Summary and Conclusions from Investigation of the Effects of Historical Mining in the Boulder River Watershed, Jefferson County, Montana

By U.S. Geological Survey

Chapter A of

Integrated Investigations of Environmental Effects of Historical Mining in the Basin and Boulder Mining Districts, Boulder River Watershed, Jefferson County, Montana

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Professional Paper 1652–A

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

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Introduction

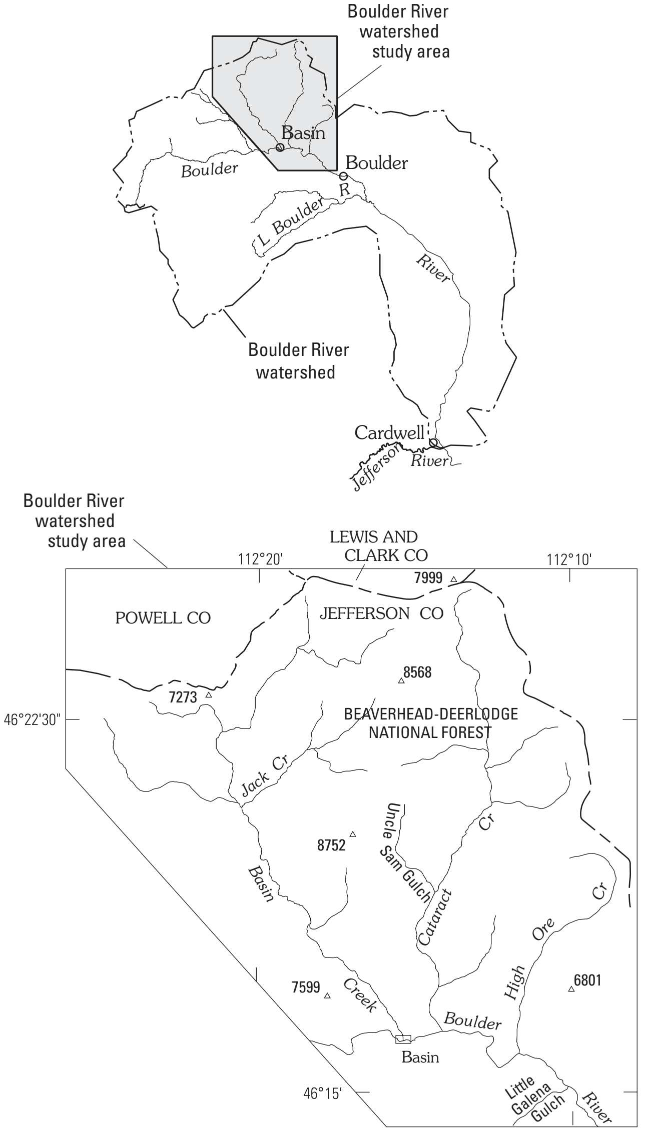
The Boulder River watershed is one of many watersheds in the western United States where historical mining has left a legacy of acid mine drainage and elevated concentrations of potentially toxic trace elements. Abandoned mine lands commonly are located on or affect Federal land. Cleaning up these Federal lands will require substantial investment of resources. As part of a cooperative effort with Federal land-management agencies, the U.S. Geological Survey implemented an Abandoned Mine Lands Initiative in 1997. The goal of the initiative was to use the watershed approach to develop a strategy for gathering and communicating the scientific information needed to formulate effective and cost-efficient remediation of affected lands in a watershed. The watershed approach is based on the premise that contaminated sites that have the most profound effect on water and ecosystem quality within an entire watershed should be identified, characterized, and ranked for remediation.

The watershed approach provides an effective means to evaluate the overall status of affected resources and helps to focus remediation at sites where the most benefit will be gained in the watershed. Such a large-scale approach can result in the collection of extensive information on the geology and geochemistry of rocks and sediment, the hydrology and water chemistry of streams and ground water, and the diversity and health of aquatic and terrestrial organisms. During the assessment of the Boulder River watershed, we inventoried historical mines, defined geological conditions, assessed fish habitat, collected and chemically analyzed hundreds of water and sediment samples, conducted toxicity tests, analyzed fish tissue and indicators of physiological malfunction, examined invertebrates and biofilm, and defined hydrological regimes. Land- and resource-management agencies are faced with evaluating risks associated with thousands of potentially harmful mine sites, and this level of effort is not always feasible for every affected watershed. The detailed work described in this report can help Federal land-management agencies decide which characterization efforts would be most useful in characterization of other affected watersheds.

Study Area

The Boulder River watershed is located near the town of Basin in southwestern Montana (fig. 1). Our study area includes Basin, Cataract, and High Ore Creeks and the short reach of the Boulder River into which these tributaries flow. The watershed study area does not include the large upstream drainage of the Boulder River or the downstream reach of the Boulder River between Little Galena Gulch and the Jefferson River, even though the effects of historical mining are apparent through this reach. Many of the areas affected by historical mining in the Boulder River watershed are within the Beaverhead-Deerlodge National Forest or on land managed by the Bureau of Land Management (Church, Nimick, and others, this volume, Chapter B).

The Boulder River watershed study area encompasses the Boulder and Basin mining districts. Mining of ore deposits containing base metals (copper, lead, and zinc) and precious metals (primarily silver and some gold) started in the early 1860s. The main period of mining was from about 1880 to 1907, and peak production occurred during 1895–1903. Mining had generally ceased by the 1940s. Ore deposits were found primarily in polymetallic quartz-vein deposits, which are thin (less than 50 feet wide) and occur within granitic host rocks, which are widespread in the watershed (O'Neill and others, this volume, Chapter D1). More than 140 inactive mines, such as the Eva May mine (fig. 2), and mining-related sites lie in the Boulder River watershed study area (Martin, this volume, Chapter D3). These sites include mines, where ore was recovered; prospects, where rock was removed in search of ore deposits; and mills, where ore was crushed and processed to concentrate the valuable metals.



Base from U.S. Geological Survey
1:100,000 Butte North, 1994

Figure 1. Location of Boulder River watershed and watershed study area, Montana. Elevations are in feet.

Environmental Effects

During historical mining, mine waste and mill tailings were discharged with little regard for any potential effect on the landscape or streams (fig. 3). Although most mining in the Boulder River watershed occurred nearly a century or more ago, effects on the environment are still present today. Physical manifestations of these effects were evident locally as land disturbances, unvegetated areas, and colorful mine drainage near mine and mill sites. At a watershed scale, these effects occurred primarily in streams, where aquatic organisms are affected downstream from the historical mine and mill sites.

In some mining districts, trace-element concentrations in soil, streambed sediment, stream water, and aquatic organisms were elevated long before any mining occurred because mineralized rocks were weathering and contributing acid and trace elements to streams. However, in the Boulder River watershed, this was not the case (Nimick and Cleasby, this volume, Chapter D5; Church, Unruh, and others, this volume, Chapter D8). At present, acidic and trace-element-rich water within the study area is associated with

- mine adits that opened and exposed the quartz-vein deposits and channeled subsurface water to the surface, or
- dumps containing mineralized mine waste or mill tailings.

Prior to mine development, the quartz-vein deposits likely produced small amounts of acid, which were neutralized by the moderate acid-neutralizing potential contained in many of the rocks in the watershed (McCafferty and others, this volume, Chapter D2).

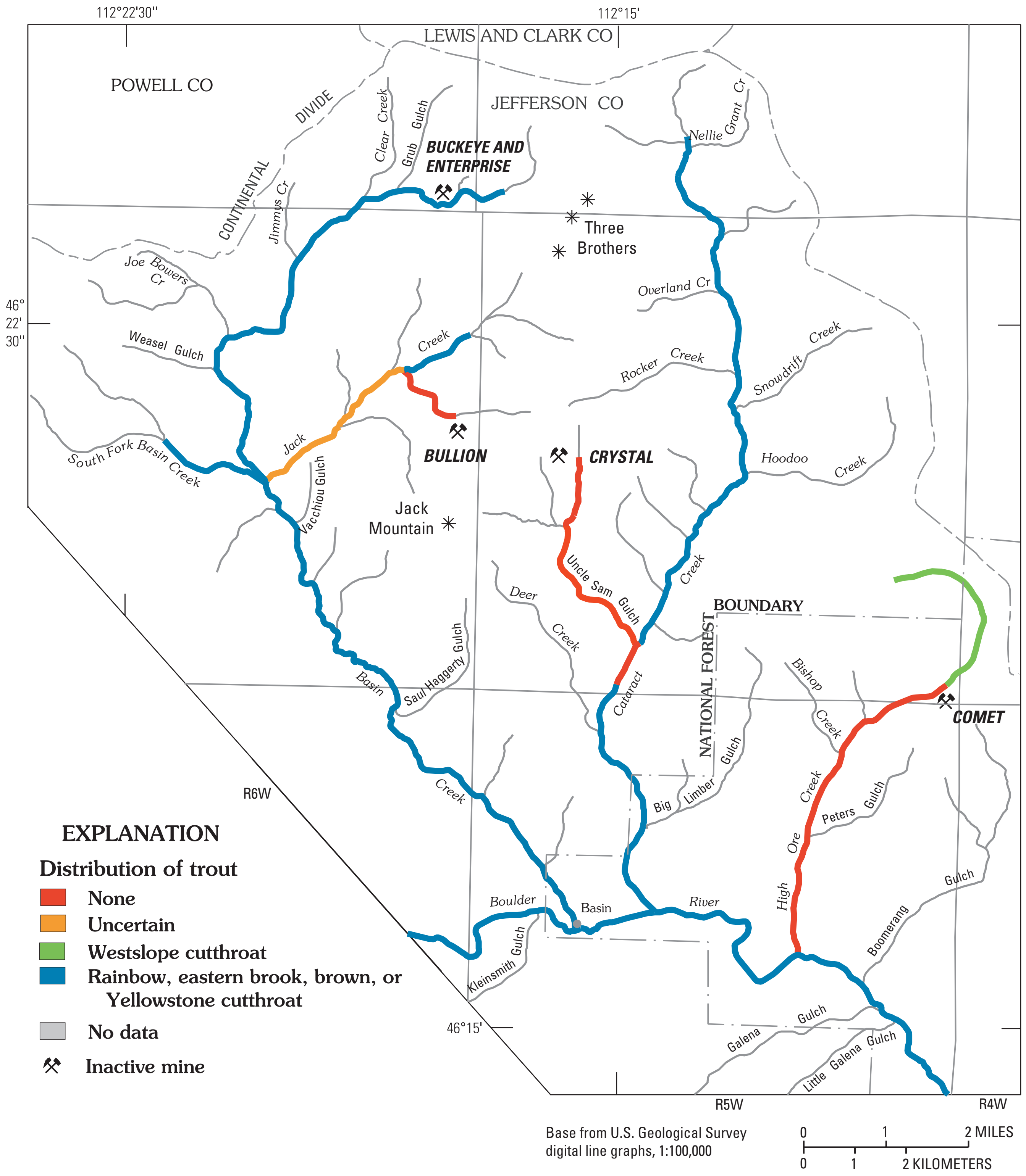
The most important environmental effect of historical mining in the watershed was impairment of aquatic life in streams. All species of fish were absent in stream reaches downstream from a few large mines because of the high trace-element concentrations caused by acid mine drainage (fig. 4). Farther downstream, trout were found in these highly contaminated reaches, but exposure to high trace-element concentrations affected the health of these fish. The presence of dissolved trace elements in the water column was shown to directly affect fish. Similarly, the presence of toxic trace elements in streambed sediment was shown to affect the aquatic food chain of fish and cause health effects through dietary exposure in trout (Farag and others, this volume, Chapter D10).

Ongoing drainage from historical mine sites has degraded the quality of water in some stream reaches. In most streams, pH values were near-neutral to slightly alkaline, but a few small streams were acidic because of drainage from mine adits. Concentrations of cadmium, copper, lead, and zinc, which are the trace elements that most strongly affect aquatic organisms in watershed streams, commonly exceeded chronic aquatic-life standards established by the U.S. Environmental Protection Agency. The highest concentrations (fig. 5, zinc as example) were in streams downstream from three large inactive mines: Crystal mine in a tributary to Cataract Creek, Comet mine in High Ore Creek, and Bullion mine in a tributary to Jack Creek (Nimick and Cleasby, this volume).

Trace elements derived from mine waste and acidic drainage typically accumulate in streambed sediment. Similar to the pattern found for water, the highest concentrations of trace elements in streambed sediment occurred immediately downstream from the Comet, Crystal, and Bullion mines. For example, figure 6 shows the pattern of concentrations of zinc, which is one of the trace elements that strongly affect aquatic organisms. All major tributary basins (Basin, Jack, Cataract, and High Ore Creeks and Uncle Sam Gulch) and the Boulder River downstream from Basin Creek had concentrations of arsenic, copper, and lead that exceeded the apparent effects threshold for aquatic organisms. These effects were traced in the Boulder River for a distance of 55 miles downstream to the confluence with the Jefferson River (Church, Unruh, and others, this volume).

Figure 2. Eva May mine in Cataract Creek valley, September 1998. Photograph by D.A. Nimick.

Figure 3. Mill tailings in High Ore Creek valley at Comet mine site, October 1996. Photograph by D.A. Nimick.



Base from U.S. Geological Survey digital line graphs, 1:100,000

Figure 4. Estimated distribution of trout in study area prior to start of large-scale remediation activities.

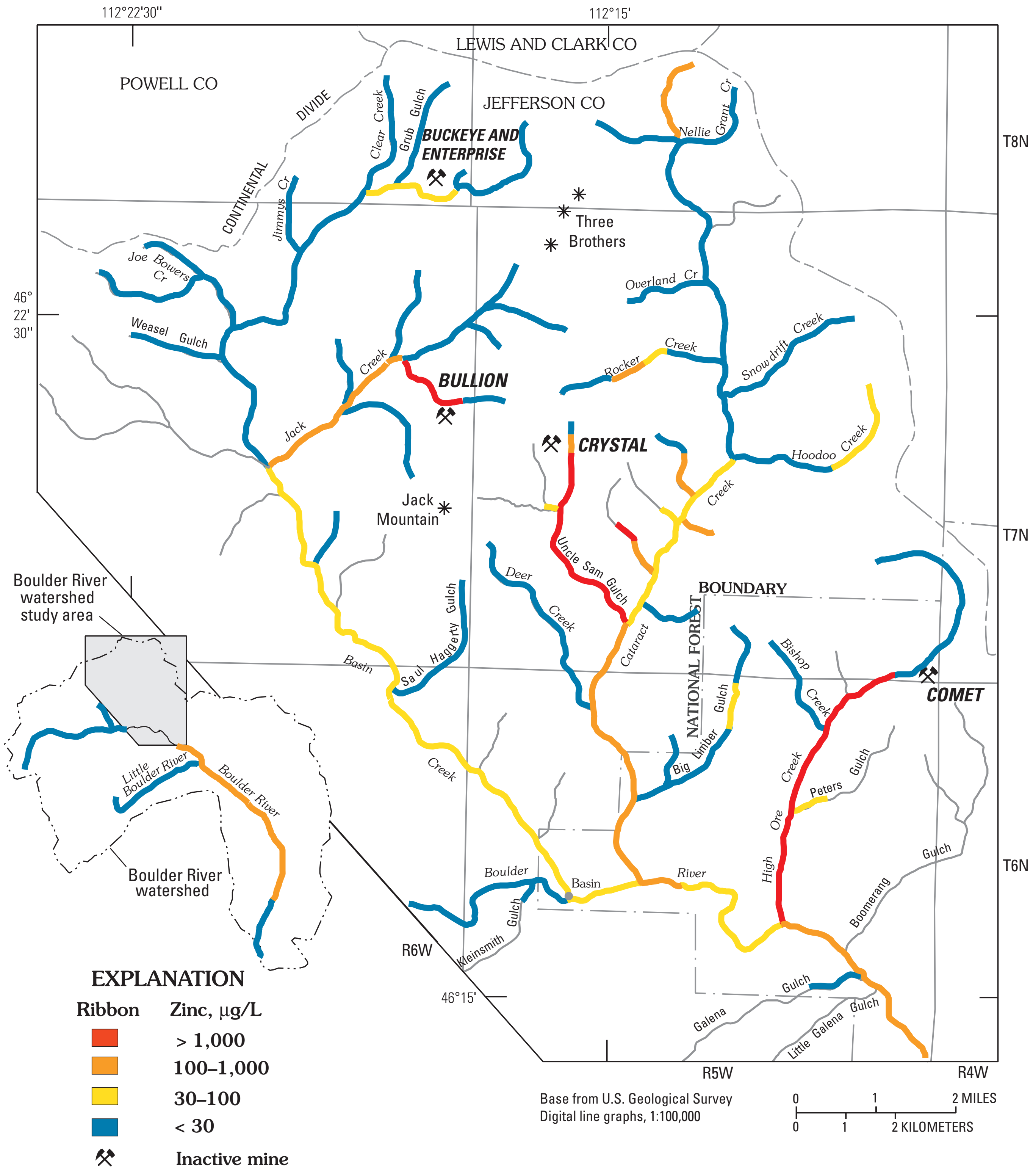


Figure 5. Approximate concentrations of dissolved zinc during low streamflow conditions, 1991–2000.

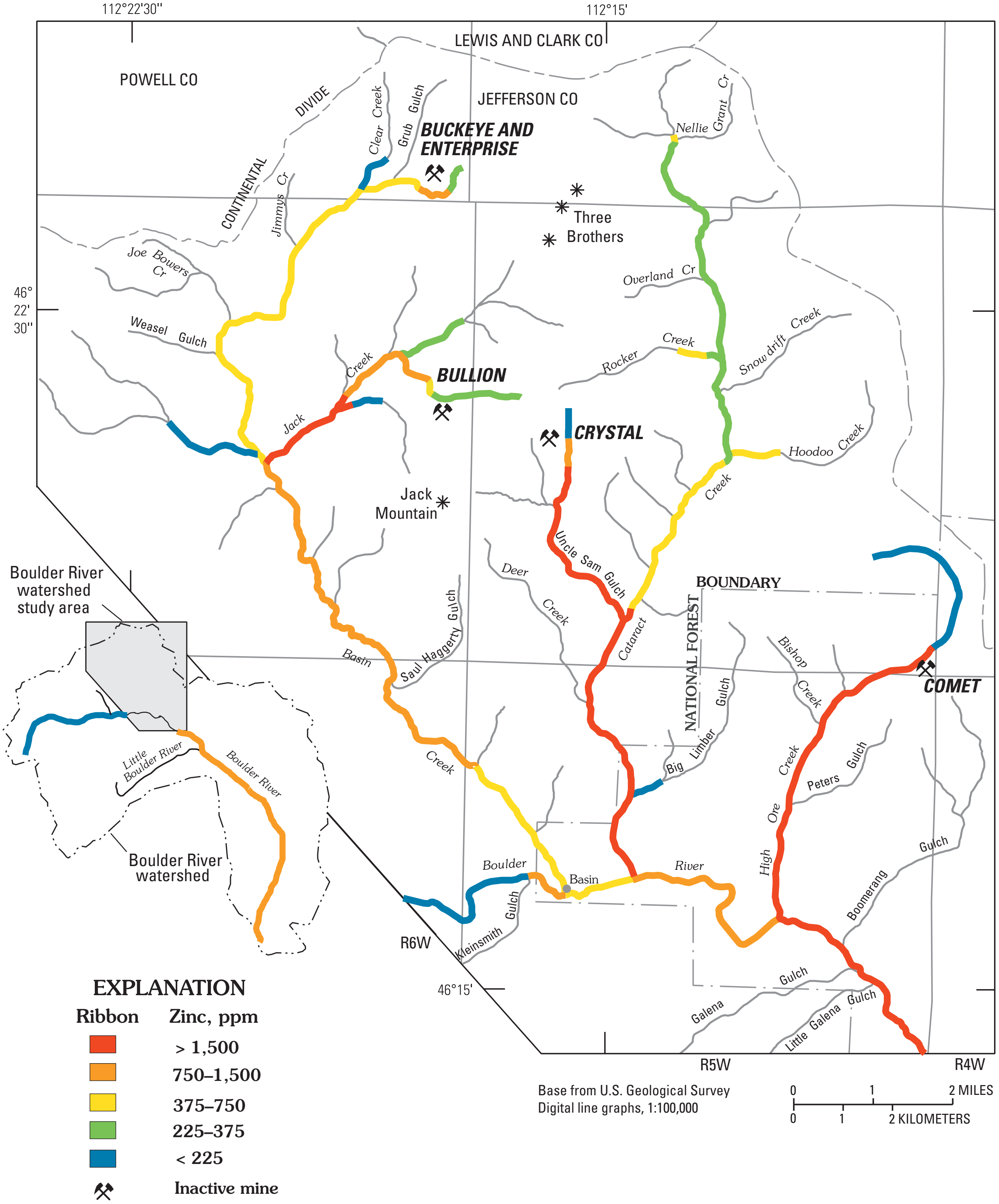


Figure 6. Concentrations of zinc in streambed sediment.

Sources of Trace Elements

Land-management agencies are charged with the task of remediating inactive mines in the Boulder River watershed. Numerous inactive mine sites contribute trace elements to streams in the study area. Therefore, the challenge facing the agencies is one of source determination. The highest concentrations of cadmium, copper, lead, and zinc in water, streambed sediment, and aquatic organisms occur just downstream from the Crystal, Bullion, and Comet mines. Because the concentrations below these mine sites are so high, the three sites clearly are the major sources of trace elements in the watershed. However, the main delivery mechanism for trace elements is not the same at each mine site. Study of streambed sediment demonstrated that much of the contaminated sediment in the Boulder River came from High Ore Creek (Church, Unruh, and others, this volume). The dam holding the mill tailings deposited in the High Ore Creek valley from the Comet mill (fig. 3) has been breached and the tailings extensively eroded and transported downstream into the Boulder River (Gelinas and Tupling, this volume, Chapter E2). Study of water quality demonstrated that Cataract and Basin Creeks contributed more than 80 percent of the dissolved cadmium and more than 50 percent of the dissolved copper and zinc to the Boulder River (Nimick and Cleasby, this volume). These and other data indicated that the Crystal mine (fig. 7) in Uncle Sam Gulch and Bullion mine (fig. 8) in a tributary to Jack Creek were the largest contributors of dissolved trace elements in the watershed (Kimball and others, this volume, Chapter D6). Based on detailed metal-loading studies, discharge from one or two adits was by far the most significant source of trace elements at each of these mine sites.

The overall conclusion from our analysis of trace-element sources is that three large mines appear to be the most important sources of trace elements in the Boulder River watershed (Finger, Farag, and others, this volume, Chapter C). Smaller loadings occur from some other sites, such as the Buckeye mine and mill and Enterprise mine in upper Basin Creek and the Hattie Ferguson, Boulder Chief, Ida M., and Eva May mine sites along Cataract Creek.

Potential for Restoration

Many of the mine sites identified as contributors of trace elements have been targeted for remediation by Federal land-management agencies. Large-scale remediation efforts began in 1997 at the Comet mine in High Ore Creek. The Montana Department of Environmental Quality removed the large quantity of mill tailings (about 500,000 yd^3 or about 750,000 tons) that had been impounded in the valley (fig. 3). In 1999, the Bureau of Land Management began removal and in-place treatment of tailings that had been washed downstream by floods and deposited on the High Ore Creek flood plain. The United States Department of Agriculture (USDA) Forest Service began remediation efforts at the Buckeye and Enterprise mine site in 2000 (fig. 9) and at the Bullion mine in 2002. Part of the earlier planning efforts by USDA Forest Service had been location of suitable repository sites for safe storage of mine waste and mill tailings removed from historical mine sites. The U.S. Environmental Protection Agency (USEPA) has recently taken over the open pit at the recently closed Basin Creek mine and converted it to a regional repository (Smith and others, this volume, Chapter E3) for mine wastes in the Boulder River and other neighboring watersheds. Basin and Cataract Creeks were added to the National Priority List (Superfund) in 1999. Soon afterwards, USEPA began removing mine and mill waste within the town of Basin, and in 2002, began cleanup work at the Crystal mine. However, to date (2003), no work has been initiated to remediate acid drainage coming from mine adits such as those at the Crystal, Bullion, or Enterprise mines.

Monitoring is an important tool for evaluating the effectiveness of remediation efforts and assessing the extent of ecological restoration. Without collecting and analyzing comprehensive monitoring data, land managers cannot objectively evaluate how successfully a remedial action performs and whether remediation goals have been met. In the Boulder basin, the primary focus of the watershed approach has been on the identification of factors affecting the health and potential for recovery of the aquatic community and its supporting habitat. Ongoing monitoring of High Ore Creek has shown that remediation has substantially reduced dissolved zinc concentrations, but that dissolved arsenic concentrations have increased slightly, probably because the imported material used to amend mine wastes increases the solubility of arsenic (fig. 10). Monitoring has also recorded improvements in High Ore Creek after remediation (Gelinas and Tupling, this volume). Continued improvements in water quality and reduced sediment loading should result in improved survival, growth, and reproduction in the fish community. Future monitoring that incorporates biological and chemical measurements will be able to demonstrate the degree of success of all cleanup projects in the watershed. However, the success of ecological restoration will be determined not only by the degree of improvement achieved in the aquatic environment, but also by the recovery of associated flood-plain and riparian habitat within the watershed. Although not specifically addressed in this volume, the issues of revegetation of the riparian area and stabilization of the flood plain are important to land managers in the overall environmental restoration of an area. Monitoring the improvement of flood-plain and riparian soils after the physical removal of tailings can be accomplished by use of both geochemical characterization and soil toxicity assessments. Such monitoring can determine the potential for successful revegetation of an area. In addition, monitoring the health and recovery of wildlife communities dependent on this terrestrial habitat can provide valuable information on ecological restoration. Although economic limitations often result in the reduction or elimination of a monitoring program following cleanup, only through a well-designed and rigorously implemented monitoring program can the success of a remedial effort be validated (Finger, Church, and Nimick, this volume, Chapter F).

Figure 7. Crystal mine, June 1997. Acidic discharge drains from adit (out of view near lower right of photograph) to Uncle Sam Gulch on far left. Photograph by D.A. Nimick.

Figure 8. Bullion mine, August 1998. Acidic drainage flows downhill from mine adit behind mine-waste piles in top center of photograph. Photograph by D.A. Nimick.

Figure 9. Buckeye flotation mill site, upper Basin Creek, before (top) and after (bottom) remediation. Photographs by Ray TeSoro.

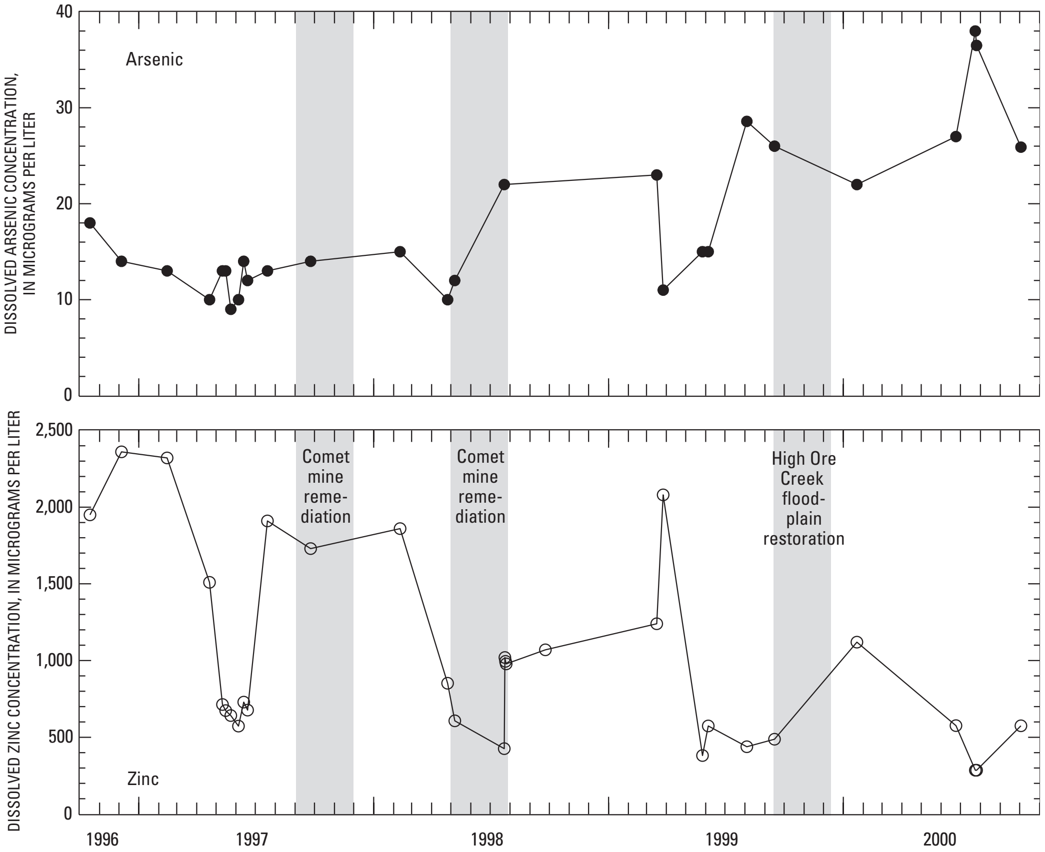


Figure 10. Dissolved arsenic (top) and zinc (bottom) concentrations at mouth of High Ore Creek, 1996–2000.