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Injury to aquatic resources caused by metals in Montana's Clark Fork River basin: historic perspective and overview[1]

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Mining wastes in the Clark Fork River drainage

The community of Butte is located in west-central Montana on the west slope of the continental divide. Copper mining became a viable enterprise in the Butte area about 1882, fueled by the increased demand for copper wire created by the recently invented telephone and electric light (Johnson and Schmidt 1988). Milling, smelting, and ore-concentrating facilities were numerous in and around Butte and many were located along the banks of Silver Bow Creek, the principal tributary to the upper Clark Fork River. These facilities produced a variety of metals-laden waste materials including waste rock, mine tailings, smelter slag, flue dust, and process waters.

Many of these wastes were discharged directly or found their way into Silver Bow Creek and subsequently were carried downstream and distributed throughout the drainage-way. Consequently the entire Silver Bow Creek floodplain is contaminated with a fluvially deposited mixture of sediments, tailings, and other mine wastes. Additionally, the upper 200 km of the Clark Fork River are affected by mining wastes present in the stream bed, banks, and floodplain. Andrews (1987) estimated that 99.8 billion kg of mining and smelting wastes were discharged into Silver Bow Creek prior to 1959. Moore and Luoma (1990) estimated that 2–3 million m^3 of contaminated sediments are present in the floodplain. Consequently, copper, zinc, cadmium, lead, arsenic, and iron are all at elevated concentrations in stream-bed sediments of Silver Bow Creek and the Clark Fork River (Brook and Moore 1988; Essig and Moore 1995).

Over the first half of this century the mining industry attempted to reduce the movement of mine wastes into the Clark Fork River. A series of three industrial treatment ponds, the Warm Springs ponds, intercept Silver Bow Creek approximately 40 km downstream from Butte. The first and downstream-most treatment pond (pond 1) was built in 1911, the second (pond 2) was constructed in 1916, and the third (pond 3) was completed in 1958 (Johnson and Schmidt 1988). Liming was initiated at the inflow to the ponds in 1959 to aid in the complexation and precipitation of metals originating from upstream sources.

Although the ponds have improved downstream water quality, conditions remain degraded. Water column concentrations of cadmium, copper, lead, and zinc in Silver Bow Creek and the Clark Fork River continue to exceed ambient water quality criteria for the protection of aquatic life (Kerr 1995); copper and zinc concentrations in Silver Bow Creek continuously exceed both acute and chronic criteria. Copper most frequently exceeds criteria in the Clark Fork (Kerr 1995) and is the most toxicologically significant because it is present at the highest concentrations relative to its toxicity (Phillips 1985).

Because of the extensive contamination in the drainage, the U.S. Environmental Protection Agency, in 1983, placed Silver Bow Creek and the upper Clark Fork River on the National Priority List for hazardous waste clean-up sites. Such sites have subsequently become known as Superfund sites and are administered under the Comprehensive Environmental Response, Compensation, and Liability Act. Clean up of the site commenced in the late 1980s and is ongoing. Activities to date have included floodplain tailings removal, in-place liming of tailings, revegetation, improved liming facilities, and increased treatment capacity at the Warm Springs ponds. We anticipate that remediation activities will continue for at least an additional 20 years.

Fisheries and fish kills

Fish surveys dating back to the late 1800s indicated that toxic mine wastes prevented fish from inhabiting Silver Bow Creek and the upper Clark Fork River. Evermann (1891) reported that "water [in Silver Bow Creek] has the consistency of thick soup, made so by the tailings that it receives from the mills at Butte... throughout the entire length of [the Clark Fork River] the water is full of this solid matter in suspension. The amount of this [material] is considerable, and of course proves fatal to all kinds of fish life. We seined the river very thoroughly in the vicinity of Deer Lodge and did not find any fish whatever."

An electrofishing survey of the Clark Fork near Garrison in 1950 yielded no fish (file memo, Montana Department

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[1] This is part of a collective group of publications on the Clark Fork River, Montana.

of Fish, Wildlife and Parks, 1420 East Sixth Avenue, Helena, MT 59620-0701). More recently, the Columbia Basin Interagency Steering Committee (1957) concluded that "...from the mouth of Rock Creek to its headwaters the Clark Fork is so heavily polluted by mine wastes that it supports no fishery and any type of development other than pollution abatement would be useless."

With the initiation of liming at the Warm Springs ponds in 1959 a fishery began to establish itself in the upper Clark Fork River. Bob Averett, a biologist with the Montana Department of Fish and Game, found dead fish near the mouth of Rock Creek in 1959 after a "yellow discharge" reportedly emanated from the Warm Springs ponds; throughout the 1960s and early 1970s reports of red or yellow water in the river were frequent (file memos, Montana Department of Fish, Wildlife and Parks). Floods, failure of the Warm Springs ponds dikes, labor strikes that interrupted the liming operation, and heavy winds that resuspended metals precipitates from the bottom of the Warm Springs ponds all contributed to intervals of high concentrations of metals in the Clark Fork River (Johnson and Schmidt 1988). For example, on November 20, 1968, a mining company representative measured 4.0 mg/L copper and 32.5 mg/L zinc in the Clark Fork River below the Warm Springs ponds (file memo, Montana Department of Fish, Wildlife and Parks), concentrations that are greater than 100 times the ambient water quality criteria for protection of aquatic life (U.S. Environmental Protection Agency 1985*a*, 1985*b*).

The U.S. Environmental Protection Agency (1971) concluded that the bottom of the river to Deer Lodge was cemented because of precipitation of gypsum and metallic hydroxides and that there were essentially no fish in the river upstream of Deer Lodge. Metals-contaminated waste discharged from the Warm Springs ponds was implicated as the cause of adverse water quality and bottom conditions.

Between 1972 and 1975 a new waste treatment system at Butte became operational and greatly reduced loadings of metals to Silver Bow Creek and the Warm Springs ponds. The ensuing improvements in water quality of the Clark Fork River resulted in successful invasion and establishment of brown trout (*Salmo trutta*). However, other than for a short distance immediately downstream of the Warm Springs ponds, numbers remain lower than in reference streams having similar habitat (Hillman et al. 1995). Additionally, Silver Bow Creek remains devoid of fish. Hillman et al. (1995) concluded that the absence of fish from Silver Bow Creek and reduced fish numbers in the Clark Fork River were due to the occurrence of metals originating from mine wastes, particularly copper and zinc in sediments, surface waters, and macroinvertebrates.

Fish kills occurred periodically in the Clark Fork River between 1959 and 1975 (file memos, Montana Department of Fish, Wildlife and Parks); however, they were generally of small magnitude because fish populations were low owing to poor water quality. Moreover, the water was so off color that dead fish were difficult to observe. After 1975, the improved waste treatment facilities at Butte and the attendant improvements in water quality of the Clark Fork River downstream of the ponds allowed river trout populations to expand. However, fish kills continued to occur frequently throughout the 1980s and early 1990s, some involving several thousand trout and affecting many kilometres of river. Recent fish kills were caused by thunderstorms that washed metals salts, which had accumulated on the surface of streamside tailings deposits, into the river.

Kills that have been monitored are typified by a sudden drop in pH and alkalinity and a concurrent increase in metals concentrations. Kills were documented in 1983, 1984, 1985, 1988, 1989, 1990, and 1991 (file memos, Montana Department of Fish, Wildlife and Parks).

Instream toxicity tests

Several investigators have evaluated the toxicity of river water in the Clark Fork drainage. In 1960, biologist Bob Averett held rainbow trout (*Onchorhynchus mykiss*) in cages upstream and downstream of Milltown Reservoir; all fish were dead in less than 3 days and the gills were coated with an orange precipitate (file memos, Montana Department of Fish, Wildlife and Parks). Bionomics (1979) tested the toxicity of water discharged from Warm Springs pond 2 to eggs and fry of rainbow trout: survival of adults and hatchability were not reduced by exposure to pond water but all fry, including those exposed to dilutions of 50 and 75% pond water, showed reduced growth. Copper and zinc concentrations in a 50% dilution of pond 2 water averaged 25 and 65 μg/L, respectively.

Beginning in 1986, instream toxicity tests were conducted in Silver Bow Creek and the Clark Fork River for 4 consecutive years (Phillips and Spoon 1990). Tests with fingerling rainbow trout (1986 and 1987) and swim-up fry (1987–1989) confirmed that toxic conditions continue to occur periodically throughout much of the upper Clark Fork River and almost continuously in Silver Bow Creek; in general, significant mortality occurred during some years at all sites in the Clark Fork upstream of the confluence with Rock Creek as compared with control sites located on Clark Fork River tributaries where metals concentrations are low.

Overview of current studies

The collection of manuscripts presented in this issue describes part of the work conducted between 1990 and 1993 to evaluate and quantify injury to brown and rainbow trout in Silver Bow Creek and the upper Clark Fork River. This assessment includes food chain toxicity of metals present in macroinvertebrates, waterborne toxicity of simulated pulses of metals, behavioral avoidance of waterborne metals over a range of concentrations, trouts' ability to acclimate to metals, and an evaluation of the physiological impairment of trout exposed to metals in the laboratory or to Clark Fork River water.

Metals in bed sediments and in the water column from the Clark Fork River are accumulated by benthic macroinvertebrates. When these invertebrates were fed to early life stages of trout in the laboratory, growth was reduced and physiological abnormalities were observed (Woodward et al. 1995*a*). Trout fed the contaminated diet experienced gut impaction, cell membrane damage, decreased production of a digestive enzyme, and sloughing of intestinal epithelial cells. Disease and nutritional deficiencies were ruled out as causative agents by pasteurizing and vitamin-fortifying the Clark Fork invertebrate diet. This work confirms that the sediment–macroinvertebrate pathway is an important route of metals exposure for salmonids in the Clark Fork River, and that metals in the diet are toxicologically significant.

Brown and rainbow trout exposed in the laboratory to metals pulses similar to those observed in the Clark Fork experienced significantly reduced survival (Marr et al. 1995*a*). Much of the mortality associated with these pulses was delayed for several days, indicating that fish were irreversibly damaged. Further, under conditions simulating a typical Clark Fork fish kill, rainbow trout were more sensitive than brown trout. Moreover, brown trout juveniles previously acclimated to levels of metals typifying ambient concentrations in the Clark Fork River were more resistant to a metals pulse than similarly acclimated rainbow trout juveniles (Marr et al. 1995*b*). Such differences in relative sensitivity and ability to acclimate to metals may partially explain the presence of brown trout and near absence of rainbow trout in the upper Clark Fork River.

Brown trout actively avoided a mixture of metals similar to that found in the Clark Fork River (Woodward et al. 1995*b*); they also avoided mixtures of 0.5 to 10 times the ambient water quality criteria for the metals mixture. Further, brown trout exposed to progressively higher concentrations of the metals mixture showed a lessened avoidance response, perhaps indicating injury to sensory tissues. Hillman et al. (1995) showed that juvenile and adult trout numbers in reference sites (containing low metals concentrations but otherwise similar to Clark Fork sites) averaged 11 and 36 times those found in the Clark Fork River. The avoidance response of brown trout further explains their reduced numbers in the upper Clark Fork River.

Brown trout from the upper Clark Fork River and hatchery trout exposed to metals in the laboratory experienced elevated concentrations of metals in internal organs, degeneration of digestive cells, and increased lipid peroxidation in several tissues (an index of cellular damage) (Farag et al. 1995; Woodward et al. 1995*a*). Furthermore, brown trout from the upper reaches of the Clark Fork River exhibited higher metallothionein concentrations in liver (a compensatory response to metals exposure) than trout from a downstream location. Microscopic copper inclusions were more common and the pathology was more severe in trout collected below Warm Springs ponds. Farag et al. (1995) conclude that the metabolic cost of metal detoxification protein induction will, at a minimum, result in less net energy available for growth and that all of these stress factors taken together contribute to poorer survival of Clark Fork River trout.

Together, these papers partly describe the mechanisms causing reduced trout numbers and the near absence of rainbow trout in the upper Clark Fork River drainage. Food chain toxicity, waterborne pulses of metals, behavioral avoidance, species-specific acclimation differences, and physiological impairment all influence the numbers, species composition, and distribution of fishes present in Silver Bow Creek and the upper Clark Fork River. While the Clark Fork River and Silver Bow Creek have experienced some recovery over the last 20 years, these studies illustrate the lingering effects of metals contamination and the difficulties of restoring streams when the sediments and floodplain have been contaminated with mine wastes.

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