Evaluating the Success of Remediation in the Boulder River Watershed

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Chapter F of

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Abstract

Historical mining has resulted in contamination of land, water, and biological resources in many areas of the Boulder River watershed. Other chapters in this volume have characterized the extent and severity of this contamination and have presented an ecological risk-based synthesis concluding that areas downstream from the Comet, Crystal, and Bullion mines were among the most contaminated in the watershed. Federal and State land managers have targeted these sites, among others in the watershed, for remediation. Monitoring can provide a means to determine the success of remedial activities and the rate or extent of recovery of the ecosystem. Monitoring tools should include measures of physical, chemical, and biological conditions similar to measurements used in the pre-remediation watershed assessment. Factors including the geology, water quality, and presence of a biological community for recolonization will determine the rate of success of ecological restoration. In addition to the reduction of trace-element concentrations in water and streambed sediment, restoration of a healthy riparian corridor is essential to ecological recovery of the aquatic environment. The importance of monitoring in documenting the success of remediation is often overlooked because of funding limitations. However, a well-designed and carefully implemented monitoring program is an extremely valuable means not only to evaluate the success of an ongoing project, but also to document ways to improve success in future restoration activities.

Introduction

Historical mining has resulted in contamination of land, water, and biological resources in many areas of the Boulder River watershed. Other chapters in this volume have characterized the extent and severity of this contamination (Nimick and Cleasby, this volume, Chapter D5; Church, Unruh, and others, this volume, Chapter D8) and have presented an ecological risk-based synthesis concluding that areas downstream from the Comet, Crystal, and Bullion mines were among the most contaminated in the watershed (Finger, Farag, and others, this volume, Chapter C). Pre-remediation assessment studies demonstrated that fish were absent from many of these stream reaches, and where fish populations did exist, their health had been compromised (Farag and others, this volume, Chapter D10). The potential for biological recovery in this aquatic environment is dependent on successful remediation of historical mine wastes and mine drainage in affected areas in the Boulder River watershed.

Mine and mill site remediation has been initiated at several locations throughout the Boulder River watershed (this volume, Chapter A). In 1997, remediation efforts began at the Comet mine in High Ore Creek. The Montana Department of Environmental Quality removed about 500,000 yd^3 of mill tailings from a breached tailings repository in the High Ore Creek valley (Gelinas and Tupling, this volume, Chapter E2). In 1999, the Bureau of Land Management began removal and in-place treatment of tailings deposits on the High Ore Creek flood plain. The USDA Forest Service also initiated remediation efforts at the Buckeye and Enterprise mine site in 2000 and at the Bullion mine in 2002. The USEPA began remediation activities in the Basin Creek and Cataract Creek basins after these areas were added to the National Priority List (Superfund) in 1999. Mining wastes were removed from the town of Basin, and in 2002, remediation was started at the Crystal mine. However, as of 2003, no work has been initiated to reduce or eliminate acidic drainage coming from mine adits such as those at the Crystal, Bullion, or Enterprise mines.

The terms remediation and restoration are closely linked, but they refer to distinct phases in the process of ecological recovery. Remediation is the cleanup of a contaminated area. Remedial actions remove or isolate contaminants from the environment. These actions are critical to promoting the recovery of both the terrestrial and aquatic ecosystems. Remediation at mine sites can involve the in-place treatment or physical removal of mine waste and mill tailings from a stream, its associated flood plain, and the terrestrial landscape.

Remediation at these sites can also involve actions that reduce or eliminate metal and acid loading from draining mines. Actual cleanup activities may cause adverse effects on the environment that must be addressed early in the planning phases of a project, because some remedial options may preclude achievement of restoration goals. Successful remedial actions result from risk-management decisions that are based on cost-benefit analyses that evaluate the potential outcomes of various alternatives ranging from a simple “no action” alternative to more costly and complicated alternatives such as complete removal of contaminated material. Performance measures for successful remediation might include (1) major sources of contamination in the watershed have been reduced or eliminated, (2) trace-element concentrations in water no longer exceed acute or chronic criteria for aquatic life, (3) trace-element concentrations in streambed sediment no longer exceed sediment-quality guidelines, (4) stream banks have been stabilized and erosion has been minimized, and (or) (5) flood-plain revegetation has reduced or eliminated the transport of contaminated sediment, mine waste, or mill tailings downstream.

Completion of this remediation or cleanup process marks the beginning of the restoration phase of ecosystem recovery. Restoration is the process of returning an ecosystem to a close approximation of its historical condition prior to a physical or chemical disturbance (National Research Council, 1992). Although an injured ecosystem may never return to conditions identical to those that existed prior to mining, it may be restored to conditions that are functionally equivalent to those of the previous environment. The underlying goal of restoration is ecological recovery. This goal must be ecologically realistic and based on the geologic, hydrologic, and biologic characteristics of the watershed. Achievement of this goal is contingent on restoration of the ecosystem’s structure and function both locally and within a broader landscape or watershed context. Therefore, in an area affected by historical mining, an understanding of premining conditions in the watershed is required (Church, Unruh, and others, this volume). Although successful remediation actions, such as physical removal of mine waste and mill tailings or reduction in acidic mine drainage, may be part of the restoration process, these remedial steps do not necessarily ensure that ecological recovery will occur. Restoration may require such things as creation of viable fisheries habitat, restocking a stream with fish, reintroduction of terrestrial species, or revegetation of the flood plain to compensate for ecological losses. Performance measures for successful restoration might include (1) self-sustaining populations of fish throughout the watershed, (2) successfully reproducing colonies of nesting birds, and (or) (3) a healthy riparian corridor.

Monitoring is an important but often undervalued and underutilized tool for determining the success of remedial efforts and assessing ecological recovery. Adequate and appropriate monitoring procedures are the most direct measure of the success of remedial strategies and the resulting rates of recovery for populations, communities, or ecosystems. However, monitoring rarely receives the attention necessary to develop and implement a successful plan. Following remediation of a site, funding limitations often reduce the frequency of monitoring or eliminate it completely. Kondolf and Micheli (1995) indicated that despite increased commitment to stream restoration, postrestoration monitoring has generally been neglected as well. Monitoring plans need not be exhaustive or complex. Rather, they need to be designed to address specific questions and applied in a consistent manner.

Purpose and Scope

The purpose and scope of this chapter are to identify factors that influence ecological recovery and discuss the appropriate procedures and tools for monitoring the success of remediation and restoration in the Boulder River watershed. We describe different types of monitoring, the questions each type is intended to address, and the endpoints that should be considered as a part of their design. Information from this chapter should have broad applicability to other watersheds impaired by historical mining.

Monitoring Strategies

Monitoring is an important tool for evaluating the success of remediation and restoration efforts and assessing the overall status of ecological recovery. Without collecting and analyzing comprehensive monitoring data, land managers cannot objectively evaluate the success of a remedial or restoration action or determine whether remediation and restoration goals have been met. As a tool, monitoring provides information for four basic purposes:

- Performance evaluation—This strategy is used to evaluate project implementation and ecological effectiveness.
- Trend assessment—This strategy includes an extended sampling plan to identify changes across spatial and temporal scales.
- Risk assessment—This strategy is used to identify hazard sources, causal relationships, and resource injury within an ecosystem.
- Baseline characterization—This strategy is used to quantify ecological conditions prior to an actual disturbance. It may also be used to collect information at a reference site to determine premining baseline conditions for a comparable disturbed habitat.

The type and extent of necessary monitoring will depend on specific management objectives (Kondolf, 1995). In the case of a historical mining area, the strategy most appropriate for evaluating the success of remediation and restoration would be performance evaluation. The three components of performance evaluation include (1) implementation monitoring, (2) effectiveness monitoring, and (3) validation monitoring. Implementation monitoring addresses the question: "Were the remediation and restoration measures properly executed?" Exploring this question may yield valuable information that will help with potential refinement of remediation or restoration practices. Effectiveness monitoring addresses the question: "Did remediation and restoration measures achieve the desired results?" Monitoring variables should focus on indicators that document achievement of desired conditions. Variables should be sensitive enough to detect change, should be both detectable and measurable, and should have statistical validity. This level of monitoring is more time consuming than implementation monitoring. However, if effectiveness-monitoring data indicate that restoration goals are not being met, problems can be evaluated in a timely manner, and ecologically beneficial adjustments can be made to the remediation and restoration designs. The most costly level of monitoring is validation monitoring. This addresses the question: "Are the underlying assumptions used in the remediation and restoration designs and the cause-effect relationships correct?" This level of monitoring is usually performed when the desired results of the remediation or restoration actions are not occurring and when further corrective action has not achieved the desired results. This level of monitoring requires scientific expertise to design and implement.

Monitoring Tools

Monitoring involves measurement of chemical, physical, and biological parameters to evaluate the magnitude of change that occurs following remedial and restoration activities and to estimate the rate of recovery of an ecosystem. A comprehensive list of all potential variables available for use in a monitoring program would be overwhelming. Therefore, we present a refined list of the types of monitoring variables applicable to an ecosystem affected by historical mining activities. An ideal monitoring program would include a combination of these chemical, physical, and biological variables.

Biological communities provide an integrated response to the chemical and physical attributes of their environment. Understanding the response of the biological community to remediation and restoration activities is the most important outcome of monitoring. Important physical and chemical variables that may significantly affect the quality of aquatic habitat include temperature, turbidity, dissolved oxygen, pH, alkalinity/acidity, hardness, nutrients, flow, channel characteristics, spawning gravel/interstitial space, pool/riffle ratio, shade, in-stream cover, bed material load, dissolved constituents, and suspended solids. For a remediated historical mining area, chemical variables would include measures of trace-element concentrations in water, in streambed sediment, and in biota deemed problematic during the assessment phase of the project. For the chemical analysis of water, measurement of the fraction (total recoverable or dissolved) that relates specifically to national or State water-quality criteria or that may be linked to bioavailability is most valuable in determining potential habitat improvement.

Ultimately, the goal of mine and mill site remediation is to restore a healthy self-sustaining ecosystem. This success can be documented through measurement of biological endpoints (table 1). Selection of biological measurements is generally determined by the species at risk. For example, in the Boulder River watershed, land managers are interested in establishing a healthy ecosystem that would support a successful trout fishery. In this case, measures of successful ecological restoration could include assessment of fish population densities, survival and health of individual fish (Karr, 1981; Farag and others, this volume), trace-element concentrations in biofilm and invertebrates, and indices of health of the aquatic invertebrate community (Klemm and others, 1990; Pflakin and others, 1989). If the species of interest were fish-eating birds such as kingfishers or eagles, focus should be on the trace-element concentrations in the tissues of fish and on the reproductive health of the birds of interest.

Factors Influencing Restoration Success

Successful ecological restoration of a stream or river that has been adversely affected by mining is dependent on the suitability of both the physical and chemical conditions in the aquatic environment. The basic geologic character of a mining area strongly influences the water quality and the biological community that can exist in an ecosystem. Therefore, knowledge of the geology of a region is critical to defining achievable restoration goals. Not only do the streambed sediment, mine waste, and mill tailings represent sources and sinks for contamination in the watershed (Church, Unruh, and others, this volume) prior to remediation, but also the nature of the mineral content, buffering capacity, acidity, and organic richness of rocks in the watershed all influence the ability of an ecosystem to recover following remediation. In addition to toxicological issues associated with sediment contamination, excessive sedimentation in the streambed can physically limit suitable habitat for survival and reproduction of benthic invertebrates and fish. If remediation addresses removal of contaminated sediment from the stream and flood plain, repair of the stream channel, and stabilization of the stream banks and flood plain, then underlying geologic characteristics of the region, such as the acid-neutralization capacity of the rocks in the Boulder River watershed (McCafferty and others, this volume, Chapter D2; McDougal and others, this volume, Chapter D9), or the particle size distribution of sediment in the streambed, will determine the potential for recovery of habitat that will support a healthy aquatic community and lead to the reestablishment of a healthy riparian corridor.

In an aquatic system, both the quality and the quantity of water also influence the ability of a system to recover. The

Table 1. Examples of biological components and corresponding parameters that may be measured to evaluate progress of ecological recovery.

Biological component	Parameter
Primary productivity	Periphyton or biofilm density
	Aquatic macrophytes species and density
	Concentration of trace elements
Aquatic invertebrate community	Species composition
	Numbers of individuals
	Diversity
	Biomass
	Concentration of trace elements
Fish community	Species composition
	Age class distribution
	Fish health assessment
	Population density
	Concentration of trace elements
	In-stream exposure experiments
Riparian wildlife/terrestrial community	Amphibian/reptile species composition
	Amphibian/reptile population density
	Mammal species composition
	Mammal population density
	Mammal health assessment
	Passerine bird species composition
	Passerine bird population density
	Passerine bird reproductive health
	Fish-eating bird species composition
	Fish-eating bird health and population density
Riparian vegetation	Species composition
	Condition
	Successional changes
	Soil toxicity assessment

water serves as a primary pathway of contaminant exposure for the biological community as well as a means to transport contamination downstream through the watershed. Remediation of targeted mine sites should result in reduction of potential contaminant load in watershed streams. During the initial assessment of the Boulder River watershed, many aspects of water and sediment chemistry, geology, hydrology, biology, and ecology were characterized. Although it was important to determine the status of the biological community in the watershed during this assessment phase, chemical variables such as trace-element concentrations in water and sediment were used to calculate hazard quotients for identifying areas of concern (Finger, Farag, and others, this volume). These quotients were useful in focusing attention on general stream reaches to target for remediation. For aquatic environments impacted by historical mining, significant scientific literature linking biological exposure and effects exists, thus making the ecological risk assessment approach useful for anticipating adverse effects on the biological community. Actual measures of fish health, population status, and toxicological assessment of larval fish survival (Farag and others, this volume) provided confirmation of effects predicted from physical measures. Overall, the measurement of physical variables during the assessment phase was extremely important for determining sources and extent of contamination in the watershed and for assessing the severity of contamination at specific sites.

If the remedial activities in any watershed are adequate, the effects of sources of contamination will be eliminated or greatly reduced. The potential for successful ecological restoration will then be greatest where healthy biological communities (1) exist in the watershed outside the zone of contamination and (2) are capable of recolonizing previously impaired stream reaches. This is the case in the Boulder River watershed where fish and invertebrates inhabit many stream reaches within the watershed (Finger, Farag, and others, this volume, fig. 1). Potentially, reestablishment of the native trout species is even possible because a reproductively viable population of westslope cutthroat currently exists in High Ore

Creek upstream from the Comet mine. Successful remediation and restoration of stream reaches affected by the Comet mine could lead to successful ecological recovery of this species by providing habitat where these native trout can survive and reproduce. However, some type of physical barrier would be necessary in High Ore Creek to prevent the migration and resultant competition of more aggressive brook and rainbow trout from the Boulder River.

Monitoring in the Boulder River Watershed

In the Boulder River watershed, 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 (Gelinas and Tupling, this volume). Continued improvements in water quality and reduced sediment loading should result in improved survival, growth, and reproduction in the aquatic community.

The selection of appropriate monitoring endpoints for use in the Boulder River watershed can be determined based on the watershed assessment. The same variables used to document impairment to the watershed can provide a measure of ecological recovery following remediation. These variables would include, at a minimum, concentrations of arsenic, cadmium, copper, lead, and zinc in water samples collected over a range of flow conditions, trace-element concentrations in streambed sediment and biofilm collected at low flow, in-stream exposures with larval fish, fish population assessment, and measures of fish health. Monitoring sites should correspond to those used in the watershed study with the possible addition of sites in areas of anticipated recovery. This approach would support the establishment of monitoring sites downstream of the Bullion mine on Bullion Mine tributary and on Jack Creek, downstream of the Crystal mine on Uncle Sam Gulch, on Cataract Creek upstream and downstream of the confluence with Uncle Sam Gulch, downstream of Comet mine on High Ore Creek, and at several locations on the Boulder River.

Future monitoring that incorporates biological and chemical measurements will be able to demonstrate the degree of success of remediation projects in the watershed. However, the success of any ecological recovery 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 (Kondolf, 1995). Monitoring the improvement of flood-plain and riparian soils after the physical removal of tailings can be accomplished through 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 recovery. Only through a well-designed and rigorously implemented monitoring program can the success of a remedial effort be validated.

Summary

Monitoring includes measures of chemical, physical, and biological parameters to evaluate the magnitude of change that occurs following remedial activities and to estimate the rate of recovery of an ecosystem. Historical mining activities have resulted in the degradation of fisheries and their supporting habitat in the Boulder River watershed. As a result of remediation in the watershed, improvements in water quality and reduced trace-element concentrations in streambed sediment should result in ecological recovery, improved physical habitat, and greater survival, growth, and reproduction rates in the aquatic community. The presence of trout in some stream reaches in the Boulder River watershed provides a local source of fish to repopulate areas where no fish were present prior to remediation.

The selection of appropriate monitoring endpoints to evaluate recovery in the Boulder River watershed can be determined based on the physical, chemical, and biological measurements used during the pre-remediation watershed assessment. This would include, at a minimum, measures of cadmium, copper, lead, zinc, and arsenic in water samples collected at high and low flows, measures of bed sediment concentrations at low flow, and chemical analysis of biofilm at low flow, in-stream exposures with larval fish, fish population assessment, and measures of fish health. Monitoring sites should correspond to those used in the watershed study with the possible addition of sites in areas of anticipated recovery.

References Cited

Karr, J.R., 1981, Assessment of biotic integrity using fish communities: Fisheries, v. 6, p. 21–27.

Klemm, D.J., Lewis, P.A., Fulk, F., and Lazorchak, J.M., 1990, Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters, EPA/600/4–90–030: U.S. Environmental Monitoring Systems Laboratory, Cincinnati, Ohio.

Kondolf, G.M., 1995, Five elements for effective evaluation of stream restoration: Restoration Ecology, v. 3, p. 133–136.

Kondolf, G.M., and Micheli, E.R., 1995, Evaluating stream restoration projects: Environmental Management, v. 19, p. 1–15.

National Research Council, 1992, Restoration of aquatic ecosystems—Science, technology, and public policy: Washington, D.C., National Academy Press, 552 p.

Plafkin, J.L., Barbour, M.T., Porter, K.D., Gross, S.K., and Hughes, R.M., 1989, Rapid bioassessment protocols for use in streams and rivers, EPA444/4–89–001: U.S. Environmental Protection Agency, Washington, D.C.