WATER QUALITY IMPROVEMENTS AT SILVER BOW CREEK RESULTING FROM REMEDIAL ACTION[1]

William H. Bucher, P.E.[2], Larry Cawlfield, P.E., Gary R. Fischer, P.E.

Abstract. Mining wastes comprised of heavy metals and arsenic and deposited along Silver Bow Creek downstream of Butte, Montana have posed a threat to human health and the environment for over 100 years. Under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), the State of Montana has undertaken the remediation of more than three million cubic meters of mine waste deposited along approximately 40 kilometers of Silver Bow Creek and its floodplain. During remediation, mine waste is excavated from the stream and floodplain and the waste is placed in a regional repository or a local repository constructed for the project. The stream and floodplain have been rebuilt to restore their natural functions and maintain streambank stability during vegetation reestablishment. This paper presents results of water quality monitoring on Silver Bow Creek. Surface water and groundwater quality have greatly improved in the remediated reaches compared to pre-remediation conditions although copper and zinc still frequently exceed aquatic life standards. Some water quality problems persist including the elevated nutrient levels originating at the Butte wastewater treatment works and the elevated copper and zinc concentrations in groundwater, which affect aquatic life in surface water systems.

Additional Key Words: mine waste, heavy metals, monitoring, surface water, groundwater.

[1] Paper was presented at the 2006 Billings Land Reclamation Symposium, June 4-8, 2006, Billings MT and jointly published by BLRS and ASMR, R.I. Barnhisel (ed.) 3134 Montavesta Rd., Lexington, KY 40502.

[2] William H. Bucher, Larry Cawlfield, and Gary R. Fischer are Senior Engineers with Maxim Technologies, Helena, MT 59604.

Proceedings America Society of Mining and Reclamation, 2006 pp 129-
DOI: 10.21000/JASMR06010129
http://dx.doi.org/10.21000/JASMR06010129

Introduction

Silver Bow Creek and its floodplain have been heavily impacted by mine waste deposited for over 100 years. The stream and its floodplain are being remediated by the Montana Department of Environmental Quality (MDEQ) under the federal Comprehensive Environmental Responsibility, Liability and Compensation Act (CERCLA), and are designated the Streamside Tailings Operable Unit (SSTOU) of the Butte/Silver Bow Creek National Priorities List (NPL) site. The site is located near Butte, Montana (Fig. 1). Impacts to the site include stream channel and bank degradation, water-quality degradation, reduction of productivity of terrestrial plants, and impairment of the benthic macroinvertebrate community. Silver Bow Creek is a headwaters tributary to the Clark Fork River that typically has flows of about 0.57 m^3/s in the area near Butte. The un-remediated portions of the stream are generally devoid of fish and most other aquatic life forms due to elevated concentrations of Cu, Zn, and other heavy metals in the water and stream sediments. The primary carcinogenic risk to human health is exposure to As in soil and groundwater although some heavy metals exceed groundwater protection standards as well (MDEQ & EPA 1995). This paper describes water quality improvements resulting from the remediation of the first ten kilometers of stream and floodplain.

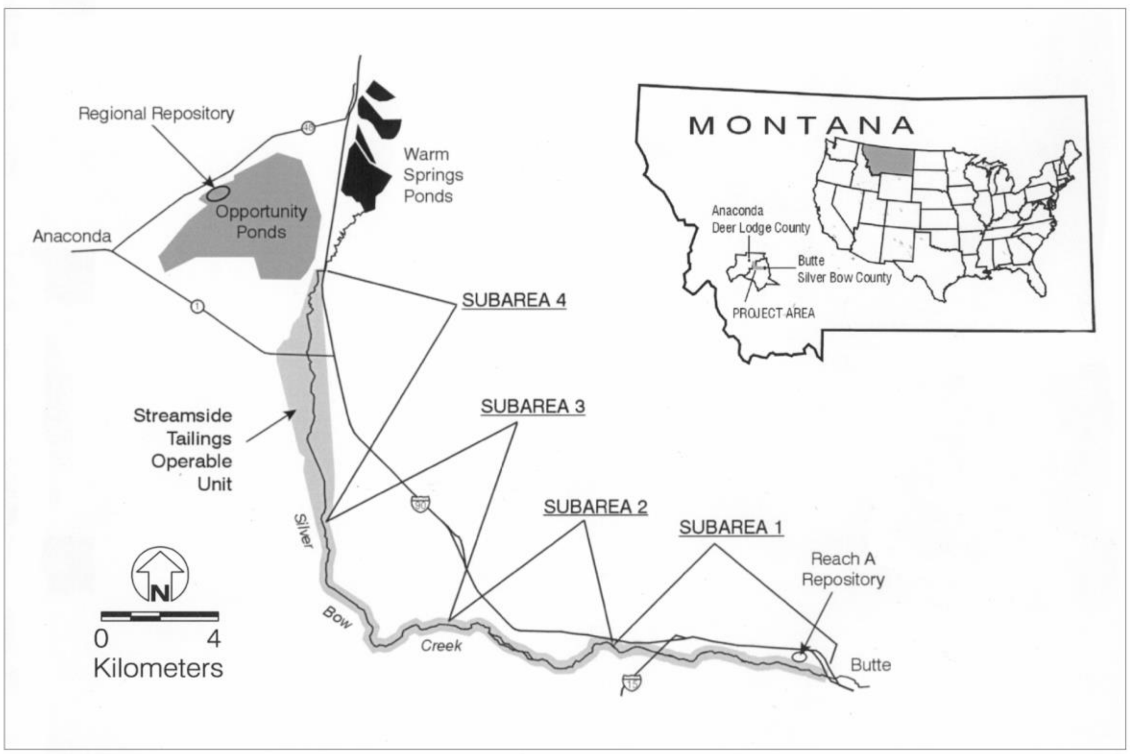


Figure 1. Site location.

Background

The remediation of Silver Bow Creek is being undertaken by MDEQ under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). The 40 kilometer-long floodplain of Silver Bow Creek from the west side of Butte to the Warm Springs

Treatment Ponds, known as the Streamside Tailings Operable Unit (SSTOU), was designated a National Priorities List (NPL) site in 1983. The Streamside Tailings Operable Unit is divided into four sub-areas as shown in Fig. 1. Remediation of the site began in 1999 and is continuing at present. About three million cubic meters of waste will be removed during the course of the project. As part of remediation, mine waste is excavated from the stream and floodplain, and the waste is placed in a regional repository or a local repository constructed for the project. The stream and floodplain are rebuilt to restore their natural function and maintain streambank stability during vegetation reestablishment. Along with remediation efforts, the Natural Resource Damage Program (NRDP) of the Montana Department of Justice (MDOJ) participates by adding restoration elements to the design that enhance aquatic and terrestrial habitat.

Remedial action at the SSTOU began in 1999 and has proceeded about 10 kilometers downstream as of the end of 2005. Long-term monitoring of the site began in 2003 for the following media: vegetation, instream sediment, water quality, vadose zone moisture, and aquatic biological parameters. Geomorphology will be studied in various reaches once initial remediation efforts are complete for five years. Monitoring data are now available from three years and are sufficient to begin evaluation of the effectiveness of the remedy in improving water quality and attaining remedial action objectives. The remedial action objective for surface water is to meet the more restrictive of aquatic life or human health standards for surface water identified in MDEQ Circular WCB-7 (MDEQ, 2004). Provided that upstream sources of Silver Bow Creek contaminants are reduced sufficiently, Silver Bow Creek should support the growth and propagation of fishes and associated aquatic life including a self-sustaining population of trout species. The remedial action objectives for groundwater within the operable unit are compliance with applicable MDEQ Circular WQB-7 standards, federal maximum contaminant levels (MCLs), and federal nonzero maximum contaminant level goals (MCLGs). A second groundwater objective is prevention of groundwater discharge that would prevent attainment of Silver Bow Creek ambient WQB-7 standards (MDEQ and USEPA, 1995).

Because the proposed remedial action included only source control or removal actions, that is, mine waste removal or containment, it is not clear how easily these quantitative remedial action objectives can be met. The monitoring program is therefore a key means of assessing whether the objectives are being met and if the remedial action is indeed appropriate and sufficient.

Description of Water Quality Monitoring Program

The monitoring program for the SSTOU is set forth in the report *Comprehesive Long-Term Monitoring Plan for Silver Bow Creek, Streamside Tailings Operable Unit* (MDEQ and NRDP, 2004). Surface water sampling is occurring at six stations along Silver Bow Creek (Fig. 2) although other stations are occasionally monitored for special purposes, such as nutrient studies. Stations SS-06A and SS-14 are upstream and downstream stations, respectively, that are occasionally monitored. The sampling program will expand as construction progresses downstream. Sampling occurs at high flow and low flow periods (twice annually) with high flow sampling in the first half of the year and low flow sampling occurring in the second half of the year. The emphasis of the surface water sampling program is to sample areas that are remediated although two stations downstream of current construction is also regularly sampled (SS-11D and SS-17). The sampling stations and frequencies have varied to some degree from this protocol in previous years. Sample parameters are total and dissolved metals, common ions, nutrients, and field parameters.

Groundwater is currently being monitored at twelve locations in or near the floodplain of Silver Bow Creek (Fig. 3) as well as six locations in the vicinity of the local Mine Waste Repository (not shown). Sampling will be expanded as construction proceeds downstream. Sampling occurs once a year at the floodplain stations during the low water period (third quarter). Sampling stations have varied from this protocol to some degree in previous years. Sample parameters include dissolved metals, common ions, and field parameters.

Sample results are described annually in monitoring reports prepared for MDEQ and MDOJ (MDEQ and MDOJ, 2004, 2005, and 2006). Reports include summary tables, graphs, and a narrative description of monitoring results.

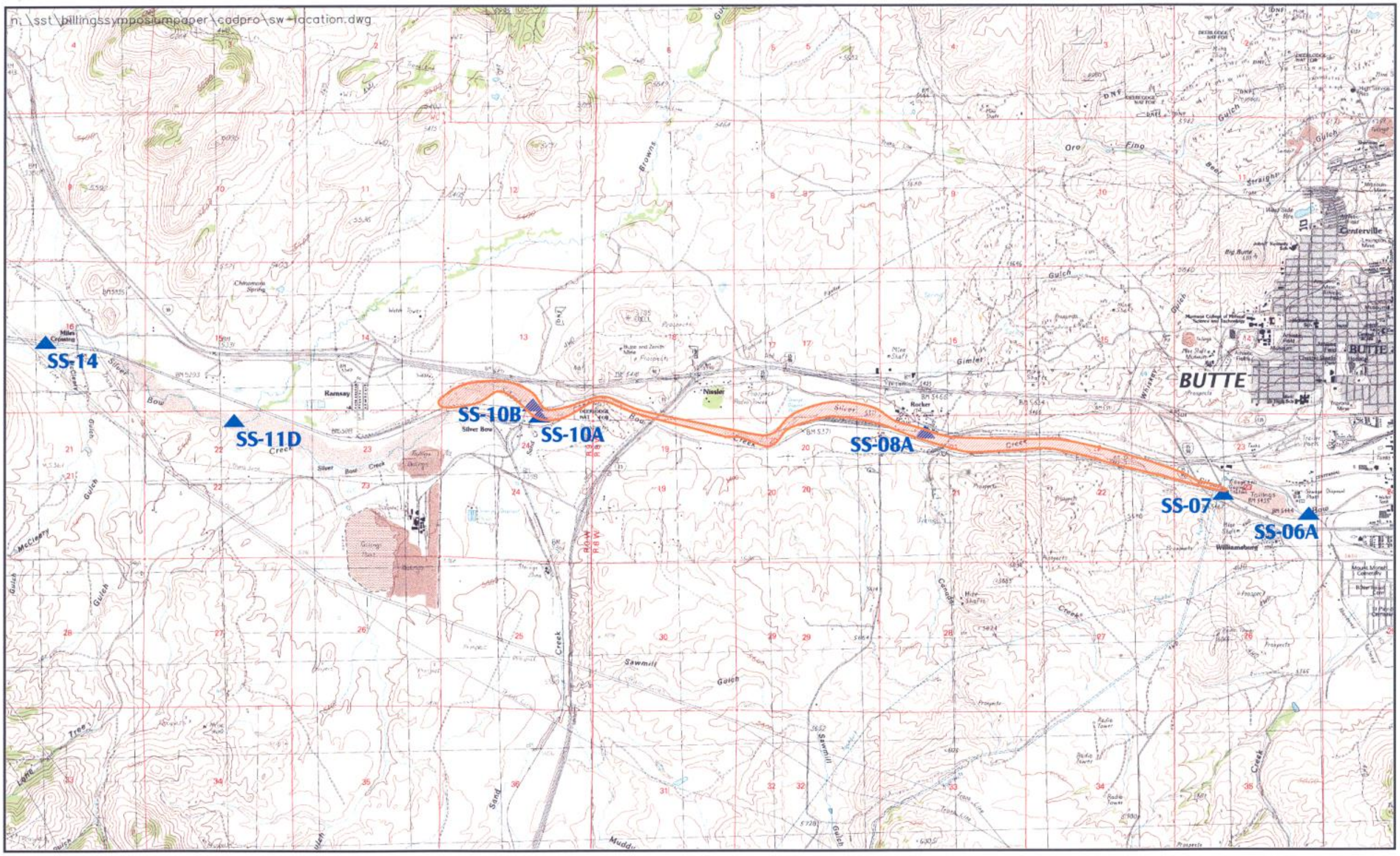
Surface Water Monitoring Results

Surface water monitoring has been undertaken to demonstrate the effectiveness of the remedy in reducing metals concentrations in Silver Bow Creek. Water quality has greatly improved in the stream since the cessation of most mining in Butte in 1982, primarily because of remedial activities upstream of the SSTOU in Butte as well as activities within the SSTOU.

Upstream Water Quality

The six contaminants of concern in the SSTOU are As, Cd, Cu, Pb, Hg, and Zn. Of the six contaminants of concern at the SSTOU, As, Cd, and Pb have not been greatly affected by upstream remediation. The 1984-85 Remedial Investigation data for the upstream station indicate no exceedences of human health standards for these three elements except for a single exceedence for Pb (MultiTech and Stiller, 1986). The upstream station for the SSTOU is Station SS-07, which coincides with the US Geological Survey Gage No. 12323250. Current monitoring also indicates no human health exceedences for As, Cd, and Pb at Station SS-07, and the concentration ranges have not changed significantly. Changes in Cu and Zn are discussed in the remainder of this section. Mercury, the remaining contaminant of concern, has not been detected at SS-07, but its detection limit is above the human health standard presented in Circular WQB-7 (MDEQ, 2004).

Figures 4 and 5 show the improvement in water quality through the years since most mining ceased in Butte. Total recoverable data are plotted although dissolved data are also available at this site. Data collected in 1985 shortly after the mine closure (MultiTech and Stiller, 1986) indicate Cu and Zn levels well above the chronic aquatic life standards for these metals (MDEQ, 2004). These standards are hardness dependent and hardness is calculated for each sampling event individually. Much of the upstream improvement in water quality occurred prior to commencement of construction in the SSTOU in 1999 as indicated by the relatively low values measured in 1998 (Dodge *et al.,* 1999). Currently, inflowing total recoverable Cu concentrations are about an order of magnitude lower than those measured in 1985, averaging 24 μg/l since construction began. However, they still exceed the chronic aquatic life standard, which ranges from 8.7 to 17.2 μg/l for the data presented.

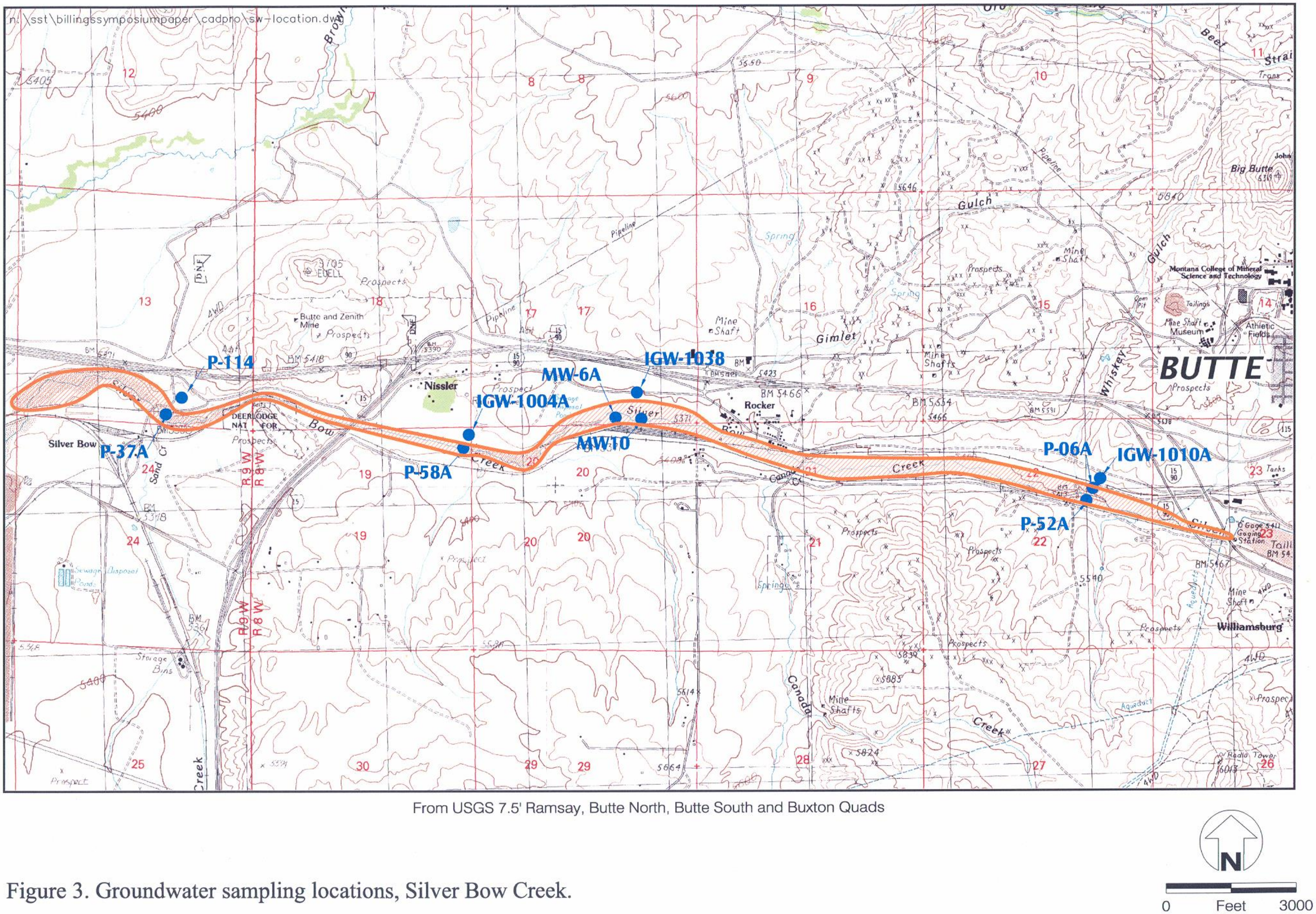


From USGS 7.5' Ramsay, Butte North, Butte South and Buxton Quads

N

0 Feet 5000

Figure 2. Surface water sampling locations, Silver Bow Creek.



From USGS 7.5' Ramsay, Butte North, Butte South and Buxton Quads

Figure 3. Groundwater sampling locations, Silver Bow Creek.

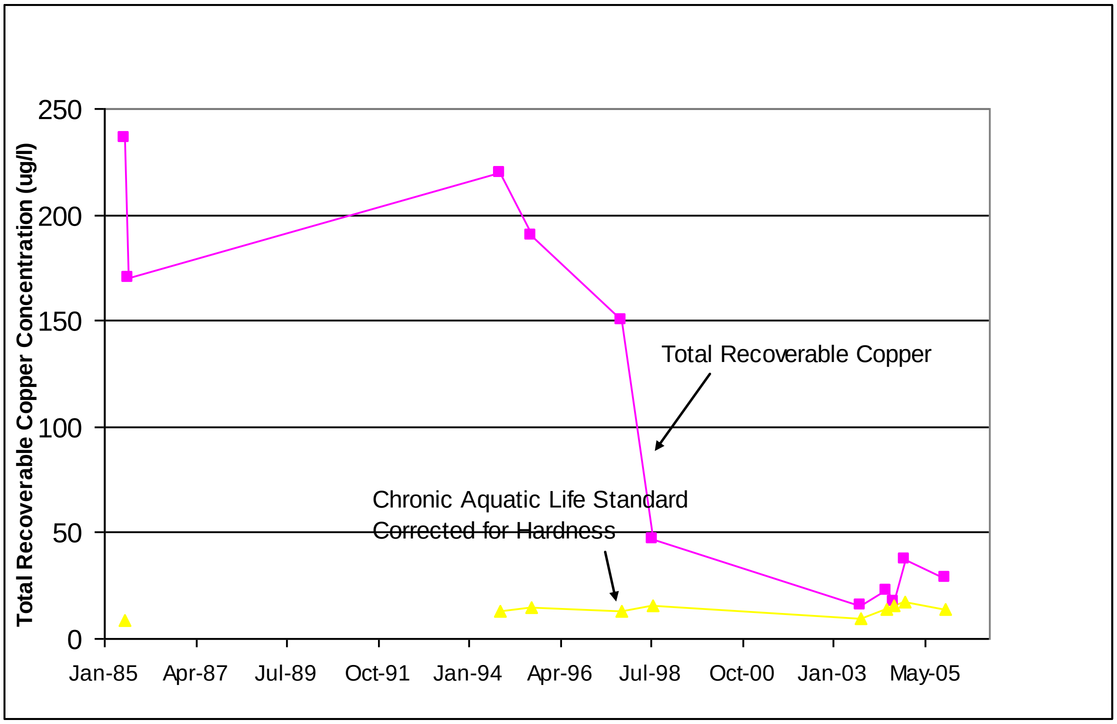


Figure 4. Total recoverable copper concentrations during low flow as a function of time at Station SS-07 (upstream station). Data sources: MultiTech and Stiller, 1986; Dodge *et al.*, 1999; Shields *et al.*, 1996; and MDEQ and MDOJ, 2004, 2005, and 2006.

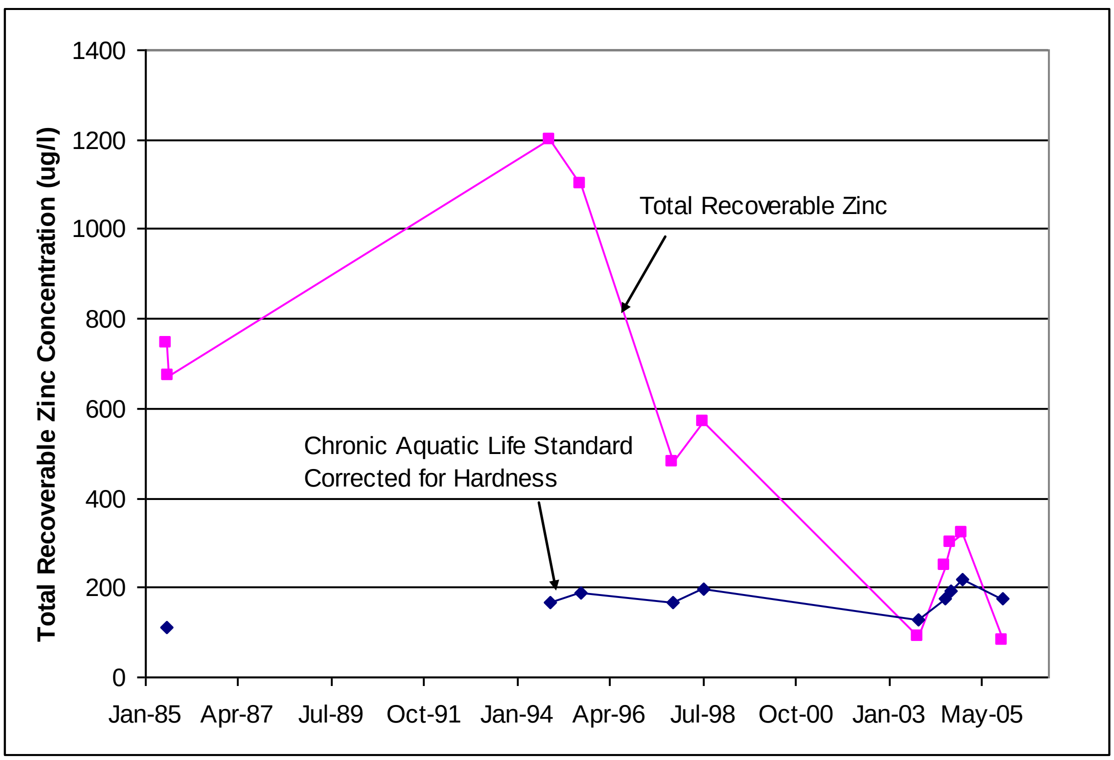


Figure 5. Total recoverable zinc concentrations during low flow as a function of time at Station SS-07 (upstream station). Data sources: MultiTech and Stiller, 1986; Dodge *et al.*, 1999; Shields *et al.*, 1996; and MDEQ and MDOJ, 2004, 2005, and 2006.

Data for total recoverable Zn (Fig. 5) are less well behaved than those for Cu potentially due to varying groundwater discharges upstream of the SSTOU. The average value for total recoverable Zn concentrations for the long-term monitoring period is 208 μg/l, which is generally above the chronic Zn aquatic life standard, which varies from 112 to 220 μg/l for these data. However, Zn levels are close to the standard when compared to data collected prior to remediation. Because Zn is found primarily in the dissolved phase in this stream, dissolved Zn levels are very close to total recoverable levels.

Water Quality within the Remediated Area

Figure 2 indicates three monitoring sites (SS-08A. SS-10A and SS-10B) in addition to SS-07 within the portion of the SSTOU that has been remediated as of late 2005. However, of these sites only Station SS-08A has experienced more than two low flow sampling events since completion of construction in its vicinity. Therefore, only a comparison of Station SS-08A with upstream Station SS-07 has been attempted. Even this comparison is limited by the small data set developed to date: just five low-flow data points since 2003.

Human health standards for As, Cd, and Zn have generally not been exceeded along Silver Bow Creek within the remediated area. Cadmium exceeded the MCL once at Station SS-08A, and lead exceeded the standard at Stations SS-07 and SS-08A during a high flow event in March 2003. Within the remediated area, there does not appear to be any source of these contaminants of concern that can be discerned against the upstream background levels.

Figures 6 and 7 present comparisons between Cu and Zn concentrations measured at SS-08A and SS-07. If the floodplain along the 3.3 km stream reach between SS-07 and SS-08A is discharging ground water of comparable or better quality than the stream water, metals concentrations should not increase between these stations. The mean total copper concentrations in Fig. 6 show a 24% increase between these stations; however, given the large variance in the data, the means are not significantly different at the 90% confidence level using a Student's t-test with paired data. The mean concentrations for dissolved Cu at the two stations are identical (10.2 μg/l) suggesting that, if there is a Cu source in this reach, it is not a groundwater source because the dissolved phase is not increasing.

The total Zn mean concentrations presented in Fig. 7 increase in the downstream direction, and the dissolved Zn mean concentrations decrease. Again, these are not statistically significant changes because the data are quite variable.

Other Water Quality Issues

Metals have been removed in the vicinity of Silver Bow Creek, and the stream is nearing chronic aquatic life standards and should be able to support aquatic life to a greater degree than it could in the past. Data on macroinvertebrates and periphyton indicate significant improvements in these populations. Pollution tolerant fish species have reentered the remediated areas of Silver Bow Creek. However, more sensitive species such as trout, which are found upstream of the site and in German Gulch, a major tributary, have not successfully reentered the remediated area. The lack of better repopulation of the stream by more sensitive species is believed to be due to the introduction of high concentrations of nutrients from the Butte POTW at the upstream end of the site. This discharge may also result in excessive siltation in Silver Bow Creek, which also adversely affects macroinvertebrates, diatoms, and fish. (MDEQ and MDOJ, 2005).

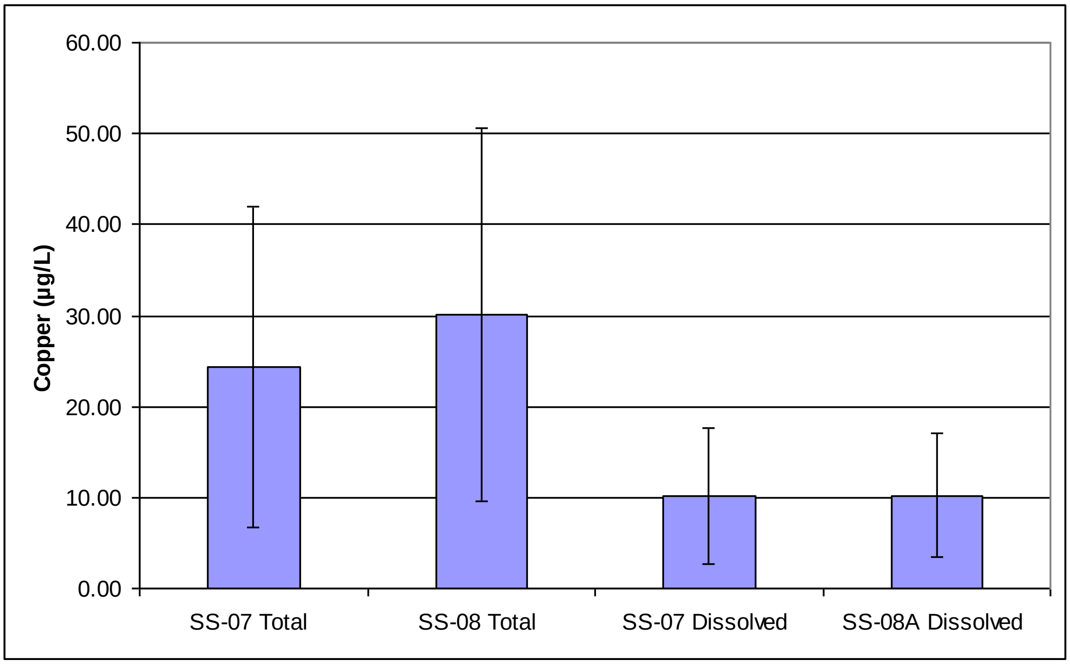


Figure 6. Comparison of mean copper concentrations between Stations SS-07 and SS-08A, low flow sampling. Data source: MDEQ and MDOJ, 2006. Error bars represent plus or minus two standard deviations.

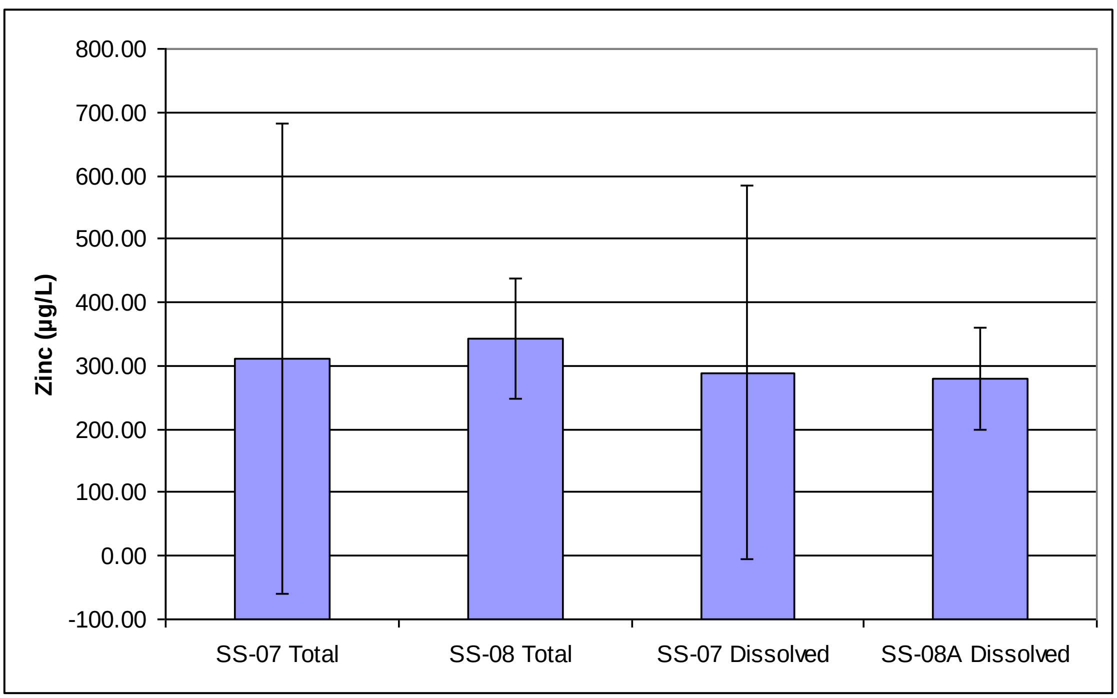


Figure 7. Comparison of mean zinc concentration between Stations SS-07 and SS-08A, low flow sampling. Data source: MDEQ and MDOJ, 2006. Error bars represent plus or minus two standard deviations.

Figure 8 shows the concentrations of dissolved P in Silver Bow Creek. It also shows a typical guideline concentration for avoiding nuisance algae in streams taken from *Quality Criteria for Water, 1986* (USEPA, 1986). Station SS-06A, which is located upstream of the POTW, has dissolved P concentrations close to but slightly higher than the guideline of 50 µg/l. However, beginning with Station SS-07 and the discharge from the POTW, the concentration climbs above 1,000 µg/l and remains significantly above the guideline for the remaining length of Silver Bow Creek. These high nutrient levels allow excessive growth of algae and other vegetation within the stream and may depress oxygen levels at night or during die-off periods. However, daytime measurements of dissolved oxygen have generally not indicated any concentrations below 6 mg/l. The standard for dissolved oxygen for a cold water fishery is a 30-day mean value of at least 6.5 mg/l (MDEQ, 2004).

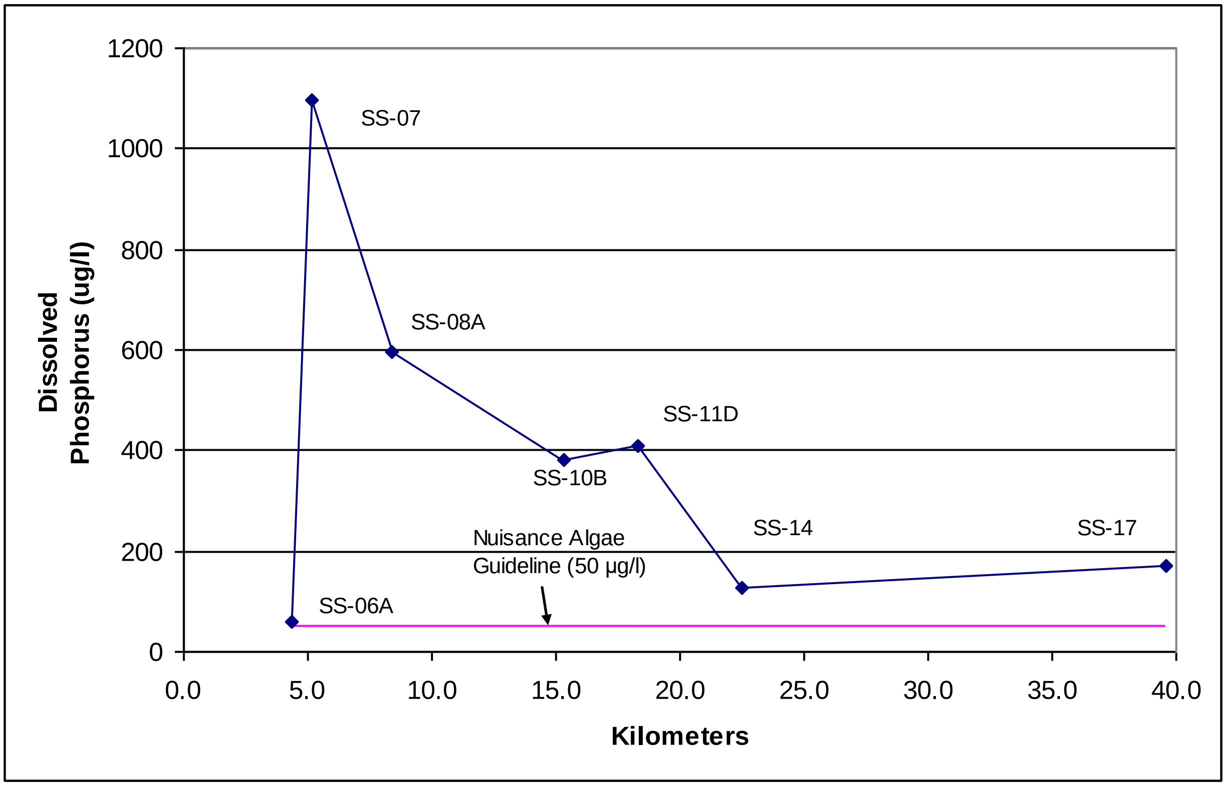


Figure 8. Dissolved phosphorus concentrations in Silver Bow Creek, 2005, June and November data. Data source: MDEQ and MDOJ, 2006.

Groundwater Quality

Surface water data collected to date document improvements in water quality in Silver Bow Creek but that improvement may not be due to remedial activities in Silver Bow Creek. It is possible that remnant contamination in the floodplain, either in solid or aqueous forms, could be affecting surface water quality through the groundwater discharge pathway. However, surface water data indicate that, if this is happening at all, it can not be shown to be significant with data collected to date. Another approach to understanding this potential contaminant source is to look at groundwater data and see how its quality has changed since the cessation of mining and the beginning of construction.

Most of the floodplain wells were removed during construction although a few that were completed below the excavation level were saved and resealed. Therefore, new wells have been constructed in the floodplain but not in the exact same locations and under the differing conditions of the reconstructed floodplain. For example, groundwater flow directions may have reversed because the stream has been relocated on the other side of a particular well location. This makes comparison of pre- and post-remediation groundwater difficult, especially considering the considerable variability of groundwater quality in both pre- and post-remediation monitoring. However, some general conclusions about ground water quality can be drawn from a review of the data.

Of the twelve wells located in the floodplain area, seven are located in remediated areas and the remainder are background wells located outside the floodplain. These wells are P-06A, P-52, MW10, MW-6A, 1GW-1004A. P-58A, and P-37A, and these are the wells on which the following interpretations are based.

Prior to remediation, some of the floodplain wells recorded As and Cd concentrations in excess of human health standards (Titan, 1994). Replacement wells in the floodplain show similar occurrences of these parameters both in frequency and magnitude. Copper, which was frequently detected in floodplain wells at levels that would be a concern to aquatic life (based on surface water standards) prior to remediation, only exceeds the chronic aquatic life standard in well P-06A in post-remediation monitoring.. Zinc has been and is present at relatively high levels (compared to the surface water aquatic life standard) in some pre- and post-remediation wells. Zinc, when present above the standard, is typically over 1,000 μg/l indicating it may be a continuing source to surface water. However, there is some indication that Zn concentrations are gradually decreasing in time. At well P-52A, which is the one of two wells constructed in an area that has been remediated for more than three years, Zn concentrations increased in the first few years after construction (2001 to 2003) but since have decreased 42% as shown in Fig. 9. This may be an indication that Zn is flushing from the groundwater system and no longer has a significant mine waste source to maintain its presence in the long-term. Additional data from more wells will be necessary to determine if this is a general occurrence or a local phenomenon.

Conclusions

Water quality monitoring data collected from 2003 through 2005 at the SSTOU indicate progress has been made towards attainment of remedial action objectives for surface water. Data also indicate that remediation of upstream sources is progressing, one of the conditions for attainment of surface water objectives. Groundwater goals are being partially met although the limited amount of groundwater data available to date and its high variability prevent definitive statements about the progress towards groundwater quality objectives.

Historic and recent surface water data collected at SS-07, the upstream measurement point for the operable unit, demonstrate considerable improvement in water quality in the upstream watershed since most mining ceased in Butte in 1982. Much of this improvement occurred prior to remedial activities in the SSTOU. Total recoverable copper concentrations have decreased about one order of magnitude and a smaller but substantial decrease occurred for total recoverable Zn.

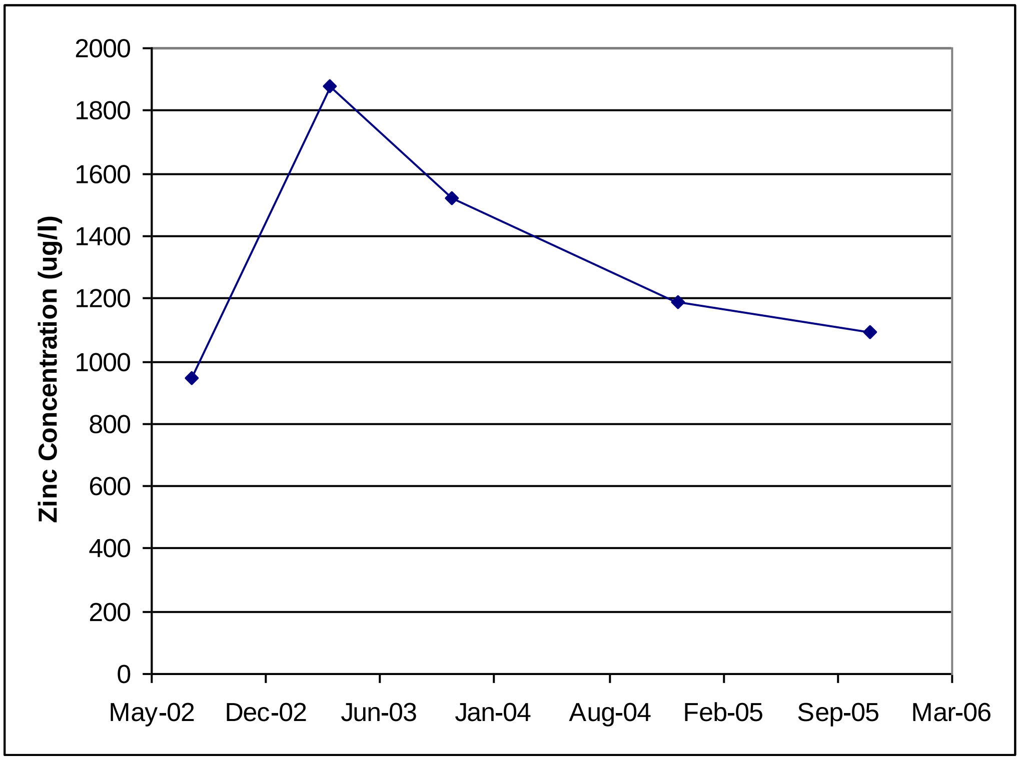


Figure 9. Zinc concentrations over time at well P-52A. Data Source: MDEQ and MDOJ, 2006.

Monitoring data collected since 2003 indicate that inflowing total recoverable copper concentrations do not yet meet chronic aquatic life standards; however, they are much closer to standards than data acquired prior to remediation. Total Zn concentrations also generally fail to meet the aquatic life standard at the upstream station although considerable progress towards this objective has occurred.

Effects of remedial activities within the SSTOU are harder to quantify than upstream sources because of the masking effects of the upstream sources and the limited data collected to date. A further complicating factor in this analysis is the variability of the Zn data. Dissolved Cu concentrations do not appear to be increasing within the first 3.3 km of the remediated area. Although total Cu concentrations appear to be increasing within this reach, this result is not statistically significant at this time. Total Zn concentrations within this reach appear to be increasing while dissolved Zn concentrations are decreasing. Again, these results are preliminary and not statistically significant.

Metals concentrations are approaching levels that should permit improvement in aquatic life health and populations. Some improvements in macroinvertebrate and algal populations have been noted, and pollution tolerant fish have re-colonized remediated portions of Silver Bow Creek. However, improvements have been limited, most likely because of factors outside the scope of mine waste remediation. The Butte POTW, which discharges immediately upstream of the SSTOU, provides a large nutrient load that causes excessive algal and plant growth in Silver Bow Creek. Phosphorus levels are well above concentrations that can cause nuisance algal growth. The plant growth can result in depletion of oxygen, which intern effects sensitive aquatic species such as trout.

Groundwater data are limited at this time and large spatial variations obscure quantitative interpretations; however, some general inferences can be attempted. Arsenic and Cd persist in groundwater in the remediated areas with exceedences of human health standards occurring about as frequently and with the same magnitude as prior to remediation. Copper concentrations no longer exceed the surface water aquatic life standard in most remediated areas, which is an improvement from pre-remediation conditions. Zinc concentrations continue to be quite elevated, above 1,000 μg/l in some locations in the floodplain, and could be increasing surface water concentrations of this constituent. However, preliminary surface water sampling results indicate that dissolved Zn is not increasing in this stream reach, contradicting this hypothesis. One encouraging interpretation of Zn data is that, at one well, Zn concentrations have decreased 42% since remediation of the surrounding area. This could be an indication that Zn is slowly being released from the floodplain aquifer, and that the mine waste that is its presumed original source is removed sufficiently to allow this decrease. Further data at more wells are needed before this interpretation can be substantiated.

Acknowledgements

The authors acknowledge the support of Joel Chavez and Shellie Haaland at the Mine Waste Cleanup Bureau of MDEQ and Greg Mullen at the Natural Resource Damage Program of MDOJ for administering the work on which this paper is based. We also thank Peter Norbeck of the Montana Bureau of Mines and Geology for his many hours in the field data collection and assembly of data reports for MDEQ and MDOJ.

Literature Cited

Dodge, K.A., M.I. Hornberger, R. M. Blouse. 1999. Water-quality, bed-sediment, and biological data (October 1997 through September 1998) and statistical summaries of data for streams in the Upper Clark Fork River Basin, Montana. Open-File Report 99-251. U. S. Geological Survey, Denver, CO.

Montana Department of Environmental Quality (MDEQ) 2004. Circular WQB-7, Montana numeric water quality standards.

Montana Department of Environmental Quality (MDEQ) & United States Environmental Protection Agency (EPA). 1995. Record of Decision, Streamside Tailings Operable Unit of the Silver Bow Creek/Butte Area National Priorities List Site. Helena: Environmental Remediation Division.

Montana Department of Environmental Quality and Montana Department of Justice. 2004. Monitoring report for 2003, Streamside Tailings Operable Unit, Silver Bow Creek/Butte Area NPL Site.

Montana Department of Environmental Quality and Montana Department of Justice. 2005. Monitoring report for 2004, Streamside Tailings Operable Unit, Silver Bow Creek/Butte Area NPL Site. May 2005.

Montana Department of Environmental Quality and Montana Department of Justice. 2006. Monitoring report for 2005, Streamside Tailings Operable Unit, Silver Bow Creek/Butte Area NPL Site. March 2006.

Montana Department of Environmental Quality and Natural Resource Damage Program. 2004. Comprehensive long-term monitoring plan for Silver Bow Creek, Streamside Tailings Operable Unit.

MultiTech and Stiller and Associates. 1986. Silver Bow Creek Remedial Investigation draft report, surface-water and point-source investigations. Prepared for Montana Department of Health and Environmental Sciences.

Titan Environmental. 1995. Silver Bow Creek/Butte Area NPL Site, Streamside Tailings Operable Unit RI/FW, draft Remedial Investigation report. Table 4-16. Prepared for Atlantic Richfield Company, Anaconda, Montana.

Shields, R. R., M. K. White, P.B. Ladd and C. L. Chambers. 1996. Water Resources Data, Montana, Water Year 1995. U.S. Geological Survey (USGS) Water–Data Report MT-95-1.

United States Environmental Protection Agency (USEPA) 1986. Quality criteria for water, 1986. EPA 440/5-86-001.