reach inflow and within-reach sources for data-summary reaches for selected periods.

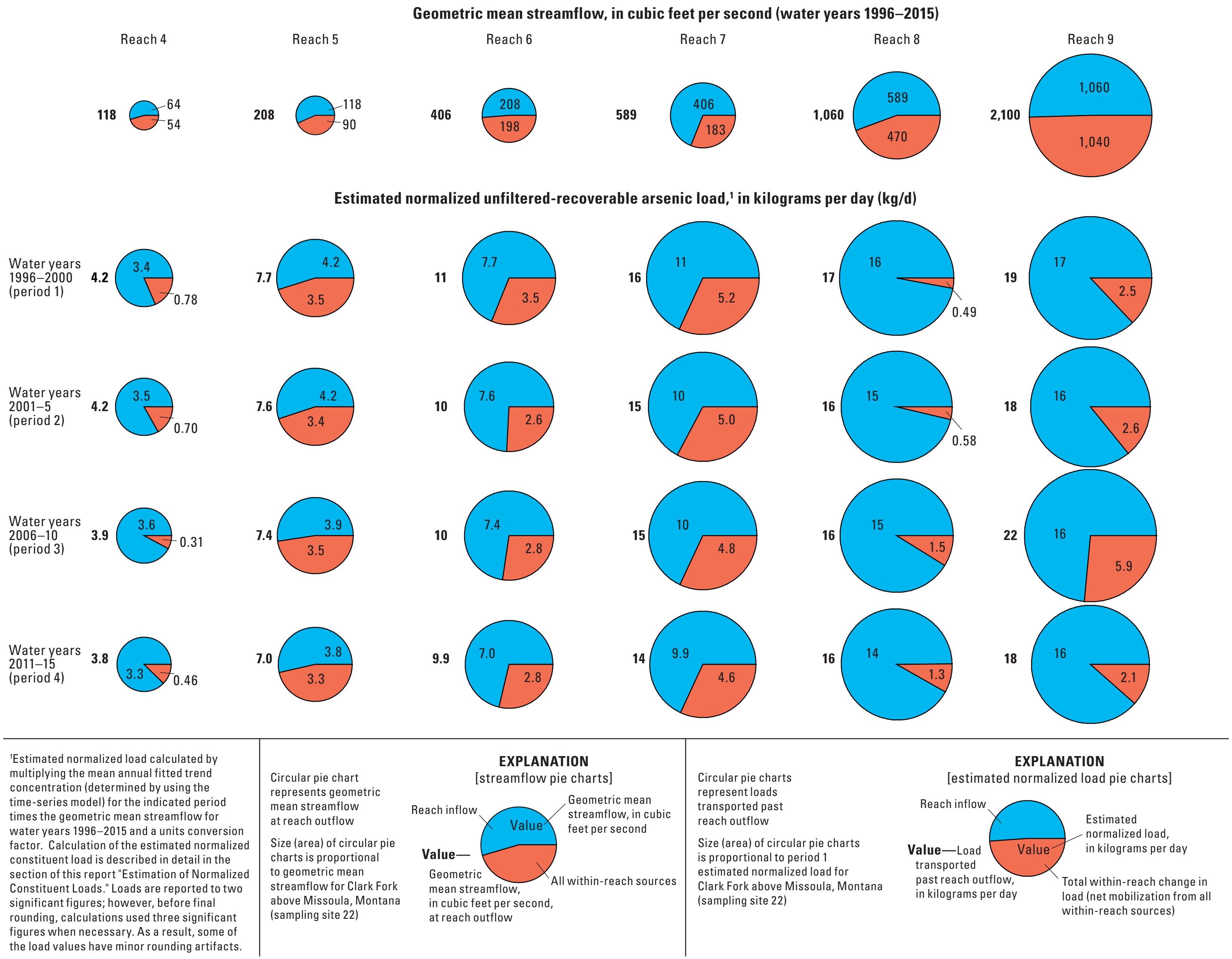

Figure 12. Pie charts representing geometric mean streamflow and estimated normalized unfiltered-recoverable arsenic loads contributed from reach inflow and within-reach sources for data-summary reaches for selected periods.

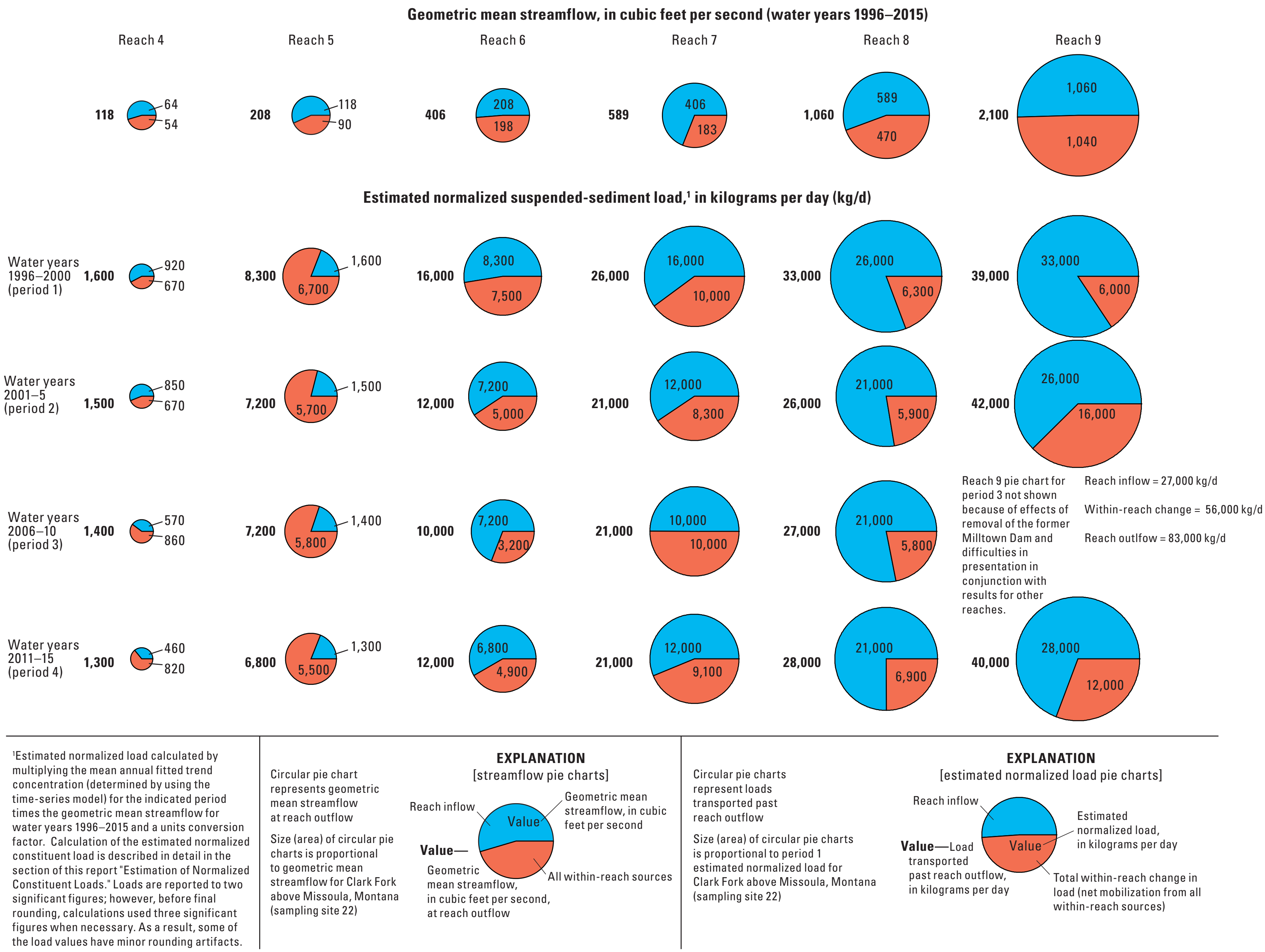

Figure 13. Pie charts representing geometric mean streamflow and estimated normalized suspended-sediment loads contributed from reach inflow and within-reach sources for data-summary reaches for selected periods.

Copper

The transport-analysis results indicate that outflow loads of unfiltered-recoverable copper decreased from the center of period 1 through the center of period 4 for all reaches (fig. 11). The largest decrease was for the reach 4 outflow load (about -27 percent, from 3.7 to 2.7 kg/d). The decrease in the reach 4 outflow load (sampling site 11) largely was because of a substantial decrease (-50 percent, from 1.9 to 0.94 kg/d) in the reach 4 inflow load (sampling site 8), with little change indicated for within-reach sources. The smallest decrease was for the reach 5 outflow load (about -8 percent from 13 to 12 kg/d). Decreases in outflow loads for the other reaches (reaches 6–9) ranged from about -16 to -25 percent.

Contributions of unfiltered-recoverable copper from reach 4 sources were proportionally similar to or slightly larger than streamflow contributions from within reach 4 (fig. 11, tables 8 and 4–1) for all periods, and thus reach 4 is somewhat indicated to be a disproportionate source of copper loading. However, the period 4 net mobilization from sources within reach 4 (1.8 kg/d) was only about 8 percent of the period 4 reach 9 outflow load (Clark Fork above Missoula, sampling site 22; 23 kg/d). Contributions of unfiltered-recoverable copper from reach 5 sources were proportionally much larger than streamflow contributions from within reach 5 for all periods; the period 4 net mobilization from sources within reach 5 (9.4 kg/d) accounted for a substantial part (about 41 percent) of the period 4 reach 9 outflow load. Thus, reach 5 is indicated to be an important disproportionate source of copper loading. Contributions of unfiltered-recoverable copper from sources within the other reaches (reaches 6–9) were proportionally smaller than the within-reach streamflow contributions.

The removal of the former Milltown Dam in 2008 warrants more detailed discussion of transport analysis results for reach 9. The segregation of period 3 into periods 3A and 3B for the reach 9 outflow (sampling site 22) is not directly incorporated into the transport analysis for reach 9; thus, the transport-analysis balance calculations for period 3 reflect the net changes in transport characteristics before and after the removal of the former Milltown Dam. For unfiltered-recoverable copper (fig. 11), the reach 9 outflow load (sampling site 22) decreased by about 21 percent from the center of period 1 (29 kg/d) to the center of period 4 (23 kg/d). Net mobilization from sources within reach 9 increased between periods 1 and 2 and also between periods 2 and 3 (fig. 11). Net mobilization from sources within reach 9 substantially decreased between periods 3 and 4. Net mobilization from sources within reach 9 were proportionally larger than streamflow contributions from within reach 9 for period 3 but were proportionally smaller than streamflow contributions for the other periods. Net mobilization from sources within reach 9 were smaller for period 4 (2.2 kg/d) than for period 1 (3.7 kg/d).

Arsenic

The transport-analysis results indicate that outflow loads of unfiltered-recoverable arsenic decreased from the center of period 1 through the center of period 4 for all reaches (fig. 12). Decreases in outflow loads for the reaches ranged from about -5 to -12 percent. Temporal decreases in unfiltered-recoverable arsenic were smaller than copper and suspended sediment, which probably reflects the dispersion and solubility characteristics of arsenic.

At the upstream end of the Milltown Reservoir/Clark Fork River Superfund site, the reach 4 inflow load is a disproportionate source of arsenic loading, with the inflow load being proportionally larger than the streamflow (fig. 12, tables 8 and 4–1). Contributions of unfiltered-recoverable arsenic from reach 4 sources were proportionally smaller than streamflow contributions from within reach 4 for all periods. Downstream from reach 4, contributions of unfiltered-recoverable arsenic from sources within reaches 5 and 7 were proportionally similar to within-reach streamflow contributions. Contributions of unfiltered-recoverable arsenic from sources within the other reaches (reaches 6, 8, and 9) were proportionally smaller than the within-reach streamflow contributions.

For unfiltered-recoverable arsenic (fig. 12), the reach 9 outflow load (sampling site 22) decreased by about 5 percent from the center of period 1 (19 kg/d) to the center of period 4 (18 kg/d). Net mobilization from sources within reach 9 increased between periods 2 and 3 (fig. 12). Net mobilization from sources within reach 9 substantially decreased between periods 3 and 4. Contributions of unfiltered-recoverable arsenic from reach 9 sources were proportionally smaller than streamflow contributions from within reach 9 for all periods. Net mobilization from sources within reach 9 were slightly smaller for period 4 (2.1 kg/d) than for period 1 (2.5 kg/d).

Suspended Sediment

The transport-analysis results indicate that outflow loads of suspended sediment decreased from the center of period 1 through the center of period 4 for reaches 4–8 but slightly increased for reach 9 (fig. 13). Decreases in outflow loads for reaches 6–8 ranged from about -15 to -25 percent.

Contributions of suspended sediment from reach 4 sources were proportionally similar to or slightly larger than streamflow contributions from within reach 4 (fig. 13, tables 8 and 4–1) for all periods, and thus, reach 4 is somewhat indicated to be a disproportionate source of suspended-sediment loading. However, the period 4 net mobilization from sources within reach 4 (820 kg/d) was only about 2 percent of the period 4 reach 9 outflow load (Clark Fork above Missoula, sampling site 22; 40,000 kg/d). Contributions of suspended sediment from reach 5 sources were proportionally much larger than streamflow contributions from within reach 5; the period 4 net mobilization from sources within reach 5 (5,500 kg/d) accounted for about 14 percent of the period 4 reach 9 outflow load. Thus, reach 5 is indicated to be a disproportionate source of suspended-sediment loading. Downstream from reach 5, contributions of sediment from sources within reach 7 were proportionally similar to within-reach streamflow contributions; the period 4 net mobilization from sources within reach 7 (9,100 kg/d) accounted for about 23 percent of the period 4 reach 9 outflow load. Contributions of suspended sediment from sources within the other reaches (reaches 6, 8, and 9) were proportionally smaller than the within-reach streamflow contributions.

For suspended sediment (fig. 13), the reach 9 outflow load (sampling site 22) increased by about 3 percent from the center of period 1 (39,000 kg/d) to the center of period 4 (40,000 kg/d). Net mobilization from sources within reach 9 increased between periods 1 and 2 and also between periods 2 and 3 (fig. 13). Net mobilization from sources within reach 9 substantially decreased between periods 3 and 4. Net mobilization from sources within reach 9 was proportionally larger than streamflow contributions from within reach 9 for period 3 but was proportionally smaller than streamflow contributions for the other periods. Net mobilization from sources within reach 9 were larger for period 4 (12,000 kg/d) than for period 1 (6,000 kg/d). The increase in net mobilization of suspended sediment from sources within reach 9 between periods 1 and 4 is in contrast to decreases in net mobilization of unfiltered-recoverable copper and arsenic between periods 1 and 4. A possible explanation for this pattern might relate to flood-plain disturbance and placement of uncontaminated fill in the flood plain associated with remediation activities. The artificially installed uncontaminated fill might be more available for mobilization than sediment within the former Milltown Reservoir during period 1.

Overview of Constituent-Transport Analysis Results

At the upstream end of the Milltown Reservoir/Clark Fork River Superfund site, the reach 4 inflow had substantial decreases from the center of period 1 to the center of period 4 in unfiltered-recoverable copper and suspended-sediment loads (about -50 percent for both constituents), but the reach 4 inflow accounts for small parts of the streamflow (about 3 percent), unfiltered-recoverable copper load (about 4 percent), and suspended-sediment load (about 1 percent) of the reach 9 outflow in period 4 (figs. 11 and 13). The reach 4 inflow is a disproportionate source of unfiltered-recoverable arsenic and accounts for about 18 percent of the reach 9 outflow load in period 4 (fig. 12). Some downstream reaches (including reaches 5 and 7) have within-reach contributions of unfiltered-recoverable arsenic that are proportionally similar to streamflow contributions and also substantially contribute to the reach 9 outflow load. For all reaches, temporal changes for unfiltered-recoverable arsenic loads are smaller than for unfiltered-recoverable copper and suspended-sediment loads.

Reach 5 is a large source of unfiltered-recoverable copper and suspended sediment, which strongly affects downstream transport of those constituents (figs. 11 and 13). Mobilization of unfiltered-recoverable copper and suspended sediment from flood-plain tailings and the streambed of the Clark Fork and its tributaries within reach 5 results in a contribution of those constituents from within reach 5 that is proportionally much larger than the contribution of streamflow from within reach 5. In reach 5, unfiltered-recoverable copper loads in the Clark Fork increased by a factor of about 4 and suspended-sediment loads increased by a factor of about 5, whereas streamflow increased by a factor of slightly less than 2 (fig. 11). For period 4 (water years 2011–15), unfiltered-recoverable copper and suspended-sediment loads sourced from within reach 5 accounted for about 41 and 14 percent, respectively, of the loads at Clark Fork above Missoula (sampling site 22), whereas streamflow sourced from within the reach accounted for about 4 percent of the streamflow at sampling site 22. During water years 1996–2015, decreases in unfiltered-recoverable copper and suspended-sediment loads (fig. 11 and 13) for the reach 5 outflow and for sources within reach 5 generally were proportionally smaller than for most other reaches.

For the reaches downstream from reach 5 (reaches 6–8), contributions of copper loads sourced from within the reaches were proportionally smaller than contributions of streamflow sourced from within the reaches (fig. 11); thus, the lower reaches contributed proportionally much less than reach 5 to unfiltered-recoverable copper loading in the Clark Fork. Although substantial decreases in unfiltered-recoverable copper and suspended-sediment loads were indicated for the reach 4 inflow (sampling site 8), those substantial decreases were not translated to the downstream reaches (reaches 5–8). The effect of reach 5 as a large source of unfiltered-recoverable copper and suspended sediment, in combination with little temporal change in those constituents for the reach 5 outflow, contributes to this pattern.

For unfiltered-recoverable copper, unfiltered-recoverable arsenic, and suspended sediment, contributions from within reach 8 generally increased between periods 2 and 4; this pattern is in contrast to patterns for most other reaches. A possible explanation for this pattern might relate to effects of the removal of the former Milltown Dam during period 3. Before the removal of the former Milltown Dam, backwater effects of the dam during high-flow conditions might have extended far enough upstream to affect the hydraulic gradient at the reach 8 outflow (sampling site 20) and also affect the transport of materials from reach 8. After the removal of the former Milltown Dam, the hydraulic gradient at sampling site 20 might have steepened and promoted transport of materials from reach 8 during high streamflow conditions.

With the removal of the former Milltown Dam in 2008, substantial amounts of contaminated sediments that remained in the Clark Fork channel and flood plain in reach 9 became more available for mobilization and transport than before the dam removal. Net mobilization of unfiltered-recoverable copper, unfiltered-recoverable arsenic, and suspended sediment from sources within reach 9 substantially decreased between periods 3 and 4. Net mobilization of unfiltered-recoverable copper and arsenic from sources within reach 9 is smaller for period 4 than for period 1 when the former Milltown Dam was in place, providing evidence that contaminant source materials have been substantially reduced in reach 9. However, net mobilization of suspended sediment from sources within reach 9 were slightly larger for period 4 than for period 1. A possible explanation for this pattern might relate to flood-plain disturbance and placement of uncontaminated fill in the flood plain associated with remediation activities. The artificially installed uncontaminated fill might be more available for mobilization than sediment within the former Milltown Reservoir during period 1.

Summary and Conclusions

This report characterizes temporal trends in flow-adjusted concentrations (filtered and unfiltered) of mining-related contaminants and assesses those trends in the context of source areas and transport of those contaminants through the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin in Montana. The Milltown Reservoir/Clark Fork River Superfund Site extends about 123 river miles from the outlet of Warm Springs Ponds on Silver Bow Creek to the outlet of the former Milltown Reservoir near Missoula. Trend analysis was done on specific conductance, selected trace elements (arsenic, copper, and zinc), and suspended sediment by using a joint time-series model (TSM) for concentration and streamflow for seven sampling sites for water years 1996–2015. The most upstream site included in trend analysis is Silver Bow Creek at Warm Springs, Montana (sampling site 8), and the most downstream site is Clark Fork above Missoula, Montana (sampling site 22), which is just downstream from the former Milltown Dam.

During the extended history of mining in the upper Clark Fork Basin in Montana, large amounts of waste materials enriched with metallic contaminants (cadmium, copper, lead, and zinc) and the metalloid trace element arsenic were generated from mining operations near Butte, and the milling and smelting operations near Anaconda. Extensive deposition of mining wastes in the Silver Bow Creek and Clark Fork channels and flood plains had substantial effects on water quality. Federal Superfund remediation activities in the upper Clark Fork Basin began in 1983 and have included substantial remediation near Butte and removal of the former Milltown Dam.

Water-quality data collection by the U.S. Geological Survey (USGS) in the upper Clark Fork Basin began during 1985–88 with the establishment of a small long-term monitoring program that has expanded through time and continued through present (2016). A previous study analyzed the monitoring data and characterized flow-adjusted trends in mining-related contaminants for 22 sampling sites in the upper Clark Fork Basin for water years 1996–2010 (water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends). An update of flow-adjusted water-quality trends for the monitoring data was needed for seven sampling sites to provide timely information for the 2016 5-year review for the Milltown Reservoir/Clark Fork River Superfund Site.

The TSM was used to detect trends in flow-adjusted concentrations (FACs). The intent of flow-adjustment is to identify and remove streamflow-related variability in concentration and thereby enhance the capability to detect trends independent from effects of climatic variability. To provide temporal resolution of changes in water quality, trend analysis was conducted on four sequential 5-year periods: period 1 (water years 1996–2000), period 2 (water years 2001–5), period 3 (water years 2006–10), and period 4 (water years 2011–15). Because of the substantial effect of the intentional breach of Milltown Dam on March 28, 2008, for Clark Fork above Missoula (sampling site 22), period 3 was subdivided into period 3A (October 1, 2005–March 27, 2008) and period 3B (March 28, 2008–September 30, 2010). The TSM was applied as consistently as possible among sampling sites and is considered to be a useful tool for simplifying the environmental complexity in the upper Clark Fork Basin to provide a large-scale evaluation of general temporal changes in constituent transport independent from streamflow variability.

In conjunction with the trend analysis, estimated normalized constituent loads were calculated and presented in the framework of a constituent-transport analysis to assess the temporal trends in FACs in the context of sources and transport. The transport analysis allows assessment of temporal changes in relative contributions from upstream source areas to loads transported past each reach outflow.

Trend results are presented for all constituents investigated; however, emphasis is placed on copper, arsenic, and suspended sediment. Trend results were considered statistically significant when the statistical probability level (p-value) was less than 0.01.

Trend results indicate that FACs of unfiltered-recoverable copper decreased at the sampling sites from the start of period 1 through the end of period 4; the decreases ranged from large for one sampling site (Silver Bow Creek at Warm Springs [sampling site 8]) to moderate for two sampling sites (Clark Fork near Galen, Montana [sampling site 11] and Clark Fork above Missoula [sampling site 22]) to small for four sampling sites (Clark Fork at Deer Lodge, Montana [sampling site 14], Clark Fork at Goldcreek, Montana [sampling site 16], Clark Fork near Drummond, Montana [sampling site 18], and Clark Fork at Turah Bridge near Bonner, Montana [sampling site 20]). For period 4 (water years 2011–15), the most notable changes indicated for the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin were statistically significant decreases in FACs and loads of unfiltered-recoverable copper for sampling sites 8 and 22. For all other sampling sites, the period 4 changes in FACs of unfiltered-recoverable copper were not statistically significant.

Trend results indicate that FACs of unfiltered-recoverable arsenic decreased at the sampling sites from the start of period 1 through the end of period 4; the decreases ranged from minor (sampling sites 8–20) to small (sampling site 22). For period 4 (water years 2011–15), the most notable changes indicated for the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin were statistically significant decreases in FACs and loads of unfiltered-recoverable arsenic for sampling site 8 and near statistically significant decreases (*p*-value of 0.012) for sampling site 22. For all other sampling sites, the period 4 changes in FACs of unfiltered-recoverable arsenic were not statistically significant.

Trend results indicate that FACs of suspended sediment decreased at the sampling sites from the start of period 1 through the end of period 4; the decreases ranged from moderate (sampling site 8) to small (sampling sites 11–22). For period 4 (water years 2011–15), the changes in FACs of suspended sediment were not statistically significant for any sampling sites.

The reach of the Clark Fork from Galen to Deer Lodge is a large source of metallic contaminants and suspended sediment, which strongly affects downstream transport of those constituents. Mobilization of unfiltered-recoverable copper and suspended sediment from flood-plain tailings and the streambed of the Clark Fork and its tributaries within the reach results in a contribution of those constituents that is proportionally much larger than the contribution of streamflow from within the reach. Within the reach, unfiltered-recoverable copper loads increased by a factor of about 4 and suspended-sediment loads increased by a factor of about 5, whereas streamflow increased by a factor of slightly less than 2. For period 4 (water years 2011–15), unfiltered-recoverable copper and suspended-sediment loads sourced from within the reach accounted for about 41 and 14 percent, respectively, of the loads at Clark Fork above Missoula (sampling site 22), whereas streamflow sourced from within the reach accounted for about 4 percent of the streamflow at sampling site 22. During water years 1996–2015, decreases in FACs and loads of unfiltered-recoverable copper and suspended sediment for the reach generally were proportionally smaller than those for most other reaches.

Unfiltered-recoverable copper loads sourced within the reaches of the Clark Fork between Deer Lodge and Turah Bridge near Bonner were proportionally smaller than contributions of streamflow sourced from within the reaches; these reaches contributed proportionally much less to copper loading in the Clark Fork than the reach between Galen and Deer Lodge. Although substantial decreases in FACs and loads of unfiltered-recoverable copper and suspended sediment were indicated for Silver Bow Creek at Warm Springs (sampling site 8), those substantial decreases were not translated to downstream reaches between Deer Lodge and Turah Bridge near Bonner. The effect of the reach of the Clark Fork from Galen to Deer Lodge as a large source of copper and suspended sediment, in combination with little temporal change in those constituents for the reach, contributes to this pattern.

With the removal of the former Milltown Dam in 2008, substantial amounts of contaminated sediments that remained in the Clark Fork channel and flood plain in reach 9 became more available for mobilization and transport than before the dam removal. After the removal of the former Milltown Dam, the Clark Fork above Missoula (sampling site 22) had statistically significant decreases in FACs of unfiltered-recoverable copper in period 3B (March 28, 2008, through water year 2010) that continued in period 4 (water years 2011–15). Also, decreases in FACs of unfiltered-recoverable arsenic and suspended sediment were indicated for period 4 at this site. The decrease in FACs of unfiltered-recoverable copper for sampling site 22 during period 4 was proportionally much larger than the decrease for the Clark Fork at Turah Bridge near Bonner (sampling site 20). Net mobilization of unfiltered-recoverable copper, unfiltered-recoverable arsenic, and suspended sediment from sources within reach 9 substantially decreased between periods 3 and 4. Net mobilization of unfiltered-recoverable copper and arsenic from sources within reach 9 were smaller for period 4 than for period 1 when the former Milltown Dam was in place, providing evidence that contaminant source materials have been substantially reduced in reach 9. However, net mobilization of suspended sediment from sources within reach 9 were slightly larger for period 4 than for period 1. A possible explanation for this pattern might relate to flood-plain disturbance and placement of uncontaminated fill in the flood plain associated with remediation activities. The artificially installed uncontaminated fill might be more available for mobilization than sediment within the former Milltown Reservoir during period 1.

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Appendixes

Appendix 1—Summary Information Relating to Quality-Control Data

Summary information is presented relating to quality-control data. Results for quality-control equipment blank and replicate samples collected during water years 1993–2015 are summarized in table 1–1. Spike recoveries for laboratory-spiked deionized-water blank samples collected during water years 1993–2015 are presented in table 1–2. Spike recoveries for laboratory-spiked stream-water blank samples collected during water years 1993–2015 are presented in table 1–3. For reference, aquatic-life standards (based on median hardness for water years 2011–15, Montana Department of Environmental Quality, 2012) are presented in table 1–4.

Evaluation of long-term spike-recovery data is particularly relevant to the long-term trend analysis. Spike-recoveries during water years 1993–2015 for laboratory-spiked deionized-water blank samples (table 1–2 and fig. 1–1) and laboratory-spiked stream-water samples (table 1–3 and fig. 1–2) indicate generally consistent recoveries over time, typically varying within plus or minus 10 percent of 100 percent recovery. However, before about water year 2000, spike recoveries for unfiltered-recoverable copper in spiked stream-water samples generally were near 100 percent (mean annual spike recovery for water years 1993–99 of 99.1 percent), whereas after about water year 2000, spike recoveries mostly were less than 100 percent (mean annual spike recovery for water years 2000–15 of 94.3 percent). Changes in spike recoveries in about water year 2000 probably were related to a change in about water year 2000 by the U.S. Geological Survey National Water Quality Laboratory from analysis of most metallic elements by graphite furnace atomic absorption spectrophotometry (Fishman, 1993) to inductively coupled plasma-mass spectrometry (Garbarino and Struzeski, 1998; Garbarino and others, 2006). The potential effects of temporal changes in spike recoveries on trend results were evaluated in exploratory analyses, as described in appendix 2.

Table 1–1. Summary information relating to quality-control samples (field equipment blank and replicate samples) collected at sampling sites in the upper Clark Fork Basin, Montana, water years 1993–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. LRL, laboratory reporting level; SRL, study reporting level; RSD, relative standard deviation; µS/cm, microsiemen per centimeter at 25 degrees Celsius; NA, not applicable; µg/L, microgram per liter; mg/L, milligram per liter]

Constituent or property, units of measurement	Summary information for field blank samples							Summary information for field replicate samples	
	Number of field blank samples	Number of field blank samples with detected concentrations greater than the LRL at the time of analysis	Percentage of field blank samples with detected concentrations greater than the LRL at the time of analysis	Maximum detected concentration for field blank samples	Median concentration in field blank samples with detected concentrations greater than the LRL at the time of analysis	SRL used in application of the time-series model	Percentage of detections in blank samples at concentrations greater than the SRL used in the application of the time-series model	Number of field replicate pairs	RSD,[1] in percent
Specific conductance, µS/cm	NA	NA	NA	NA	NA	NA	NA	162	0.1
Cadmium, filtered, µg/L	193	5	2.6	0.337	0.071	NA	NA	179	13.4
Cadmium, unfiltered-recoverable, µg/L	189	1	0.5	0.010	0.010	NA	NA	180	4.5
Copper, filtered,[2] µg/L	192	15	7.8	3.6	0.50	1.0	1.0	182	12.4
Copper, unfiltered-recoverable,[2] mg/L	189	11	5.8	3.0	1.0	1.0	2.1	180	9.0
Iron, filtered, µg/L	189	4	2.1	5.9	4.8	NA	NA	171	9.8
Iron, unfiltered-recoverable, µg/L	185	10	5.4	35.6	7.0	NA	NA	178	5.5
Lead, filtered, µg/L	193	6	3.1	0.600	0.101	NA	NA	178	11.0
Lead, unfiltered-recoverable, µg/L	189	10	5.3	0.16	0.05	NA	NA	180	16.3
Manganese, filtered, µg/L	188	22	11.7	0.62	0.36	NA	NA	183	5.7
Manganese, unfiltered-recoverable, µg/L	185	10	5.4	0.3	0.2	NA	NA	180	5.8
Zinc, filtered, µg/L	191	39	20.4	6.2	0.9	NA	NA	181	9.6
Zinc, unfiltered-recoverable,[2] µg/L	187	20	10.7	3.4	1.4	2.0	2.7	181	9.0
Arsenic, filtered,[2] µg/L	193	1	0.5	0.1	0.1	1.0	0.0	182	5.4
Arsenic, unfiltered-recoverable,[2] µg/L	189	3	1.6	0.1	0.1	1.0	0.0	181	6.8
Suspended sediment,[2] mg/L	NA	NA	NA	NA	NA	1	NA	170	9.1

[1]*RSD* is calculated according to the following equation (Taylor, 1987):

$$RSD = \frac{S}{\overline{X}} \times 100,$$

where

RSD is the relative standard deviation;

S is the standard deviation; and

$\overline{X}$ is the mean concentration for all replicate analyses.

[2]Property or constituent was analyzed for temporal trends.

Table 1–2. Summary information relating to quality-control samples (laboratory-spiked deionized-water blank samples) collected at sampling sites in the upper Clark Fork Basin, Montana, water years 1993–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. F, filtered; UFR, unfiltered-recoverable]

Water year	Cadmium, F	Cadmium, UFR	Copper, F	Copper, UFR	Iron, F	Iron, UFR	Lead, F	Lead, UFR	Manganese, F	Manganese, UFR	Zinc, F	Zinc, UFR	Arsenic, F	Arsenic, UFR
Mean spike recovery, in percent (values in parentheses indicate 95 percent confidence intervals)														
1993	93.4 (85.9, 101)	97 (93.5, 101)	99.5 (95.9, 103)	101.7 (94.4, 109)	94 (90.0, 98.0)	103.3 (92.4, 114)	105.8 (99.5, 112)	100.5 (95.2, 106)	96.9 (96.3, 97.5)	95.6 (82.2, 109)	106.5 (99.7, 113)	96.3 (94.1, 98.5)	94 (89.6, 98.4)	102.6 (95.8, 109)
1994	97.5 (89.1, 106)	98.8 (90.6, 107)	101.1 (98.4, 104)	99.7 (94.3, 105)	100 (93.0, 107)	94.6 (84.2, 105)	100.5 (98.5, 102)	99.1 (94.3, 104)	95.7 (90.8, 100)	101.5 (96.2, 107)	106.5 (95.8, 117)	102.6 (91.5, 114)	100.6 (95.6, 106)	109.3 (104, 114)
1995	100 (97.3, 103)	101.3 (97.5, 105)	102.7 (101, 105)	97.6 (92.3, 103)	102.2 (97.8, 107)	93.8 (87.9, 99.7)	102.3 (97.7, 107)	100.8 (96.6, 105)	96.5 (92.0, 101)	98.5 (93.1, 104)	102.3 (97.1, 108)	101.5 (97.1, 106)	103.9 (99.1, 109)	106.8 (103, 110)
1996	95.3 (92.2, 98.4)	82.3 (79.7, 84.9)	99.2 (91.4, 107)	99.6 (93.5, 106)	89.8 (76.0, 104)	90.8 (70.9, 111)	100.5 (93.3, 108)	97.4 (80.2, 115)	89.2 (77.9, 100)	96.5 (91.6, 101)	96.1 (84.3, 108)	87.8 (82.8, 92.8)	89.7 (77.1, 102)	104.1 (101, 107)
1997	98.5 (92.1, 105)	85.7 (77.7, 93.7)	101.1 (86.2, 116)	106.4 (82.0, 131)	94.7 (78.5, 111)	96.1 (80.2, 112)	101 (93.4, 109)	101.1 (88.9, 113)	90.3 (82.7, 97.9)	99.3 (95.8, 103)	97.9 (78.1, 118)	92.7 (86.4, 99.0)	93.9 (87.8, 100)	106.1 (104, 108)
1998	104 (93.8, 114)	97.4 (87.0, 108)	100.4 (93.4, 107)	103.4 (98.8, 108)	101.8 (90.7, 113)	95.7 (89.9, 102)	100.2 (91.8, 109)	104.8 (88.8, 121)	102.8 (94.4, 111)	99 (92.1, 106)	95.2 (85.9, 104)	101.3 (86.9, 116)	91.5 (87.3, 95.7)	105.4 (99.2, 112)
1999	100.9 (92.6, 109)	103.4 (99.9, 107)	107.5 (99.5, 116)	105 (102, 108)	97.7 (94.3, 101)	96.5 (90.0, 103)	97.4 (87.9, 107)	96.2 (85.2, 107)	96 (91.8, 100)	95.9 (86.3, 106)	96.9 (92.9, 101)	93.3 (88.9, 97.7)	108.9 (95.4, 122)	102.9 (97.8, 108)
2000	103.8 (97.3, 110)	105 (96.0, 114)	104 (96.0, 112)	100.3 (92.4, 108)	97.4 (92.3, 102)	100.6 (89.2, 112)	98.3 (88.9, 108)	102.6 (97.3, 108)	100.8 (93.3, 108)	103.2 (96.8, 110)	107.8 (95.8, 120)	102.6 (90.0, 115)	101.6 (95.3, 108)	101.4 (95.1, 108)
2001	102.9 (98.9, 107)	107.9 (101, 115)	105.2 (98.6, 112)	96.8 (93.7, 99.9)	101.3 (95.5, 107)	98.3 (86.7, 110)	97.3 (91.9, 103)	96.4 (93.7, 99.1)	101.9 (79.0, 125)	103.7 (89.9, 118)	102 (87.9, 116)	99.1 (82.7, 116)	99.2 (92.3, 106)	97.7 (86.6, 109)
2002	101.1 (98.8, 103)	97.6 (96.3, 98.9)	99.4 (95.0, 104)	98.8 (96.7, 101)	95.1 (89.3, 101)	102.3 (93.0, 112)	98.5 (89.9, 107)	96.9 (90.5, 103)	98.5 (95.4, 102)	96.5 (88.8, 104)	103.9 (94.4, 113)	98.3 (91.8, 105)	105.1 (95.8, 114)	97.9 (93.0, 103)
2003	98.6 (92.6, 105)	97.5 (94.1, 101)	100.4 (93.0, 108)	97.6 (93.2, 102)	101.6 (96.4, 107)	93.1 (87.4, 8.8)	97.2 (92.3, 102)	96 (93.9, 98.1)	95.8 (90.7, 101)	96.6 (79.7, 114)	101.4 (89.8, 113)	99.1 (93.2, 105)	87.9 (71.3, 104)	96.6 (78.5, 115)
2004	97.4 (95.6, 99.2)	100 (98.6, 101)	98.9 (92.7, 105)	99.6 (95.4, 104)	101 (96.3, 106)	96.1 (88.8, 103)	96 (91.9, 100)	98.9 (97.3, 100)	99.1 (92.3, 106)	98.6 (90.6, 107)	102 (91.7, 112)	100 (96.3, 104)	101 (75, 127)	102 (93.6, 110)
2005	102 (97.3, 106)	97.5 (88.1, 107)	102 (97.4, 107)	97.6 (88.4, 107)	97.6 (90.5, 105)	100 (95.2, 105)	101 (95.5, 106)	104 (99.4, 108)	93.8 (82.2, 105)	102 (86.4, 117)	102 (88.3, 116)	96.1 (83.5, 109)	97.4 (95.5, 99.3)	101 (90.7, 111)
2006	100 (92.6, 107)	98.9 (94.1, 104)	102 (97.7, 107)	98.7 (93.8, 104)	106 (101, 112)	103 (95.4, 111)	99 (89.3, 109)	98 (91.2, 105)	97 (90.7, 103)	105 (95.3, 115)	105 (95.4, 115)	94.9 (90.1, 100)	95.2 (89.2, 101)	98.5 (94.7, 102)
2007	107 (103, 112)	103 (94.4, 111)	105 (99.2, 111)	98.4 (86.9, 110)	99.9 (92.1, 108)	104 (98.5, 110)	99.6 (93.9, 105)	103 (100, 106)	107 (99.9, 114)	107 (97.0, 116)	107 (102, 113)	103 (96.5, 110)	105 (96.6, 114)	102 (95.2, 109)
2008	102 (88.2, 116)	101 (91.9, 110)	105 (88, 121)	97.9 (87.2, 109)	103 (95.9, 110)	101 (96.5, 106)	101 (89, 112)	101 (98, 105)	102 (92.9, 111)	102 (92.5, 112)	99.8 (87.9, 112)	103 (96, 111)	103 (89.2, 117)	102 (93.9, 110)
2009	102 (97.4, 107)	97.2 (93.6, 101)	102 (92.0, 113)	96 (94.0, 97.0)	102 (91.4, 112)	104 (78.8, 130)	102 (96.0, 107)	98.4 (96.1, 101)	105 (103, 106)	99.7 (94.6, 105)	111 (104, 118)	93.3 (88.5, 98.1)	101 (92.3, 110)	97 (94.9, 99.1)
2010	106 (94.9, 117)	100 (88.4, 112)	97.2 (84.9, 109)	98.6 (84.0, 113)	108 (101, 115)	102 (95.8, 108)	102 (91.5, 113)	102 (91.0, 113)	103 (95.2, 111)	105 (97.2, 112)	113 (94.7, 132)	101 (89.6, 113)	105 (96.7, 113)	102 (89.7, 114)

Table 1–2. Summary information relating to quality-control samples (laboratory-spiked deionized-water blank samples) collected at sampling sites in the upper Clark Fork Basin, Montana, water years 1993–2015.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. F, filtered; UFR, unfiltered-recoverable]

Water year	Cadmium, F	Cadmium, UFR	Copper, F	Copper, UFR	Iron, F	Iron, UFR	Lead, F	Lead, UFR	Manganese, F	Manganese, UFR	Zinc, F	Zinc, UFR	Arsenic, F	Arsenic, UFR
Mean spike recovery, in percent (values in parentheses indicate 95 percent confidence intervals)—Continued														
2011	105 (97.9, 111)	95.7 (92.4, 99)	96.2 (89.4, 103)	93.9 (91.6, 96.2)	111 (89.3, 132)	107 (98.2, 117)	106 (98.8, 113)	99.8 (98.4, 101)	101 (97.0, 104)	98.9 (97.8, 100)	108 (94.3, 122)	96.1 (92.2, 100)	105 (102, 109)	94.7 (90.2, 99.3)
2012	102 (93.2, 112)	101 (95.1, 108)	98.4 (93.1, 104)	100 (92.5, 107)	105 (102, 108)	106 (96.2, 117)	102 (96.8, 106)	103 (98.4, 107)	105 (101, 110)	101 (95.4, 106)	103 (96.5, 109)	100 (94.9, 106)	98.1 (90.4, 106)	101 (94.3, 108)
2013	96.3 (92.4, 100)	96.6 (92.9, 100)	92.4 (87, 97.9)	96.3 (92.6, 100)	103 (95.5, 111)	105 (98.2, 112)	97.5 (92.3, 103)	99.9 (97.1, 103)	98.1 (92.3, 104)	98.5 (94.8, 102)	98.6 (90.9, 106)	95.2 (91.7, 98.7)	98 (93.1, 103)	99.3 (96, 103)
2014	99.4 (95.1, 104)	101 (99.0, 104)	98.1 (91.0, 105)	100 (98.8, 102)	103 (95.8, 111)	103 (99.7, 106)	102 (100, 104)	103 (100, 107)	99.2 (91.6, 107)	100 (97.7, 103)	110 (103, 117)	101 (97.1, 104)	94.7 (87.6, 102)	102 (99.0, 105)

Table 1–3. Summary information relating to quality-control samples (laboratory-spiked stream-water samples) collected at sampling sites in the upper Clark Fork Basin, Montana, water years 1993–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. F, filtered; UFR, unfiltered-recoverable]

Water year	Cadmium, F	Cadmium, UFR	Copper, F	Copper, UFR	Iron, F	Iron, UFR	Lead, F	Lead, UFR	Manganese, F	Manganese, UFR	Zinc, F	Zinc, UFR	Arsenic, F	Arsenic, UFR
Mean spike recovery, in percent (values in parentheses indicate 95 percent confidence intervals)														
1993	97.1 (92.3, 102)	98.1 (95.2, 101)	97.4 (95.8, 99.0)	97.2 (92.3, 102)	94.6 (86.7, 103)	102.2 (94.4, 110)	104.7 (98.5, 111)	96 (93.0, 99.0)	95.7 (92.1, 99.3)	100.2 (96.4, 104)	105.7 (93.4, 118)	95.7 (92.2, 99.2)	95.2 (92.0, 98.3)	99.9 (96.5, 103)
1994	101.3 (97.5, 105)	97.9 (94.4, 101)	96.6 (93.3, 99.8)	98.4 (91.1, 106)	98.2 (94.8, 102)	99.3 (90.6, 108)	103 (101, 105)	99.3 (95.6, 103)	98.1 (95.4, 101)	100.4 (95.4, 105)	97.5 (92.4, 102)	106 (95.4, 117)	97.3 (90.4, 104)	106.9 (101, 113)
1995	101.3 (96.7, 106)	102.9 (98.0, 108)	99.8 (96.2, 103)	98 (92.7, 103)	99.5 (96.1, 103)	101.4 (96.2, 107)	102.9 (98.6, 107)	100 (96.7, 103)	97.4 (92.9, 102)	103.8 (99.0, 109)	104.7 (101, 108)	101.1 (99.1, 103)	103.8 (94.6, 113)	102.2 (97.1, 107)
1996	100.2 (91.5, 109)	88.4 (57.8, 119)	101.1 (91.9, 110)	100.3 (92.3, 108)	93.8 (73.3, 114)	101.5 (88.5, 114)	105.1 (90.4, 120)	105.6 (98.4, 113)	90.3 (79.1, 102)	99.5 (92.9, 106)	103.2 (90.2, 116)	99.3 (74.8, 124)	105.9 (94.4, 117)	102.8 (96.0, 110)
1997	98.1 (83.5, 113)	84.3 (75.0, 93.6)	97.3 (88.3, 106)	100.5 (71.9, 129)	99.3 (81.0, 118)	97.5 (78.2, 117)	100.8 (91.6, 110)	102.1 (99.1, 105)	93 (84.0, 102)	99.8 (94.5, 105)	97 (89.9, 104)	92.7 (74.4, 111)	93.3 (73.5, 113)	107.1 (99.9, 114)
1998	104.4 (97.3, 112)	99.5 (92.7, 106)	97.2 (90.6, 104)	99.1 (88.4, 110)	97.5 (82.8, 112)	101.8 (90.2, 113)	102.2 (94.3, 110)	105 (92.9, 117)	99.5 (85.8, 113)	101.5 (98.0, 105)	99.5 (89.1, 110)	98.8 (85.6, 112)	90.1 (85.5, 94.7)	104 (95.8, 112)
1999	102.6 (92.4, 113)	103 (100, 106)	102.7 (89.1, 116)	100.5 (97.5, 104)	97.2 (93.5, 101)	99.9 (90.6, 109)	100.2 (94.0, 106)	101.1 (93.7, 108)	99.8 (92.8, 107)	98.8 (89.3, 108)	98.6 (95.7, 102)	96.2 (91.1, 101)	105.2 (97.5, 113)	103.6 (96.4, 111)
2000	104.2 (100, 108)	98.1 (88.9, 107)	101.6 (97.3, 106)	94.6 (87.7, 102)	96.5 (88.0, 105)	98 (88.3, 108)	101.4 (97.3, 106)	105.3 (103, 108)	97.3 (83.3, 111)	101.7 (91.4, 112)	101.5 (90.9, 112)	97.8 (91.1, 104)	102.5 (97.5, 108)	98.9 (87.8, 110)
2001	103.2 (100, 106)	105.8 (95.9, 116)	106.8 (104, 110)	91.8 (87.7, 95.9)	95.8 (91.4, 100)	101.6 (92.1, 111)	99.7 (95.2, 104)	97.3 (95.3, 99.3)	100 (84.4, 116)	100.9 (90.3, 112)	100.8 (85.7, 116)	96.9 (75.9, 118)	102.8 (95.1, 110)	100.1 (96.7, 104)
2002	106 (97.5, 114)	102 (98.6, 101)	97.3 (91.2, 103)	96.9 (92.9, 101)	92.6 (83.3, 102)	107.1 (103, 111)	101.4 (91.9, 111)	98.9 (92.2, 106)	98.3 (92.5, 104)	94.3 (88.4, 100)	101.3 (92.6, 110)	95.8 (89.9, 102)	105.8 (97.1, 114)	99.9 (86.0, 114)
2003	100.5 (91.4, 110)	99 (94.4, 104)	95.8 (88.9, 103)	91.6 (89.7, 93.5)	106.4 (100, 113)	96.7 (91.6, 102)	96 (90.2, 102)	96.8 (93.7, 99.9)	93.9 (78.8, 109)	99.3 (86.2, 112)	98.4 (93.6, 103)	93 (87.5, 98.5)	94.6 (80.2, 109)	108.6 (100, 117)
2004	101 (94.2, 108)	101 (100, 103)	95.4 (93.8, 97)	93.8 (89.5, 98.1)	104 (99.5, 108)	111 (91.2, 130)	98.7 (93, 104)	100 (98.6, 102)	103 (89.8, 117)	96 (91.8, 100)	100 (95.3, 105)	94.4 (91, 97.8)	97.3 (86.9, 108)	112 (106, 118)
2005	97.8 (62.7, 133)	98.2 (88.5, 108)	93.6 (57.9, 129)	93 (84.8, 101)	102 (95.9, 108)	99.3 (95.6, 103)	102 (96.1, 109)	103 (99.7, 106)	88.3 (78.3, 98.3)	97.5 (87.3, 108)	94.3 (60.8, 128)	91.6 (80.8, 102)	103 (98.3, 107)	104 (101, 108)
2006	104 (99.0, 108)	99.6 (94.7, 104)	101 (96.7, 104)	94.8 (91.0, 98.6)	105 (102, 109)	102 (93.6, 110)	102 (94.2, 111)	100 (92.9, 106)	94.9 (88.2, 102)	106 (97.9, 113)	108 (93.3, 123)	91.2 (87.8, 94.6)	96.5 (89.0, 104)	99.1 (94.9, 103)
2007	108 (102, 114)	98 (92.2, 104)	100 (89.8, 110)	96.3 (91.8, 101)	107 (103, 111)	103 (94.7, 112)	109 (103, 115)	104 (102, 107)	106 (100, 113)	101 (96.1, 106)	104 (95.7, 113)	98 (89.2, 107)	106 (100, 113)	102 (98.2, 106)
2008	101 (91, 112)	97 (93.6, 100)	98.9 (92, 106)	92.8 (86.4, 99.1)	105 (94.1, 117)	99.4 (92, 107)	100 (91.3, 109)	103 (99.5, 106)	98.9 (90.3, 108)	98.4 (92.5, 104)	106 (88.1, 124)	95.7 (93.1, 98.2)	100 (90.2, 110)	101 (98.5, 104)
2009	106 (101, 112)	94.7 (89.5, 99.8)	96.2 (91.2, 101)	91.4 (87.8, 95.0)	107 (89.7, 124)	102 (86.9, 118)	100 (97.0, 103)	100 (98.8, 101)	97 (88.0, 106)	92.8 (81.7, 104)	114 (104, 124)	89.8 (80.4, 99.2)	106 (97.7, 114)	100 (89.6, 111)
2010	110 (87.6, 132)	98.2 (87.1, 109)	93.8 (83.6, 104)	96.5 (84.4, 108)	105 (91.7, 119)	111 (103, 118)	101 (87.7, 115)	104 (91.5, 116)	104 (93.3, 114)	98.7 (86.4, 111)	109 (101, 118)	94 (81.3, 107)	106 (96.0, 116)	102 (90.1, 113)

Table 1–3. Summary information relating to quality-control samples (laboratory-spiked stream-water samples) collected at sampling sites in the upper Clark Fork Basin, Montana, water years 1993–2015.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. F, filtered; UFR, unfiltered-recoverable]

Water year	Cadmium, F	Cadmium, UFR	Copper, F	Copper, UFR	Iron, F	Iron, UFR	Lead, F	Lead, UFR	Manganese, F	Manganese, UFR	Zinc, F	Zinc, UFR	Arsenic, F	Arsenic, UFR
Mean spike recovery, in percent (values in parentheses indicate 95 percent confidence intervals)—Continued														
2011	104 (99.2, 109)	93.9 (91.5, 96.3)	96.6 (79.9, 113)	88.3 (85.4, 91.2)	108 (92.0, 124)	101 (85.2, 117)	104 (98.8, 110)	96.5 (94.5, 98.4)	98.2 (92.2, 104)	91.3 (88.3, 94.2)	102 (90.2, 114)	86.7 (80.7, 92.7)	106 (101, 111)	94.7 (90.5, 99.0)
2012	107 (104, 110)	98.8 (91.9, 106)	94 (90.9, 97)	93.9 (87.2, 101)	108 (102, 114)	100 (98.6, 102)	102 (97.9, 107)	101 (96.3, 105)	101 (97.7, 104)	95.5 (88, 103)	102 (95.2, 109)	89.8 (82.4, 97.2)	104 (101, 106)	97.5 (91.8, 103)
2013	94.8 (90.4, 99.3)	91.3 (87, 95.7)	90.9 (86, 95.8)	90 (87.5, 92.4)	102 (94.8, 110)	101 (92.6, 110)	101 (92.8, 108)	96.7 (92.3, 101)	97.2 (95.4, 99)	93 (84.9, 101)	99.5 (92, 107)	84.1 (79.5, 88.7)	99.5 (91.2, 108)	94.9 (91, 98.8)
2014	103 (95.6, 110)	95.5 (92.0, 99.0)	96.6 (90.1, 103)	93.8 (89.8, 97.8)	97.6 (92.7, 103)	101 (92.7, 109)	100 (96.7, 103)	99.7 (94.9, 104)	97.1 (90.4, 104)	94.8 (89.3, 100)	101 (94.2, 108)	88.9 (82.7, 94.6)	92.4 (82.7, 102)	97.7 (93.5, 102)
2015	104 (97.6, 111)	106 (96.6, 115)	97.4 (92.3, 102)	97.8 (92.9, 103)	93.5 (83.2, 104)	104 (101, 106)	103 (101, 105)	106 (96.0, 115)	102 (98.3, 105)	101 (92.0, 110)	93.8 (86.2, 101)	98.1 (88.9, 107)	96.8 (86.5, 107)	104 (87.3, 121)

Table 1–4. Aquatic-life standards (based on median hardness for water years 2011–15) for selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. $CaCO_3$, calcium carbonate]

Sampling site number (fig. 1, table 1)	Abbreviated sampling site name (table 1)	Aquatic-life standards (Montana Department of Environmental Quality, 2012), in micrograms per liter								
		Median hardness for water years 2011–15, in milligrams per liter as $CaCO_3$	Cadmium		Copper		Lead		Zinc	
			Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic
8	Silver Bow Creek at Warm Springs	170	3.66	0.401	23.1	14.7	160	6.25	188	188
11	Clark Fork near Galen	164	3.53	0.390	22.3	14.2	153	5.97	182	182
14	Clark Fork at Deer Lodge	200	4.32	0.452	26.9	16.9	197	7.69	216	216
15	Clark Fork near Garrison	202	4.36	0.456	27.2	17.0	199.8	7.79	217	217
16	Clark Fork at Goldcreek	165	3.54	0.391	22.4	14.3	154	6.00	183	183
18	Clark Fork near Drummond	190	4.09	0.435	25.6	16.1	184	7.18	206	206
20	Clark Fork at Turah Bridge	132	2.82	0.331	18.1	11.8	116	4.51	151	151
22	Clark Fork above Missoula	109	2.33	0.288	15.2	10.0	91	3.55	129	129

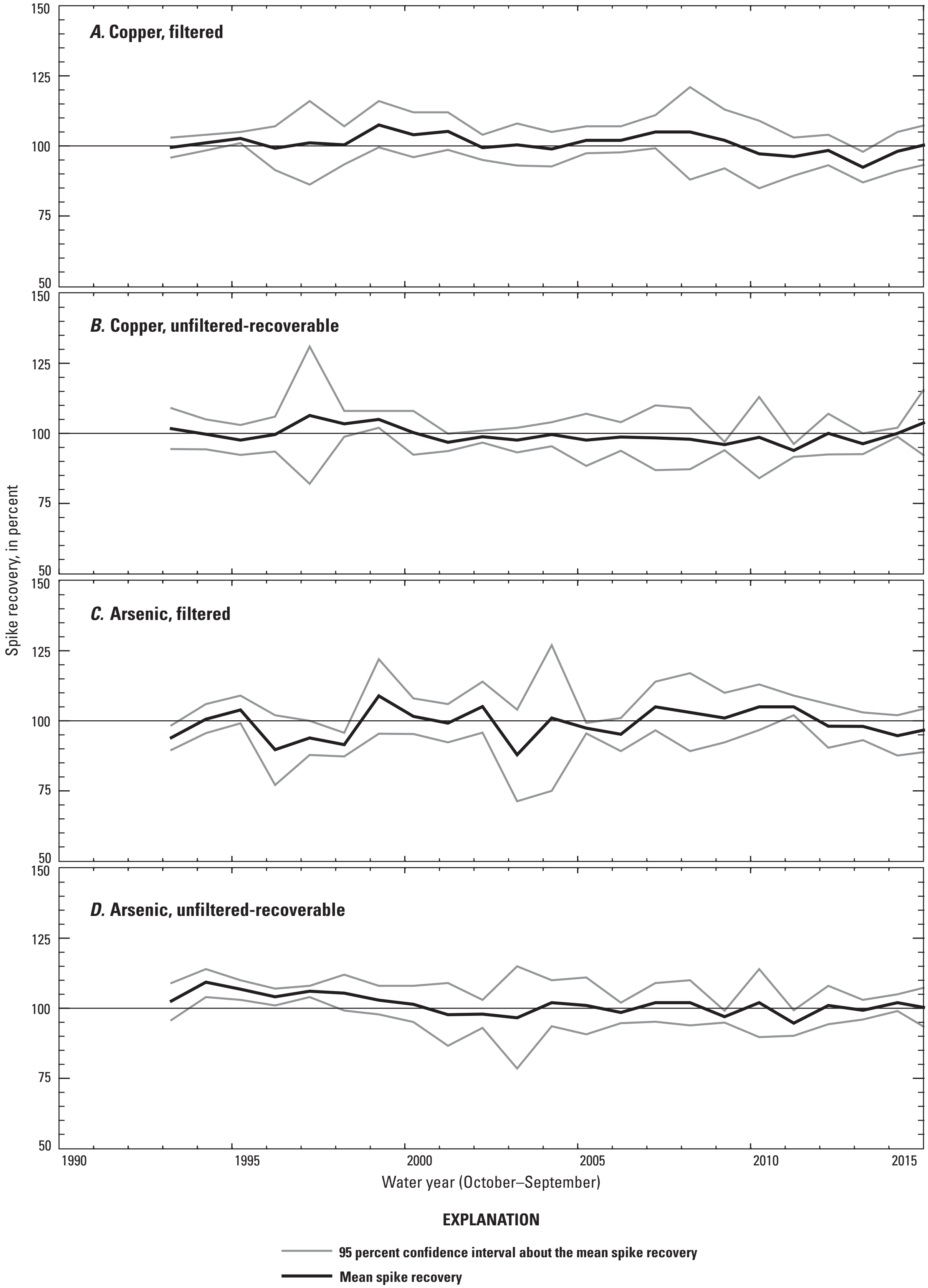

Figure 1–1. Spike recoveries for laboratory-spiked deionized-water blank samples, water years 1993–2015. *A*, copper, filtered; *B*, copper, unfiltered-recoverable; *C*, arsenic, filtered; *D*, arsenic, unfiltered-recoverable.

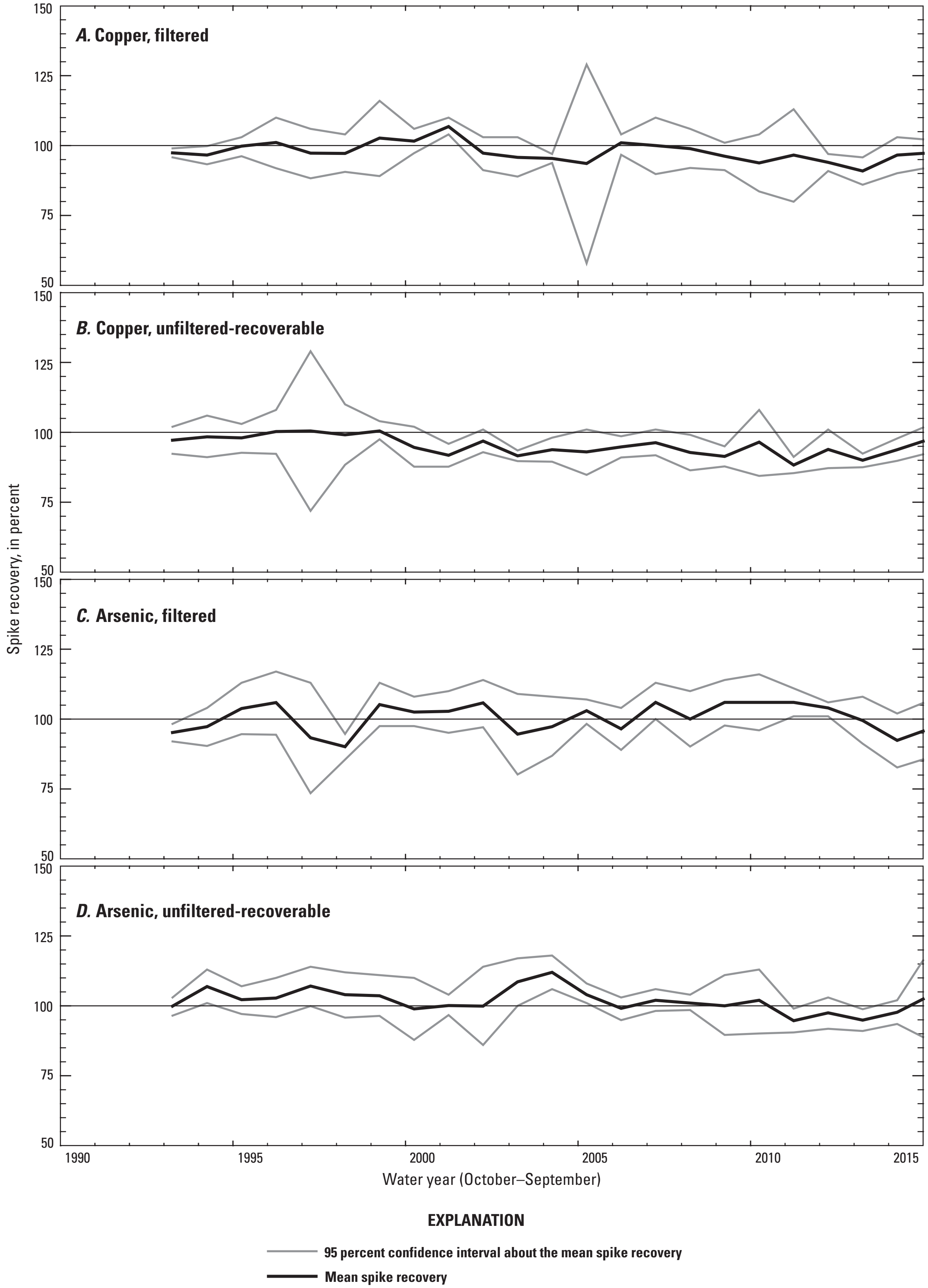

Figure 1–2. Spike recoveries for laboratory-spiked stream-water samples, water years 1993–2015. *A*, copper, filtered; *B*, copper, unfiltered-recoverable; *C*, arsenic, filtered; *D*, arsenic, unfiltered-recoverable.

Appendix 2—Summary of the Time-Series Model as Applied in this Study

This appendix presents somewhat detailed information on theoretical and computational aspects of the time-series model (TSM). Also, specific aspects of the application of the TSM in this study are described.

Theoretical and Computational Information

The theory and parameter estimation for the TSM are described in detail in Vecchia (2005). In the TSM, log-transformed concentration data are partitioned into several components according to equation 1:

$$\log(C) = M_C + ANN_C + SEAS_C + TREND + HFV_C \qquad (1)$$

where

log denotes the base-10 logarithm;
C is the concentration, in milligrams per liter;
M_C is the long-term mean of the log-transformed concentration, as the base-10 logarithm of milligrams per liter;
ANN_C is the annual concentration anomaly (dimensionless);
$SEAS_C$ is the seasonal concentration anomaly (dimensionless);
$TREND$ is the concentration trend (dimensionless); and
HFV_C is the high-frequency variability of the concentration (dimensionless).

In equation 1, ANN_C, $SEAS_C$, and HFV_C terms represent natural variability in concentration for different timescales. The term ANN_C is an estimate of the interannual variability in concentration that can be attributed to long-term variability in streamflow. The term ANN_C is quantified by relating annual means (for the 365-day period immediately before a given sample) of log concentration and log streamflow to long-term means (for the entire period of record). Extended droughts and wet periods can change the chemical and suspended-material composition of streamflow by changing the degree of contact between surface runoff and soil particles, availability of particulate material in stream channels and near-stream areas, and the relative composition of runoff among groundwater, overland flow, and subsurface flow (Vecchia, 2005).

The term $SEAS_C$ is an estimate of the seasonal variability in concentration that can be attributed to seasonal variability in streamflow or to factors other than variability in streamflow. The term $SEAS_C$ is quantified by relating seasonal means (for the 30-day period immediately before a given sample was collected) of log concentration and log streamflow to annual means (for the 365-day period immediately before a given sample was collected). For example, the seasonal snow-accumulation and snowmelt cycle causes seasonal fluctuations in streamflow and water quality. Seasonal differences in the relative amount of streamflow that comes from natural sources compared to anthropogenic contributions (such as wastewater inputs) also might cause seasonal fluctuations in concentration that are more complicated than a simple relation between concentration and streamflow could produce.

The term HFV_C is an estimate of the variability in concentration for timescales that are smaller than the seasonal timescale (timescales of several days to several weeks). Thus, high-frequency variability is the variability that remains after the removal of seasonal and annual anomalies and trends. The term HFV_C is quantified by relating log concentration and log streamflow for the day of sampling to log concentration and log streamflow for each of the two 10-day periods immediately before a given sample. Short-term changes in meteorological conditions might cause high-frequency variability in concentration and streamflow. The high-frequency variability depends on a periodic autoregressive moving average model that accounts for the presence of serial correlation among concentrations (for example, the tendency for high or low values to persist for several days to several weeks before returning to normal levels; Vecchia, 2005).

The term *TREND* is an estimate of the long-term systematic changes in concentration during the study period that are unrelated to long-term variability in streamflow. For this report, a significant trend might indicate changes in the extent to which mining wastes affect chemical composition of surface water or changes in other activities that can change the amount of suspended sediment or trace elements that reach the stream. The term *TREND* consists of piecewise monotonic trends during specified trend-analysis periods. The overall significance of *TREND* (determined by using the generalized likelihood ratio principle; appendix 1 of Vecchia, 2005) specifies whether there were any significant changes during any of the specified trend-analysis periods. If *TREND* was determined to be nonsignificant for a given sampling-site and constituent combination, the trends for all of the specified trend-analysis periods were considered nonsignificant, and p-values were not reported. If *TREND* was determined to be significant for a given sampling-site and constituent combination, the slope coefficient (γ; appendix 1 of Vecchia, 2005) for the trend for each specified trend-analysis period was used to determine the significance and magnitude of the trend for the specified trend-analysis period. The null hypothesis in the test for trend significance in a given trend-analysis period is that there is no trend (that is, $\gamma = 0$). If the two-tailed p-value for γ was less than the selected alpha level (0.01 in this report), the null hypothesis was rejected, and the trend was determined to be significant. Determination of a nonsignificant trend (that is, a p-value greater than 0.01) does not imply that the null hypothesis is accepted (that is, that there is no trend). It indicates that in the statistical framework of the analysis, a significant trend was not detected. The magnitude of the trend for a specified trend-analysis period is expressed as the percent difference between the geometric mean concentration at the end of the period and the geometric mean concentration at the start of the period and is determined by the equation

$$\%\Delta FAC = 100\left(10^{\gamma} - 1\right), \quad (2)$$

where

$\%\Delta FAC$ is the percentage change in the geometric mean of the flow-adjusted concentration, and

γ is the slope coefficient of the trend for the specified trend-analysis period in log-transformed units.

Log-transformed concentrations that have ANN_C and $SEAS_C$ removed are referred to in this report as "flow-adjusted concentrations." By using equation 1, the flow-adjusted concentration is defined as

$$FAC = \log(C) - ANN_C - SEAS_C = M_C + TREND + HFV_C \quad (3)$$

where FAC is the flow-adjusted value, as the base-10 logarithm of the original units of measurement. The *FAC*s defined by equation 3 are analogous to *FACs* defined in other publications as the residuals from a regression model that relates concentration to concurrent daily streamflow (Helsel and Hirsch, 2002); however, the TSM approach generally is more effective than a regression-based approach for removing streamflow-related variability (Vecchia, 2005). Time-series plots showing *FAC*s along with the fitted trend ($M_C + TREND$) illustrate long-term changes in geometric mean concentration that might indicate changes in effects of mining wastes on water-quality in the selected watersheds.

The key to making TSM a powerful trend-analysis tool is that the entire time series of daily streamflow data are used in the model, not just streamflow for the days when concentration samples are available. The model uses a three-per-month, or approximately 10-day, sampling frequency. Each month is divided into three intervals—days 1–10, days 11–20, and day 21 through the end of the month. If a water-quality sample is available for a particular interval, it is paired with daily streamflow for the same day of the water-quality sample. If no water-quality sample is available, the concentration value for the interval is missing, and streamflow for the middle of the interval (day 5, 15, or 25) is used. If more than one concentration sample is available for the interval, the value nearest to the midpoint of the interval is used. The log-transformed streamflow time series (consisting of three values per month) is divided into an annual anomaly, seasonal anomaly, and high-frequency variability according to the following equation:

$$\log(Q) = M_Q + ANN_Q + SEAS_Q + HFV_Q \quad (4)$$

where

Q is daily mean streamflow, in cubic feet per second;

M_Q is the mean of the log-transformed streamflow for the entire trend-analysis period, as the base-10 logarithm of cubic feet per second;

ANN_Q is the annual streamflow anomaly, computed as the 1-year lagged moving average of $\log(Q) - M_Q$ (dimensionless);

$SEAS_Q$ is the seasonal streamflow anomaly, computed as the 3-month lagged moving average of $\log(Q) - M_Q - ANN_Q$ (dimensionless); and

HFV_Q is the high-frequency streamflow variability, computed as $\log(Q) - M_Q - ANN_Q - SEAS_Q$ (dimensionless).

The water-quality time-series model (equation 1) is directly tied to the streamflow time-series model because the streamflow anomalies (ANN_Q and $SEAS_Q$ from equation 4) are used as predictor variables for concentration (equation 1). For example, ANN_C is assumed to equal a constant coefficient (estimated from the TSM) times ANN_Q. The different scales of streamflow variability often affect concentration in different ways. The relation between HFV_C and HFV_Q can be particularly complicated, changing depending on the time of year and the degree of serial correlation in the concentration data and cross-correlation between concentration and streamflow.

Specific Aspects of the Application of the Time-Series Model in this Study

The TSM residuals for each sampling-site and constituent combination were examined graphically to verify the model assumptions that the residuals had constant variance, were serially uncorrelated, and were approximately normally distributed. Because of the application of the TSM to the large number of sampling-site and constituent combinations and practical considerations to keep the trend periods comparable among sampling sites and constituents, some minor deviations of the residuals from model assumptions were tolerated. Such deviations included small changes in residual variance through time and short-term (about 1–2 years) unresolved trending in the residuals. In cases where unresolved residual trends were considered to be large enough to possibly affect the magnitudes and significance levels of reported fitted trends, more complicated trend models were tested, and in all cases the more complicated models did not substantially affect the overall descriptions of the trends and also did not change the general findings and conclusions of this report. Thus, the reported TSM results were judged to provide acceptable fits representative of linearity through nearly all of the range in FACs for a given sampling-site and constituent combination. Standard errors of estimates (SEEs) for the TSM analyses are presented in table 2–1. In this report, SEEs are expressed in percent and were converted from log units by using procedures described by Tasker (1978). Mean SEEs for all trace elements combined range from 20.8 to 50.7 percent. Mean SEEs for unfiltered-recoverable copper and arsenic concentrations are 48.3 and 27.3 percent, respectively. Mean SEE for suspended-sediment concentration (65.2 percent) is substantially higher than mean SEEs for trace elements. The SEEs indicate reasonably accurate definition of concentration and streamflow relations for the purpose of trend analysis; however, a higher mean SEE for suspended sediment than mean SEEs for trace elements indicates lower confidence in results. For each sampling-site and constituent combination, the fit of the TSM can be assessed by examination of the fitted trends in relation to FACs that are shown in figures 3–1 through 3–7 in appendix 3. The distribution of FACs about the fitted trend lines shows the extent to which the residuals might exhibit nonconstant variance or unresolved trends.

Application of the TSM in this study generally followed the methods applied by Sando and others (2014) who reported water-quality trends for 22 sampling sites in the upper Clark Fork Basin for water years 1996–2010. However, two factors might contribute to differences between Sando and others (2014) and this study: (1) this study included additional data collected after the study period of Sando and others (2014), and (2) this study included preliminary dummy trend periods that were inserted prior to period 1. The additional data after the study period of Sando and others (2014) represent an increase of about 25 percent and provide improvement in definition of concentration and streamflow relations used in determining FACs. Also, during exploratory analysis for this study, close scrutiny of the fitted trends reported by Sando and others (2014) indicated that in some cases the fitted trend values at the start of period 1 (1996) were not precisely centered at the median FAC at the start of period 1. In this study, dummy trend periods were inserted before period 1 to more precisely center the 1996 fitted trend values at the median FAC. The combination of the two factors (inclusion of additional data and insertion of preliminary dummy trends) sometimes resulted in generally minor differences in the fitted trend lines between this report and Sando and others (2014). The trend results of this report supersede the trend results of Sando and others (2014).

Exploratory analyses were conducted to investigate two ancillary factors that might affect trend results, including potential effects of (1) temporal changes in spike recoveries (as discussed in appendix 1) and (2) diel cycling of trace elements. The potential effects of temporal changes in spike recoveries (as discussed in appendix 1) on trend results were evaluated by using two approaches: (1) exploratory trend analysis with inclusion of a step trend in the trend model and (2) exploratory trend analysis on constituent concentrations adjusted based on annual mean spike recoveries. For the exploratory step-trend approach, a step trend for the period water years 1996–99 was included in the TSM model for each sampling-site and constituent combination, in addition to including trends for periods 1–4. Inclusion of a step trend allowed evaluation of whether there was a distinct change in data structure between pre-2000 and post-2000 data that might have affected trend results. Results of the exploratory step-trend analysis indicated that among all sampling-site and constituent combinations, statistically significant step trends were infrequently detected (less than 20 percent of analyses). In all cases of statistically significant step trends, the difference in the percent change from the start of period 1 to the end of period 4 between the exploratory analysis including the step trend and the reported analysis without the step trend was less than 5 percent. Thus, it was concluded that temporal changes in spike recoveries did not have a substantial effect on the overall trend results and the study objectives of evaluating relative spatial and temporal changes in FACs in the upper Clark Fork Basin as a whole. For the exploratory spike-recovery adjustment approach, constituent concentrations for each year were adjusted by multiplying the concentrations times the annual mean spike recovery for laboratory-spiked stream-water samples; then exploratory trend analysis was done. Results of the exploratory spike-recovery adjustment analysis were similar to the results for the exploratory step-trend approach and resulted in the same general conclusion that temporal differences in spike recoveries had minor effects on trend results.

An important consideration in trend analysis for trace elements is potential effects of diel cycling in trace-element concentrations. Complex biogeochemical processes affected by the daily solar photocycle produce regular and dynamic changes in many physical and chemical characteristics of streams (Nimick and others, 2011). In some streams (including some of the sampling sites in this study), the biogeochemical processes can result in diel variability in trace-element concentrations (Nimick and others, 2003).

Diel cycling in trace-element concentrations has the potential to affect trend results if (1) there is strong diel cycling for a given sampling-site and constituent combination and (2) there is a systematic temporal bias in the dataset with respect to the time of day of sampling. During exploratory analysis, potential effects of diel cycling on the trend results were quantitatively evaluated by including decimal day (time of sampling) as an ancillary variable in the trend models. The decimal day variable indicates the strength of diel cycling for a given sampling-site and constituent combination and also allows evaluation of the effect of temporal variability in time of sampling on the trend results. Although some sampling-site and constituent combinations had statistically significant diel cycling, in no case did the inclusion of the decimal day variable in trend models provide substantially different trend results from the reported results. Thus, potential effects on trend results of diel cycling of trace elements were determined to be minor; however, it should be noted that samples were collected during daylight hours and diel variations in the night cannot be evaluated.

Table 2–1. Statistical summaries of standard errors of estimates for the trend models.

[SEE, standard error of estimate]

Constituent or property	Number of sites for which trend results are reported	SEE, in percent		
		Minimum	Mean	Maximum
Specific conductance	7	8.2	11.0	13.1
Copper, filtered	7	24.6	31.6	37.4
Copper, unfiltered-recoverable	7	38.3	48.3	60.7
Zinc, unfiltered-recoverable	7	41.0	50.7	65.7
Arsenic, filtered	7	15.2	20.8	26.7
Arsenic, unfiltered-recoverable	7	21.8	27.3	34.0
Suspended sediment	7	57.4	65.2	80.5

Appendix 3—Trend-Analysis Results

For all constituents investigated, detailed results for trend magnitudes, computed as the total percent changes in FAC geometric means from the beginning to the end of each 5-year period, are presented in tables 3–1 (for most sampling sites) and 3–2 (for Clark Fork above Missoula, Montana [sampling site 22]). Detailed trend results are graphically presented in figures 3–1 through 3–7. The detailed graphical presentations in appendix 3 present fitted trends for all constituents and allow evaluation of the fitted trends for a given sampling site in conjunction with FACs.

Table 3–1. Flow-adjusted trend results for selected water-quality constituents and properties for selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Values in parentheses indicate *p*-values for associated percentage change. Gray shading indicates statistical significance at *p*-value less than 0.01. *p*-value, statistical probability level; SEE, standard error of estimate; <, less than; NR, not reported]

Constituent or property	Number of samples	Total percentage change for water years 1996–2000 (period 1)	Total percentage change for water years 2001–5 (period 2)	Total percentage change for water years 2006–10 (period 3)	Total percentage change for water years 2011–15 (period 4)	*p*-value for overall trend analysis[1]	SEE, in percent	Percentage of values affected by recensoring at study reporting level used in the application of the time-series model[2]
Silver Bow Creek at Warm Springs, Montana (sampling site 8, fig. 1, table 1)								
Specific conductance	186	-1 (0.645)	-3 (0.226)	2 (0.380)	-13 (<0.001)	<0.001	10.5	0.0
Copper, filtered	186	-48 (<0.001)	-12 (0.187)	-8 (0.427)	-24 (0.023)	<0.001	32.9	0.0
Copper, unfiltered-recoverable	186	-38 (<0.001)	-14 (0.105)	-12 (0.246)	-28 (0.005)	<0.001	38.3	0.0
Zinc, unfiltered-recoverable	178	-54 (<0.001)	-47 (<0.001)	16 (0.112)	-37 (<0.001)	<0.001	45.0	4.5
Arsenic, filtered	186	1 (0.902)	5 (0.449)	5 (0.481)	-18 (0.015)	0.002	24.8	0.0
Arsenic, unfiltered-recoverable	186	-1 (0.907)	5 (0.303)	1 (0.894)	-16 (0.004)	0.002	24.5	0.0
Suspended sediment	188	17 (0.450)	-27 (0.072)	-40 (0.010)	15 (0.515)	<0.001	65.9	0.0
Clark Fork near Galen, Montana (sampling site 11, fig. 1, table 1)								
Specific conductance	217	1 (0.134)	-8 (NR[3])	7 (NR[3])	-12 (NR[3])	0.027	12.7	0.0
Copper, filtered	215	-45 (<0.001)	-5 (0.593)	-17 (0.085)	4 (0.759)	<0.001	28.4	0.0
Copper, unfiltered-recoverable	213	-31 (<0.001)	7 (0.527)	-5 (0.702)	-24 (0.035)	<0.001	44.4	0.0
Zinc, unfiltered-recoverable	205	-56 (<0.001)	-31 (0.003)	30 (0.060)	-39 (0.001)	<0.001	41.0	4.8
Arsenic, filtered	215	-8 (0.332)	12 (0.165)	-21 (0.014)	11 (0.303)	<0.001	26.7	0.0
Arsenic, unfiltered-recoverable	215	-3 (0.708)	3 (0.741)	-17 (0.082)	13 (0.294)	0.005	29.4	0.0
Suspended sediment	229	12 (0.494)	-19 (0.211)	8 (0.678)	-25 (0.168)	0.002	60.0	0.0
Clark Fork at Deer Lodge, Montana (sampling site 14, fig. 1, table 1)								
Specific conductance	264	1 (0.747)	-4 (0.089)	-2 (0.419)	1 (0.860)	<0.001	11.2	0.0
Copper, filtered	231	-16 (0.003)	6 (0.400)	-12 (0.087)	8 (0.397)	<0.001	28.9	0.0
Copper, unfiltered-recoverable	229	-22 (0.019)	5 (0.661)	1 (0.963)	-8 (0.595)	<0.001	52.7	0.0
Zinc, unfiltered-recoverable	227	-37 (<0.001)	-2 (0.850)	-7 (0.560)	-13 (0.334)	<0.001	54.0	0.9
Arsenic, filtered	231	-3 (0.501)	17 (<0.001)	-16 (<0.001)	4 (0.540)	0.001	15.6	0.0
Arsenic, unfiltered-recoverable	230	-8 (0.184)	7 (0.308)	-12 (0.114)	2 (0.828)	0.357	27.0	0.0
Suspended sediment	281	-17 (0.121)	-8 (0.555)	8 (0.643)	-17 (0.294)	0.001	80.5	0.0

Table 3–1. Flow-adjusted trend results for selected water-quality constituents and properties for selected sampling sites in the Milltown Reservoir/Clark Fork River Superfund Site in the upper Clark Fork Basin, Montana, water years 1996–2015.—Continued

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Values in parentheses indicate *p*-values for associated percentage change. Gray shading indicates statistical significance at *p*-value less than 0.01. *p*-value, statistical probability level; SEE, standard error of estimate; <, less than; NR, not reported]

Constituent or property	Number of samples	Total percentage change for water years 1996–2000 (period 1)	Total percentage change for water years 2001–5 (period 2)	Total percentage change for water years 2006–10 (period 3)	Total percentage change for water years 2011–15 (period 4)	*p*-value for overall trend analysis[1]	SEE, in percent	Percentage of values affected by recensoring at study reporting level used in the application of the time-series model[2]
Clark Fork at Goldcreek, Montana (sampling site 16, fig. 1, table 1)								
Specific conductance	186	-2 (0.372)	-3 (0.063)	-2 (0.317)	0 (0.972)	<0.001	9.9	0.0
Copper, filtered	185	-20 (0.003)	13 (0.046)	-12 (0.077)	3 (0.752)	0.002	24.6	0.0
Copper, unfiltered-recoverable	185	-5 (0.688)	-18 (0.036)	-6 (0.564)	7 (0.569)	0.002	44.0	0.0
Zinc, unfiltered-recoverable	183	-25 (0.015)	-37 (<0.001)	24 (0.103)	-14 (0.349)	<0.001	43.8	1.7
Arsenic, filtered	186	-13 (NR[3])	8 (0.048)	-3 (0.548)	-4 (0.365)	0.026	15.2	0.0
Arsenic, unfiltered-recoverable	186	-17 (NR[3])	3 (0.582)	-4 (0.522)	-3 (0.616)	0.086	21.8	0.0
Suspended sediment	187	15 (0.396)	-51 (<0.001)	54 (0.012)	-17 (0.352)	<0.001	58.4	0.0
Clark Fork near Drummond, Montana (sampling site 18, fig. 1, table 1)								
Specific conductance	186	0 (0.535)	-2 (0.018)	-3 (<0.001)	6 (<0.001)	<0.001	11.3	0.0
Copper, filtered	183	0 (0.991)	10 (0.037)	-24 (<0.001)	13 (0.194)	0.013	33.5	0.0
Copper, unfiltered-recoverable	184	-13 (0.219)	-9 (0.369)	-10 (0.408)	-5 (0.730)	0.002	47.6	0.0
Zinc, unfiltered-recoverable	182	-48 (<0.001)	-18 (0.067)	12 (0.437)	-23 (0.147)	<0.001	50.7	2.2
Arsenic, filtered	186	-6 (0.093)	4 (0.107)	-11 (NR[3])	3 (0.378)	0.907	15.9	0.0
Arsenic, unfiltered-recoverable	186	-15 (0.001)	3 (0.398)	-6 (0.171)	0 (0.930)	0.003	23.9	0.0
Suspended sediment	187	-24 (0.134)	-20 (0.174)	29 (0.190)	-23 (0.242)	0.065	65.6	0.0
Clark Fork at Turah Bridge near Bonner, Montana (sampling site 20, fig. 1, table 1)								
Specific conductance	259	-5 (<0.001)	-2 (0.378)	3 (0.184)	-2 (0.502)	<0.001	13.1	0.0
Copper, filtered	228	-23 (<0.001)	9 (0.357)	-6 (0.525)	-20 (0.077)	<0.001	35.0	0.0
Copper, unfiltered-recoverable	227	-13 (0.073)	-8 (0.385)	-1 (0.920)	-4 (0.762)	0.002	50.3	0.0
Zinc, unfiltered-recoverable	219	-36 (<0.001)	-32 (0.005)	52 (0.004)	-31 (0.026)	<0.001	55.1	5.0
Arsenic, filtered	229	-5 (<0.001)	5 (0.002)	3 (0.435)	-16 (0.002)	<0.001	21.6	0.0
Arsenic, unfiltered-recoverable	229	-10 (0.051)	-1 (0.879)	9 (0.258)	-16 (0.052)	0.204	30.3	0.0
Suspended sediment	284	-13 (0.222)	-25 (0.059)	36 (0.067)	-21 (0.246)	0.002	57.4	0.0

[1]Determination of and distinction between *p*-value for individual trend period and *p*-value for overall trend analysis are discussed in the section of this report “Appendix 2—Summary of the Time-Series Model as Applied in this Study.”

[2]Procedures for determining and applying the study reporting level used in the application of the time-series model are discussed in the section of this report “General Description of the Time-Series Model.”

[3]Results not reported because of nonsignificant overall trend analysis (*p*-value greater than 0.01).

Table 3–2. Flow-adjusted trend results for selected water-quality constituents and properties for Clark Fork above Missoula, Montana (sampling site 22), water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Values in parentheses indicate *p*-values for associated percentage change. Gray shading indicates statistical significance at *p*-value less than 0.01. *p*-value, statistical probability level; SEE, standard error of estimate; <, less than; NR, not reported]

Constituent or property	Number of samples	Total percentage change for water years 1996–2000 (period 1)	Total percentage change for water years 2001–5 (period 2)	Total percentage change for October 1, 2005–March 27, 2008 (period 3A)	Total percentage change for March 28, 2008–September 30, 2010 (period 3B)	Total percentage change for water years 2011–15 (period 4)	*p*-value for overall trend analysis[1]	SEE, in percent	Percentage of values affected by recensoring at study reporting level used in the application of the time-series model[2]
Clark Fork above Missoula, Montana (sampling site 22, fig.1, table 1)									
Specific conductance	227	0 (0.840)	-2 (0.250)	1 (0.585)	4 (0.101)	-7 (NR[3])	0.161	8.2	0.0
Copper, filtered	206	-25 (0.006)	25 (0.057)	13 (0.357)	-21 (0.089)	-27 (0.032)	<0.001	37.4	0.0
Copper, unfiltered-recoverable	205	-23 (0.035)	41 (0.017)	120 (<0.001)	-59 (<0.001)	-52 (0.002)	<0.001	60.7	0.0
Zinc, unfiltered-recoverable	186	-49 (<0.001)	43 (0.082)	192 (<0.001)	-65 (<0.001)	-52 (0.003)	<0.001	65.7	8.5
Arsenic, filtered	207	-15 (0.005)	14 (0.033)	10 (0.171)	-3 (0.664)	-24 (<0.001)	<0.001	26.1	0.0
Arsenic, unfiltered-recoverable	207	-21 (0.006)	16 (0.110)	25 (0.036)	-17 (0.099)	-25 (0.012)	<0.001	34.0	0.0
Suspended sediment	250	-4 (0.796)	25 (0.242)	168 (<0.001)	-60 (<0.001)	-40 (0.032)	<0.001	68.7	0.0

[1]Determination of and distinction between *p*-value for individual trend period and *p*-value for overall trend analysis are discussed in the section of this report "Appendix 2—Summary of the Time-Series Model as Applied in this Study."

[2]Procedures for determining and applying the study reporting level used in the application of the time-series model are discussed in the section of this report "General Description of the Time-Series Model."

[3]Results not reported because of nonsignificant overall trend analysis (*p*-value greater than 0.01).

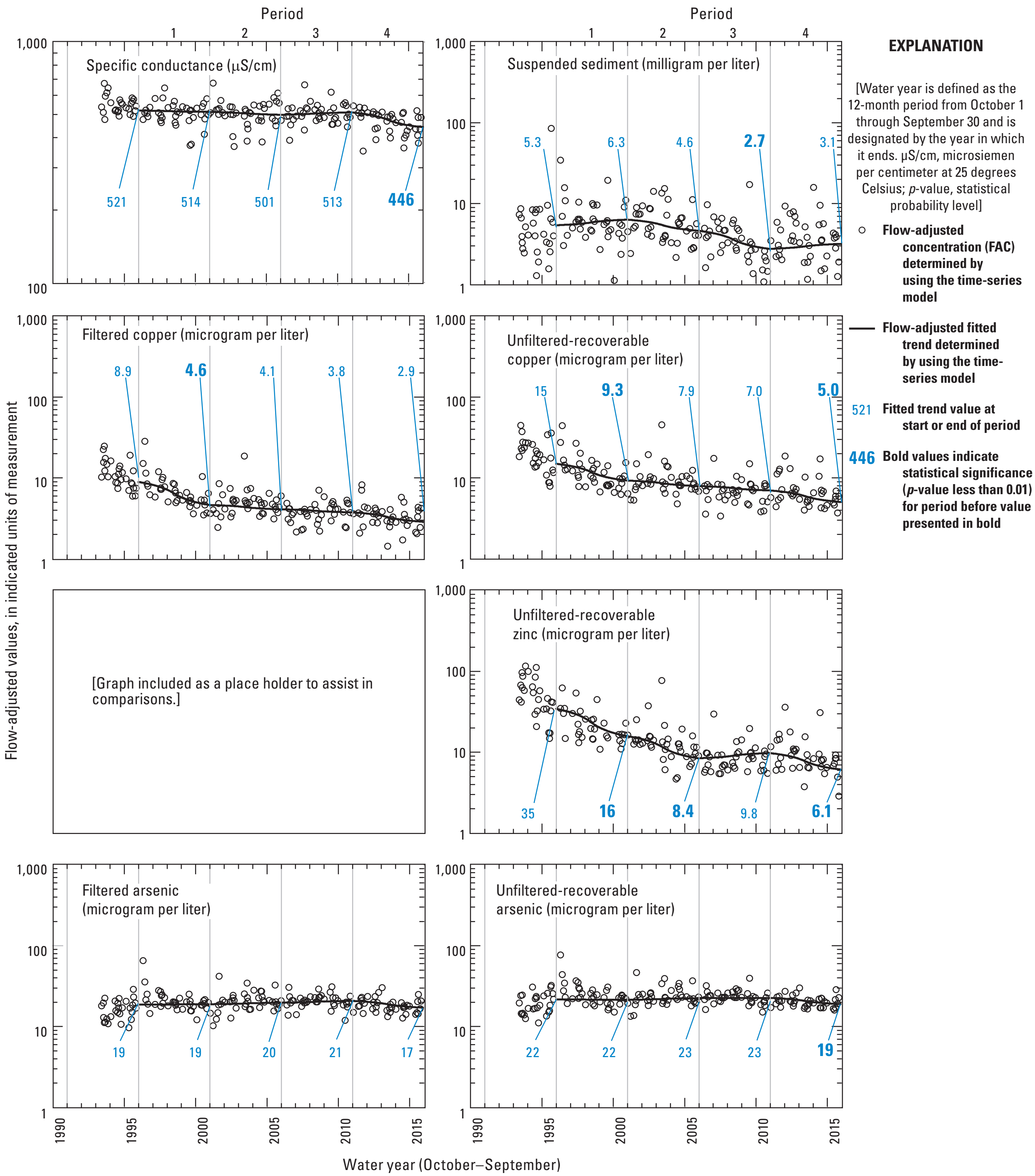

Figure 3–1. Flow-adjusted fitted trends for selected water-quality constituents and properties for Silver Bow Creek at Warm Springs, Montana (sampling site 8), water years 1996–2015.

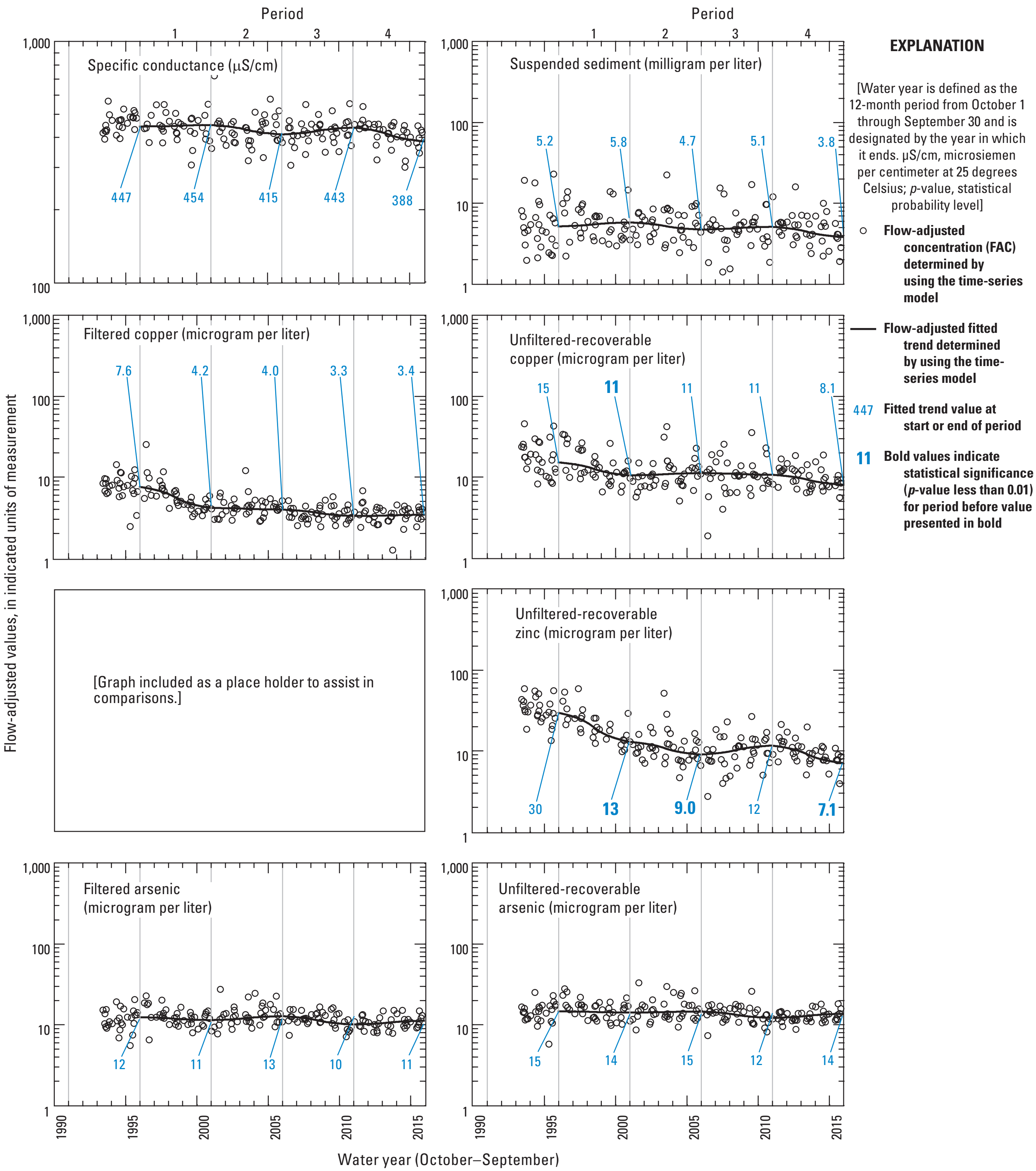

Figure 3–2. Flow-adjusted fitted trends for selected water-quality constituents and properties for Clark Fork near Galen, Montana (sampling site 11), water years 1996–2015.

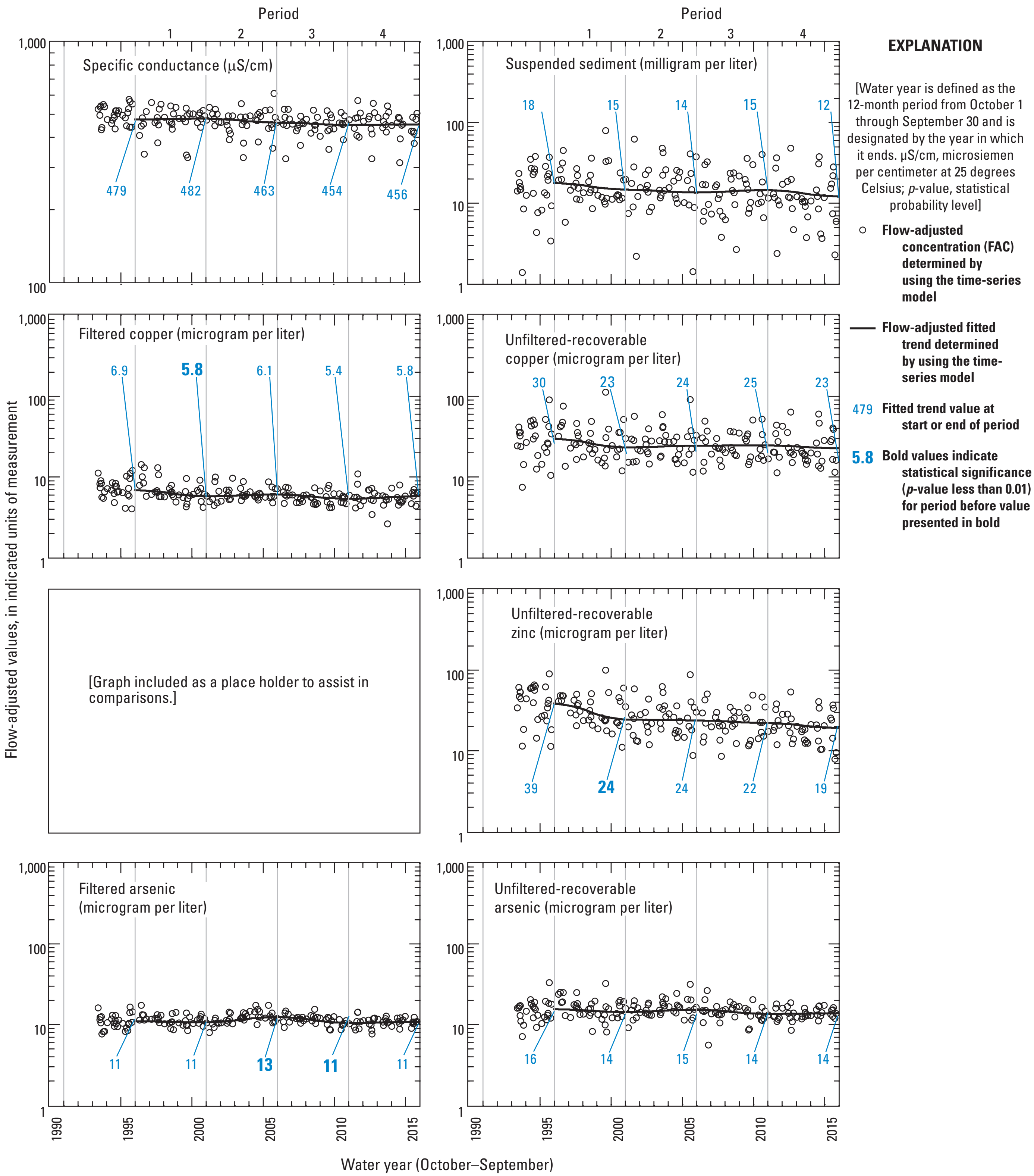

Figure 3–3. Flow-adjusted fitted trends for selected water-quality constituents and properties for Clark Fork at Deer Lodge, Montana (sampling site 14), water years 1996–2015.

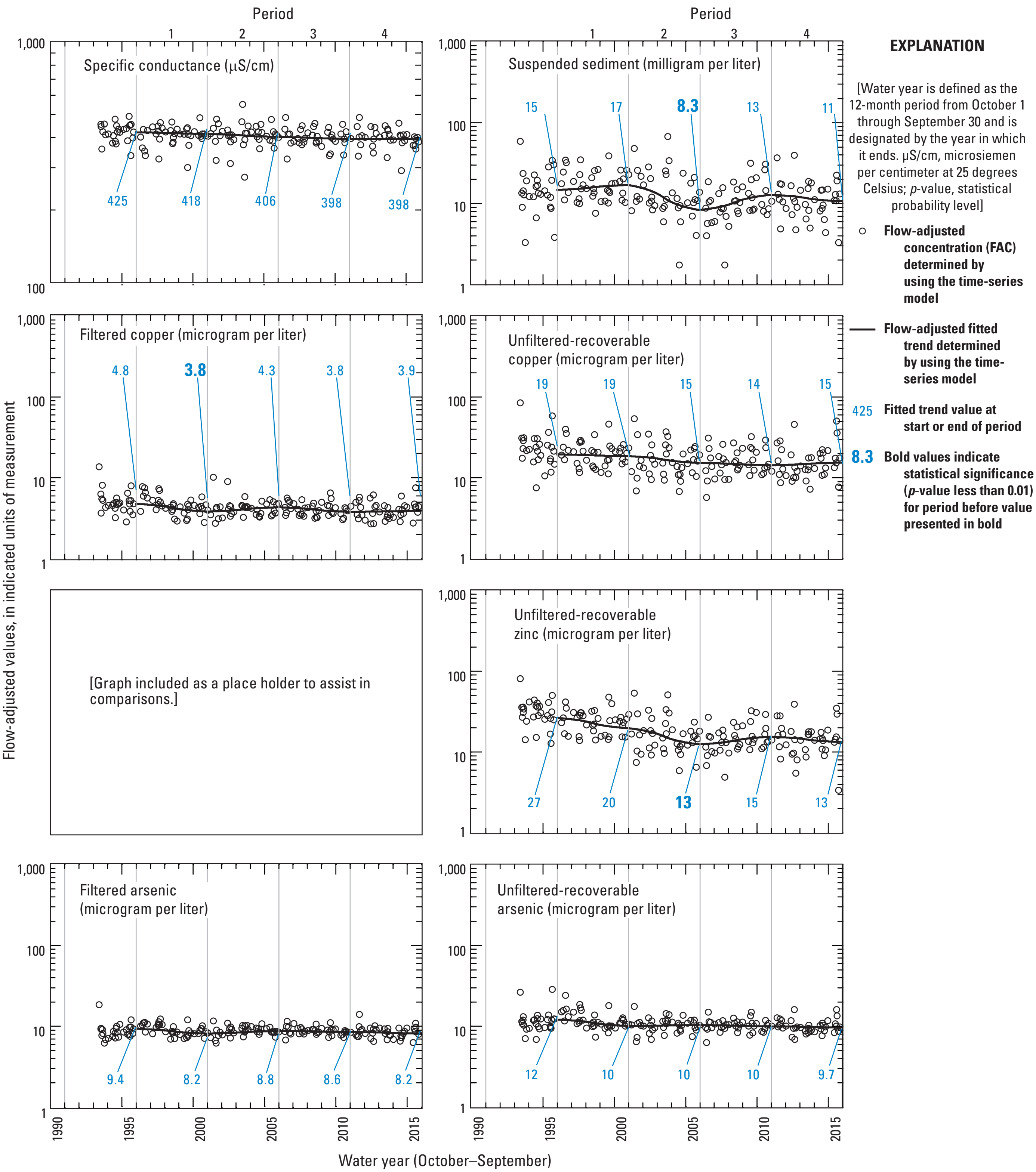

Figure 3–4. Flow-adjusted fitted trends for selected water-quality constituents and properties for Clark Fork at Goldcreek, Montana (sampling site 16), water years 1996–2015.

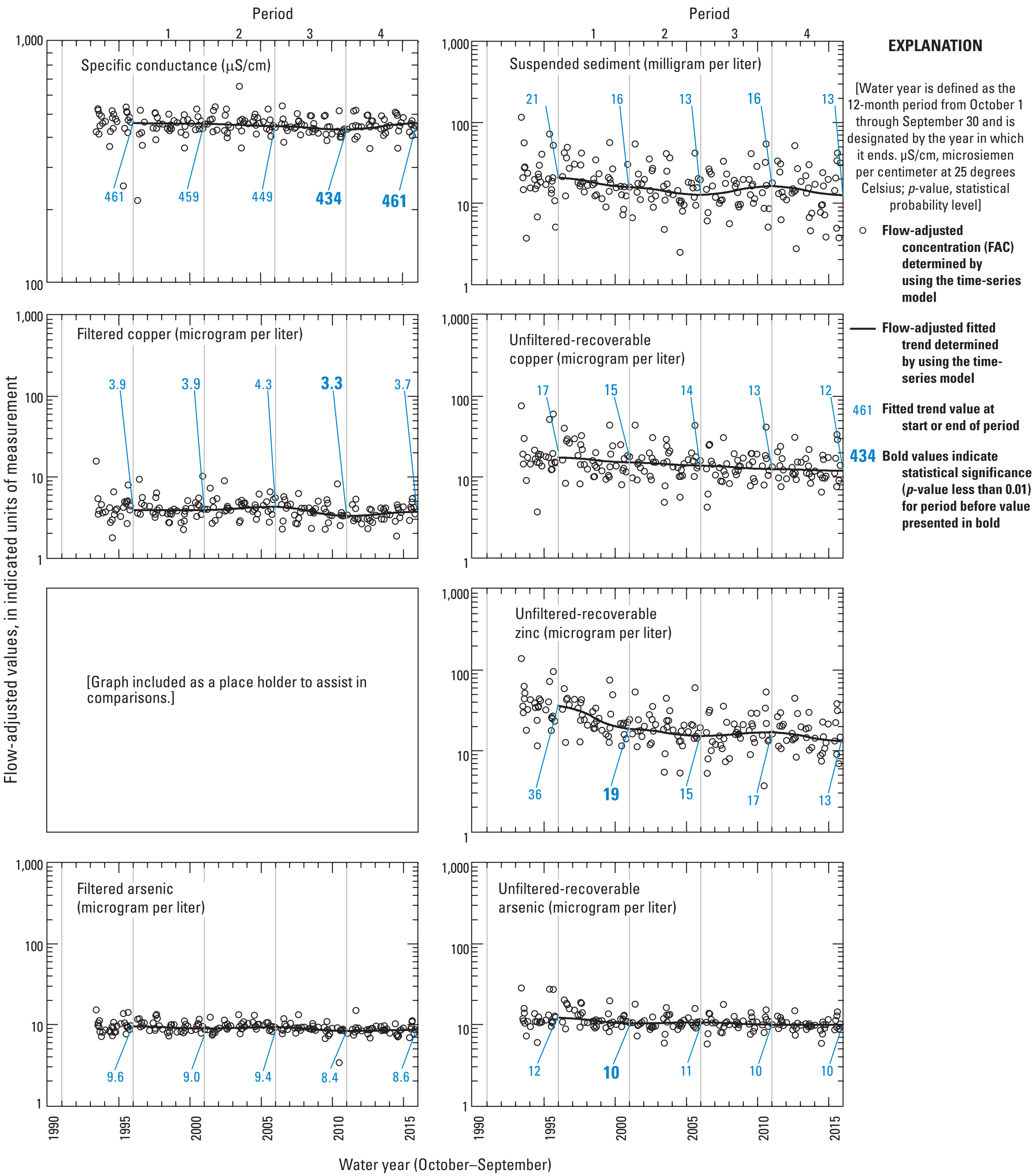

Figure 3–5. Flow-adjusted fitted trends for selected water-quality constituents and properties for Clark Fork near Drummond, Montana (sampling site 18), water years 1996–2015.

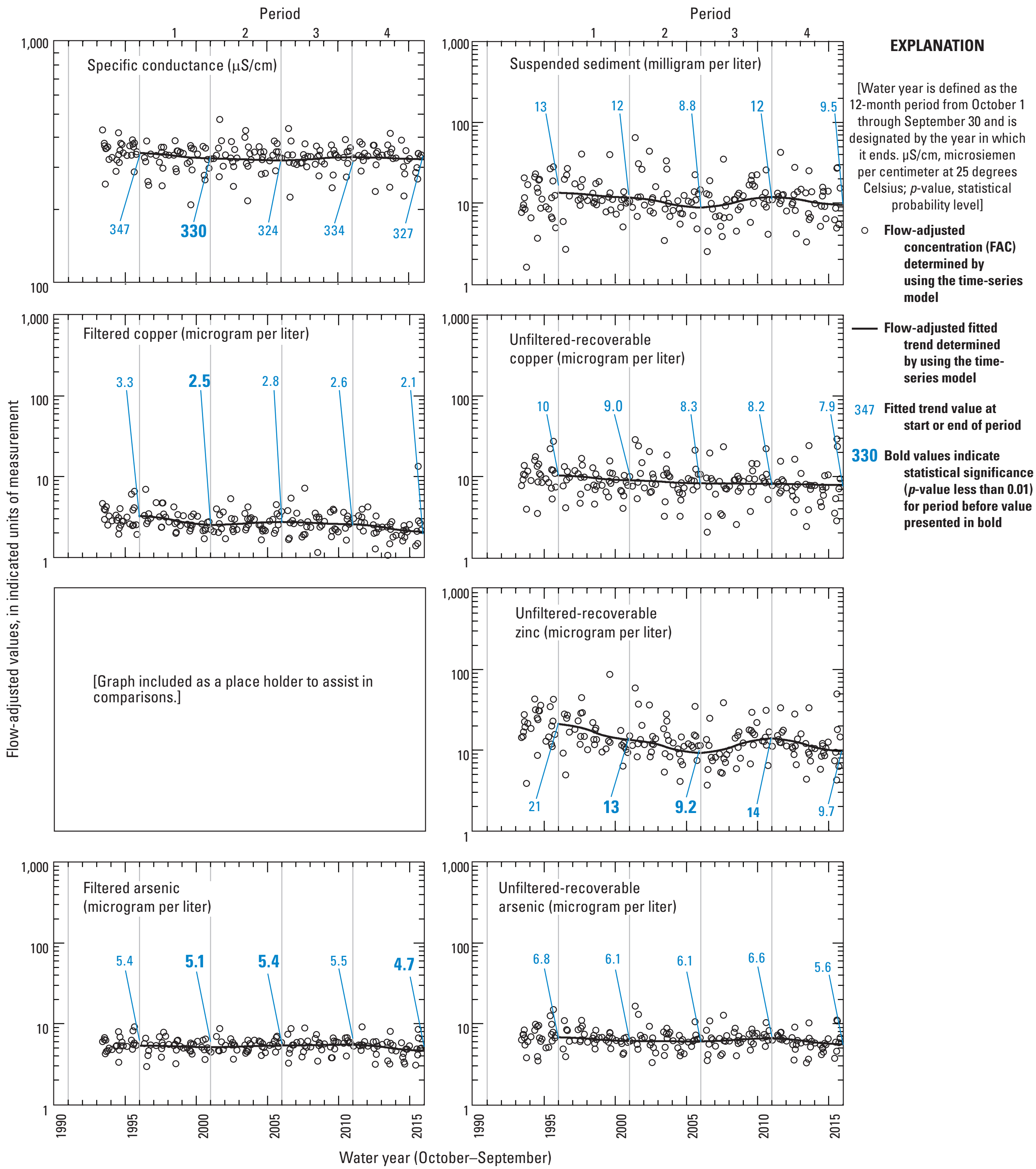

Figure 3–6. Flow-adjusted fitted trends for selected water-quality constituents and properties for Clark Fork at Turah Bridge near Bonner, Montana (sampling site 20), water years 1996–2015.

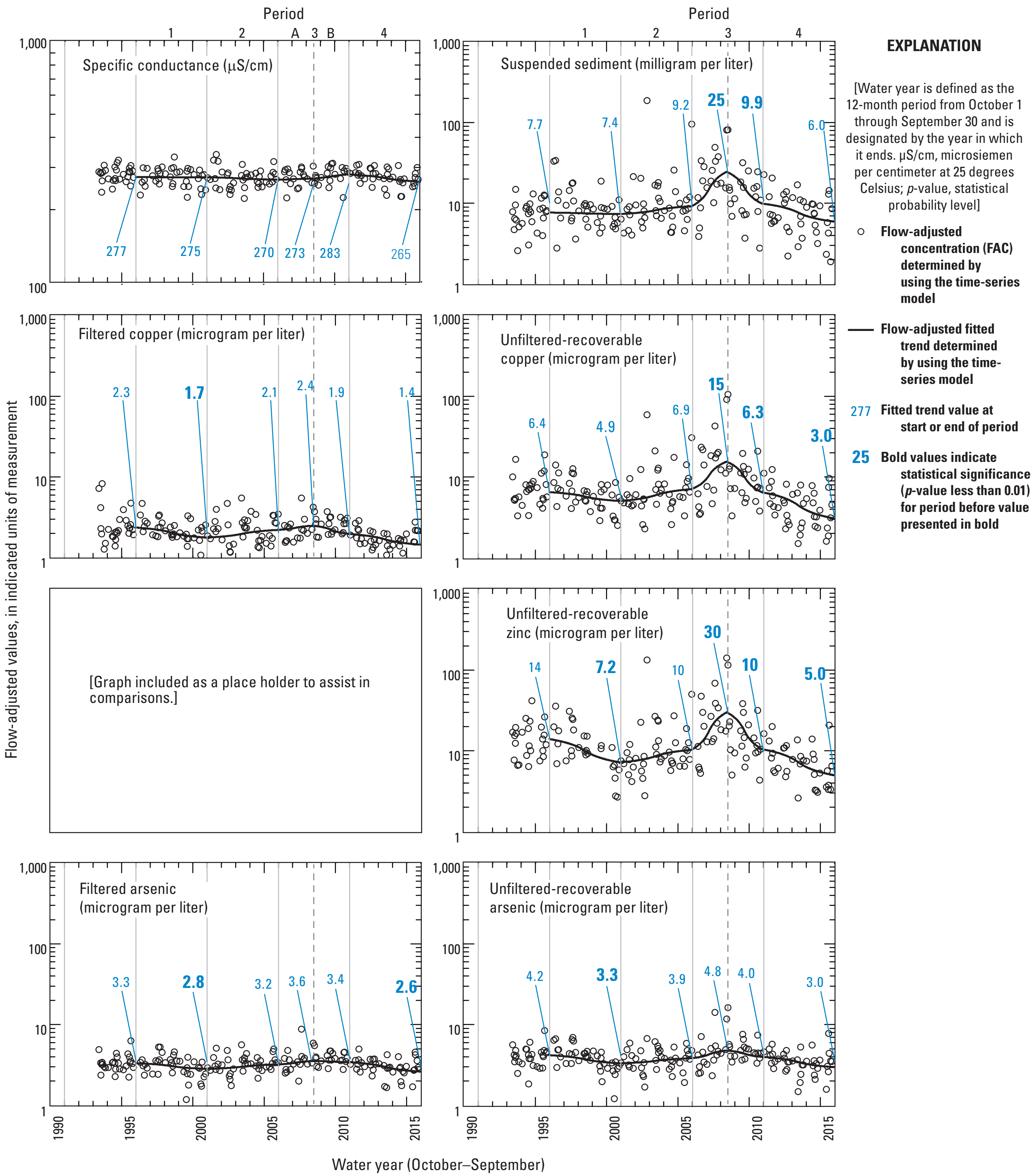

Figure 3–7. Flow-adjusted fitted trends for selected water-quality constituents and properties for Clark Fork above Missoula, Montana (sampling site 22), water years 1996–2015.

Appendix 4—Transport-Analysis Balance Calculations for Data-Summary Reaches

Balance calculations for the transport analysis (that is, differences between reach inflows and reach outflows) are presented in tables 4–1 through 4–6 for reaches 4–9, respectively, in appendix 4. The transport balance calculations indicate within-reach changes in estimated normalized loads and allow assessment of temporal changes in relative contributions from upstream source areas to loads transported past each reach outflow.

Table 4–1. Constituent-transport analysis balance calculations for sampling sites in reach 4, extending from Silver Bow Creek at Warm Springs, Montana (sampling site 8), to Clark Fork near Galen, Montana (sampling site 11), for selected periods, water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends]

Abbreviated sampling site name (table 1) and number or summation category	Estimated normalized load,[1] in kilograms per day		
	Unfiltered-recoverable copper	Unfiltered-recoverable arsenic	Suspended sediment
Water years 1996–2000 (period 1)			
Inflow			
Silver Bow Creek at Warm Springs (sampling site 8)	1.9	3.4	920
Outflow			
Clark Fork near Galen (sampling site 11)	3.7	4.2	1,600
Total within-reach change in load—outflow (sampling site 11) minus inflow (sampling site 8) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	1.8	0.78	670
Water years 2001–5 (period 2)			
Inflow			
Silver Bow Creek at Warm Springs (sampling site 8)	1.4	3.5	850
Outflow			
Clark Fork near Galen (sampling site 11)	3.1	4.2	1,500
Total within-reach change in load—outflow (sampling site 11) minus inflow (sampling site 8) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	1.8	0.70	670
Water years 2006–10 (period 3)			
Inflow			
Silver Bow Creek at Warm Springs (sampling site 8)	1.2	3.6	570
Outflow			
Clark Fork near Galen (sampling site 11)	3.2	3.9	1,400
Total within-reach change in load—outflow (sampling site 11) minus inflow (sampling site 8) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	2.0	0.31	860
Water years 2011–15 (period 4)			
Inflow			
Silver Bow Creek at Warm Springs (sampling site 8)	0.94	3.3	460
Outflow			
Clark Fork near Galen (sampling site 11)	2.7	3.8	1,300
Total within-reach change in load—outflow (sampling site 11) minus inflow (sampling site 8) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	1.8	0.46	820

[1]The estimated normalized load was computed by multiplying the mean annual fitted trend concentration (determined by using the time-series model) for the indicated period times the geometric mean streamflow for water years 1996–2015 and a units conversion factor according to equation 1 in the section of this report "Estimation of Normalized Constituent Loads." Loads are reported to two significant figures; however, before final rounding, calculations used three significant figures when necessary. As a result, some of the load values have minor rounding artifacts.

Table 4–2. Constituent-transport analysis balance calculations for sampling sites in reach 5, extending from Clark Fork near Galen, Montana (sampling site 11), to Clark Fork at Deer Lodge, Montana (sampling site 14), for selected periods, water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends]

Abbreviated sampling site name (table 1) and number or summation category	Estimated normalized load,[1] in kilograms per day		
	Unfiltered-recoverable copper	Unfiltered-recoverable arsenic	Suspended sediment
Water years 1996–2000 (period 1)			
Inflow			
Clark Fork near Galen (sampling site 11)	3.7	4.2	1,600
Outflow			
Clark Fork at Deer Lodge (sampling site 14)	13	7.7	8,300
Total within-reach change in load—outflow (sampling site 14) minus inflow (sampling site 11) (positive values indicate net mobilization from within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	9.8	3.5	6,700
Water years 2001–5 (period 2)			
Inflow			
Clark Fork near Galen (sampling site 11)	3.1	4.2	1,500
Outflow			
Clark Fork at Deer Lodge (sampling site 14)	12	7.6	7,200
Total within-reach change in load—outflow (sampling site 14) minus inflow (sampling site 11) (positive values indicate net mobilization from within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	9.0	3.4	5,700
Water years 2006–10 (period 3)			
Inflow			
Clark Fork near Galen (sampling site 11)	3.2	3.9	1,400
Outflow			
Clark Fork at Deer Lodge (sampling site 14)	13	7.4	7,200
Total within-reach change in load—outflow (sampling site 14) minus inflow (sampling site 11) (positive values indicate net mobilization from within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	9.4	3.5	5,800
Water years 2011–15 (period 4)			
Inflow			
Clark Fork near Galen (sampling site 11)	2.7	3.8	1,300
Outflow			
Clark Fork at Deer Lodge (sampling site 14)	12	7.0	6,800
Total within-reach change in load—outflow (sampling site 14) minus inflow (sampling site 11) (positive values indicate net mobilization from within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	9.4	3.3	5,500

[1]The estimated normalized load was computed by multiplying the mean annual fitted trend concentration (determined by using the time-series model) for the indicated period times the geometric mean streamflow for water years 1996–2015 and a units conversion factor according to equation 1 in the section of this report "Estimation of Normalized Constituent Loads." Loads are reported to two significant figures; however, before final rounding, calculations used three significant figures when necessary. As a result, some of the load values have minor rounding artifacts.

Table 4–3. Constituent-transport analysis balance calculations for sampling sites in reach 6, extending from Clark Fork at Deer Lodge, Montana (sampling site 14), to Clark Fork at Goldcreek, Montana (sampling site 16), for selected periods, water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends]

Abbreviated sampling site name (table 1) and number or summation category	Estimated normalized load,[1] in kilograms per day		
	Unfiltered-recoverable copper	Unfiltered-recoverable arsenic	Suspended sediment
Water years 1996–2000 (period 1)			
Inflow			
Clark Fork at Deer Lodge (sampling site 14)	13	7.7	8,300
Outflow			
Clark Fork at Goldcreek (sampling site 16)	19	11	16,000
Total within-reach change in load—outflow (sampling site 16) minus inflow (sampling site 14) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	5.4	3.5	7,500
Water years 2001–5 (period 2)			
Inflow			
Clark Fork at Deer Lodge (sampling site 14)	12	7.6	7,200
Outflow			
Clark Fork at Goldcreek (sampling site 16)	17	10	12,000
Total within-reach change in load—outflow (sampling site 16) minus inflow (sampling site 14) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	4.6	2.6	5,000
Water years 2006–10 (period 3)			
Inflow			
Clark Fork at Deer Lodge (sampling site 14)	13	7.4	7,200
Outflow			
Clark Fork at Goldcreek (sampling site 16)	15	10	10,000
Total within-reach change in load—outflow (sampling site 16) minus inflow (sampling site 14) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	2.2	2.8	3,200
Water years 2011–15 (period 4)			
Inflow			
Clark Fork at Deer Lodge (sampling site 14)	12	7.0	6,800
Outflow			
Clark Fork at Goldcreek (sampling site 16)	15	9.9	12,000
Total within-reach change in load—outflow (sampling site 16) minus inflow (sampling site 14) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	2.7	2.8	4,900

[1]The estimated normalized load was computed by multiplying the mean annual fitted trend concentration (determined by using the time-series model) for the indicated period times the geometric mean streamflow for water years 1996–2015 and a units conversion factor according to equation 1 in the section of this report "Estimation of Normalized Constituent Loads." Loads are reported to two significant figures; however, before final rounding, calculations used three significant figures when necessary. As a result, some of the load values have minor rounding artifacts.

Table 4–4. Constituent-transport analysis balance calculations for sampling sites in reach 7, extending from Clark Fork at Goldcreek, Montana (sampling site 16), to Clark Fork near Drummond, Montana (sampling site 18), for selected periods, water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends]

Abbreviated sampling site name (table 1) and number or summation category	Estimated normalized load,[1] in kilograms per day		
	Unfiltered-recoverable copper	Unfiltered-recoverable arsenic	Suspended sediment
Water years 1996–2000 (period 1)			
Inflow			
Clark Fork at Goldcreek (sampling site 16)	19	11	16,000
Outflow			
Clark Fork near Drummond (sampling site 18)	24	16	26,000
Total within-reach change in load—outflow (sampling site 18) minus inflow (sampling site 16) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	4.6	5.2	10,000
Water years 2001–5 (period 2)			
Inflow			
Clark Fork at Goldcreek (sampling site 16)	17	10	12,000
Outflow			
Clark Fork near Drummond (sampling site 18)	21	15	21,000
Total within-reach change in load—outflow (sampling site 18) minus inflow (sampling site 16) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	4.1	5.0	8,300
Water years 2006–10 (period 3)			
Inflow			
Clark Fork at Goldcreek (sampling site 16)	15	10	10,000
Outflow			
Clark Fork near Drummond (sampling site 18)	19	15	21,000
Total within-reach change in load—outflow (sampling site 18) minus inflow (sampling site 16) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	4.3	4.8	10,000
Water years 2011–15 (period 4)			
Inflow			
Clark Fork at Goldcreek (sampling site 16)	15	9.9	12,000
Outflow			
Clark Fork near Drummond (sampling site 18)	18	14	21,000
Total within-reach change in load—outflow (sampling site 18) minus inflow (sampling site 16) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	2.9	4.6	9,100

[1]The estimated normalized load was computed by multiplying the mean annual fitted trend concentration (determined by using the time-series model) for the indicated period times the geometric mean streamflow for water years 1996–2015 and a units conversion factor according to equation 1 in the section of this report "Estimation of Normalized Constituent Loads." Loads are reported to two significant figures; however, before final rounding, calculations used three significant figures when necessary. As a result, some of the load values have minor rounding artifacts.

Table 4–5. Constituent-transport analysis balance calculations for sampling sites in reach 8, extending from Clark Fork near Drummond, Montana (sampling site 18), to Clark Fork at Turah Bridge near Bonner, Montana (sampling site 20), for selected periods, water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends]

Abbreviated sampling site name (table 1) and number or summation category	Estimated normalized load,[1] in kilograms per day		
	Unfiltered-recoverable copper	Unfiltered-recoverable arsenic	Suspended sediment
Water years 1996–2000 (period 1)			
Inflow			
Clark Fork near Drummond (sampling site 18)	24	16	26,000
Outflow			
Clark Fork at Turah Bridge (sampling site 20)	25	17	33,000
Total within-reach change in load—outflow (sampling site 20) minus inflow (sampling site 18) (negative values indicate net accumulation in reach channel; positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	1.6	0.49	6,300
Water years 2001–5 (period 2)			
Inflow			
Clark Fork near Drummond (sampling site 18)	21	15	21,000
Outflow			
Clark Fork at Turah Bridge (sampling site 20)	22	16	26,000
Total within-reach change in load—outflow (sampling site 20) minus inflow (sampling site 18) (negative values indicate net accumulation in reach channel; positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	1.5	0.58	5,900
Water years 2006–10 (period 3)			
Inflow			
Clark Fork near Drummond (sampling site 18)	19	15	21,000
Outflow			
Clark Fork at Turah Bridge (sampling site 20)	21	16	27,000
Total within-reach change in load—outflow (sampling site 20) minus inflow (sampling site 18) (negative values indicate net accumulation in reach channel; positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	2.3	1.5	5,800
Water years 2011–15 (period 4)			
Inflow			
Clark Fork near Drummond (sampling site 18)	18	14	21,000
Outflow			
Clark Fork at Turah Bridge (sampling site 20)	21	16	28,000
Total within-reach change in load—outflow (sampling site 20) minus inflow (sampling site 18) (negative values indicate net accumulation in reach channel; positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	3.2	1.3	6,900

[1]The estimated normalized load was computed by multiplying the mean annual fitted trend concentration (determined by using the time-series model) for the indicated period times the geometric mean streamflow for water years 1996–2015 and a units conversion factor according to equation 1 in the section of this report "Estimation of Normalized Constituent Loads." Loads are reported to two significant figures; however, before final rounding, calculations used three significant figures when necessary. As a result, some of the load values have minor rounding artifacts.

Table 4–6. Constituent-transport analysis balance calculations for sampling sites in reach 9, extending from Clark Fork at Turah Bridge near Bonner, Montana (sampling site 20), to Clark Fork above Missoula, Montana (sampling site 22), for selected periods, water years 1996–2015.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends]

Abbreviated sampling site name (table 1) and number or summation category	Estimated normalized load,[1] in kilograms per day		
	Unfiltered-recoverable copper	Unfiltered-recoverable arsenic	Suspended sediment
Water years 1996–2000 (period 1)			
Inflow			
Clark Fork at Turah Bridge (sampling site 20)	25	17	33,000
Outflow			
Clark Fork above Missoula (sampling site 22)	29	19	39,000
Total within-reach change in load—outflow (sampling site 22) minus inflow (sampling site 20) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	3.7	2.5	6,000
Water years 2001–5 (period 2)			
Inflow			
Clark Fork at Turah Bridge (sampling site 20)	22	16	26,000
Outflow			
Clark Fork above Missoula (sampling site 22)	30	18	42,000
Total within-reach change in load—outflow (sampling site 22) minus inflow (sampling site 20) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	7.7	2.6	16,000
Water years 2006–10 (period 3)			
Inflow			
Clark Fork at Turah Bridge (sampling site 20)	21	16	27,000
Outflow			
Clark Fork above Missoula (sampling site 22)	54	22	83,000
Total within-reach change in load—outflow (sampling site 22) minus inflow (sampling site 20) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	32	5.9	56,000
Water years 2011–15 (period 4)			
Inflow			
Clark Fork at Turah Bridge (sampling site 20)	21	16	28,000
Outflow			
Clark Fork above Missoula (sampling site 22)	23	18	40,000
Total within-reach change in load—outflow (sampling site 22) minus inflow (sampling site 20) (positive values indicate net mobilization from all within-reach sources including groundwater inflow, tributaries, the main-stem channel, and flood plain)	2.2	2.1	12,000

[1]The estimated normalized load was computed by multiplying the mean annual fitted trend concentration (determined by using the time-series model) for the indicated period times the geometric mean streamflow for water years 1996–2015 and a units conversion factor according to equation 1 in the section of this report "Estimation of Normalized Constituent Loads." Loads are reported to two significant figures; however, before final rounding, calculations used three significant figures when necessary. As a result, some of the load values have minor rounding artifacts.

Publishing support provided by:
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Sando and Vecchia—**Water-Quality Trends and Constituent-Transport Analysis for Selected Sampling Sites**—Scientific Investigations Report 2016–5100

ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20165100